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WOFEX 2020

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Preface

The workshop WOFEX 2020 (PhD workshop of Faculty of Electrical Engineering and Computer Science) was held on September 8th September 2020 at the VŠB – Technical University of Ostrava. The workshop offers an opportunity for students to meet and share their research experiences, to discover commonalities in research and studentship, and to foster a collaborative environment for joint problem solving. PhD students are encouraged to attend in order to ensure a broad, unconfined discussion. In that view, this workshop is intended for students and researchers of this faculty offering opportunities to meet new colleagues.

This book of proceedings includes 83 papers of faculty PhD students and 3 papers of external authors. The proceedings of WOFEX 2020 are also available at the web site <http://wofex.vsb.cz/2020/>. I would like to thank the authors and the Organizing Committee from Department of Computer Science, namely Jiří Dvorský and Pavel Moravec, for their arduous editing work.

September 2020

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WOFEX 2020

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Table of Contents

Study Programme P2649 Electrical Engineering

Electrical Power Engineering (3907V001)

Verification of the Selected Sources of the Obtrusive Light and Quantification Amount of the Luminous Flux Radiated to the Upper Hemisphere	1
<i>Petr Běčák and Tomáš Novák</i>	
Power Quality Analysis in the Off-Grid Platform Based on AC-DC Topology	6
<i>Vojtech Blazek and Stanislav Misak</i>	
Power quality parameters short-term forecasting system	13
<i>Ibrahim S. Jahan and Stanislav Misak</i>	
Analysis of the Time and Workforce Required for Substation Maintenance	18
<i>David Lazecky</i>	
PowerLine Communication in the Off-Grid	24
<i>Michal Petružela</i>	
MCA methods for assessing the reliability of PV connections to the distribution system	31
<i>Petr Seroišzka</i>	
Computational-performance Analysis of the Pandapower Implementation of the Newton-Raphson Method for AC-power-flow Analysis Solution	37
<i>Jan Vysocký</i>	

Electrical Machines, Apparatus and Drives (2642V004)

Induction motor drive with RF-MRAS speed observer based on a neural network	44
<i>Jakub Bača and Daniel Kouřil</i>	
Implementation of Genetic Algorithm in Control Structure of a DC Motor Drive	50
<i>Daniel Kouřil and Jakub Bača</i>	
Active and Reactive Power in a Rolling Mill	56
<i>Stanislav Nowak and Stanislav Kocman</i>	

Electronics (2612V015)

Implementation of Programmable Control Unit for the Central Electronics System of the Experimental Electric Vehicle..... 62
Tomas Harach

The HIL Testing of Automotive Electronic Systems 68
Tomas Klein

Vehicle trip altitude profile precision comparison 74
Martin Koreny

Fall Time Optimization of the C2M0045170D SiC Transistor According to the Voltage Peak Stress 81
Jan Strossa and Vladislav Damec

Technical Cybernetics (2612V045)

Development of Application for Control of SMART Parking Lot 87
Jan Baros and Radek Martinek

Autoencoder as a Tool for Data Compression 93
Monika Borova

Virtual Instrumentation Based Ballistocardiographic Monitoring System Designed for Cardiac Triggering of Magnetic Resonance Imaging . 99
Jindřich Brablík and Radek Martinek

Methods of Modern Medical Diagnostics of Burn Injuries 105
Iveta Bryjová

Speedgoat RT Simulator For HIL And PIL Simulation Purposes 111
Radek Byrtus

Software Defined Equalization Techniques for Visible Light Communication 117
Lukas Danys and Radek Martinek

Battery Electric Vehicle Passive Consumption 123
Jan Dedek and Jan Zidek

Optimal Control Problem Solving by Calculus of Variation 129
Tomas Docekal

Vibration Measurement and Analysis of Hydraulic Shears 135
Jakub Dohnal

Blood Glucose Prediction: A Review of the Use of Neural Networks in Diabetes Melitus 141
Klara Fiedorova and Martin Augustynek

Node Control Optimization Using Neural Networks and Cloud Data: A Review 147
Karolína Gaiová

Design of a Parking House Control System	152
<i>Matej Golembiovský and Radek Martinek</i>	
Application Of Big Data Analysis In Smart Homes	158
<i>Ojan Majidzadeh Gorjani</i>	
Comparison of SCG and ECG Hearth Rate Monitoring in Laboratory Conditions	163
<i>Jakub Kolarik and Radek Martinek</i>	
Comparison of Two NLP Solvers Used in MPC	169
<i>Filip Krupa</i>	
Wood classification and Imaging Inspection Systems	174
<i>Martin Kryl and Petr Bílík</i>	
Evaluation and Analysis of the Efficiency of a Segmentation Algorithm Based on Hybrid Methods for Blood Vessels Extraction	179
<i>Alice Krestanova</i>	
New Approaches to MRI Cardiac Triggering	185
<i>Martina Ladrova and Radek Martinek</i>	
Dynamic Modelling of PEM Fuel Cells Stack System	191
<i>Jakub Němčík</i>	
Proposal of Electrogastrography Measurement Method based on the Spatial Biopotential Distribution	197
<i>David Oczka</i>	
Multifrequency Bioimpedance Analysis of Human Calf Muscles	203
<i>Martin Schmidt and Marek Penhaker</i>	
Test Measurement of TEG for Power Supply in Energy Harvesting Applications	209
<i>Miroslav Schneider</i>	
Application of Advanced Signal Processing Methods for the Purpose of Vital Signs Monitoring in Car Seats: An Overview	215
<i>Michaela Sidikova and Radek Martinek</i>	
The Review of Phasor Measurement Unit Actual State	219
<i>Lukas Soustek and Petr Bílík</i>	
Monitoring the Condition of the Protective Fence above the Railway Track Praha-Zbraslav	225
<i>Jan Velička, Radovan Hájovský, Martin Pieš, and Štěpán Ožana</i>	
Filtering VCG Records Using Wavelet Transform	231
<i>Jaroslav Vondrak and Marek Penhaker</i>	

Study Programme P1807 Computer Science, Communication Technology and Applied Mathematics

Informatics (1801V001)

Astronomical Time Series Classification using Artificial Neural Networks .	237
<i>David Andrešič, Petr Šaloun, and Bronislava Pečíková</i>	
Integration of natural deduction and resolution method into Transparent intensional logic	243
<i>Michal Fait</i>	
An approach for multi-objective optimization problem	249
<i>Lingping Kong and Václav Snášel</i>	
Natural gas consumption forecasting from big data collection	255
<i>Vojtěch Kotík and Jan Platoš</i>	
Community detection in networks using clustering methods and graph's distance metric	261
<i>Petr Prokop and Jan Platoš</i>	
Multi-services systems monitoring	267
<i>Lukáš Révay</i>	
Detection of Anomalies During Car Driving Based on Singular Value Decomposition	273
<i>Radek Simkanič</i>	
High-Dimensional Text dimensionality Reduction by Stacked-Random Projection	279
<i>Yujia Sun and Jan Platoš</i>	

Computational and Applied Mathematics (1103V036)

Finding the first eigenpair of p -Laplacian using inverse iteration method .	285
<i>Michaela Bářlová</i>	
Mixed formulation of the log-transformed permeability in the stochastic Galerkin formulation of the Darcy flow problem	291
<i>Michal Bérés</i>	
Bayesian identification of material parameters in infinite dimension	297
<i>Simona Domesová</i>	
MPRGP with Projected Conjugate Gradient Expansion and Fallback	303
<i>Jakub Kružík and David Horák</i>	

Randomization of the Initial Guess in the Constrained Optimization on Grassmann Manifolds	309
<i>Martin Mrovec</i>	
Nonadiabatic molecular dynamics	315
<i>Stanislav Paláček</i>	
2-phase Volume Segmentation Exploiting Null-Spaces of Graph Laplacians	320
<i>Marek Pecha and David Horák</i>	
Parallel finite element method of transient piezo-acoustic problem	326
<i>Erika Straková and Dalibor Lukáš</i>	
Classification algorithms and compositional data	332
<i>Adéla Vrtková</i>	
Graph Theory in Sport Tournaments Scheduling	338
<i>Jakub Závada</i>	

Communication Technology (2601V018)

Determination of Spam over Internet Telephony detection parameters ...	343
<i>Ladislav Behan</i>	
Optimized IoT Architecture Based on Fog Computing: An Overview ...	349
<i>Jakub Jalowiczor and Miroslav Voznak</i>	
Measurements of Changes of the Energy Propagation in SM Splitters due to High-Power and Gamma Radiation Load	355
<i>Jakub Kolar</i>	
LoRaWAN Infrastructure for Hydro-meteorological Sensors	360
<i>Tomas Putna</i>	
Fiber-optic sensors in civil engineering	364
<i>Stanislav Zabka</i>	

Study Programme P1701 Physics

Applied Physics (1702V001)

Sensing of gaseous analytes via surface waves in the spectral domain ...	370
<i>Michal Gryga, Dalibor Ciprian, and Petr Hlubina</i>	

Study Programme P0713D060003/P0713D060004 Electrical Power Engineering

Analysis of Partial Discharges Count in Relation to Charge Value	376
<i>Ondřej Kabot</i>	

Island operation of wastewater treatment plant during blackout	382
<i>Matuš Vrzala and Radomír Goňo</i>	

Study Programme P0714D150001/P0714D150002 Cybernetics

Use of Empirical Mode Decomposition as a Part of Hybrid System for Non-Invasive Fetal ECG Extraction	388
<i>Kateřina Barnová and Radek Martinek</i>	

Statistical Analysis of Pulse Wave Measurement on Vascular Model	394
<i>Daniel Barvik and Martin Cerny</i>	

Automated Identification Of Leukemic Cells From Microscopic Peripheral Blood Smear Images	399
<i>Alexandra Bodzás and Pavel Kodytek</i>	

Nonlinear optimization with REXYGEN and SOLNP	405
<i>Akshaya Raj and Štěpán Ožana</i>	

Statistical Analysis of the Distribution of Intensities from MR Images of Abdominal Area	411
<i>Dominik Vilimek and Marek Penhaker</i>	

The Use Of The Digital Twin In The Critical Real-Time Systems	417
<i>Adam Vůjtek</i>	

Study Programme P0613D140005/P0613D140006 Computer Science

Seeking Relevant Information Sources	422
<i>Adam Albert and Marie Duží</i>	

Towards Faster Matching Algorithm Using Ternary Tree in the Area of Genome Mapping	428
<i>Rostislav Hřivňák and Petr Gajdoš</i>	

TIL meaning, context and anaphora	434
<i>Vojtěch Patschka</i>	

Short-term natural gas consumption forecasting using machine learning ..	440
<i>Radek Svoboda and Jan Platoš</i>	

Big Data Image Processing in MPI Parallelized Fiji	446
<i>Daniel Trnka</i>	

Study Programme P0613D140020/P0613D140021
Computational Science

Bolt pretension 452
Marek Konečný and Tomáš Kozubek

Benchmarking DGX-2 Platform..... 458
Matej Spetko

Study Programme P0714D060001/P0714D060002
Communication Technology

Mobile sensor with optical FBG for traffic density monitoring 464
Michael Fridrich

3D printed FBG sensor for heart rate monitoring of the human body 470
Michal Kostelanský

Machine learning methods for isolated word automatic speech recognition 475
Martina Slívová

Study Programme P0533D110005/P0533D110006
Applied Physics

Surface plasmon resonance and a phase detection in the spatial domain .. 478
Roman Kaňok, Petr Hlubina, and Dalibor Ciprian

External Authors

Analysis and Classification of Vibroarthrographic Signals 484
 Adam Lysiak

The Pepper humanoid robot as a testbed for interaction design and
sentiment analysis research 490
 Agnieszka Rozanska and Michal Podpora

Designing a Human-Machine Interface of a humanoid robot for people
with disabilities 495
 Emilia Surma, Agnieszka Rozanska, and Michal Podpora

Author Index

Verification of the Selected Sources of the Obtrusive Light and Quantification Amount of the Luminous Flux Radiated to the Upper Hemisphere

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Abstract. The article focuses on the verification of the software goniophotometer in the Wils Building Design computational program in terms of the possibility of the calculation of the radiation of the luminous flux flowing into the upper hemisphere from selected sources of the obtrusive light. The obtrusive light cannot be completely prevented, but it can be reduced by effective lighting. Luminaires and lighting systems that do not directly radiate into the upper half-space should be installed only. The obtrusive light is not caused only by public lighting, but also by architectural lighting of buildings, billboards, lighting of sports facilities and parking places. It is also the light escapes from interiors of buildings, as well as the light from cars headlights. All these artificial lighting, not just public lighting, is a negative phenomenon and nowadays it is a "thorn in astronomers and environmentalists side,,. Therefore, it is necessary to verify all sources of the obtrusive light and quantify amount of the luminous flux radiated to the upper hemisphere. The goal of the modeling is to quantify the amount of the luminous flux radiated to the upper hemisphere from the LED lighting system of the public lighting then the replacement of this system by HPS lighting system. Furthermore, the proportion of the obtrusive light from the windows, billboards, lighting of facade and cars headlights is quantified on a simple model.

Keywords: software goniophotometer, modeling, obtrusive light sources, upper hemisphere

1 Introduction

The provision of an electric lighting is not without consequences for the environment. The electricity generation always causes pollution of the environment, either directly, as in air pollution caused by the burning of fossil fuels, or indirectly, when generating and transmission equipment has to be scrapped. But light itself can also be considered a form of pollution. Indeed, over the last two decades, public concern over the consequences of the use of light outdoors at night has been growing, driven by wellorchestrated advocacy campaigns using such emotive slogans as “Our children

will never see the stars”. As a result, there have been moves by governments in a number of countries to limit the use of light outdoors at night by regulation or legislation. [1]

The obtrusive light represents a total luminous flux that spreads into the upper half-space and therefore increases sky brightness. It is formed by direct and indirect (reflected) part of the luminous flux from a terrain and outdoor objects. The most important is the evaluation of the luminous flux radiated directly to the upper half-space by ULR, see equation below:

$$ULR = \frac{ULOR}{ULOR + DLOR} \quad (1)$$

where:

ULR - proportional direct luminous flux radiated to the upper half-space

ULOR - luminous flux radiated directly from the luminaire to the upper half-space

DLOR - luminous flux reflected from the surfaces of the surrounding objects

ULOR + DLOR - total luminous flux radiated to the upper half-space [2]

2 Modeling of the luminous flux radiated into the upper hemisphere by software goniophotometer

This part of the article is a description of the software goniophotometer possibilities. It will show modeling of the luminous flux into the upper hemisphere generated by artificial outdoor lighting sources. The simple model was prepared because of necessity to predict behavior of the lighting systems from the point of view obtrusive light. Until this time it was possible to do only some partial short or long term measurements.

The goal during development of the software goniophotometer was to insert calculation grid in the shape of a sphere with calculation points showing normal illumination in the direction to the center of a sphere. The function principle is based on square law and duplicates the function of the real goniophotometer which is a photometric laboratory instrument for measurement of the luminous intensity or luminous intensity distribution curves. New possibility is an option to choose density of the calculation grid in angle step according to standard used levels for luminaire measurement in C, γ planes. For correct calculation it is necessary to take each object as a simple point source. In praxis this ratio is requested higher than 5 so as light source was taken as a simple point source. The software goniophotometer is working on basis of inverse square law. It means that each calculation point of the grid represented normal illuminance and after it is converted to the luminous intensity in solved direction. The result is the luminous intensity distribution curve for whole calculated lighting system, which is possible exported to the LDT file. All calculations were

done with maintenance factor 1. It represents the worst case of the obtrusive light level. [3]

3 Simple model of a city with road M5 and selected sources of the obtrusive light

The city with a road and a build-up area was used as a base of the design. The class of the road was set to be M5. The built-up area is composed of the residential houses and an industrial building situated near the road. The built-up area as well as the road with a pavement is obstacles with a certain reflectivity for a lighting system and the spread of its luminous flux. All these surfaces are described by their average reflectivity. It means 10 % for road and grass, 30 % for pavement and buildings.

Fig. 1. Model of the city with build-up area, road M5 and inserted selected sources of the obtrusive light.

The road M5 was designed to be in accordance with the standards. The luminaires are situated on pillars 30m away in a height of 7m. The lighting system is composed of 5 pillars with luminaires.

The calculation was realized with the LED lighting system at first. These luminaires radiate only to the under half-space and they are specifically designed to illuminate roads. Therefore it can be assumed that the entire luminous flux of this lighting system gets to the upper half-space is reflected from the modeled objects and surfaces.

The lighting system that uses HPS park luminaires with rotary symmetrical distribution curve with primary radiation to the upper half-space was used to compare differences of the distribution curves of the city model for the illumination of the same road in the same geometrical layout. Therefore it can be assumed the luminous flux of the lighting system gets to the upper half-space directly and by reflection from the modeled objects.

Five windows were placed randomly on the residential buildings for further calculation. Their dimensions are 1,2 x 1,2m. The luminous intensity distribution curve of the window corresponds to the cosine radiator and it was created based on luminous analysis of 6cd/m². It can be assumed mainly direct radiation into the upper half-space nearly 50% of their total luminous flux.

Computational data representing 1 billboard and the lighting of the industrial building facade were inserted on the same principle. The size of the billboard is 9,6 x 4,8m with brightness of 50cd/m² and the size of the facade is 30 x 10m with brightness of 25cd/m². It can be assumed mainly the direct radiation into the upper half-space nearly 50% of their total luminous flux again.

Finally the computational data of one pair of low beam headlights of representing car were entered. It can be assumed that almost the whole luminous flux gets to the upper half-space by reflection from the modeled objects and surfaces, mainly from the road.

4 Evaluation of the results

The table below shows the results of the modeling by software goniophotometer.

Table 1. Parameters of the obtrusive light sources in the model and their counts.

Source of obtrusive light	System power (W)	System luminous flux (klm)	ULOR (klm)	DLOR (klm)	ULOR + DLOR (klm)	ULOR + DLOR (%)
5x	140	13,5	0,00	1,10	1,10	8,12
5x	750	50,0	11,5	3,40	14,9	29,8
1x	-	7,37	3,26	0,48	3,74	50,8
5x	-	0,14	0,06	0,01	0,07	49,7
1x	-	23,6	11,1	2,10	13,2	55,8
1x	-	1,47	0,04	0,11	0,15	10,2

Even though both of the public lighting systems were designed to have approximately the same level of maintained illuminance, the high pressure sodium lighting system has more than 5 times greater power consumption (3,7 times greater luminous flux) which in the end means much higher expenses from the economic point of view.

It also can be stated that the level of the obtrusive light is the most affected by the radiation direction of the individual luminaires and its geometry. The total luminous flux that was radiated to the upper half-space by the HPS lighting system is 13,6 times greater than in case of the LED lighting system. It is also important to mention that while using the HPS lighting system, the luminous flux going to the upper half-space (14,9klm) is greater than the total luminous flux of the LED lighting system (13,5klm). Therefore it is necessary to use suitable luminaires with a suitable distribution curve for road lighting. The obtrusive light cannot be completely prevented, but it can be reduced by effective lighting. The luminaires and lighting systems that do not directly radiate into the upper half-space should be installed only.

According to the table, it can be seen that another important source of the obtrusive light is the lighting of the facade and billboard. With regard to the build-up area the results correspond with the previous assumptions and more than 50% of their total luminous flux leads up to the upper half-space.

Windows have a relatively small effect on the amount of the obtrusive light, but the impact can be different for large glazed buildings in big cities.

We must not forget to the cars headlights. Most of the luminous flux is reflected to the upper hemisphere from roads and adjacent pavements. [4]

5 Conclusion

From the above mentioned we can conclude the luminous flux radiated to the upper hemisphere is not caused only by public lighting, but also by other more or less major light sources. This article showed a relatively simple method for quantification obtrusive light based on illuminance calculation of the road and luminous analysis recalculation. It would be good to implement weather conditions into the software and compare the size of the obtrusive light during fog and cloudless nights.

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Power Quality Analysis in the Off-Grid Platform Based on AC-DC Topology

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Abstract. Nowadays, there is a significant international development of renewable energy sources and Off-Grid systems. The Off-Grid can be built according to several topologies. This paper focuses on AC-DC topology. The article describes the measured power quality parameters in the Off-Grid household for one week. The control system platform is based on artificial intelligence methods that try to optimize the energy source and appliance part of the Off-Grid system according to the priority plan of switching appliances so that there is no power failure from the battery or renewable sources in the Off-Grid while maintaining power quality parameters according to the standard ČSN EN 50160 ed.3.

Keywords: Off-Grid System, Power Quality, Renewable Energy Sources Introduction

1 Introduction

Today, there is a boom in Off-Grid systems the size of a family house. These Off-Grid system can be divided into several basic topologies. The first topology can be classified as an Off-Grid based on DC topology. The second topology is a system built on AC topology and the last is a combination of both AC-DC topologies. [1][2]

The article describes measurements on the current version of the test platform of the house Off-Grid, which is located on the campus of VSB – Technical University of Ostrava. This Off-Grid built on an AC-DC topology [3][4][5].

Recently, the system has a major update on hardware infrastructure. The motivation of this article is to measure the normal run of this system after this change for a period of one week in which we simulate the normal run appliances in the household. We will verify these changes in the AC part of the Off-Grid system.

2 Description of the Off-Grid Testing Platform

Fig. 1. Testing platform of the Off-Grid with vehicle to grid technology

Figure 1 shows the electric scheme of the Off-Grid platform. The center of the test platform is the Schneider Conext XW + 8548 hybrid converter with a rated output of 6.8 kW, and you see in figure 2. Lead-acid batteries Hawker 12XFC115 in Off-Grid is in series-parallel connection allow for accumulating electrical energy. All batteries have a capacity of 115 Ah and a nominal voltage of 12 V. Serial-parallel connection is demonstrated in 4 groups connected in parallel, where one group has 4 batteries in series to achieve a voltage of 48 V. The resulting usable capacity of the battery is 20 kWh of electricity. The battery can be seen in the figure 2.

Fig. 2. The infrastructure of the Off-Grid

The main energy sources for the Off-Grid is currently two photovoltaic strings, each with an output of 2 kWp. The first photovoltaic string is located on the roof of the Off-Grid building. This photovoltaic string is assembled with polycrystalline panels. The second string consists of monocrystalline panels and it is part of the solar tracker, which is located next to the building of the Off-Grid. The panels are connected to Xantrex XW MPPT 80600 photovoltaic inverters. These inverters are then connected directly to the DC 48 V bus. Another source of electricity is a wind power plant with an output of 10 kWp.

The appliances in the Off-Grid are controlled by a control system based on the QUIDO I / O module. The control system works with the active demand side management (ADSM) algorithm based on the demand response (DR) principle. The Off-Grid contains several common household appliances necessary for simulating a normal household. Appliances that are not physically connected to the system can be simulated by a controlled electronic load. The electronic load can be set to a power of up to 4 kW with a step of 100 W.

The measurement of electrical values in the system is provided by a measuring card from National Instruments. These are NI – cDAQ 9185 cards. The measuring cards measure with Elkom SMC 101 and SMC 111 converters. The cards send the measured data via Ethernet to a server, where the measured data are further processed. The measurement of the quality of electrical energy in the Off-Grid is provided by the analyzer KMB SMC 144.

3 Measuring Results

The measurement lasted for one week, when users started the appliances according to plan or as needed. The individual appliances used in the experiment can be seen in the table 1.

Table 1. Appliance

Appliance	Power consumption (W)			Power factor (-)
	Avg.	Min.	Max.	Avg.
Kettle	919.10	917.00	928.30	1.00
Fridge	207.60	195.50	219.50	0.72
PC and LCD monitor	410.00	409.70	420.20	0.78
Air Conditioning	880.00	852.50	910.00	0.91
Microwave	203.00	76.80	1348.30	0.84
Boiler	307.00	305.80	346.50	0.99
TV	44.00	42.80	50.50	0.60
Lights	150.00	152.50	165.10	0.84

Electric vehicle and wind turbine were disconnected from Off-Grid during the experiment because the connection of this part of the system is still under development. Power quality measurement devices is analyzer KMB SMC 144. The measured values of power quality parameters were processed into the following chapters:

3.1 Flicker

The Compatibility level for short term flicker (P_{st}) is 1.2 for 95 % time in a week and for compatibility level for long Term flicker (P_{lt}) is 1.0 for 100 % time in a week. [6]. Figure 3 show measured value P_{lt} and P_{st} for one week.

Fig. 3. Measured values P_{lt} and P_{st} for one week

3.2 Total harmonic distortion

Limits for Total harmonic voltage distortion (THDV) are 8 % for 100 % time and 5% for 10 minutes for one week. Total harmonic current distortion value (THDI) is THDI is not specified in the standard ČSN EN 50160 ED.3. Figure 4 show THDV and figure 5 shows THDI for one week.

Fig. 4. Measured values THDV for one week

Fig. 5 Measured values THDI for one week

3.3 Frequency

Limit for frequency is $50\text{ Hz} \pm 0,1\text{ Hz}$ for 100 % time [6]. Figure 6 shows frequency for one week.

Fig. 6 Measured frequency values for one week

3.4 Power factor

Power factor is not specified in the standard ČSN EN 50160 ED.3. Figure 7 show power factor for one week.

Fig. 7. Measured frequency values for one week

3.5 Voltage

The limit for Voltage are $230 \text{ V} \pm 23 \text{ V}$ for 100 % time [6]. Figure 8 show measured voltage for one week.

Fig. 8. Measured voltage values for one week

4 Discussion and Conclusion

The results of the measurement provided in this paper clearly the power quality in the Off-Grid system with AC-DC topology. During the measurement, it was found that Plt and Pst according to the ČSN EN 50160 ed3. standard significantly exceed the set limits. Finding the cause and how improving Plt and Pst will be part of future research. Other power quality parameters are in the limits for the grid.

Our future work will apply measurements on shorter time scales to obtain more precise values. We also aim at the increase of the number of appliances to obtain dataset with more serious PQ disturbances.

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Power quality parameters short-term forecasting system

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Abstract. This study focuses on designing a short-term power quality parameters forecasting system as parts of my thesis. The main goal of my thesis is to design PQPs forecasting models, which contributes as a main task of smart control power system. Many articles have been published included designing models of smart power system, but still the controlling of power from generation to users in optimal way remains an open issue. In this article, five power quality parameters (PQPs) forecasting systems have been designed. These parameters are- power frequency, magnitude of the supply voltage, total harmonic distortion of voltage (THD_u), total harmonic distortion of current (THD_i), and short term flicker severity (P_{st}).

The proposed system used regression tree, and trained using dataset taken from off-grid platform. The output of the system can be used to set a switch process program and redirect the power to the load. As well the study explained the effect and the relevance of the input variables with the output (PQPs).

Keywords: power quality, power quality parameters, forecasting system, renewable energy, power system.

1 Introduction

In the recent years, the power quality has considered as important issue due to new devices which need to specific limits of the power parameters.

The main task of power systems is to supply electrical power to users at required limits of power quality. The very important PQPs are power frequency and the magnitude of the supply voltage, so the power utility should supply the users with power of good quality, as in power standard limits of the European standard [EN 50160].

The electrical power of standard power quality is required for sensitive modern devices to work efficiently. The renewable energies as solar and wind power is used to generating the electricity as clean and free power sources. The challenge is how to generating a good quality power from theses sources whether in off-grid or on-grid system. Power quality parameters forecasting system are considered as a main part of smart control system. They needed to forecast in advance values of the power quality

parameters. The outputs of these models used to redirect the power to load in optimal way with consider of the power quality.

The article organized as following- In section 2 we discussed some previous works. Section 3 describes the planned model and experiment results. The last section 4 concludes the study.

2 Related Works

This study deals with an important part of smart power system, focused on designing power quality parameters short-term forecasting models. There are many studies which focus on the designed of smart control systems to control and operate power systems using different models. This section includes some previous studies either on the design of smart power systems, optimization of power flow systems, or reconfiguration of power grids. All these tasks aim at the same goal of supplying users with power of good quality. Stuchly et al, used Artificial Intelligence with Backpropagation Learning tool for forecasting power quality parameters (PQPs), and the model used as supporting off-grid system to produce power with good quality [1]. Vantuch et al, used optimized random forest to forecasting PQPs- frequency, voltage, THD, and flicker as supporting tool in off-grid platform. The forecasted results exceed 90% for 15 min time step [2]. Teshome and Lian, apply a hybrid algorithm with particle swarm optimization (PSO) and genetic algorithm (GA) to automat power grid reconfiguration [3]. The approach has been testes using standard IEEE 33-bus distribution network. The experiment outcome confirmed the validity of planned system with low time computation [3]. For minimizing power loss, Ashour and Strickland used particle swarm optimization to find optimal reconfiguration of power grid. The results of designed model were compared with others, and 29% of power loss improved [4]. Hamour et al. applied grasshopper optimization algorithm to reconfiguration power system of purpose reduce power loss. The model has been tested using IEEE 33-bus radial distribution system. The system gas high performance when capered with others [5]. The idea of Salp Swarm Algorithm used for find optimal power network reconfiguration applied by Yodphet et al. The planned approach was carried out using 33 and 69 bus distribution network. The reconfigured results that archived by this method was better than others as Genetic Algorithm [6]. Sudhakara and Damodar, applied Meta-heuristic Dragon Fly Algorithm to find the optimal restructure of the power distribution network. The model has been evaluated using IEEE 16-bus, 33-bus and 69-bus systems. The experiment outcome confirmed that the efficiency of the proposed technique, and improvement of power voltage profile [7]. Belazzoug et al. applied Genetic algorithm to solve optimal reconfiguration of the radial distribution power grid. The designed approach tested on 106 buses distribution system and compared with classical method that confirm the validity of proposed method [8]. Despite the reported improvements, designing a reliable reconfiguration of electrical power system still remains a challenge, in particular in the off-grid platform. This paper proposes a forecasting approach to predict PQ parameters in off-grid platforms by means of selected input variables, and describes the model construction.

3 Experiment

3.1 Data set

The data set of June and July 2019 are used in this article. They were obtained from the off-grid platform constructed at the Faculty of Electrical Engineering and Computer Science at VSB-Technical University of Ostrava, the Czech Republic.

This data set includes several variables related to power data, such as:- magnitude of the supply voltage, power frequency, THD_u , THD_i , flicker, and the type of running load (as AC heating, fridge, light, TV). In addition, the data set includes weather conditions at the same time step. The weather dataset was available every five minutes as time step, so at same time step, by the same way the power dataset samples were selected in each five minute time step.

3.2 Experiment Setup

The experiments are built in five separating forecasting systems. The proposed system was trained using data set taken from off-grid system in VSB-TUO Technical university of Ostrava. The used input variables are- power load, temperature, ultraviolet step, and home appliances (AC heating, fridge, light, and TV), as well PQPs as target outputs. The data set used in training the model is from 14 June till 5 July 2019, while we forecasted one day ahead, the day of 6 July was used to predict every one hour, as can be seen in Figure 1 planned model.

Fig1. Scheme of planned system

3.3 Results

The five forecasting systems constructed in the same procedure. The experiments run many times and the best results were selected. MAPE and RMSE errors were used to evaluate the experiment results, as in following equations and forecasted results in the Table 1.

$$MAPE = \frac{100}{n} \sum_{i=1}^n \left(\frac{A_i - F_i}{A_i} \right) \quad (1)$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (A_i - F_i)^2} \quad (2)$$

Where A_i is the actual value of the PQPs, F_i is the forecast value of the PQPs, n is the number of evaluated forecast values.

Table 1. MAPE and RMSE Error for five PQPs Forecasting Models.

PQPs Types	MAPE	RMSE
Frequency	$5.4701 \times 10^{-7}\%$	1.7487×10^{-5}
Voltage	$2.3 \times 10^{-4}\%$	0.0189
THD_u	0.0253%	0.0267
THD_i	0.0176%	0.2416
Flicker	1.227%	0.529

The model was forecasted PQPs for one day ahead, in every one hour, it means 24 points were forecasted.

The MAPE and RMSE errors were for power frequency $5.4701 \times 10^{-7}\%$, 1.7487×10^{-5} , for voltage 0.0002%, 0.0189, for THD_u 0.0253%, 0.0267, for THD_i 0.0176%, 0.2416, and flicker 1.227%, 0.529, respectively.

The experiments noted that- the forecasted voltage was affected by power load and step of ultraviolet, the power frequency was very sensitive to power load and air temperature, THD_i was more affected by power load and type of home appliances, THD_u was slightly influenced by power load and slightly by the step of ultraviolet, and flicker was slightly affected by power load and step of ultraviolet.

4 Conclusion

Accurate smart control power models are important for the operation and control of power grid as they ensure the supply of accurate and stable electrical power to consumers. The main task of the smart control systems is to allow the power utility to generating the power with good quality. There are a number of previous researches focused on the structure of different types of smart control power models, the challenge remains to design and apply it in the real time.

In this study, five PQPs forecasting systems designed and tested, using data set from off-grid system. The input variables fed directly to decision tree with one target output. The planed model taken low computation time. The forecasted results can be used to shifting the load to run in switch time, and the study showed the influence of input variables on PQPs.

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Analysis of the Time and Workforce Required for Substation Maintenance

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Abstract. Maintenance optimization is a very important topic in electrical networks, especially in terms of reliability on one side and cost reduction on the other side. Since the distribution network has to be reconfigured for every scheduled maintenance task, it costs the time of dispatchers, common workers, etc. Therefore proper use of planned time and prepared workplace should be considered. Additionally, in the Czech environment, maintenance tasks are divided into two categories – safety and reliability, where technical standards specify safety-related tasks, and therefore, it is not possible to change the intervals easily. According to the described problems, the paper presents a part of current student's research in maintenance optimization topic - an analysis for planning maximum utilization of planned interruption of operation of a substation, or its part. A common distribution network substation was selected for a pilot and investigation of possible maintenance options in collaboration with local distribution system operator.

Keywords: Electrical Networks, Maintenance, Optimization.

1 Introduction

One of the possibilities for optimizing maintenance in electrical networks is the unification of intervals for performing works in substations or their parts. In principle, this involves planning maintenance by individual functional blocks, while maximizing the tasks performed and the appropriate number of workers. Coordination of such tasks can be challenging, especially in terms of individual work procedures and division of activities into reliability and safety (according to the relevant valid technical standards). At the same time, with proper planning and organization, it is possible to reduce the time required to reach the workplace and also the actions that are performed before the start or end of maintenance works (preparation of material or workplace, etc.).

2 Substation Description

A common substation in the 22 kV network was selected for the analysis. It is a two-floor building situated at the town limits with MV bushings located on the second floor, where is located the rest of the MV elements for network interconnection. Due to the design solution, it is not possible to maintain safety distances to define only a part of the workplace, but the entire substation must be disconnected from the network and grounded. In this case, the distribution network in the area must be completely reconfigured to maintain flawless electricity distribution for all consumers. Six MV lines are terminated in the substation, which correspond to the six sections with circuit breakers (AVA01 - AVA06), and the measurement section (AVA07). The lightning arresters of each line are located outside; the rest of the substation equipment is located indoors.

Fig. 1. Single-line substation diagram

Fig. 1 depicts a single-pole substation diagram with the model specification for each MV element (with years of production for switchgear). Table 1. lists all elements.

Table 1. List of elements of one section of substation

unit	count	model
circuit breaker	1	ABB-EJP VF 25-12-16
discloser	2	SEZ OM30
voltage transformer	1	ABB-EJP TJP6
current transformer	1	ABB-EJP TP60.1
lightning arrester	1	Raichem HDA24N
protection unit	1	Siemens Siprotec 7SJ85

3 Input Data

For the substation equipment, it is possible to determine the minimum time required for individual activities independent of external conditions. Due to the low complexity (estimated time), elements with an interval of 96 months (instrument transformers and busbars) will also be considered for maintenance at intervals of 48 months. Wear cannot be expected for these elements by performing maintenance at shorter intervals. For each element, there are tasks specified in the Czech Technical Standards as safety tasks which means those must be performed.

Times in tab. 2 were obtained in consultation with the employees of the distribution system operator. This is only an estimate based on experience.

Table 2. Time needed for performing required tasks

task	time needed (hours)
substation preparation	3
network reconfiguration	10
one section/one worker	ca. 30
substation/six workers	ca. 14
circuit breaker diagnosis	ca. 7.5 (workday)

For the purposes of this analysis, only elements not subject to maintenance by the diagnostics department are considered for maintenance, or they are solved as separate activities with the necessary assistance of a maintenance worker. When planning, it is necessary to assign tasks so that individual employees (and departments) do not commit themselves, but it is possible to use a secured workplace. This is an important condition and limitation in the case of this station because due to the spatial disposition, it is not possible to place diagnostic equipment in the station premises and, at the same time, perform maintenance (even of non-diagnosed elements).

4 Evaluation

The analysis is a functional dependence limited by the number of currently available sections (secured workplaces), workers, and time intensity of the sum of necessary / assigned tasks. Tab. 4 shows this dependence based on the obtained data.

Initial conditions/assumptions of evaluation:

- The most efficient number of employees to complete the task in the shortest possible time is six (current state), maintenance can no longer be performed faster;
- More than six workers are available at a given time required for the maintenance of the entire substation (work on other tasks and places in the network);
- The station was handled and secured in advance.

From the obtained data, the dependence described by the following equations can be deduced:

$$f(1) = t_{pole} \cdot n_{prac} \quad (1)$$

$$f(2) = t_{pole} \cdot n_{prac} - \frac{t_{pole} \cdot n_{prac}}{2} 0.8 \quad (2)$$

$$\vdots$$

$$f(n) = f(n-1) - \frac{f(n-1)}{2} 0.8 \quad (3)$$

where: $n \leq n_{prac}$; $n \in \mathbb{N}$

t_{pole} is the time required for the maintenance of one section / workplace

n_{prac} is the number of available / considered workplaces

n is the number of considered workers

Table 3. Evaluation of needed time for maintenance

workers	section	substation		
	hours	hours	workdays	
			acc.	rounded
1	30.00	180.00	24.00	24.0
2	18.00	108.00	14.40	14.5
3	10.80	64.80	8.64	9
4	6.48	38.88	5.18	5.25
5	3.89	23.33	3.11	3.25
6	2.33	14.00	1.87	2
7	2.33	14.00	1.87	2

Fig. 2. Evaluation of needed time for maintenance

The number of workplaces is determined by the available space and workplace security options - in this case the entire station - and by network reconfiguration. This limit is reflected in the inefficiency of the allocation of more than six employees (fig. 2).

The evaluation of the above results in the following limits:

- number of workplaces (available area/secured field/...)
- number of available staff
- length of working hours (and possible transfer to a new workplace - tasks shorter than about half of working hours are likely to be inefficient)

5 Conclusion

The proposed analysis can be applied with the appropriate setting of internal communication, assignment of employees, etc. It requires appropriate tools for planning in the individual steps of scheduling and assigning work. It might contribute to the optimal use of employees, where the planning of individual tasks can be divided on the basis of work procedures.

In order to verify and possibly refine the methodology, it is necessary to perform an analysis of another, at least partially similar, substation. Moreover, in general, consult the outputs of prepared works with distribution system operator employees for securing relevant conclusions applicable in real condition.

Further research on this topic will be performed.

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PowerLine Communication in the Off-Grid

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Abstract. Two ways of communication are proposed in this paper, wireless and wired represented by PowerLine Communication (PLC). Two types of appliance (ordinary, smart) and two ways of communication give 4 concepts. Concept of ordinary appliances and PLC is selected to be investigated, because reliable communication is necessary for proper operation of an Off-grid system driven by demand response based control system. For such control system it is vital to have information what appliances are connected and running. And in case of smart appliance it is important to know whether is allowed to start operation. Off-Grid and its control system is described first, then are selected, tested and analysed communication parameters of the network created by PLC. Different appliances were running during testing to investigate their impact on these communication parameters.

Keywords: Off-Grid, Power Quality, PowerLine Communication

1 Introduction

Recently, there is substantial growth of electric vehicle (EV) deployment, both in local and global measure [1]. Such growth supported emergence of new ideas how to utilize EV batteries in non-traditional ways [2], [3]. Example of such technology is Vehicle to Home (V2H) and its principle is to supply energy to home appliances from EV batteries. Ways of V2H implementation differs in scale of EV utilization. Implementation ranges from EV acting as an UPS [4] over peak demand load shaving [5] to Off-Grid's primary accumulation system.

Currently developed test platform of V2H technology is based on Off-Grid system located in VSB-Technical University of Ostrava. Power quality (PQ) and other electric parameters are monitored in the test platform during various operating conditions testing.

At the moment, each appliance and its characteristic load is assigned to specific socket. Therefore every appliance must be connected to the right socket otherwise control system will not be able to properly manage load in the Off-Grid. Such limita-

tion is inconvenient for daily use of appliances that are regularly connected to different sockets. This was the stimulus to investigate communication between control system and appliances, which will allow user to connect appliances anywhere to the system and control system still will work properly.

In this article, PoweLine communication (PLC) between control system and ordinary (not smart) appliance is investigated. Brief description of Off-Grid system and its components is given first. Then a model day is used to describe operation of control system. Next, four cases of communication between control system and ordinary/smart appliance are proposed. Last, test results are given and discussed.

2 Test platform description

Fig. 1 shows electric scheme of Off-Grid system with connected EV which will serve as test platform for communication. Main unit of Off-Grid system is hybrid inverter Schnieder Conext XW+ 8548 with 6.8 kW rated power. Accumulation is formed by 40 series connected Ferak KPL 375 NiCd batteries with capacity 375 Ah and 1.2 V rated voltage. Off-Grid is supplied by renewable energy sources (RES). These RES are two photovoltaic panels (mono- and polycrystalline) each 2 kWp

Fig. 1. Test platform electric scheme

connected to the solar charge controllers Xantrex XW MPPT 80 600 which are DC coupled to the Off-Grid. Control system driven Quido I/O module is used to physically control appliance switching. Number of typical household appliances are present and connected to the system, those that are missing are substituted by programmable

electronic load. Programmable electronic load has maximum power of 4 kW with step 100 W and 5 options of power factor (1, 0.95 C or L and 0.5 C or L).

Control system algorithm active demand side management (ADSM) is based on demand response (DR). Generally, DR is load management with goal to match energy production. ADSM's control of appliance switching is based on following factors: remaining energy in batteries, prediction of energy consumption and generation.

3 Communication between control system and appliances

Concept is that every appliance plugged in the Off-Grid system also communicates with control system. Appliance will inform control system about its parameters: rated load, energy consumed over operation cycle (washing machine etc.). First parameter is directly connected to the rated power of hybrid inverter which cannot be exceeded by total load. Then, second parameter allows to calculate if is or will be enough energy in Off-Grid to finish whole operating cycle. Those are crucial information for control system with ADSM.

There are 2 options how to transfer information - over wire represented by PLC and wireless by Wi-Fi. Next factor is type of appliance - ordinary or smart. Ordinary appliance is every appliance which isn't able to communicate with control system itself and to do so requires additional module. Additional module is for example any single-board microcontroller.

Case of PLC and ordinary appliance is investigated further. Appliances may affect PLC, because section of conductor used to supply power to the appliance is also used for data transmission.

PLC uses digital modulation to carry data on a conductor whose primary purpose is to supply energy into appliances and its principle of function is very similar to the wireless one. Orthogonal frequency division multiplexing (OFDM) is digital modulation encoding data on multiple carrier frequencies used for data transmission in lowest layer of ISO/OSI model. Phase shift keying (PSK) is adaptively applied to each carrier based on the channel characteristic between transmitter and receiver. Data transmission is designed in such manner that the frequencies in power line with high noise are eliminated. This feature is similar to the ADSL. Thus, it is expected that transmission quality depends on distance and level of noise. Higher background noise in Off-Grid system is expected because even its main power source hybrid inverter is source of higher harmonics. One of the latest standards is HomePlug AV2 from year 2011. Standards allows theoretical speed of 1900 Mbit/s, carriers from 1.8 to 86.13 MHz are used for communication [6].

4 Experiment description

In this paper, we are testing case of Ordinary appliance – PLC. Experiment was performed in the Off-Grid system. To ensure experiment repeatability PLC was performed between two PCs (Raspberry Pi) and Off-Grid system was powered only by batteries. Batteries were fully recharged before each measurement. Fig. 2 shows

experiment block scheme, appliance was connected to the same socket as one of PLC adapters. PLC adapters were TP link TL-PA4010 whose technical specifications are given in Table 1.

Table 1. Technical specifications TP-TLPA4070 [7]

Plug Type	EU, UK, US
Standards and Protocols	HomePlug AV, IEEE802.3, IEEE802.3u
Interface	1*10/100Mbps Ethernet Port
Power Consumption	Max.: 4.60W (220V/50Hz) Typical: 4.26W (220V/50Hz) Standby: 0.88W (220V/50Hz)
Range	300 m in house

Fig. 2. Experiment block scheme

Power quality was measured by SMC KMB 144 device which is located at the power source (hybrid inverter). In case of measurement with 100 m extension cord, KMB 144 is in the middle because two 50 meter extension cords of 1.5 mm² cross-section were used. Both PCs were equipped by network card 100 Mbit/s, with Linux/Debian operating system. One PC had installed TFTP server and second PC had TFTP client. File of size 50 MB was created in the root folder of the server PC. First test was transfer on localhost to examine if the data reading from disk doesn't add significant error to whole measurement.

5 Results

Localhost transfer of 50 MB file took 0.93 s which is short in comparison with times of transfer over LAN and thus negligible. Following measurements were transfers over LAN.

Six different appliances were separately operating during the file transfer to investigate appliance effect on data transfer speed. PQ parameters were aggregated into average values over time of file transfer. Effect of power line length was also tested. Once, length was 5 m and results are given in Table 2. Table 3 shows results with 100 m extension cord. Based on results shown in Fig. 3, we can say that tested PLC adapters are designed to be used on longer distances than a few meters, because such short distances can be easily covered by ordinary Ethernet cable. Only case with lights turned on contradicts this statement.

Table 2. Results for power cord length 5 m

Parameter	N/A	Kettle	Inductive cooker	Vacuum cleaner	Microwave oven	Lights	Drill
U_{avg} (V)	224,5	229,2	226,1	228,3	225,5	224,4	226,7
I_{avg} (A)	0,394	4,352	5,06	4,631	2,261	0,616	2,408
S_{min} (VA)	87	994	296	1052	102	138	539
S_{avg} (VA)	88	997	1105	1057	513	138	546
S_{max} (VA)	95	1003	1956	1063	1418	142	554
Power Factor _{avg} (-)	0,657	0,998	0,957	0,987	0,896	- 0,697	0,966
$P_{inst_{avg}}$ (-)	5,315	1,617	5,258	2,565	3	2,24	0,829
THDV _{avg} (%)	2,5	4,3	3,7	3,6	3,7	2,5	3,2
THDI _{avg} (%)	50,5	7,1	13,2	17,5	37,0	41,4	31,1
Time (s)	394	380,6	383,6	363,8	358	396,8	371,6
Speed (Mbit/s)	1,04	1,076	1,068	1,126	1,144	1,032	1,103

Table 3. Results for power cord length 100 m

Parameter	N/A	Kettle	Inductive cooker	Vacuum cleaner	Microwave oven	Lights	Drill
U_{avg} (V)	224,4	229,1	226,2	224,4	225,5	224,4	226,7
I_{avg} (A)	0,424	4,192	5,072	0,424	2,178	0,606	2,323
S_{min} (VA)	94	957	166	1014	99	135	452
S_{avg} (VA)	95	960	1149	1019	494	136	527
S_{max} (VA)	99	965	2070	1030	1384	141	681
Power Factor _{avg} (-)	0,62	0,997	0,96	0,988	0,905	- 0,691	0,966
$P_{inst_{avg}}$ (-)	1,954	3,393	2,344	4,581	3,66	2,389	0,441
THDV _{avg} (%)	2,6	4,3	3,7	3,6	3,5	2,4	3,2
THDI _{avg} (%)	50,0	7,4	13,6	16,8	37,5	41,9	27,2
Time (s)	360,2	365,1	364,4	354,7	357,3	433,1	366,7
Speed (Mbit/s)	1,137	1,122	1,124	1,155	1,146	0,946	1,117

Fig. 3. Total transfer time for both cases

6 Conclusion

Test of PLC in the Off-Grid was performed with aim to investigate effect of an appliance on communication. Experiments of 50 MB file transfer between two PCs Raspberry PI during different conditions were performed. Different conditions (power quality parameters) were caused by various appliances connected to the Off-Grid and running. First was measured localhost transfer with result 0.93 seconds, such value is small compared to time of LAN transfers. Transfer was generally faster or at least same in case with 100 m power grid. However, this doesn't apply to the lights, possible cause is their capacitive power factor. Actually, case with running lights and 100 m power cord achieved slowest transfer which took 433 seconds.

From results in Table 3 and Table 4 we can say that there is no direct connection between any PQ parameter and transfer time. Such result is explained by operating frequency of PLC adapter which is in MHz.

This type of communication proved to be stable. Results are more than satisfactory for our needs of simple communication.

Future work lies in testing narrowband PLC operating in CENELEC band (3 – 148.5 kHz) might be more affected by PQ parameters, especially total harmonic distortion. Therefore, another noise source is hybrid inverter working in lower part of its power spectrum. Future work also lies in testing PLC with numerous PLC adapters connected and communicating.

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MCA methods for assessing the reliability of PV connections to the distribution system

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Abstract. This article deals with the use of multi-criterial analysis to determine the reliability of the photovoltaic system connection to the distribution network. The first part defines the fault variants that affect the reliability of the connection and the supply of electricity to the distribution network. These variants, i.e. unreliability options, will be evaluated according to the criteria chosen and the weights assigned to them, which are subjectively assigned according to the actual severity of the same variant and criteria. In the second part, the three methods of calculation will be used by a multi-criteria analysis for the monitored photovoltaic power plant and the actual data of the outages on the PVP will be evaluated.

Keywords: reliability, insulation resistance, multi-criteria, analysis, method

1 Introduction

As the name implies, this method makes it possible to evaluate each variant with several criteria and to determine which variant of the power failure to the distribution network is the most serious and which is the least serious. We can assemble the order from the highest to the smallest reliability of the delivery. For this method of calculation, you must first build the base array of variants and install the actual downtime data. Then, according to the selected multi-criteria method, we calculate the degree of reliability of the given photovoltaic system.

2 Variants affecting Reliability to connect the Photovoltaic System's to the Distribution Network

The reliable day-to-day connection of the PV system to the distribution network can be influenced by several factors that are subject to the aforesaid inspections. The factors influencing reliability can be defined:

- **Low insulation state of the system**-when the insulation monitoring device of the solar PV system does not allow connection to a central or a local inverter to the network. If the system reports such fault, we have to assess how to detect it effectively. The most frequent cause of decreased reliability is either defective or inappropriate DC cabling that is not suited for placing in water and burying in the ground.

- **Mechanical wear of power parts and servo drives**-this variant is represented primarily by power disconnectors both on the AC side and on the DC side.

They are electromechanical devices consisting of knife contacts, which sets in motion the electromechanical unit that is most strained and is most vulnerable

- **Custom power supply failure**- there may be several causes of a power failure, a fault in the self-consumption transformer, a faulty battery in the UPS, or only automatic disconnection due to overvoltage on the mains. Here it is almost always enough to reconnect the disconnected power supply, thus the power supply of the control circuits of the central inverter is restored and the production and delivery to the distribution network starts.

- **High voltage asymmetry**-voltage and overcurrent protection located in the production station of the PVP disconnects the production from the distribution network due to its immediate unsymmetry) or unfavourable conditions on the distribution network (short circuit and thus overcurrent and undervoltage). These quality monitors of the distribution network, as well as the energy produced, which should continue to travel to the distribution network, are usually subject to regular checks according to the MPP in four-year periods [3]

3 Assessment of power failures to the MCA method assistance distribution network

The general MCA procedure for evaluation of variants can therefore be defined by establishing a system of criteria-variants, setting weights of criteria, establishing model criteria, partial evaluation of variants, risk assessment, selection of the most appropriate variants, and by sorting variants according to reliability.

According to the principle of calculation, we divide the methods of multi-criterial analysis (MCA) by maximizing the utility, minimizing the distance from the ideal variant and evaluating variants based on the preferential session. In this case, we used the first two methods to assess reliability and evaluation.

We summarize the above variants:

- a_1 -low insulation state,
- a_2 -mechanical wear of power parts,
- a_3 -failure of own power supply,
- a_4 -high voltage asymmetry

Selection of balances of criteria (variants)

The selected criteria f are listed below in Table 1. Criteria :

- f_1 -Production losses in MWh (min),
- f_2 -Operating costs for service in 10 ths (min),
- f_3 -number of working forces to service (min),
- f_4 -time of failure in hour

For the owner or investor of the PV plant, the most important is the economic factor. In this case, these are the cost of loss of production and operating costs. This is related to the question of reliability, the number of manpower to eliminate the fault and the time of failure.[2] Table No.1 also lists the individual weights of the criteria that we have compiled from our subjective feeling and with the help of the owner of the PV.

Table 1. Criteria

Criteria Scales	0,35	0,26	0,21	0,18
Criteria	$f_1 = \min$	$f_2 = \min$	$f_3 = \min$	$f_4 = \min$
Variants	Loss in production (MWh)	Service costs (10000 CZK)	Number of workers	Downtime (hours)
a_1	100	20	4	24
a_2	300	10	2	72
a_3	33	4	2	8
a_4	20	10	2	5

Choosing MCA methods

To calculate the reliability of the energy supply from the photovoltaic power plant to the distribution network, we have chosen the following three methods:

- A) WSA- Weighted Sum Approach
- B) IPA- Ideal Points Analysis
- C) TOPSIS - Technique for Order Preference by Similitary to Ideal Solution

3.1 Method WSA-Weighted Sum Approach

This method uses the principle of maximizing utility, but only if the linear function of utility [1]

Criteria matrix (1)

	f_1	f_2	f_3	f_4
a_1	100	20	4	24
a_2	300	10	2	72
a_3	33	4	2	8
a_4	20	10	2	5

(1)

Criteria matrix after finishing (2)

Selection-Worst Values	300	20	4	72
	f_1	f_2	f_3	f_4
a_1	200	0	0	48
a_2	0	10	2	0
a_3	267	16	2	64
a_4	280	10	2	67

(2)

Maximum H and minimum D values from each column f (3)

$$H = \begin{pmatrix} 280 & 16 & 2 & 67 \end{pmatrix}$$
$$D = \begin{pmatrix} 0 & 0 & 0 & 0 \end{pmatrix}$$

(3)

Normalized criteria matrix (4)

	f_1	f_2	f_3	f_4	
a_1	0,71	0,00	0,00	0,72	(4)
a_2	0,00	0,63	1,00	0,00	
a_3	0,95	1,00	1,00	0,96	
a_4	1,00	0,63	1,00	1,00	

Normalized criteria matrix with criteria scales (5)

	f_1	f_2	f_3	f_4		
v	0,35	0,26	0,21	0,18		after sorting
a_1	0,250	0,000	0,000	0,129	$u(a_1) = 0,38$	1. $u(a_3) = 0,98$
a_2	0,000	0,163	0,210	0,000	$u(a_2) = 0,37$	2. $u(a_4) = 0,9$
a_3	0,334	0,260	0,210	0,172	$u(a_3) = 0,98$	3. $u(a_1) = 0,38$
a_4	0,350	0,163	0,210	0,180	$u(a_4) = 0,9$	4. $u(a_2) = 0,37$

In conclusion, the maximum value of the benefit is achieved by the a_3

3.2 Method IPA- Ideal Points Analysis

The criteria matrix, criterion matrices after modification and normalized criteria matrix are the same as for the WSA method [1]

Normalized criteria matrix with criteria scales

	f_1	f_2	f_3	f_4		
v	0,35	0,26	0,21	0,18		after sorting
a_1	0,100	0,260	0,210	0,051	$u(a_1) = 0,62$	1. $u(a_3) = 0,02$
a_2	0,350	0,098	0,000	0,180	$u(a_2) = 0,63$	2. $u(a_4) = 0,1$
a_3	0,016	0,000	0,000	0,008	$u(a_3) = 0,02$	3. $u(a_1) = 0,62$
a_4	0,000	0,098	0,000	0,000	$u(a_4) = 0,1$	4. $u(a_2) = 0,63$

In conclusion, the minimum value of the benefit is achieved by the a_3

3.3 Method TOPSIS - Technique for Order Preference by Similarity to Ideal Solution

The criterion matrix [1][4]

- is the same as for WSA and IPA method according to formula (1)

Normalized criterion matrix (8) is according to the formula (7)

$$r_{ij} = \frac{y_{ij}}{\sqrt{\sum_{i=1}^p (y_{ij})^2}} \quad (7)$$

	f_1	f_2	f_3	f_4
a_1	0,313899	0,805823	0,755929	0,313813
a_2	0,941698	0,4029115	0,377964	0,941438
a_3	0,103587	0,1611646	0,377964	0,104604
a_4	0,06278	0,4029115	0,377964	0,065378

(8)

Weighted criterion matrix (9)

	f_1	f_2	f_3	f_4
v	0,35	0,26	0,21	0,18
a_1	0,240	0,050	0,051	0,124
a_2	0,020	0,155	0,131	0,011
a_3	0,314	0,218	0,131	0,161
a_4	0,328	0,155	0,131	0,168

(9)

maximum H and minimum D values from each column f (10)

$$\begin{aligned}
 H &= (\quad 0,328 \quad 0,218 \quad 0,131 \quad 0,168 \quad) \\
 D &= (\quad 0,020 \quad 0,050 \quad 0,051 \quad 0,011 \quad)
 \end{aligned}$$
(10)

Variant distance from ideal variant (11)

	d_i^+	d_i^-	c_i
a_1	0,210	0,247	0,4595
a_2	0,351	0,131	0,72776
a_3	0,016	0,378	0,04041
a_4	0,063	0,370	0,14527

$$d_i^+ = \sqrt{\sum_{j=1}^k (w_{ij} - H_j)^2}$$

$$d_i^- = \sqrt{\sum_{j=1}^k (w_{ij} - D_j)^2}$$

$$c_i = \frac{d_i^+}{d_i^+ + d_i^-}$$

after sorting

1.	$u(a_3) = 0,04$
2.	$u(a_4) = 0,15$
3.	$u(a_1) = 0,46$
4.	$u(a_2) = 0,73$

11)

The minimum distance from the ideal variant is the a_3 variant according to this method.

4 Conclusion

In this project, we evaluated the help of multi-criteria analysis of the MCA, which of the four possible variants of failures is the worst or most favorable in the selected model of the selected model. Initially, we selected variants of faults that can cause power supply to be interrupted to the distribution network. We have chosen these variants – low insulation state of the system, mechanical wear of power parts, failure of the power supply and non-symmetry of the VN distribution network, which together with the undervoltage and overcurrent protection of the photovoltaic power plant will cause the photovoltaic production to disconnect the photovoltaic power plant from the distribution network. This is closely related to the time of downtime, staffing in the event of intervention, loss in MWh and the cost of service intervention.

For comparison, we chose multi-criteria methods WSA, IPA and TOPSIS.

The first method WSA (weighted Sum Approach) consisted in finding the maximum value of the benefit, which came out for variant a_3 , where we can conclude that the failure of the power supply itself has a minimal effect on the reliability of the supply of energy to the distribution network compared to the wear of mechanical parts of the power switches listed as variant a_2 representing the highest risk.

The second Ideal Points Analysis (IPA) method is similar to the WSA method, except that the lowest value in the list of variants is the best value. The a_3 variant was released, which ultimately represents the same results as the WSA variant, i.e. again the least risk is for the a_3 variant and the highest for the a_2 variant.

The third method of TOPSIS - this method consists in minimizing the distance from the ideal variant. The ideal option-all criteria values achieve the best values. The result for this method again indicates the best a_3 variant, and the highest risk for the a_2 variant, which is the mechanical wear of the power part. It should be added that the scales to the criteria were assigned on the basis of our subjective estimate from practice. With a different weight distribution, the results could be slightly different. Therefore, we tried to confuse the importance between a_2 and a_4 criteria for the WSA method and were given a standardized criterion matrix in the form (12):

	f_1	f_2	f_3	f_4		after sorting
v	0,35	0,18	0,21	0,26		
a_1	0,250	0,000	0,000	0,186	$u(a_1)= 0,44$	1. $u(a_3)= 0,97$
a_2	0,000	0,113	0,210	0,000	$u(a_2)= 0,32$	2. $u(a_4)= 0,93$
a_3	0,334	0,180	0,210	0,248	$u(a_3)= 0,97$	3. $u(a_1)= 0,44$
a_4	0,350	0,113	0,210	0,260	$u(a_4)= 0,93$	4. $u(a_2)= 0,32$

(12)

The calculation shows that the result has not changed, the show is the safest variant a_3 and the variants with the greatest risk remain variant a_2 .

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Computational-performance Analysis of the Pandapower Implementation of the Newton-Raphson Method for AC-power-flow Analysis Solution

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Abstract. The AC-power-flow analysis is a basic tool for the description of an electrical network's steady state. It provides a lot of valuable information about an electrical network (values of node voltages, power lines currents or power losses at individual network elements). There are some pieces of power-system control software that need to be able to perform AC-power-flow analysis in a very short time (e.g. software controlling a power system in real-time). Nowadays, there are many methods for the AC-power-flow analysis solution. However, individual methods differ in computational efficiency and robustness. This paper focuses on one of these methods: the Newton-Raphson method (N-R). This paper presents the study that analyzes the computational efficiency and robustness of the implementation of the N-R in the pandapower software. The pandapower implementation of this method was tested using a set of tests with (10x10)-node meshed electrical network model of various topologies. Test results show that the pandapower's N-R implementation is very efficient regardless of the topology, but it is not robust, and the value of its convergence success-rate strongly depends on the current network topology.

Keywords: AC-power-flow analysis, pandapower, Newton-Raphson method, Computational efficiency, Computational robustness

1 Introduction

The AC-power-flow (or AC-load-flow) analysis is the basic component of the analysis of an AC power system's steady-state, and the AC-power-system design. It is necessary for the optimal planning of future expansion, optimal control, economic scheduling, and optimal management of a power system of any type and any voltage level. In addition, the AC-power-flow analysis is required for many other analyses such as transient stability and contingency studies [1]. The form, inputs, and outputs of the mathematical system for the AC-power-flow analysis of an electrical network is detailed in [2]. Since the AC-power-flow equations are non-linear, it is necessary to use iterative numerical methods to find the system unknowns' (approximate) true final values. There are several iterative numerical methods capable of finding AC-power-

flow equations solution, e.g. the Newton-Raphson method (N-R), the Gauss-Seidel method, or the Fast-decoupled load-flow method. Since the algorithms of these methods differ greatly from each other, their computational efficiency and robustness greatly differ too and the different methods achieve their highest computational performance with different types of electrical networks [1].

Today, when a researcher, power system designer, or power system operator needs to perform an AC-power-flow analysis of a power system, he no longer has to describe the power system using mathematical equations but can describe it using a model created in AC-power-system analysis software. Such software is equipped with a user interface that allows its user to create the power system's model in a fast and user-friendly way. The analysis and tests for this paper were performed in the pandapower software. Specifically, in this software, there was studied the local implementation of the N-R, which is the pandapower's default iterative numerical method for AC-power-flow analysis. The detailed description of the algorithm and strategy of the N-R can be found in [1]. The pandapower was chosen for this study because currently, the power system research community pays big attention to this software and it is being developed extensively. Thanks to its many advanced features (e.g. it can use the innovative numba functions or the parallel computing), the pandapower outperforms other AC-power-flow analysis software in terms of computational efficiency [3]. The detailed description of the pandapower is presented at [3] and in [4].

The remainder of this paper is organized as follows. Section 2 describes the tests performed and the test electrical-network model, Section 3 presents the results of the tests and Section 4 discusses the study's findings and concludes the paper.

2 Description of Tests Performed

To analyze the computational efficiency and robustness of the pandapower implementation of the N-R, extensive testing was performed. The version of the pandapower used was 2.1.0. The calculation of test tasks was performed on a computer equipped with an Intel Core i5-7400 CPU @ 3.00GHz processor, RAM with a capacity of 8GB, and the Windows 10 Education operating system.

In all tests performed, the same test network model was used (i.e. its basic structure and parameters were the same for all tests), but in each individual test, a unique network topology was used. Each network topology used was described by a combination of power-line sections that were switched off here.

A total of 150 test sets were used. The individual test sets differed from each other only in the number of the test network model's power-line sections that were switched off there, so, in the first set, network topologies with a power-line section switched off were tested, in the second set, network topologies with two power-line sections switched off were tested, and so on. Each test set consisted of 100 tests. The individual tests within a test set differed from each other only in the exact appearance of the combination of power-line sections switched off. Thus, in the n -th set, 100 unique network topologies with n power-line sections switched-off were tested, and across a series of test sets, n went from 1 to 150. Thus, a total of 15,000 unique tests were

performed. Since the test network model consists of a total of 180 power-line sections and it was necessary to keep a sufficient part of the network model in operation during each test, the maximum value of the number of power-line sections switched off was set at 150.

The definition of the combinations of switched-off power-line sections for individual tests was created by a random-number generator using a uniform probability distribution. Here each power-line section was represented with a special number (you can see these numbers next to power-line sections marks in Fig. 1). Within a test set, if two or more combinations generated had described the same network topology, one of those combinations was retained and the other ones were replaced with new ones.

Each individual test was performed as follows: the test network model was set to the topology that should be tested now, then an AC-power-flow analysis of the model was performed and finally, the current computation time was entered the computation-time database (the value entered described the computation time in seconds; the time spent for editing internal pandapower data before and after the AC-power-flow problem solution process was not included in this value). The individual AC-power-flow problem computation processes were terminated when the tolerance was reached (the tolerance was set so that the difference in the node-apparent-power magnitude must be lower than 10^{-6} for any network node) or when the limit of the maximum allowed number of iterations was reached (this limit was set to 100).

In its basic configuration, the test network model consisted of 100 0.4-kV and 2 22-kV nodes (these 22-kV nodes were set as reference nodes), 2 transformers (each one connects one 22-kV node with one 0.4-kV node), and 180 power-line sections. Transformers were modeled by the t-equivalent model and power-line sections were modeled by the pi-equivalent model. Each power-line section is realized by cable CYKY 4x50 mm² (the capacitance: 0 F/km, the series resistance: 0.387 Ω /km, the series reactance: 0.076969 Ω /km). The length of each power-line section is 0.1 km. One active and reactive power consumer is connected in each low-voltage node (there is an exception: in case of the two 0.4-kV nodes where the transformers are connected, there is no power consumer connected to them). The power consumption of each consumer is $P = 6$ kW, $Q = 1$ kvar. A Python-script with a detailed description of the test network model's basic configuration is published at [5]. Fig. 1 shows the scheme of the test network model's basic configuration.

Fig. 1. Scheme of the test electrical-network model

3 Test Results

The value of the AC-power-flow problem computation time was the only output data from the individual tests performed. If the solution process reached the limit of the maximum allowed number of iterations, the number 1000 entered the computation-time database as the value of the current computation time. Later, during data post-processing, the number 1000 in the database was read as a state where the AC-power-flow problem solution process did not achieve a result with the set tolerance within the set iteration limit (i.e. the true final result).

The processed data are presented in Fig. 2 and Fig. 3. The structure of Fig. 2 is inspired by the structure of the box plot: this figure shows the zero, first, second, third, and fourth quartile of the computation-time data of individual test sets. Fig. 3 shows the convergence success-rate measured, it means the number of tests (or the number of network topologies) that reached the true final result within individual test sets divided by the total number of tests within individual test sets.

All measured data are published at [5].

Fig. 2. The zero, first, second, third, and fourth quartile of the computation-time data of individual test sets; the first and third quartile values are presented by the blue lines, the second quartile values are presented by the red line, and the zero and fourth quartile values are presented by “+” signs

Fig. 3. The convergence success-rate of the AC-power-flow analysis process of individual test sets

4 Discussion and Conclusion

This paper presents the results of a study that analyses the computation efficiency and robustness of pandapower implementation of the N-R, which is the default AC-power-flow analysis solution method in the pandapower software. The pandapower's N-R implementation was subjected to extensive testing: 15,000 tests were performed. In all the tests, the (10x10)-node meshed electrical network model was used, but in each individual test, unique network topology of the network model was used.

The study results presented in Section 3 show that the pandapower's N-R implementation is very efficient regardless of the topology. Considering the results of all tests performed except the ones where the AC-power-flow analysis solution process did not converge to the true final solution, the sum-up statistics of the measured computation time say follows: The median of the computation time was 944.5 μ s. The minimum value was 289.1 μ s (it was for a network topology with 116 power-line sections switched off) and the maximum value was 4,033.5 μ s (it was for a network topology with 42 power-line sections switched off). The statistics focusing on the differences between individual test sets say that the lowest value of the median (521.4 μ s) was observed for a set of network topologies with 150 power-line sections switched off (with respect to the dynamics of this quantity observed in Fig. 2, it is probable that an even lower value of the median would be achieved if network topologies with more power-line sections switched off than 150 were also examined), and the highest value of the median (2,283.3 μ s) was observed for a set of network topologies with 48 power-line sections switched off.

The results of the computational robustness analysis are presented in Fig. 3 using the convergence success-rate parameter. For a set of tests, the value of this parameter equals to the ratio of the number of AC-power-flow analysis processes that converged to the true final value to the total number of the AC-power-flow analysis processes performed. Fig. 3 clearly shows that the convergence of the pandapower's N-R implementation is not robust and the value of its convergence success-rate strongly depends on the current network topology. Convergence success-rate reaches its highest values for those network topologies where the number of power-line sections switched-off is low (it is in the interval between 1 and 13) or where the number of power-line sections switched-off is large (it is in the interval between 125 and 150). For these numbers of power-line sections switched-off, the convergence success-rate reaches 100%. On the other hand, it reaches the lowest values for those network topologies where the number of power-line sections switched-off is in the interval between 62 and 76. For the numbers of power-line sections switched-off over this interval, the convergence success-rate equals only around 30%. Its minimum value is 24% and this value is reached when the number of power-line sections switched-off equals 69.

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Induction motor drive with RF-MRAS speed observer based on a neural network

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Abstract. This paper presents the results of our research on the use of artificial neural networks for sensorless control of induction motor drives. The conventional rotor flux MRAS speed observer suffers from parameters sensitivity and pure integration which limits the performance at low and zero speeds. This can be improved by replacing the voltage model with an artificial neural network. An offline-trained feedforward artificial neural network with one hidden layer was designed to replace the voltage model. The neural network-based observer is experimentally compared with the conventional MRAS scheme. The experimental results show that the use of a neural network improves the speed estimation performance.

Keywords: Artificial neural network (ANN), Rotor flux model reference adaptive system (RF-MRAS), Sensorless control, Field-oriented control (FOC), Induction motor.

1 Introduction

Induction motor is the most common type of electric motor employed in industry due to its low maintenance requirements, reliability, simple construction and relatively low cost. This is especially true in the case of the squirrel-cage induction motor, as there are no brushes or slip rings which would wear out. For demanding electrically driven systems, where very high dynamic and the accuracy of regulated quantities are essential, the vector control or direct torque control is applied to control the speed of an induction motor.

Vector control and direct torque control aim to achieve AC drive characteristics comparable to DC drives. This means these methods are supposed to allow the independent control of the torque and excitation (magnetic flux) of an electric machine [1]. The required course of the actual speed is then achieved by controlling these two quantities.

There are two major problems concerning the speed estimation – measurement of quantities and system modeling. Most of sensorless algorithms benefit in some way from the knowledge of the mathematical model of an electric motor [1]. The model comprises of equations, describing the relationship between input and output quantities,

and parameters of these equations, whose values map the general model to a particular system. If the model is known, then the speed of an induction motor can be determined from the measured values of the input quantities. The performance of the used estimation algorithm depends on the accuracy of the model and measured inputs, therefore, measuring as well as modeling is important.

In connection with induction motors, many papers presenting different applications of artificial neural networks in MRAS observer schemes have been published (e.g. [2]–[5]). The presented solution is based on a feedforward neural network that acts as a model of induction motor. A more detailed description can be found in [6] and [7]. The network is offline-trained, which means that a set of training patterns need to be available before it can be trained and applied to a particular drive and later the network is not being adapted during operation.

The network was trained and tested in Matlab using the Neural Network Toolbox. The modified RF-MRAS observer was tested out using an experimental drive equipped with a 2.2 kW induction machine and controlled by a control system which is based on the TMS320F28335 digital signal controller.

2 Sensorless control scheme

The conception of the implemented control structure is shown in **Fig. 1**. In the case of the experimental application, the superior system was an application created using the LabVIEW development environment that allows the user to operate the control system, and thus the whole electric drive. The key element of the structure is the vector control that ensures the actual speed follows the setpoint speed given by the superior system. The output from the vector control is six signals that determine switching of transistors in the frequency converter powering the induction motor with three-phase voltage.

Fig. 1. Simplified block diagram of the sensorless control structure

The last element, which is the scope of this paper, is the MRAS observer that provides the actual (estimated) rotation speed of the induction motor and actual rotor flux. The estimation algorithm receives the actual stator voltage and current of the motor on its

input and calculates the speed of the motor. More precisely, the input values are four – two voltages u_α, u_β and two currents i_α, i_β . The indexes α and β refer to the stator (or stationary) reference frame. The current is obtained by transformation of phase currents i_a and i_b from the three-phase coordinates ABC. The voltage is not measured directly, it is estimated by making use of DC link voltage u_d . It follows that three quantities in total are necessary to be measured: DC link voltage and two phase currents.

3 Designed neural network

There is no general way to design a neural network for a specific application. Most of the available available are usually rules of thumb rather than theoretically derivable principles. Without any prior experiences with the application, the only way is the method of trial and error. Knowledge of the mathematical model is beneficial for the design.

The structure of the network can be seen in **Fig. 2**. It is a fully connected feedforward neural network with eight inputs, a single hidden layer and two output. The number of hidden neurons is twelve, therefore the network is marked as 8-12-2. The expressions z and $z - 1$ denote that two consecutive sets of samples are passed to the network's input. The output is the estimated rotor flux expressed in the stationary reference frame.

Fig. 2. Neural network structure (8-12-2)

4 Experimental Results

Measurements were carried out at a laboratory workplace. The laboratory drive comprised of an induction motor, a loading mechanism (separately excited DC motor), an indirect frequency converter with DC link and the control system. Rated parameters of the induction motor are summarized in this listing: *Power 2.2 kW; Rotor speed 1425 min⁻¹; Torque 14.7 Nm; Stator voltage 400Y/230Δ V; Stator current 4.8 A; Frequency 50 Hz*. The DC link voltage was set to $U_{DC} = 200$ V.

Fig. 3. Experimental results of the RF-MRAS speed observer: $0, \pm 25, \pm 50, \pm 200$ rpm and 0% load

Fig. 4. Experimental results of the ANN-RFMRAS speed observer: $0, \pm 25, \pm 50, \pm 200$ rpm and 0% load

First, it was necessary to measure training patterns that comprised of stator voltage, current and actual speed. The measurement was being performed for 61 seconds for different speeds and loads, a collection of 1220000 patterns was gathered. The network was trained on a set of 5000 patterns that were selected randomly. The used training algorithm was the Levenberg–Marquardt backpropagation algorithm, the training was terminated in the 112th epoch and resulted in the mean squared error $4.7 \times 10^{-4} \text{ Wb}^2$.

5 Conclusion

A laboratory implementation of sensorless induction motor drive utilizing ANN-based MRAS speed observer has been developed. An offline-trained feedforward artificial neural network with one hidden layer is used as the reference model. The experimental results show that the use of a neural network improves the speed estimation performance.

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Implementation of Genetic Algorithm in Control Structure of a DC Motor Drive

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Abstract. This article describes the design and tuning process of a speed PI controller, which is based on the Genetic Algorithm (GA) and it is used for speed control of a DC motor drive. The paper introduces soft-computing methods [1][2][3] that are used for an adaptive control of modern drives, and briefly introduces the principle and properties of GA in the first part. Other parts of the article are devoted to the description of speed PI controller optimization proposal using GA and the influence of various performance indices on the quality of control is performed. The last part is devoted to the analysis of experimental simulations results.

Keywords: Soft-Computing, Genetic Algorithm, PI Controller, PI Controller Tuning, DC Motor Drive

1 Introduction

The use of soft-computing methods in the field of controlled drives is still the subject of intensive research. Most often it is the implementation of various combinations of Artificial Neural Network (ANN), fuzzy logic method and GA used for optimization, estimation and identification of parameters in the electric motor drive structure. Modern control structures often require, in addition to the most accurate mathematical model, the need to adapt the parameters of the model in response to changes of the controlled system parameters influence, of fault signal, changes in operating state of the controlled system, this significantly affects technical parameters of the control process. Controllers must react quickly to these changes and adapt, therefore structures with so-called adaptive controllers are used, which can adapt their settings to new conditions, as well as their structure. Soft computing methods achieved higher control quality compared to the conventional designing method.

However, there is no such thing as a free lunch, implementation of these mentioned control algorithms is quite time-consuming in real-time. Therefore, they experienced more massive deployment in industry only in the last two decades, where due to growing demands on computing power, special peripherals, price and speed of development, manufacturers began to produce powerful Digital Signal Controllers (DSC), where more cores are available and commonly have mathematical and trigonometric accelerators to increase computing power.

2 Genetic algorithm and performance indices

GA is a powerful, generally applicable, meta-heuristic, complex method that relies on the laws of natural selection and genetics using the theory of evolution. The algorithm does not need to know the derived functions in order to find the optimal setting of the parameters where the function is minimized or maximized.

Thus, GA generally works on the principle of survival of the most capable individual, where the optimal solution is obtained by examining new solutions that arose by solving the following steps(Fig.1.): Initialization (creating a starting population with individuals, where each individual represents a possible solution/ population); creating the most suitable group for crossover; crossover process, subsequent mutation of the crossed result. The big advantage is the possibility of using it for both continuous and discrete optimization of problems.

Fig. 1. Flowchart of genetic algorithm

Structures with PI controllers are sufficient in conventional automation, the PI controller is a sufficiently robust and universal solution that suits most applications. This may not always be the case in applications with electric drives, so there are a number of ways to improve the capabilities of PI controllers and eliminate their disadvantages. [1][4]

Performance indices

In general, this is a number that indicates a good system performance. The aim is to design an optimal system by correctly selecting its parameters so that the specified performance index is extremely small or maximum. It is a positive number or zero. Commonly employed error criteria to achieve optimized PID tuning values are integrated square error (ISE), integral absolute error (IAE), and integrated time absolute error (ITAE), which are used to as an objective function J to obtain PID parameters through genetic algorithm. [5][6] see Equation (1-5)

$$J_{ISE} = \int_0^{\infty} e^2(t)dt \quad (1)$$

$$J_{ITSE} = \int_0^{\infty} te^2(t)dt \quad (2)$$

$$J_{IAE} = \int_0^{\infty} |e(t)|dt \quad (3)$$

$$J_{ITAE} = \int_0^{\infty} t|e(t)|dt \quad (4)$$

$$J_{MSE} = \int_0^{\infty} t|e(t)|dt \quad (5)$$

3 Optimization methods for speed PI controller

Ziegler – Nicholson optimization

This is an empirical method that is suitable for setting linear controllers with the structure P, PI, PD, PID, with the possibility to change constants independently. The principle of the method is based on monitoring the system at the limit of stability. Based on the detected behavior, it is then possible to derive settings and optimization of the controller for a specific application.

Offline GA-PI optimization

GA initially generates a random population, which is implemented with a small population size in order to allow the controller to be optimized and converge at a faster rate. The initial population is set by encoding the PI parameters, K_p , K_i into strings known as a chromosome. The fitness of each chromosome is calculated by converting its string into a real value which represents the PI parameters. Each of PI parameters is passed to the PI controller. The complete response of the system for each PI parameters value and its initial fitness value is computed using individual cost functions like ISE, IAE, ITAE and MSE. Equation (1-5) This process will go through these steps until the end of the generations where the best fitness value is founded. [5][6] For GA parameters setting see Table 1.

Table 1. Parameters setting

GA parameters setting	
Selection method:	normGeomSelection
Population size	100
Generation size	100
Crossover probability	4%
Mutation probability	8%
Range of gains setting	0 - 100

Table 2. Quality parameters comparison

quality parameter	Ziegler-Nichols	offline GA (ITAE)
Rise time (sec)	0,02	0,10
Settling time (sec)	0,47	0,18
Overshoot (%)	65,03	0
Peak amplitude	24,27	14,70
Final value	15	15
P gain	54,12	64,09
I gain	100,00	0,07

Fig. 2 shows a step response curve for comparison of Ziegler- Nichols and Genetic algorithm optimization method with different performance indices. In this particular solution, the ITAE performance index has the best quality parameters. See (Table 2.)

Fig. 2. Step response curve of Ziegler-Nichols and Genetic algorithm with different performance indices

Fig. 3. variation of proportional K_p and integral K_i gain during 100 generations for $GAPI(MSE)$

4 GA optimization of a DC Motor Drive speed controller

DC Motor parameters:

$$U_{an} = 220 \text{ V}; I_{an} = 47 \text{ A}; n_n = 1400 \text{ otmin}^{-1}; P_n = 9,31 \text{ kW}; L_a = 0,8 \text{ H}; J = 1,3 \text{ kgm}^2$$

DC Motor is powered by a three-phase, bridge, fully controlled rectifier.

Current and speed sensor parameters:

Current sensor gain K_i : 0,21

Speed sensor gain K_ω : 0,068

Control circuit with slave current loop

The slave current loop is often part of the speed control. The dynamics of the current regulator significantly influences the behavior of the speed control. A motor with external excitation needs to limit the real current values, therefore a slave current loop is necessary. It is possible to easily limit internal quantities, controller structures with easy adjustment. It is also much better to eliminate faults affecting the controlled system and reduce the controlled variable. The result is a stable and damped control circuit. [7] [8] See (Fig.6)

Fig. 4. Block diagram of a DC Motor Drive speed control structure

Fig. 5. Comparison of Genetic algorithm and Ziegler-Nichols tuning of a speed PI controller, required speed (blue), ZN-PI speed (orange), GA-PI speed (yellow)

5 Conclusion

The article introduces the application of a GA in the structure of a DC Motor Drive, where it is used as an optimization tool for offline speed PI controller tuning. GA achieved higher control quality compared to the conventional designing method. This algorithm has more massive deployment in industry in the last two decades. This is mainly due to the great progress in the field of microcomputer technology.

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Active and Reactive Power in a Rolling Mill

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Abstract. The electrical consumption of the rolling mill is usually very high, above 10 MW, and significantly changes during the rolling process. The rolling mill drives consume not only active but also reactive inductive energy. This reactive consumption is directly compensated in the rolling mill. In order to achieve good energy efficiency, it is necessary to maintain a balance between the actual reactive inductive consumption of the drives and the actual reactive capacitive consumption of the compensating devices.

Keywords: Active power · Reactive power · Rolling mill · Drive.

1 Introduction

Steel is one of the basic materials necessary for modern civilized society. Steel consumption per capita is often used as a measure of the degree of development of the community. The vast majority of steel is produced in the form of rolled products; these are long, wide thin and wide thick products. The process is called rolling; there are hot and cold rolling.

Rolling is a metal forming process in which a metal stock is passed through one or more pairs of rolls to reduce the thickness [1] and to make the profile of rolled metal material uniform and correct. The roll gap (a gap between the working rolls) is smaller than the thickness of the entering metal profile. The rolling rolls are held in the working position in a massive frame, with which they form the basic unit of the rolling process - the rolling stand, see Fig. 1. The rolling mill is a series of rolling stands placed one behind the other. The rolled material always passes gradually from one stand to the next stand and thus passes through the entire line. Rolling is, therefore, a forming process that requires a large amount of mechanical energy.

2 The rolling mill drives

The mechanical energy in the form of rotational movement of the rolls against the resistance of the rolled material is generated in a large electric motor. The rotational speed of this motor must be very rapidly and precisely controllable in

conditions of quickly varying mechanical load. Asynchronous motors, in combination with frequency converters, are used to drive the stands in the newly built rolling mills. Earlier, practically from the beginning of the use of rolling

Fig. 1. Components of a roll stand, available from [1].

technology, DC motors were used for driving the rolling stands [2]. DC motors are more expensive than AC asynchronous motors and are much more difficult and costlier to maintain. The power supply of these motors was provided by electro-mechanical rotary converters, usually called Leonard control system. This converter is a combination of an AC motor and a DC generator. Thus, each stand has its power DC generator for its electrical power supply. It is possible to change the output voltage of a DC generator by simple DC generator excitation control. From the point of view of powering the rolling stands, in this concept the rolling stands are driven by uncontrolled AC motors with subsequent mechanical-electrical and reverse electro-mechanical energy conversion. This historical concept is very expensive, energy inefficient, and the equipment is complicated to maintain. However, AC motors represent harmonic loads, and in case of partial use of AC synchronous motors, it is possible to control the resulting power factor of the whole rolling mill.

In the investigated rolling mill, all stands are driven by DC motors, which are powered by controlled thyristor rectifiers usually called "DC converters" in the text below. Every stand, and therefore every DC motor, has its own MV 6 kV supply transformer transforming electrical energy on its specific supply voltage (500 V, 690 V, 750 V). The transformers are in D/y or Y/y connection. All motors are equipped with the speed transmitters that are connected to the DC converters as feedback. The feedback control allows an exact setting of the required speed and its high stability. The input current of the DC converter changes very quickly depending on the actual mechanical load of the drive.

3 Electrical supply system in the rolling mill

The use of a combination of a DC converter and a DC motor is accompanied by a non-harmonic current consumption from the AC supply [3]. The thyristor phase control also results in a phase shift between the voltages and currents of

the individual harmonics. Also, the voltages and currents of the fundamental frequency are phase-shifted considerably. These facts require the installation of devices that reduce the consequences of the mentioned negative phenomena [4]. For this purpose, two different units are used in the rolling mill under investigation. An older device, an AC MV synchronous motor, which serves as a rotating compensator, is used for reducing the content of harmonics in the total current consumption of the rolling mill. Its effect is broadband, so it filters harmonics regardless of their frequency. At the same time, it serves as a controllable reactive power compensator.

A newer device, a filter-compensation unit for filtering harmonics and at the same time compensating for undesired reactive power is composed of series resonant circuits for the 3rd and 5th harmonics. Its total compensating power is 8 MVar; the value of this power cannot be controlled. The described units are located in different places of the rolling mill but work together on the MV bus on the level of 6 kV. The basic block diagram of the rolling mill supply is shown in Fig. 2.

Fig. 2. Basic supply block diagram.

Electrical energy from the public grid 110 kV / 50 Hz is transformed in the transformer T2 to the level of 22 kV. The transformer T2 is also used for other equipment. The subsequent transformer TP2 is used only for the rolling mill; it transforms the voltage of 22 kV to the level of 6 kV. Most of the rolling mill's drives are supplied at the 6 kV level directly from the main substation R2. New stands were added during several upgrades. These stands also required connection to the power, but it was not possible to expand the main substation R2. Therefore, a new substation R5 was built. Four important stands (Stands I to IV) are connected to the substation R5, which the filter-compensation unit is also connected in.

The Stands I to IV are the largest drives of the entire rolling mill. The stands work in a characteristic sequence that is well visible in the time course of the active consumption of the substation. Under full load, they represent almost 70% of the total active consumption of the substation R5, whereas under the no-load mode of the Stands I to IV the substation R5 consumes only 1 MW of active power, so the substation R5 is heavily overcompensated.

4 The power measurement

The measurement of active and reactive power was possible only in some points of the main substation R2. The main inlet to substation R2, the outlet to secondary substation R5 and the outlet to the rotating compensator were investigated. The measuring points are shown in Fig. 2. The currents were also measured at positions 1, 3, and 4. Since all measured points work at a common potential, the necessary voltages were obtained from common point 2. Point 1 was used to measure the total consumption of the whole rolling mill; point 3 was used to measure the consumption of substation R5, point 4 was used to measure the consumption of the rotating compensator.

A network analyser C.A 8335 Qualistar+ was used for the measurement [5]. It is a three-phase network analyser with graphic display. The used analyser allows the displaying instantaneous measured values and at the same time, recording measured and calculated data into a file. The shortest record period is one second; this recording period was chosen. Selected recorded values were converted into graphs in the form of time courses of monitored powers. The recording time always exceeded 5 min, so that more than 300 records were obtained at each point. The analyser can display a vector representation of the voltages and currents called a Fresnel diagram. Snapshots of the Fresnel diagram were taken and saved during measurements. The phase shifts between the voltage and current vectors are well visible in the recorded Fresnel diagrams. The measurements were performed within 40 min. Unfortunately, it was not possible to measure at individual points simultaneously. During this time, the whole rolling mill worked evenly and stably, so the recorded power time courses can be assessed in time context.

The active power time course of the substation R5 consumption in Fig. 3 shows four very similar characteristic peaks, which represent the processing of four two-ton hot billets. The input profile of the billet 150x150 mm is reduced to the profile of 100x100 mm. The energy required for this forming corresponds to the area of the individual peaks. This large, rapidly variable consumption is visible in the total consumption of the rolling mill. The reactive power time course of the substation R5 consumption in Fig. 4 shows the level of the resulting substation overcompensation. During operation, the stand drives generate high inductive consumption, which significantly reduces the substation R5 overcompensation. On the contrary, when the stand drives are not mechanically loaded, their active and inductive reactive consumption is low, and thus the substation R5 is strongly overcompensated.

The active consumption of the rotating compensator in Fig. 5 is relatively stable, ranging from 73 to 83 kW. Also, the capacitive reactive consumption of the rotating compensator in Fig. 6 does not change much. Its total possible compensating capacity of 6.5 MVar is far from its actual reactive consumption. In point 1 in Fig. 2, the total consumption of the whole rolling mill was measured. The measured time courses in Fig. 7 and Fig. 8 show a significant effect of the substation R5 consumption on the total active and reactive consumption of the

Fig. 3. Active consumption of the substation R5.

Fig. 4. Reactive consumption of the substation R5.

Fig. 5. The active consumption of the rotating compensator.

Fig. 6. The reactive consumption of the rotating compensator.

whole rolling mill. The reactive consumption is mainly of an inductive type but partly passes into the capacity type.

Fig. 7. The active consumption of the whole rolling mill.

Fig. 8. The reactive consumption of the whole rolling mill.

5 Conclusion

The measured consumption time courses of the whole rolling mill show that the reactive power compensation is quite good. Due to the fact that the compensating potentiality of the rotating compensator is not used sufficiently and the reactive consumption does not change much over time, it would be probably possible to improve the time course of reactive consumption with the control potentiality of the rotating compensator. Future research is going to be focused on the control of the rotating compensator.

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Implementation of Programmable Control Unit for the Central Electronics System of the Experimental Electric Vehicle

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Abstract. This paper deals with an analysis of central electronics system of the experimental electric vehicle, programmable platform integration and an analysis of further application of the designed control system layout. The overview about used electronics in the vehicle had to be conducted, described in the first section. The system connection and behavior had to be analyzed for a better understanding of the central electronics system. The next step was the integration of the selected programmable control unit. A model-based algorithm was designed in Matlab-Simulink. An experimental analysis and algorithm calibrations were conducted in order to ensure the proper functionality of the vehicle. The potential applications for research topics were then discussed.

Keywords: Central control unit · Electric vehicle · Electric drive · ECU · EV · Model-based development · Matlab · OpenECU · Simulink.

1 Introduction

Electromobility is an increasingly used term and current trend in transport. As the situation in Europe suggests, conventional internal combustion engines will be increasingly replaced by hybrid or pure electric propulsion in the future. In the case of passenger cars, Asian countries follow the path of hydrogen propulsion.

The domestic market is significantly influenced by the European Union's policy, which aims to reduce the production of greenhouse gases and by stricter standards is gradually leading carmakers and their suppliers to replace internal combustion engines with electric motors or hybrid systems. With the vision not only of a fundamental improvement in the air quality, but also of parallel pressure to increase the share of the use of renewable energy.

For these reasons, many carmakers on the European market are starting to integrate hybrid or pure electric propulsion into vehicles in addition to combustion units. However, this is not the only reason to bring this hundred-year-old

concept back to life. Such vehicles are commercially viable and available today. Not only electric cars, but also electric motorcycles, electric scooters, electric bicycles, etc. At present, we are witnessing a visible increase in sales of these types of personal vehicles. This expansion has been made possible by advances and availability in the field of power electronics and microprocessor technology [1].

2 Topology Analysis of Biro Vehicle Electronic Systems

The interaction of all the above-mentioned electronic systems is important. The vehicle uses two concepts, where the cooperation of the systems is ensured either by bringing the information directly over a dedicated driver or the communication takes place via the CAN bus.

Fig. 1: Biro system layout.

The analysis of the vehicle's electronic systems was performed using basic electrical measuring instruments. First, it was necessary to find out how the individual electronic systems are connected.

In the case of power supply of appliances, their current consumption was determined for later design of the programmable control unit connection.

Information was obtained from the CAN bus by monitoring and analyzing data messages. A USB-CAN converter was used to analyze the bus, which enables monitoring of data frames with identifiers.

Fig. 2: Drive system topology.

2.1 Requirements for the Programmable Control Unit

Based on the information obtained during the analysis, it is necessary to define the requirements that the programmable control unit must meet. During operation of the vehicle, shocks will occur, and ambient temperatures may vary widely. In terms of hardware requirements, the new programmable controller should allow:

- 2x CAN bus for e-drive and comfort (CAN1, CAN2),
- supply voltage 12 VDC or 48 VDC,
- connection of all necessary input sensors and transducers,
- switching and control of all output elements.

3 Integration of the Programmable Control Unit

Based on the analysis, the Pi Innovo unit, OpenECU M220, was selected. This programmable unit meets the requirements in terms of compactness, cost, possible powerful Freescale processes, the possibility of up to two CANs, the number of input and output interfaces.

The OpenECU M220 platform offers solutions in the design of motor vehicles and vehicle electronic systems. Using this user platform benefits from the auto-coding feature of rapid prototyping. The physical side of the unit meets automotive requirements and meets the degree of protection IP69K - fully dust-proof, resistant to high pressure hot water. Operating temperature is from $-40\text{ }^{\circ}\text{C}$ to $105\text{ }^{\circ}\text{C}$. It is possible to apply for highly demanding computational applications such as electronic engine control, fuel system control, vehicle unit control or hybrid powertrain system control unit [3].

Fig. 3: Integration of the programmable control unit within the vehicle systems.

4 Implementation of Model-Based Algorithms

Input Processing

There are input signal processing blocks in this subsystem. The subsystem reads sensor signals, feedback signals and decodes communication messages. The input processing can be further divided into other subsystems, for example the analog input and digital input reading subsystem and the signal verification subsystem.

Model Processing

The part for processing the input data. After successfully obtaining the input signals from the previous section, the Model processing contains the control algorithm itself. Of course, there is a division into other subsystems for each electronic system that the unit controls.

Output Processing

In order to be able to control the operation of the vehicle's central electronics using OpenECU, the model must contain an output part. This subsystem provides targeted control of output elements based on the created algorithm.

System Configuration

Contains blocks of the Pi Innovo library. Special configuration blocks contain information about the control unit model used, CAN and CCP bus settings. In

addition to these configuration blocks, the subsystem includes a nested subsystem for setting the default power values of the individual outputs or, if necessary, changing the unused inputs / outputs [2].

Fig. 4: Integration of the programmable control unit within the vehicle systems.

5 Conclusion

This work is dedicated to one of the interesting design representatives of electromobility, a Biro vehicle, the Italian manufacturer Estrima. In cities and metropolises, you can already find the possibility of shared transport by more people today. The use of electric vehicles for these purposes is a suitable solution. The vehicle will also fulfill its function at the Faculty of Electrical Engineering and Informatics as a teaching laboratory aid in the exercises of the subjects of the study program Automotive Electronic Systems, but also as a means of creating bachelor's, diploma and doctoral theses. We must not forget possible future projects in the IT field, such as the implementation of machine vision and autonomous control.

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The HIL Testing of Automotive Electronic Systems

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Abstract. This paper describes the practical implementation of the HIL test device and verification of its functionality using tests designed for car headlights. The steps in the design of tests are implemented by processing requirements, creating a test plan, programming test tasks, performing tests and finally evaluating the results.

Keywords: CAN Bus · Electronic control unit · Hardware in the loop · Modeling and simulation.

1 Introduction

The number of electronic systems in cars is constantly increasing and the systems are becoming more accurate, more complex and more reliable. With the increasing number of systems in cars, emphasis is placed on their testing and diagnostics. Due to the complexity of car electronic systems, it is necessary to approach their testing more comprehensively and from the beginning of their development. Section 2 describes the principles of modeling and simulation for automotive, Sec. 3 HIL testing and Sec. 4 the car headlight test system.

2 Modeling and Simulation of Automotive Systems

The Model-Based Design (MBD) is an important tool in automotive to facilitate some development steps in the field of control systems and signal processing. In the first part of system development (without MBD), models describing the behavior of the developed system are created. The whole implementation is later created from this model. Thanks to MBD, we look at the model of the developed system not only as a template, but also as its source of system implementation. Thanks to this mechanism, it is possible to generate source code from this model later. It is also an advantage that the model is dynamically developed and tuned during development [1].

Simulation is a process whose goal is to replace the investigated system with a simulation model with which it is dynamically experimented in order to obtain

information about the investigated system. The simulation itself is the simulation environment ensuring the running of the simulation and the mathematical model of the investigated system. If the simulation or the dynamic properties of the investigated system depend on the surrounding environment of the model, it is necessary to add to the mathematical model of the system the mathematical model of its surroundings.

The biggest advantage is the ability to test the investigated system without the need to produce a real prototype, which makes it a cheaper option. The mathematical model is easily expandable and editable without the need to produce a new prototype, also thanks to it we eliminate emergency situations during testing.

3 HIL Testing

In Hardware in the Loop (HIL) testing, the subject of testing is usually the Electronic Control Unit (ECU) of the developed automotive system in a simulated, fully adjustable environment. This can be achieved by a special configurable environment, the parameters of which can be controlled through simulation. Thanks to the simulation of the environment, we can set and then generate various states that can occur at the ECU in a real environment. During testing, the ECU is connected in a so-called loop, either in a modified real environment or in a simulated environment. This type of testing is called HIL testing. HIL testing allows the system to be tested directly during development, thus accelerating development itself. By implementing HIL testing, manufacturers can obtain information from the entire development process of a given control unit.

Fig. 1: Principle of HIL testing.

The principle of HIL testing is to simulate the input signals of the tested electronic system and analyze output signals. The tested ECU is connected to the test environment in a loop, hence HIL testing. Modern ECUs usually communicate via the data bus with the communication protocol (CAN, LIN, FlexRay, Ethernet and others). In this case, the communication on the bus is monitored and tested. The tests are usually controlled and evaluated on a computer connected to the HIL via a communication interface. Modern Ethernet communication protocols also have a timestamp in their message headers. In other cases, the message marking for HIL analysis is arranged by the analyzer contained in the HIL communication interfaces. These timestamps determine the order in which messages arrive and can also be used to make it easier to evaluate and measure some measurements (e.g. response testing).

3.1 Components for HIL Testing

Components for HIL testing include hardware and software for creating, managing, and evaluating tests. In terms of the complexity of the tested system, the required performance for testing and modeling itself, we can consider two basic solutions. For simpler systems, testing can take place directly on the PC via the appropriate communication interfaces. With more complex systems and tests, the number of operations that the PC would have to perform increases, which increases the required computing power of the PC itself. It is now more advantageous to implement a HIL testing platform that provides computing power for testing. A test configuration is created on the computer in a special environment, which then controls the HIL testing itself. At the same time, the results from the current testing come to the computer from HIL. The results are processed according to customer requirements or standards.

Company dSpace offers a single-board HW solution for integration directly into a PC via a PCI or ISA slot, modular HW Scalexio, and a compact MicroAutoBox designed for in-vehicle use. It allows testing the correctness of the algorithms used in a real car environment. Scalexio includes a highly flexible and modular system for HIL and RCP applications in various industries, such as automation, aerospace, healthcare, automotive and more. Thanks to the modularity, it is possible to adapt the resulting device to the specific requirements of the HIL test system. dSpace also offers ControlDesk simulation, control and visualization software in addition to its test HW. The simulations are implemented in the C code and can also be implemented using block diagrams. ControlDesk allows import of simulation models from Matlab and Simulink [2].

Another company Vector focuses on automated industrial testing with a specialization in the automotive industry. Vector offers the modular HW VT System, or its compact solution from the VX1000 series designed for use directly in the vehicle. Thanks to the modularity of the VT System HW, it is possible to adapt the resulting device to the specific requirements of the HIL test system. This system is also easily customizable and expandable. CANoe is a control and

visualization SW from Vector designed for configuration and control of simulations. The simulations are solved by sending messages between the ECUs via the bus. The simulation model is implemented using ECU blocks on the buses. The behavior of individual ECUs is described in the CAPL code of the given ECU. CANoe enables connection to Matlab and Simulink [3].

4 HIL Test System for Car Headlights

Figure 2 shows the block diagram of HIL test of the vehicle headlamp. The communication between the PC and the HIL test device is realized by the VT6051A module from Vector, which is connected to the PC via Ethernet. Programmable DC power supplies are controlled by VT7001A modules through an analog voltage interface and the power supply output is the supply voltage for the tested ECU. VT6104A is a module implementing communication using the CAN or LIN communication protocol. In this case, the CAN bus is used to ensure communication between the HIL test device and the tested ECU of car headlights. To control the simulation during its operation, the control panel was created.

Fig. 2: Block diagram of HIL test device.

It is shown in Fig. 3. The simulation is controlled by graphical controls on the panel, which are linked to the system variables.

Fig. 3: Simulation control panel.

The selected functional test is a test labeled FR1, which aims to test the behavior of the headlights after activating the Lock and Unlock signals. The test itself is implemented by preparing the tested equipment and four test tasks. The headlights should flash the hazard warning lights once when the vehicle is locked (FR1.1) and the hazard warning lights should flash three times when unlocked (FR1.2). In addition, the headlamps should indicate that the vehicle is locked (FR1.3) or unlocked (FR1.4) within fifteen seconds by changing the state of the position lights.

Figure 4 shows the voltage, current and logic state of the position lights during the FR1 function test. The first part displays the preparation of the test device. In the second part are displayed the voltage, the current and the logical state of locking and unlocking. When the lock button is pressed, the logic state on the ECU communication bus is changed from log. 0 to log. 1. This change triggers the hazard warning lights for 0.666 s. This time is derived from the frequency with which the hazard warning lights flash, which flash at a frequency of 1.5 Hz. In the third part, the profile of measured values is visible after pressing the unlock button. A message is again captured on the bus, in which the change

of the logical state of the unlock variable can be seen. It is visible in the graph, that the warning lights switched on three times with a frequency of 1.5 Hz. In the fourth and fifth part, the signals and the states of the position lights are measured. Lights must respond within fifteen seconds after pressing the lock button.

Fig. 4: The profile of FR1 test variables.

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Vehicle trip altitude profile precision comparison

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Abstract. This paper introduces different methods of obtaining trip altitude profile as a part of an electric vehicle energy planning system. The focus is to compare the precision of altitude using a barometric pressure sensor, GNSS receiver, domestic Digital Model of the Relief of the Czech Republic (DMR) the fifth generation and locally very popular trip planner mapy.cz.

Keywords: altitude measurement, electric vehicle, energy consumption, BME280 pressure sensor, u-blox NEO-M8N GPS receiver, DMR 5G.

1 Introduction

Energy consumption of electric vehicle depends on many factors. Currently, the research in the Technical University of Ostrava is running to create vehicle model based on energy losses which would allow to plan the energy consumption for the planned trip even before physically driving the Estrima Biro small electrical vehicle. One important part of such model is to know the topography of the road where the vehicle would ride.

In [1] is described vehicle dynamics model, where several forces need to be overcome to propel the vehicle. In this article, we focus on grade force as the one dependent on the road inclination which is directly related to the road topography. Mechanical power is given as a force multiplied by the vehicle speed so we can see the correlation between road inclination and needed power which influences energy consumption. Grade force in case of inclination (positive angle) is decelerating the vehicle and in the case of declination (negative angle) grade force is accelerating the vehicle.

$$F_{grade} = mg \sin(\theta) \text{ (N)} \quad (1)$$

where

m	–	vehicle mass [kg],
g	–	gravity acceleration [m/s^2],
θ	–	road inclination angle [°].

2 Altitude measurement

For the practical measurement datalogger based on ESP32 platform was developed to be able to interface barometric sensor BME280, GNSS receiver u-blox NEO-M8N, Real Time Clock and SD card. The datalogger was installed to Biro electrical vehicle from Italian manufacturer Estrima to log latitude, longitude and altitude. The best option to get the most precise altitude data would be to implement Real Time Kinematics (RTK) module e.g u-blox NEO-M8P or purchase professional gear. However, the goal is to find economical and open service way. Due to paid RTK service in Czech Republic and several thousand EUR investment in case of professional gear, best cost option is to use proven and readily available high precision pressure sensor and compare its precision with publicly available services of relief altitude models like DMR or mapy.cz.

An important factor for GPS data quality is Position Dilution Of Precision (pDOP), which is related to the geometrical constellation of received satellites and has no physical unit. The narrower view angle between satellites on the sky from the receiver perspective the worse is the precision. According to [2] in the Czech Republic is expected in average pDOP 1.9 from the range of 1.35 as the best precision and 3.6 as the worst precision. Visualization in the Matlab of the Altitude and pDOP during the vehicle trip is shown in Fig.1. Matlab also provides an easy way to visualize the track given by the longitude and longitude by OpenStreetMap web-based interface as shown in Fig.2. The red line is the trip started at the university parking place out of the building where the garage is located. For the symmetry check purposes vehicle drove the same way back by making U turn after approximately 1220 m where the blue line starts. For demonstration purposes, the car on its way back to the university has not stopped on the parking place but has continued to the garage space which is inside building with very weak GPS signal. This is the reason why blue line behind the garage entry is so chaotic. The corresponding pDOP is much higher than 10, so it is not visible in Fig.1 for better scaling.

Fig.1 GNSS altitude and pDOP during the trip

Fig.2 Track of the vehicle visualized in Matlab (red from VSB, blue back to VSB)

The objective of the investigation how to get precise altitude data is to use publicly available Digital Elevation Models (DEM) of the Czech Republic. DMR (Digital Model of the Relief of the Czech Republic) is owned by Land Survey Office of the Czech Republic and end user interaction with the model is possible through web-based application [3]. We will use its free service to calculate the altitude of the relief given by latitude and longitude in our case logged by the datalogger application. The altitude and the longitude data stored by datalogger application during the trip of the vehicle are imported via the web-based interface. This service is free of charge and accepts geometry given by GPX (GPS exchange format) or SHP (Shapefile) format. The visualization by the DMR of the same data shown in Fig.2 is shown in Fig.3.

Next step is to generate altitude description file out of the DMR based on the given track, in Fig.3 the magenta curve. This is achieved by selecting the curve in the web interface and select "Use curve for the calculation". In this step, it is necessary to select the resolution for the calculation either in meter or data points. The result with a resolution of 5 meters is shown in Fig.4. The interactive graph with the cursor measurement is part of the web interface however the graph allows to export the data in SHP, DGN, DXF and TXT format. A text file which is most simple to use in Matlab was used to generate the altitude of the track relief.

Fig.3 Track of the vehicle visualized in DMR 5G

Fig.4 Altitude profile generated out of DMR 5G web interface

(translation: vzdálenost = trip, výška = altitude)

Trip planner Mapy.cz is one of many public services of the most popular domestic search portal Seznam.cz. It is possible to import the GPX track logged by a generic GPS device, so we can import the track stored by the datalogger application in similar way like in the previous chapter into the DMR. It is also possible to switch the language to English which works well in the user interface however is limited in the help menu. Import of the track is over the Tools button located in the low right corner of the page over submenu Import GPX. The import function is limited for GPX files containing tracks attributes. Files with route or waypoints are not supported and will not be imported. The visualization by the Mapy.cz of the same data shown in Fig.2 is shown in Fig.5.

Similar to DMR mapy.cz can export altitude profile either directly in the web interface in the form of interactive graph or to GPX or KML file. Altitude profile is calculated from the digital model composed of more data sources. In the Czech Republic and Slovakia is aerial photogrammetric mapping used and for foreign countries Shuttle Radar Topography Mission (SRTM) supported by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) model around north and east pole.

Fig.5 Altitude profile generated out of Mapy.cz

3 Altitude profile precision comparison

Finally, Fig.6 shows altitude profile comparison between so far mentioned data sources. The graph shall be symmetric around 1220 m due to the fact of U turn made. Symmetry can be seen in all sources except altitude gathered by u-blox GNSS sensor which in general is not providing very precise altitude measurement. Very comparable results are given by models used in DMR and mapy.cz. Very similar results are given by barometric pressure sensor which is much more stable than GNSS and follows the DMR and mapy.cz. The offset is caused by non-calibrated altitude resp. pressure and it is not relevant for road inclination calculation.

Fig.6 Altitude profile comparison from different sources

4 Conclusion

This paper presents the results of the vehicle trip altitude profile precision acquired by four different methods. Two methods use physical of the shelf barometric and GNSS sensors integrated in the datalogger application and two use public digital elevation models data. The target was to investigate if physical sensors can be replaced by the digital model and shown in Fig.6. The positive answer shows benefits of system cost reduction as well as opportunity to calculate the glider model before the real trip being started and therefore calculate the energy consumption before the trip.

It shall be noted that there are others digital elevation models alongside SRTM, ASTER, DMR like Japan Aerospace Exploration Agency's Advanced Land Observing Satellite (ALOS) or even Mars Orbiter Laser Altimeter (MOLA) or many LiDAR based models. Although they are out of the scope of the article all serve similar basic functionality.

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Fall Time Optimization of the C2M0045170D SiC Transistor According to the Voltage Peak Stress

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Abstract. This article describes the limitation of achievement of the maximum falling time provided by SiC power transistor C2M0045170D within the switching-off process. This limitation is studied according to the impact of the supposed remanent irremovable parasitic inductance within the current loop and the related voltage peak caused by decreasing the current flowing via this inductance before beginning of the transistor switching-off process.

Keywords: C2M0045170D, Parasitic Switching Loop Inductance, Transistor Fall Time, Voltage Stress.

1 Introduce

Electronics power switching devices, e.g. transistors, thyristors, diodes, etc. produce power energy losses, which decrease the general efficiency of the whole semiconductor power converter. These losses can be sorted onto well-known static and dynamic ones. The static losses represent the power loss produced by voltage drop in power device on-state and by leakage current in it's off-state. The dynamic losses represent the power loss peaks, these occur within changing the power switching device from off-state onto on-state or vice versa.

Fig. 1. Simplified waveforms of drains-source transistor voltage, drain current and power loss between and within switching-on and switching-off the power transistor

The dynamic losses - a.k.a. switching ones - constitute the major portion of the power losses at the power converters performing hard switching techniques at the relatively high modulation frequency. This means, that it is important to increase the slope of rising and falling the voltage and current during changing the transistor between on- and off-state as much as possible, according to minimize the power losses, because speeding up the switching-on and -off process decreases the square volume of the switching power losses, which means less of dissipated energy.

Fig. 2. H-bridge based inverter including discussed parasitic inductance

However, the requirement for speeding up the switching process of the transistor brings some problems even though it gives a potentiality of decreasing the power loss. Generally, when the switching device couple a voltage source with a load, some parasitic inductance occurs in the current loop, which generates an appreciable impact just

with a high slope of the current waveform changing. This inductance can be seen in an H-bridge, see Fig. 2.

The presence of the parasitic inductance is usually decreased as much as possible by the use of a low inductance capacitor located close to the transistor H-bridge, power structure resp., but it is not possible to fully eliminate it, furthermore, the parasitic inductance is not contained in the bus bar, resp. power supply wires, only, but it also can be seen as a feature of the smoothing capacitor.

The consequence of the parasitic inductance is originating of voltage, which can be determined as:

$$u_{LPar} = L_{Parasitic} \cdot \frac{di_D}{dt} \quad (1)$$

This voltage has an inverse polarity with reference to the voltage source – e.g. U_1 in Fig. 2 – causing a decrease of the current slope during transistor switching-on process and the same polarity during switching-off process. It means, that the transistor is stressed by a total of steady-state drain-source voltage and u_{LPar} , when the switching-off process is performed. Consequently, in some cases the necessity of speeding down the switching-off process can occur because of the risk of exceeding the absolute maximum drain-source voltage of the switching transistor. This process is accompanied by the subsequent smoothed harmonic voltage, current resp. oscillations originated between the discussed parasitic inductance and parasitic transistor drain-source capacity.

Fig. 3. Simplified waveforms of drains-source transistor voltage and drain current including the impact of a parasitic inductance

Fig. 3 illustrates the example of current and voltage waveforms within the switching-off process, accurate forms of waveforms are depended on general characteristics of switching circuit, and can also be aperiodic.

2 Studied Converter Possibilities

Next research was performed for C2M0045170D SiC transistor with a combination of DHH55-36N1F load clamping diode, these are intended for use in a new semiconductor power converter prototype, which is in a process of develop in Department of Electronics, FEECS, VŠB – Technical University of Ostrava.

Transistor C2M0045170D enumerated absolute maximum ratings are according to [1]:

- $U_{DS} = 1\,700\text{ V}$
- $I_D = 72\text{ A}$
- $t_r = 20\text{ ns}$
- $t_f = 18\text{ ns}$

Clamping diode DHH55-36N1F enumerated absolute maximum ratings are according to [2]:

- $U_{\text{RRM}} = 1\,800\text{ V}$
- $I_{\text{FAV}} = 60\text{ A}$
- $t_{\text{IT}} = 230\text{ ns}$

The studied problem of the considered power structure was modeled by an alternate circuit diagram, which was simulated in PSpice. For simulating the C2M0045170D Spice model was used [3]. The diode C2M0045170D was simulated according to the forward voltage drop u_{to} , dynamic resistance r_d and parasitic anode-cathode capacity C_d , these features were taken from datasheet [2]. The intended input voltage was 1 500 V, the supposed parasitic input inductance was 200 nH.

Fig. 4. Alternate circuit diagram for simulations of the transistor C2M0045170D switching off process created in PSpice

Fig. 5. Simulated waveforms for drains-source transistor voltage – green line – and drain transistor current – red line – for switching off 50 A at 1 500 V, fall time 34 ns

As can be seen in Fig. 5, when the transistor of the simulated circuit switches off the current 50 A at 1 500 V during ca. 34 ns, the transient drain-source voltage is more than 2 kV, which exceeds the absolute maximum rating of 1 700 V. In this case the gate resistivity needs to be increased for speeding down the switching process.

Fig. 6. Simulated waveforms for drains-source transistor voltage – green line – and drain transistor current – red line – for switching off 50 A at 1 500 V, fall time 260 ns

It was discovered, that for the conditions stated below, the fall time must be approx. at least 260 ns, to not be exceeded drain-source voltage 1 700 V. Dependence of fall time on switching off current, can be seen in. Fig. 7.

Fig. 7. Ascertained minimum falling time for studied circuit to not exceed absolute maximum drain-source transistor voltage

3 Conclusions

It was ascertained that for the intended power converter including the C2M0045170D of the studied circuit diagram the fall time of transistor must not be less, then 360 ns for 70 A of drain current. The fall time can be decreased for lower switching currents, but according to the limits of changing the switching times possibilities – which can be performed mainly by changing the gate transistor resistors – the adaptation just for the most critical situation at 70 A is supposed.

4 Acknowledgement

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Development of Application for Control of SMART Parking Lot

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Abstract. This article is about development of application to control SMART parking lot. Control is made through the implementation of Virtual Instrumentation. First part of the article is about brief description of actual trend in term of designing applications based on Virtual Instrumentation. Another part is about BROADBAND^{LIGHT} testing polygon at parking lot near Faculty of Electrical Engineering and Computer Science at Technical University of Ostrava. Last part of the article is about development of application that is suitable enough for controlling SMART Light testing polygon.

Keywords: LabVIEW, Architectures, Application Development, BROADBAND^{LIGHT}

1 Introduction

When developing LabVIEW application, several approaches can be taken. First and most used approach is to write the program without using any design template and make it work. [1] This approach is useful for small applications which functionality is single-purpose and with only little possibility of redevelopment or extending functionality. Such applications are for example onetime test measurement, signal processing, simple educational programs etc. However, using this approach to create applications that are more complex can be difficult. Unexperienced users tends to make LabVIEW diagrams bigger than one-screen and when they add other functions the diagram grows. The code is not modular; reusability is very low and it is most times unreadable due to the size. To make diagram smaller and clearer, users can make subVIs. [2] This solves the size of the diagram and if subVI is written well, user can use it again in other applications. Nevertheless, the modularity and extendibility of code is still poor.

As experience of the user grows, he starts to use design templates or patterns. Most common patterns in LabVIEW community are State Machines, Producer-Consumer, Event-driven state machine and Queued Event-Driven Message Handler. Every of these patterns is designed for certain functionality. If the application needs to run automatically without, or with minimal user input the state

machine is good choice. State machine template can be seen on Fig. 1. The code is scaled to one-screen and the course of the program is made via changing the states.

Fig. 1. State-Machine pattern

Disadvantage of state machine is that the machine runs continuously without any event driving. This means that every, in this case 200ms, the state is called. Consider that we have states Initialize, Measure, Save and Exit. Between every state there is 200ms wait and users input is read only after the Save state. If user pressed exit button earlier, for example in the Initialize state, the program have not registered it yet and the machine continues to make complete cycle until the state of the button is read and the program quits. For simple applications, this can be good approach but it is inappropriate for applications that are far complex.

Fig. 2. Event driven state machine pattern

Event-driven state machine is extended by usage of queues and event structure. This solves the problems described earlier. If button is pressed between the states, or some other GUI event is captured, it is saved in the memory buffer of event structure and performed when Idle state is called (as seen on Fig. 3). In addition, the states can be now buffered via usage of queues. Also, the wait between states has disappeared. This is because when no button is pressed or no state is in memory, the program waits at event structure for another command. Disadvantage of this approach is that GUI and performance are in the same loop. This means that if the button is pressed in middle of another state, for example some kind of complex signal processing, it is registered but not executed immediately. Therefore, user sees the GUI as frozen which is not responding [3].

Solution to avoid this problem is to distribute the functionality between two processes. One maintains solely GUI and another is for computing, processing etc. This pattern is called Queued Event-Driven Message Handler and can be seen on Fig. 4. It is combination of Event-driven state machine, and Producer-Consumer template. Upper loop is for the GUI, and the lower one is for computation. Now, every GUI event is immediately executed and put in the queue. For example, if user presses Stop button and it is put in the queue with higher priority (LIFO instead of FIFO) the program shuts down immediately and does not need to wait to proceed complete cycle. With same template, users can easily create other computing processes for different tasks. One possible disadvantage could be that the code grows and it is very hard to keep it in one-screen, therefore decreasing instant readability of code by another user. Another disadvantage is that the code is still not modular and is hardly portable.

Fig. 3. Queued Event-Driven Message Handler

In order to avoid those problems, user can create abstraction layer above everything with Subpanel plugin architecture. This architecture is combination of so-called MainVI with subpanel container and plugins, which are individual Queue Event-Driven Message Handlers. This approach is modular because every plugin is individual and can be coded by different developers outside of the main architecture. In addition, it is flexible, because the VI running as plugin can be anything that fits the size within the subpanel. The architecture of MainVI can be very simple, because its only functionality is to run all plugins and then change subpanel accordingly to the user demands. The loading and running of plugins can be done by, for example scanning directory to look for VI's with specific key in their names. This architecture can be seen on Fig. 5 and is later used for the development of application that is subject of this article.

2 Developed Application

In order to achieve high modularity, the plugin design has been chosen. The main advantage of this approach is that every plugin “module” runs independently. Also, because of the modularity, the system can be easily extended, changed or reduced. This approach can help to mitigate the costs and risks that are

Fig. 4. Subpanel plugin architecture

associated with hardware that becomes obsolete or needs to be replaced. Also, makes it possible for development to proceed concurrently on different parts of the application [4].

Above all plugins runs the MAIN.VI which is used to asynchronously run all plugins which are included in the specific directory and their name is ended with key word “_plugin.vi” [5] When VI starts, the reference in memory for this VI is obtained. These references are later used to show specific Front Panel of the plugin chosen by user. All plugins run in background and their front panels are not shown. Only task of the MAIN.VI is that it shows front panels of chosen plugins and manages users and their privileges. Also, it takes care of correct termination of all plugins in case that the STOP button is pressed.

Fig. 5. Front panel of designed application. 1 – Main menu, 2 – Plugin window, 3 – Secondary menu, 4 - Header

Main window is designed as multi-paned front panel with each pane splitter separated. This design is practical because the layout and position of each pane stays with change of resolution. Only thing changed is vertical size of Main menu, Plugin window and Secondary menu and horizontal size of Plugin window.

Main menu is dynamically filled with the names of running plugins. If button is pressed, then the front panel of specified plugin is shown in the Plugin window.

All plugins written for the application follows Queued Message Handler template. In order to reduce future development time, the blank design template was prepared. In fact, the blank template is fully functional plugin, but without any code that would do the plugins specific function. It contains only architecture that is mandatory for correct running of the application.

Every plugin consists from two processes. First is for catching user interface events and second is for the main code. In order to make the application functional it is mandatory to use the Queue Library which is described further below.

2.1 Plugins Developed

Currently there are five developed plugins for the control of SMART parking lot application. As mentioned before, every plugin can work independently or can be part of the main architecture. This is very good for development because user can work only with sections of code that are necessary and does not need to start complete application with all required systems.

Part of the study is focused on power quality evaluation of the grid that consist many SMART elements. User can read various variables that are related to the Power Quality as Active Power, Reactive Power, amount of harmonic distortion of the grid, or Voltage and Current spectra etc. Also, the measurement must comply with *EN50160* and *IEC61000* norms. In order to fulfil these conditions, the National Instruments Electrical Power Toolkit was used combined with DAQmx library. Another function of this plugin is data aggregation followed with data saving.

To control the SMART lights the MQTT (Message Queuing Telemetry Transport) protocol had to be implemented. Every Thorn, Boss and Schreder light pylon has DALI (Digital Addressable Light Interface) to Ethernet converter and then is connected to the Wi-Fi router. This net is connected to server which acts as broker for the MQTT protocol. Plugin and all light pylons act as clients.

Surveillance system is developed with usage of m4LabVIEW (Media for LabVIEW) library that can access various camera streams and decode them. Library also makes possible to save videos in various formats such as .mkv, .mp4 and others. Currently, main functionality of the plugin is security surveillance of the parking lot. In future, there will implemented state license plate recognition for the incoming cars and parking lot free spaces management. Because the library returns the video in IMAQ format, it is very easy for user to program screen recognition with Vision library [5].

Because one of the SMART devices is weather measurement station, the plugin for grabbing data from it was developed. Communication with the station is made through Ethernet with Telnet protocol. Station returns variables as wind speed, temperature, wind-chill, atmospheric pressure and wind direction. Because of the nature of polygon, it is necessary to put data in context with other variables so every 5 seconds all variables are saved into .TDMS file. User can view these data in a figure with variable length, so he can view week data or month data. To ensure that there is enough memory the data are read dynamically according to zoom level.

In order to put the data from various plugins into context with other the Parking Lot Map plugin was made. The map in the plugin is not static picture but is dynamically read from Google Maps via Google Maps Static API. This API is approached via HTML protocol functions with specific formatting of URL address. Then the text given from HTML Read function is transformed into the PNG picture which is shown to the user. Because Google Maps works with Latitude and Longitude, first step is to convert these variables to pixels of the picture. Then other information as parking lot fill or SMART light status is parsed into the picture in front of the map.

3 Conclusion

In order to make own SMART Light Testing Polygon, it was necessary to have control application that is robust, user-intuitive and easily extendable. Our designed software architecture meets every requirement that was mentioned earlier. Actually, five plugins, which can run independently, are completed. These plugins are Power Quality Measurement, SMART Lights control system, Parking Lot Map and Weather Measurement station. For a future research our team plans to implement various plugins to test Visible-Light Communication to extend functionality of SMART Lights.

In addition, architecture of the application is very versatile, so it can be used for completely different tasks e.g. signal processing application, testing of adaptive filtration or biomedical engineering tasks such as foetal electrocardiogram extraction application etc.

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Autoencoder as a Tool for Data Compression

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Abstract. A data compression approach using the autoencoders represents one of possible edge computing solutions. The main advantage of this proposal is reduction of transmitted data amount which can lead to lower energy demands of wireless transmission in wireless sensor networks. Acquired environmental data are compressed in a microcontroller implemented as central computational unit and then they are transferred by a communication interface. In this article the autoencoders is used for compression of dataset with environmental data.

1 Data Compression

Many compression algorithms exist for data compression in WSNs, but it is necessary to find one that produce better compression ratios and less loss of data in the reconstructed data. Data compression techniques can be either lossy or lossless. *Lossless Compression* means that the original data stays without degradation of quality and can be reused. The original data is not changed permanently during compression, which is a great advantage. On the other hand, the compression achieved is not very high. *Lossy compression* means that parts of the original data are removed permanently to reduce file. Due to the loss of a lot of data, the data may be skewed after reconstruction and the quality degraded [2].

Data compression is one of common application of neural networks. The basis is the use of a neural network that has the same number of input neurons as number of input neurons and has a smaller number of neurons in one of the hidden layers. The task of such a selected network is to learn the identity of the submitted data. After learning the network, it will be divided into two parts at the output of the mentioned hidden layer - the input half of the network now serves as a compressor and the other as a decompressor (Fig. 1).

Autoencoders Autoencoders are types of neural networks that compress and then decompress input data with the least possible loss. Denoising signal [3] and reduction of dataset dimensions [4] are the main uses of these models. Autoencoders are determined automatically from data samples and it is relatively simple to learn these type of neural network on specific input data. Since they learn features specific for the given training data, they are different than a standard data

Fig. 1. Example of a neural network used for signal compression and decompression [7].

compression algorithm like gzip. Autoencoder algorithms are taught to store during data compression and subsequent decompression as much information as possible. The systems based on autoencoder consist of three parts:

1. **Encoder:** The model reduces the dimensions of the dataset and compresses the input data into an encoded form.
2. **Code:** This layer contains compressed data. The data is reduced to the lowest possible dimension value.
3. **Decoder:** The model reconstructs the data into original form or converts into space with the same number of dimensions as the number of dimensions of the input data.

At the input of the autoencoder is a dataset of training data $x^{(1)}, x^{(2)}, x^{(3)}, x^{(4)}, \dots$, where $x^{(i)} \in \mathbb{R}^n$. The goal of the autoencoder is to reach $y^{(i)} = x^{(i)}$, which means that the output is equal to the input. The first function $f_1(x) = z$ compresses the input data. The second function $f_2(z) = y$ decompresses the compressed data. Between these functions, a vector z is created which indicates the amount of compression and is a key point in the design of the entire autoencoder [6].

Compared to PNG compression, compression using autoencoders is designed from training data, so same autoencoder will perform different compression on different training data. The size of the input is fixed when designing the autoencoder, so it is not possible to use a 200-pixel image for a 100-pixel image as an input for the created autoencoder.

Fig. 2. The scheme of an autoencoder with input vector, code layer, compression layer, decoding layer and output vector. The autoencoder learns by comparing the input with the output and adjusting the weights of the individual neurons of the encoder and decoder [8].

In the case of an autoencoder, the activation function of a neuron is usually a sigmoid

$$f(z) = \frac{1}{1 + e^{-z}}, \quad (1)$$

whose range of values is in the interval $(0, 1)$. The derivation of this function is:

$$f'(z) = f(z)(1 - f(z)). \quad (2)$$

The autoencoders is a type of unsupervised learning and it based on learning general characters of input data and looking for connection between them. The aim of learning is to set the weights W and biases b between the neurons so that the output values y_i coincide as much as possible with the values of the input data x_i . The information about the input data is stored in weights of autoencoders [9].

For training the autoencoder two algorithms are used - an optimization algorithm (i.e. Conjugate gradient method) is used to minimize the objective function and an algorithm for calculating the weight gradients (Backpropagation). The optimalization function of the autoencoder has the form:

$$J(W, b) = \left[\frac{1}{m} \sum_{i=1}^m \frac{1}{2} \left| h_{W, b}(x^{(i)}) - x^{(i)} \right|^2 \right] + \lambda \frac{1}{2} \sum_{l=1}^2 \sum_{i=1}^{s_l} \sum_{j=1}^{s_{l+1}} (W_{ji}^{(l)})^2, \quad (3)$$

where the first member of this function calculates the error rate of the autoencoder and the second member - called *weight decay* penalizes weights with large values. Backpropagation algorithm for autoencoders:

1. First, the hidden layer activations are calculated for each input data sample, and then the output layer activations are calculated. An activation function (e.g. sigmoid) is used for calculations.
2. The error δ is calculated for each neuron. The autoencoder tries to reconstruct the input values on the output layer. The error for each neuron on the output layer - in this case of the third layer - is calculated:

$$\delta_i^{(3)} = \frac{\partial}{\partial z_i^{(3)}} \frac{1}{2} |h_{W,b}(x_i) - x_i|^2 = -(x_i - a_i^{(3)}) f'(z_i^{(3)}) \quad (4)$$

3. The error size of neurons in the hidden layer are calculated. The error size of one neuron depends on the errors of all neurons to which this neuron transmits its activations and on the size of the weights between this neuron and the higher layer neurons. In the hidden layer the error size - in case of the second layer - is given by the equation:

$$\delta_i^{(2)} = \left(\sum_{j=1}^{s_3} (W_{ji}^{(2)})^T \delta_j^{(3)} \right) f'(z_i^{(2)}), \quad (5)$$

where s_3 is the number of neurons located in the output layer, $W_{ji}^{(2)}$ is the weight between the neuron j in the output layer and the neuron i , which is in the hidden layer. $(A)^T$ indicates the transposed matrix.

4. In the last step, the gradients of weights and biases of output layer ($\Delta W^{(2)}$, $\Delta b^{(2)}$) are set. The gradients of weights and biases of hidden layer ($\Delta W^{(1)}$, $\Delta b^{(1)}$) is given by the equation [5]:

$$\Delta W^{(2)} = \frac{1}{m} \delta^{(3)} (a^{(2)})^T + \lambda W^{(2)}, \quad (6)$$

$$\Delta b^{(2)} = \frac{1}{m} \delta^{(3)}, \quad (7)$$

$$\Delta W^{(1)} = \frac{1}{m} \delta^{(2)} (a^{(1)})^T + \lambda W^{(1)}, \quad (8)$$

$$\Delta b^{(1)} = \frac{1}{m} \delta^{(2)} \quad (9)$$

2 Experiments and Results

For experimental purposes we are using the dataset consist with data about temperature. A total of 14 days time-log was used, giving data at 5 minute intervals the each data series counts 288 measurement per day. Two variants of autoencoders settings were tested.

The Fig. 3 shows the setting of an autoencoder that has five neurons in the hidden layer. The original signal is plotted, and for comparison the signal that was reconstructed using a trained neural network is also plotted. The mean

Fig. 3. Input and output of autoencoder - five neurons in hidden layer - $MSE = 0.059$

Fig. 4. Input and output of autoencoder - sixty neurons in hidden layer - $MSE = 0.029$

squared error (MSE) was determined for evaluation of distortion between these two signals. In this case, the value of MSE is 0.059.

In the second case (Fig. 4), the autoencoders has sixty neurons in hidden layer and has sigmoid as an activating function. The mean squared error of this settings is 0.029.

3 Conclusion

The paper provides description and visualization of the research results describing the using of neural networks as a tool for data compression. The experiments was performed on data about temperature and the mean squared error was determined for evaluation of distortion.

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Virtual Instrumentation Based Ballistocardiographic Monitoring System Designed for Cardiac Triggering of Magnetic Resonance Imaging

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Abstract. This paper introduces a concise description of designed virtual instrumentation based ballistocardiographic monitoring system for cardiac triggering of magnetic resonance imaging. Description of monitoring system setup together with sensor, hardware and software used is provided. A comparison study of designed system with conventionally used ECG-based system was conducted based on classification of peak detection in acquired signals. Achieved results shown high precision of the designed system with quality parameters (ACC, SE, PPV, F1 score) exceeding values of 99 %.

Keywords: MRI, Virtual Instrumentation, cDAQ, cRIO, FPGA, Ballistocardiography, Seismocardiography

1 Introduction

Cardiac magnetic resonance imaging (CMRI) examination is very important method in diagnostics of heart's ischemic or inflammatory diseases, ventricular disfunctions or other cardiomyopathies. Due to constant movement of heart during its cycle an imaging synchronization by methods of triggering and gating is needed in the clinical practice to achieve sufficient quality of heart's image applicable for diagnosis. These synchronization methods are based on monitoring of cardiac and respiratory activity. Purpose of the monitoring is to provide triggering signal at specific moment of heart (ventricular ejection or isovolumic relaxation) and respiratory cycle (exhale) to minimize the effect of heart and thorax motion on the resulting scan [1].

Conventional systems used for CMRI triggering are based on electrocardiography (ECG) signal monitoring and detection of R peak based on which a triggering signal is generated with a specific delay. There are many complications related to usage of ECG monitoring system (skin preparations, strong electromagnetic interference caused by operation of MR scanner, magnetohydrodynamic effect caused by interaction of flowing blood and strong magnetic field) in MR test room [1] [2] [5]. Mentioned problems with ECG signal monitoring raised efforts to use different approach to monitor heart activity. Among the examples of alternative approaches are acoustic systems based on phonocardiography (PPG), systems using fiber-optics bragg grating interferometers

that allow measurement of ballistocardiographic (BCG) signal as well as respiratory activity and systems utilizing principles of pulse oximetry or photoplethysmography[4], [6], [7], [8], [9], [10].

In this paper we present a virtual instrumentation based system for monitoring heart activity by techniques of BCG/SCG (Seismocardiography) using pneumatic sensory system developed by our team. Main advantage of our system is its complete immunity to electromagnetic interference. To verify reliability of the designed system we conducted a comparison study with conventionally used ECG based system.

2 Pneumatic System for Cardiac Activity Monitoring

We tested two different ways to sense heart activity with our pneumatic system. As first concept we used a plastic funnel fixed to patients chest (close to the heart) by elastic textile belt. At the end of the funnel we attached a PVC acoustic tube, which extended all the way from magnetic resonance room to test room, where it was connected to a measuring microphone. In this case source of the signal is movement of patients skin (as result of heart activity) under the plastic funnel. Skin movement creates pressure changes in the plastic funnel, which propagate through to PVC tube to the measuring microphone. Signal obtained by this sensor corresponds to SCG method of monitoring heart activity.

Second type of sensor works on the principle of BCG and it senses the movement of blood at specific area of patients body (back or gluteal muscle). Sensor consists of closed pneumatic system made of deformable plastic tube arranged in shape of spiral to maximize sensing area. Slight movements of patients body (cause by movement of blood in the area) in contact with the tube causes pressure changes in the tube. Sensing tube is connected to another plastic tube with worse deformation ability, which transmits the pressure changes from the magnetic resonance room to measuring microphone in control room. Concept of the pneumatic system is schematically depicted on figure 1.

Fig. 1. Pneumatic system for cardiac activity monitoring. Plastic funnel sensor (a) connected to PVC tube (b) transmitting SCG signal to measuring microphone (c). Signal from microphone is measured and analyzed by cRIO system (d), which generates triggering signal (e) for MRI. [1]

Second type of sensor has fundamental advantage over the first sensor in fast preparation time (no need to place the sensor). On the other hand the signal acquired by second sensor has lower signal-to-noise ratio and signal quality is very dependent on the weight of measured subject.

3 Software and Hardware Description of Monitoring and Triggering System

System was completely build around concept of virtual instrumentation. We used software (SW) and hardware (HW) products from NI company. As a controller unit we used cRIO platform, specifically model cRIO-9073. This platform contains combination of field programmable gate array (FPGA) and microcontroller running real-time operation system (RTOS) and ethernet interface for connection to PC or any other supervisory system. Selected cRIO does have any human machine interface (HMI). For that reason we also used a host PC that is running LabVIEW application providing user interface (triggering configuration, datalogging and real-time display of measured signal). SCG or BCG signal is sensed using a GRAS 40PP microphone and then measured by cRIO-9250 module designed for measurement of acoustic and vibration signals with support for IEPE sensors. Digital output module cRIO-9472 was used to generate the triggering signal. Sample of measured SCG signal is depicted on fig. 2.

Function of the system is controlled by a three SW layers programmed in LabVIEW and its extension modules. Lowest SW layer is implemented as FPGA logic. It reads the values digitized by ADC, processes and analyzes the measured signal in real-time and generates a triggering signal based on peak detection algorithm and trigger signal configuration (delay and width). Signal processing involves fourth order low-pass IIR filter with Butterworth approximation and cut-off frequency of 40 Hz. Peak detection algorithm is described in detail on fig. 3 together with principal schematic of the monitoring and triggering system. Second SW layer is implemented on RTOS and serves and communication bridge between FPGA and PC by means of TCP server and client architecture. Last SW layer is implemented on host PC and serves and beforementioned user interface. It allows user to configure the triggering systems by sending commands to the FPGA logic. Configuration includes refractory phase period, signal level threshold coefficient, peak polarity, size of peak pattern, triggering pulse width and delay.

Fig. 2. Filter SCG signal with detected peaks and generated triggering pulses. [1]

Fig. 3. Principal schematic of designed monitoring and triggering system with detailed description of peak detection algorithm. [2]

4 Results

To verify a reliability of the designed system, we conducted a comparison study with ECG-based system as “gold standard”, because it is most commonly used in clinical practice. For each subject both ECG and BCG/SCG signals were monitored and continuously logged. Synchronization of the two monitoring systems was not possible. Signals were synchronized based on offline analysis of heart rate curves determined from detected peaks. All ECG signals used for the study were classified semi-automatically in terms of R- R interval determination to make ensure that all peaks were detected correctly. Comparison study was conducted on 28 subject, 12 females and 16 males.

Detection of significant points in reference ECG and tested SCG signals was performed for all 28 subjects. Classification of all peaks detected in SCG/BCG was performed and each peak was identified as either true positive (TP), false positive (FP) or false negative (FN) based on following rules. If a peak in BCG/SCG signal was detected withing range of ± 20 ms around R wave detected in ECG signal then it was detected correctly and evaluated peak is classified as TP. In case there is no peak detected in BCG/SCG signal around defined range of ECG R wave then this peak is classified as FN. False positives (FP) peaks were classified if there was detected peak in BCG/SCG signal outside a specified range of detected R wave in ECG signal. Results of binary classification were then used to determine 4 performance parameters (equations 1-4) of peak detection in SCG signal.

$$ACC = \frac{TP}{TP + FP + FN} \cdot 100 (\%) \quad (1)$$

$$SE = \frac{TP}{TP + FN} \cdot 100 (\%) \quad (2)$$

$$PPV = \frac{TP}{TP + FP} \cdot 100 (\%) \quad (3)$$

$$F1 = 2 \cdot \frac{SE \cdot PPV}{SE + PPV} \cdot 100 (\%) \quad (4)$$

Sample of verified SCG signal and reference ECG signal together with results of peak classification is displayed in fig. 4. Results of the comparison study for 10 selected subjects are summarized in table 1.

Fig. 4. Sample of verified SCG signal and reference ECG signal together with results of peak classification [1].

Table 1. Results of the comparison study for 10 selected subjects.

Subject	N (-)	TP (-)	FP (-)	FN (-)	ACC(%)	SE(%)	PPV(%)	F1(%)
1 - SCG	1003	998	3	2	99.5	99.8	99.7	99.75
2- SCG	887	885	1	1	99.77	99.88	99.88	99.88
3- SCG	1100	1081	11	8	98.27	99.26	98	99.12
4- SCG	1034	1020	6	8	98.64	99.22	99.49	99.54
5- SCG	831	822	4	5	98.91	99.39	99.51	99.45
6- BCG	713	707	3	3	99.15	99.57	99.57	99.57
7 - BCG	751	749	1	1	99.73	99.86	99.86	99.86
8 - BCG	955	939	8	8	98.32	99.15	99.15	99.15
9 - BCG	757	729	14	14	96.3	98.11	98.11	98.11
10 - BCG	815	752	31	32	92.26	95.71	96.04	95.97

5 Conclusion

We presented a concise HW, SW and sensor description of designed virtual instrumentation based ballistocardiographic monitoring system for cardiac triggering of

magnetic resonance imaging. System was verified based on comparison study with conventionally used ECG-based monitoring system, which is considered as “gold standard” in clinical practice. Comparison was based on classification of peaks detected in BCG/SCG signal in relation to peaks detected in ECG signal. Outputs of peak qualification were used to determine 4 performance parameters (ACC, SE, PPV, F1) and results for 10 selected subjects were presented. Method is considered as accurate if the presented parameters are above 95 %. In most of the cases we were able to results exceeded 98 % accuracy (all if the cases for SCG signal), which implies that designed system is suitable substitution for ECG-based systems.

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Methods of Modern Medical Diagnostics of Burn Injuries

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Abstract. Current methods of diagnosis of burn injuries based on laser dopplerometry play an important role both in the objective evaluation of thermal traumas and therapeutic procedures, and in the estimation of the prognosis of healing. Another method that also significantly contributes to the objective evaluation of treatment, particularly related to the assessment of the process of scarring after thermal trauma, and the time evolution based on data obtained by measuring viscoelastic parameters by non-invasive suction method is the so-called cutometry. Improvement of both diagnostic methods are the subject of the dissertation and their brief principles are outlined in this review article.

Keywords: Burns, Burn Medicine, Laser Doppler Imaging, LDPI, Viscoelastic Properties of Skin, Hypertrophic Scars, Cutometry.

1 Introduction

Assessment of blood perfusion into skin (by means of laser dopplerometry) and viscoelastic parameters of skin (by means of cutometry) play an important role in burn medicine in diagnostics both in the objective evaluation of therapeutic procedures and in the estimation of the prognosis of healing. The method of laser dopplerometry is used mainly for the evaluation of early perfusion and subsequent verification of scar blood flow, for example after surgery. The potential of this method lies mainly in the further development of mathematical models of the evolution of blood perfusion, which can be a valuable tool in the prognosis of healing.

One of the complications in a burn trauma is hypertrophic scarring, especially in the deep degree of burns, when the epidermis and dermis are destroyed. With complicated healing, there is a particularly high risk of developing hypertrophic, functionally limiting and aesthetically unsatisfactory scars. Cutometry is one of the methods of objective assessment of scars and their time development based on data obtained from measuring viscoelastic parameters of skin. The method uses a number of viscoelastic parameters, and, provided the conditions are controlled and the correct procedure of statistical processing is maintained, it allows objective temporal and interpersonal comparison without ultrasonic measurement of skin thickness.

2 State of the Art

2.1 Laser Dopplerometry

In the clinical practice of burn wards, early diagnosis of burns is a key issue. The standard diagnostic method – widely used today – is scanning the blood perfusion of the area affected by thermal trauma using Laser Doppler Imaging (LDI, see Figs 1 and 2). Research has shown that the prognosis of burns depends not only on the instantaneous perfusion value at the time the perfusion scan was taken but also on the perfusion dynamics, i.e. evolution of perfusion in time [1, 2]. Consequently, a condition necessary for healing without surgery is not only the above-threshold value of perfusion but also its above-threshold change in time (in other words, the first derivative). So far, these parameters (if perfusion dynamics are taken into account at all) are evaluated globally on average for the entire burned area. This can lead to an underestimation of the risk, which, leads to later complications and hypertrophic scarring with an impact on the quality of treatment and the patient's life and to overestimating which results in unnecessary operations and pain as well as a negative economic impact. The methodology and software being developed can help to compensate the above-mentioned shortcomings in medical decision-making in the field of burn treatment and in the future may contribute in achieving more relevant diagnostics key to the further development of the disease [3, 4, 5].

Fig. 1. Laser Doppler imaging device, PeriScan PIM 3 System, Perimed AB.

Fig. 2. Examples of typical color-coded perfusion maps obtained from a LDI device.

2.2 Cutometry

Hypertrophic burn scarring is the most common complication in a burn injury. The worldwide prevalence of hypertrophic scarring is considerably alarming. In addition to the cosmetic aspect it manifests itself in a number of functional complications and pathophysiology of the skin. The risk of hypertrophic scarring is significantly high, especially in deep burns, when the epidermis and dermis are destroyed. Hypertrophic scars arise in the extent of the primary wound and protrude above the level of the surrounding skin, are painful, stiff, itchy, and may develop into scarring contractures requiring surgical treatment [6, 7].

Fig. 3. Cutometer MPA 580 by Courage + Khazaka electronic GmbH, the most widely used cutometric device.

The method of the first choice in the objective assessment of burn scars and their time development by measuring viscoelastic parameters by a non-invasive suction method is cutometry (see Figs 3 and 4).

Fig. 4. Bottom: time dependence of pressure. Top: Typical response of skin. As soon as the abrupt suction is applied, skin almost immediately extends until it reaches the transition point I_s , from this point on viscoelastic creep occurs (analogous but reverted is valid from relaxation segment). Only the first cycle (one suction and one relaxation segment) is depicted, nine other cycles follow, each next slightly higher than the preceding one.

Cutometry is a non-invasive in vivo method of measuring the viscoelastic (VE) parameters of human skin based on the deformation response of the skin to abruptly invoked changes in atmospheric pressure [8, 9]. Use of exclusively fractional VE parameters $R2 = U_a/U_f$ (gross-elasticity, total retraction to total distension), $R5 = U_r/U_e$ (net-elasticity, elastic retraction to elastic distension), $R6 = U_v/U_e$ (viscoelastic distension to immediate elastic distension) distension), $R7 = U_r/U_f$ (biological elasticity, elastic retraction to total distension), or robust Qu's area parameters $Q1 = (Q_e + Q_r)/Q_0$, $Q2 = Q_e/Q_0$, $Q3 = Q_r/Q_0$ eliminates the need for ultrasound thickness measurement skin [10].

3 Expected contribution from current research

3.1 Laser Dopplerometry

In the field of laser dopplerometry, the topic of the dissertation focuses on the topographic analysis of the early temporal development of LDI measured blood perfusion of burn traumas. The solution under investigation is the dynamics of blood perfusion in the burn capable to distinct areas of increase and stagnation or decrease in blood perfusion in the early stages after the burn. The key is to determine both the above-threshold value of blood perfusion locally in the perfusion map (not in the global average as the current state) and the above-threshold time changes of blood perfusion locally in the perfusion map of differences.

A key component of this idea is the matching of pairs of perfusion maps so that their subtraction can provide relevant results. This type of problem is related to image registration widely used in medical imaging. Here, however, a complication arises in the form of short-term visual variability of the burn which results in the failure of standard registration algorithms. The applicability of developed (semi-automatic and manual methods of registration of perfusion maps) will be verified. The result will be robust and user-friendly software enabling physicians to assess both aspects (static and dynamic) reflecting the potential of spontaneous (surgically unassisted) healing of burned skin.

3.2 Cutometry

The cutometric curve is usually formed of ten suction-relaxation cycles, each consisting of a suction and a relaxation segment. Standard algorithms implemented in the evaluation software supplied along with the cutometric instruments take into account the very first cycle only. Remaining nine cycles are left unprocessed. Examining a large number of cutometric curves we revealed that there is a wealth of valuable data buried in the cutometric curve as a whole. Moreover, certain viscoelastic parameters of skin strongly depend on the transition point, i.e. the point in which rapid elastic distention changes in much slower viscoelastic creep. The accuracy of determining the transition point is critical for calculating related viscoelastic parameters. The standard software puts the transition point to time 0.1 s after suction (relaxation) onset, which is in average true (at least approximately), but due to inevitable variability of the properties of the skin

and a very steep slope of the elastic distention line may lead to enormous errors. We tackle both these topics – getting more data from all cycles of the cutometric curve (with all possible consequences for medical diagnostics), and a reliable, robust and accurate method for determining the transition point, and all related viscoelastic parameters.

4 Results

From the point of view of image analysis and processing, the task of registration of perfusion scans taken with time lap approximately 48 hrs. is difficult but solvable. An innovative component is the creation and evaluation of perfusion dynamics maps using the DSPTA (Digital Subtraction Perfusion Topography Analysis, see Fig. 5) algorithm. Subtraction perfusion maps will enable more accurate spatial and temporal diagnosis and improved topographic accuracy when planning surgical treatment.

As pointed out above, in the field of cutometry we mainly focus on implementation of more accurate methods of determining the transition point between elastic distention and viscoelastic creep which is vital for better evaluation of certain viscoelastic parameters of skin. The other topic in cutometry is taking all cycles of the cutometry curve into account to retrieve as much as possible information contained in it. We plan to implement these ideas in an application called Cuticurve which is expected to supersede the software supplied along with the cutometric device in many aspects. In the first period it is expected to be utilized in clinical research, later it hopefully could be helpful in clinical practice.

Fig. 5. Typical appearance of subtraction perfusion map. Blueish and reddish colors mark regions of decreased and increased perfusion, respectively. Regions of perfusion stagnation are white.

5 Conclusion

The methods and software tools being developed are expected to have a wide application in the treatment of early burns, where the targeting of the product is primarily directed. In the field of blood perfusion visualization, the software environment will include methods of preprocessing LDI scans and, using semi-automatic or manual algorithms, will provide comprehensive information on the area distribution of perfusion and perfusion dynamics, including the necessary statistical information to support the decision-making process. In the field of measurement of viscoelastic parameters of skin, the software environment will comprise massively improved precision of cutometric parameters (particularly of those depending of the transition point) and utilizing data of all cycles contained of cutometric curve.

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Speedgoat RT Simulator For HIL And PIL Simulation Purposes

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Abstract. This paper describes purpose and use of the Speedgoat RT simulator, which is used now and will be used in the future in many cases here at VSB-TU Ostrava. With the advent of new complex technologies, which are used by many disciplines today, there is also a need to constantly improve testing and debugging processes. This increases the demands on modeling physical devices as part of the production process for debugging needs. This has resulted in the need to have specialized equipment for hardware-in-the-loop and processor-in-the-loop simulation and modeling. In the case of our projects, such equipment is used to simulate industrial buses and, with other cards, will also be used to create digital twins of real production lines.

Keywords: Industrial bus, CAN, Profibus, Profinet, EtherCat, sensors, hardware-in-the-loop, processor-in-the-loop, MATLAB, Simulink, modeling, digital twin

1 Introduction

Since the turn of the 1970s, it has been characterized by a sharp increase in electronic systems not only in the aerospace and automotive industries[2, 7]. The size and complexity of electronic control units, production lines and all related systems is growing significantly[1, 4, 7].

However, this trend brings with it an increasing risk of errors both in the finished system and during its design. Enormous demands for testing such complex systems come from the design stage. HIL and PIL simulations are just one of the methods to perform these tests[3, 4]. Today's technologies are also increasingly based on the modeling of entire control systems or production lines, where this trend is known as "digital twin" [5, 7].

It is for these reasons that from the turn of the millennium, specialized devices for performing HIL and PIL simulations are beginning to emerge. These are mainly specialized RT systems on a common x86 platform equipped with an input/output interface and also having modules for communication via industrial buses. Among the main benefits of this technology for testing can be mentioned[2, 5]:

- **Save costs and reduce risks**

Reduce costs by increasing the speed and scope of continuous verification and validation

Perform tests beyond the range of normal parameters or plant capabilities without risking damage to equipment

Lower innovation costs by being able to continuously try new ideas, even when the actual plant is not available

- **Save costs and reduce risks**

Shift the traditional sequential V-diagram to a circular workflow to enable continuous verification and validation of your designs at the earliest possible stages

Unlike physical plants, real-time simulators can easily be expanded with new I/O at any time

1.1 MIL, PIL And HIL Simulation Approach

To approach this issue, it is appropriate to start with a model-in-the-loop (MIL) approach. The simulated model of control system is built purely with a software environment, where it is then compiled and operated. A model of controlled system is then built for such a model, which is again operated on the same device. Whether the MIL-type simulation leads to good or bad results, it is clear that the degree of idealization of the whole task is almost unbearable in this case. However, the fact that the model cannot always capture the properties of a real system faithfully enough and is only an approximate approximation of it. Such a model does not capture many other influences, such as countless non-linearities, computational power of the control hardware used in practice, transmission speeds of communication lines, etc. [6]

Assuming reasonable results, it is possible to move one step closer to reality by moving the implemented control system to a development board or similar device to the target one. This divides the control and managed system, which are interconnected by selecting the communication bus. PIL simulation thus allows to test the control system already on the target platform and it is possible to verify its behavior, performance or parameters[6].

The next step is the HIL type simulation. The principle is based on a PIL simulation with a difference in the communication interface used. This type of simulation is used mainly for complex control tasks with a large amount of resources spent - automotive, aircraft, etc. In addition to the connection to the real system, special hardware is used here to simulate physical quantities. These are usually A/D and D/A converters, current loops and other sensors. The link to the interrupt system is a matter of course. By simulating the HIL type, it is possible to get as close as possible to the real control process and thus many errors can be detected before the final deployment. The differences between the individual types of simulation are described in Fig. 1 [6].

Hardware-in-the-loop simulators are commonly available from small portable devices to rack solutions depending on the input requirements of the simulated system.

Fig. 1. Principle of MIL, PIL and HIL simulations

2 Real-Time Simulator

For the needs of projects at VSB-TU Ostrava within the solution of topics including simulation of industrial buses, creation of digital twins, or operation of HIL simulations, a real-time simulator was purchased from Speedgoat. This device is built on Intel’s classic x86 platform. The motherboard is equipped with an Intel i7 processor, 32GB of DDR4 RAM and an SSD hard drive with a capacity of 512GB. The operating system is FreeDOS with the Simulink RT extension.

However, one of the most important components is the communication interface for industrial buses, which allows you to run PIL simulations. In 2020, a new I/O modules will be added, thanks to which it will subsequently be possible to run HIL simulations. The RT simulator modules are listed below in Fig. 2.

Present			Planned for 2020		
Module	Port or I/O	Purpose	Module	Port or I/O	Purpose
Motherboard	2x Ethernet	Host port and communication	IO135-Perf	32x DIFF 16-bit AI 16x SE 16-bit AI 8x Digital TTL	Voltage ranges +/- 10 V TTL 3,3 V and 5 V.
Motherboard	Serial port	Communication			
Motherboard	4x USB	Devices, communication			
IO712	2x Ethernet	EtherCAT master, RT UDP, XCP or PTP, TCP/IP	IO306-Perf	64x FPGA TTL	TTL 3,3 V and 5 V.
IO611	2x CAN & LIN	CAN FD I/O; CAN HS & LS, LIN protocols	IO306-Ext	4x PWM 4x CAP 2x Interrupt	Extension for IO306-performance. TTL logic.
IO641	1x PROFIBUS	PROFIBUS master			
IO642	1x PROFIBUS	PROFIBUS slave	2x IO204-24	16x 24V input 16x 24V/0,5A output	I/O modules for HIL simulation purposes.
IO750	2x Ethernet	EtherCAT Slave			
IO751, IO752	2x Ethernet	PROFINET master, PROFINET slave			
2x IO758	2x Ethernet	POWERLINK communication node			

Fig. 2. Figure of table describing installed modules.

The work is now limited only to the interface for communication via industrial buses and thus the possibility of using processor-in-the-loop access, however, several use cases have been prepared and tested including CAN, PROFIBUS and PROFINET communication.

2.1 Working With RT Simulator

The prerequisite for work is a workstation with MATLAB and Simulink software with a real-time license. Of course, there must be installed library from Speedgoat company, which allows access to I/O interfaces, communication modules and the use of utilities. For the needs of working with the simulator, a suitable workspace was created with the following network layout, which allows to manage both part of the PLC and work with the simulator from one user device (PC).

Fig. 3. RT simulator workbench

On the workstation are installed software MATLAB and Simulink with RT license, which are used for creating models, which are after then compiled and downloaded to the target RT simulator. At the same time, the software for PLC programming TIA Portal V15.1 is installed here. For creating an industrial network it is necessary to prepare XML configuration files for I/O modules using Sycon application from Hilscher and GSD-ML files for PLC, which contains hardware description of I/O module of RT simulator.

3 Simulator Use Cases

Following section 2, cases of using the RT simulator are described in more detail here. Models for CAN, PROFIBUS and PROFINET were created. In the case of the CAN bus, it was a loopback. PROFIBUS and PROFINET are used for PIL control, when the system is operated on the RT simulator and the control of the given system is subsequently created on the PLC.

3.1 CAN Loopback

As a first use case, a simple DEMO with a CAN bus in a loop was created **(a)**. The IO611 module was used, which contains two CAN ports. The upper one was the sender, lower one was receiver. I was sending a generated sine wave signal converted to data type double. This meant setting 8 bytes for sending and 8 bytes for receiving. This test using the CAN bus verified the correct parametrization of the system.

3.2 Ethernet Loopback And PROFIBUS Test

After successful testing of the CAN bus, we switched to testing the Ethernet ports on the motherboard and the IO750 module. The loopback was started again and a sine signal was sent again **(b)**. However, the connection of the Siemens S7 1500 PLC and the RT simulator using the PROFIBUS bus became more interesting. The PROFIBUS master consisted of the IO641 module and the PLC formed a slave device. again, one double value of the generated signal was forwarded, but this time it was about connecting an external device to the RT simulator. This involved the proper configuration of the interface on both sides and the time spent on debugging.

Fig. 4. Tested use cases with RT simulator

3.3 Model Of Inverted Pendulum

The commissioning of the inverse pendulum model on the RT simulator side and the control on the Siemens PLC side can be considered the latest solved problem. The two parts are connected using the PROFINET bus. The PLC controls the system using speed v and the system provides information on the position of the inverted pendulum and the speed of truck. Thus, 4 bytes is transmitted to the system and 8 bytes from the system **(c)**. However, the actual solution has a problem with insufficient speed of response, which causes bad regulation

quality. It means, that controller is not able to control the system. Currently, the IRT part is being solved on the PROFINET bus, which would, in addition with synchronization, also speed up the data transfer between the system and the control. One tick would be set to time under 2 ms.

4 Conclusion And Future Work

This paper describes actual work progress done on RT simulator from Speedgoat, which is located here on VSB-TU Ostrava for project purposes. RT simulators are used today in every industry way, where rapid prototyping and thorough testing are used in order to tune the device or system to the highest possible level of reliability. Use of PIL and HIL simulations lower total time and final cost of development. Currently, it is possible to work with our device only on simulations with the PIL approach, but this will change with the new modules. Subsequently, it will be possible to model entire physical systems, which brings us to the level of application of digital twins, where not only this approach is widely used today, for example in the automotive industry.

After the successful elaboration of the example with inverted pendulum, the work will be shifted to the application of other industrial buses and the extension of existing ones.

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Software Defined Equalization Techniques for Visible Light Communication

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Abstract. This paper focuses on a channel feed-forward software defined equalization (FSDE) of visible light communication (VLC) multi-state quadrature amplitude modulation (M-QAM) based system, implemented in the LabVIEW programming environment. A highly modular platform is introduced; the whole platform is thoroughly explored and analyzed during practical measurements in the laboratory, simulating real-world situations. The whole platform is based on modified National Instruments software defined radios (NI SDR) and a commercially available Philips light source, often used in Czech government institutions. Three FSDE algorithms were tested: least mean squares (LMS), normalized least mean squares (NLMS), and QR decomposition based RLS (QR-RLS).

Keywords: Visible Light Communication, Quadrature Amplitude Modulation, LabVIEW.

1 Introduction

In wireless and visible light communications (VLC), data are susceptible to interference caused by variations in the transmission channel. In the ideal communication channel model, the signal propagates directly from the transmitter to the receiver. However, the ideal model is practically unreachable as a number of reflected signals caused by various obstacles influence the whole platform. As their time of arrival (ToA) at the receiver varies in comparison to the direct wave, they cause a phenomenon called multipath propagation. In addition, various atmospheric effects, such as rain, fog, or even temperature turbulence can cause additional noise; see [1, 2, 3, 4].

2 Measurements

Measurements were carried out on a custom platform developed around software defined radios (National Instruments USRPs) and virtual instrumentation (LabVIEW 2018). The Philips Fortimo LED 3000 44W/840 was used as a transmitting element. Three previously mentioned adaptive algorithms—LMS, NLMS,

and QR-RLS—were used during the measurements. The monitored parameters were E_b/N_0 , MER, EVM, and BER. The block diagram of the whole platform can be seen in Figure 1.

Fig. 1. Block diagram of the tested platform.

2.1 Software

As mentioned before, the software side was implemented in LabVIEW 2018. This platform offered a high level of modularity and adaptability, as the software side, which was the backbone of the whole prototype, communicated directly with the software defined radios. Therefore, any modifications of the software side could be instantaneously tested during the real measurements.

The front panel of the prototype consisted of four parts. The first part was used to set the proper signal parameters (carrier, bandwidth, USRP gain, sample width), modulation parameters (mainly QAM order). The second part focused on equalizations, offering variable configurable parameters, like the regularization factor, leakage, or forgetting factor. The third part or block was mainly used for measurement, offering various readable parameters (BER, MER, EVM, etc.). Blocks 4 and 5 showed the waveform graphs on the transmitting and receiving side.

2.2 USRP, Amplifier, Bias Tee and Photodetector

Two NI USRP-2921 were used for the experiments. These older USRPs use standard Ethernet as an interface between the device itself and the controlling computer. It originally offered daughterboards operating at 2.4 to 2.5 GHz and 4.9 to 5.9 GHz, which were not suitable for VLC experiments. Therefore, two boards—Ettus LFTX for the transmitter and LFRX for the receiver—which operated at 0-30 MHz, were used during the experimental measurements.

The amplifier constructed by Chinese engineers was used during the measurements. It operated at 1 to 500 MHz and amplified the signal by 1.6 W.

The Mini-Circuits ZX85-12G-S+ bias tee was used to modulate Philips light source. It offered a low insertion loss of 0.6 dB, wideband operation (0.2 to 12,000 MHz), a high current capability of 400 mA, and a rugged unibody construction. The bias tee itself was a diplexer, which used the low-frequency port to set the bias, and the high-frequency port passed the RF signal, but blocked the biasing. The combined port used both bias and RF to modulate the light source itself.

Thorlabs PDA36A-EC was used as a receiving element. It offered a bandwidth of up to 10 MHz and a peak sensitivity at 970 nm.

2.3 Configuration, Scenario, and Results

The following configuration was used during the measurements: a carrier frequency of 3 MHz with a variable bandwidth from 1 MHz to 4 MHz. However, since NI USRPs had some channel widths fixed, it used a slightly wider channels (for example 3.0303 MHz instead of 3 MHz). The number of transmitted symbols was 10,000.

The Philips Fortimo ceiling light was mounted on a moveable holder, which could be freely adjusted on a custom ceiling rail system.

The receiving photodetector was mounted on a movable laboratory cart. Therefore, it was possible to change the position of the detector, but always keeping the same height. This scenario can be seen in Figure 2. The Philips light source illuminated conical area with diameter of 700 cm.

Fig. 2. Visualization of reached M-QAM modulation formats based on measured parameters—3 MHz channel width and carrier frequency.

The measurement itself was carried out only in the X axis up to a maximum distance of 350 cm, which corresponded to the radius of the illuminated area

(Figure 2). As the illuminated area was a symmetrical cone, the measurement was carried out only in one direction: from the center to the “right” side.

The Rohde & Schwarz ZVB4 network analyzer was used to measure the attenuation characteristics of the entire communication chain. This attenuation frequency response was measured against the reference that was set when the analyzer input and output were connected directly. After measuring this characteristic, it was decided that the measurement would be carried out at a carrier frequency of 3 MHz, mainly to use as much bandwidth as possible. The attenuation frequency characteristics measured at various distances (1 m, 2 m, and 3 m) from the center of the illuminated area are visible in Figure 3 as well.

Fig. 3. Attenuation frequency response of the entire communication chain using a Philips Fortimo LED 3000 44W/840 lamp at a distance of 202 cm between the source and the photodetector.

The dependence of E_b/N_0 on the measured distance and configured adaptive algorithm can be seen in Figure 4. This figure correspond to measurements with 4-QAM modulation and the 1 MHz. It is noticeable that the QR-RLS adaptive algorithm provided the best results of E_b/N_0 across the board (in comparison to the non-equalized data). The parameter was improved by 9 dB at the center of the illuminated area and by 11 dB at a threshold value of almost 300 cm. The other algorithms improved the measured signal as well, but the difference was lower. LMS managed to improve the E_b/N_0 by 2 dB at the center and 7 dB at the threshold. NLMS improved the values by 3 dB at the center and 8 dB at the threshold. As is visible, each algorithm noticeably improved the received signal.

Figure4 also include two sets of constellation diagrams, one for the scenario without equalization and one with the QR-RLS adaptive algorithm. Each set

Fig. 4. Dependence of E_b/N_0 on the distance and adaptive algorithm, bandwidth 1 MHz, 4-QAM.

had two constellation diagrams corresponding to the values in the center of the illuminated area and at the measurable threshold (350 cm for QR-RLS and 325 cm for the scenario without equalization). By comparing both figures, it can be seen that wider bandwidths had a significant impact on E_b/N_0 . Figure 4 shows the better results of E_b/N_0 by approximately 4 dB in comparison to Figure ?? . However, wider channels also offered higher transmit speeds.

Complete results were published in multiple articles [5, 6, 7, 8] and two additional articles are currently in review process or writing phase.

3 Conclusion

This work dealt with channel feed-forward software defined equalization in a QAM VLC system. The whole platform based on LabVIEW and National Instruments hardware was introduced. QR-RLS was preliminarily identified as the best algorithm for deployment; however, this argument had to be backed by certain data.

The main part described the whole measuring phase, which backed up the earlier statement. QR-RLS managed to improve BER values by up to one whole order. It also improved EVM up to 10%. LMS and NLMS improved the measured values as well, but the impact was lower. NLMS managed to improve EVM up to 7% in the best-case scenario, whereas LMS reached only up to 5%. Based on the measurements, the used amplifier suffered from significant non-linearity. Alternative models are currently being explored, and LZY-22+ from Mini Circuits is the most likely candidate for future testing. Non-linearity significantly influ-

enced the results, and the values might be even improved by at least 30%. The receiver was another limiting factor of the whole platform.

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Battery Electric Vehicle Passive Consumption

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Abstract. This paper aims to present a measurement of passive consumption in battery electric vehicle (BEV) for overall consumption estimation and thru range calculation. The goal of my dissertation thesis is to create an algorithm which will be able from a map data, BEV model, and weather forecast precisely estimate range on a route and suggest changing or limitation of consumption. In this paper, I am dealing with passive consumption for BEV model. Passive consumption is the power required for running lights, whippers, ventilation, air condition, brake pump, cooling systems, compartment systems, and many others. Unlike the route consumption, which is depending on hilliness, speeds, and mainly on the length of the journey, passive consumption is time and weather dependent. This type of consumption is mostly noticeable in city traffic or traffic jams and can reduce the range of up to 30 %.

Keywords: Battery electric vehicle, Passive consumption, Range estimation, Peugeot IoN.

1 Introduction

Due to an enormous quantity of energy stored in nowadays batteries scientific work aiming rather on precise estimating the active consumption like acceleration, speed, hilliness, and recuperation then on minor, passive consumption include electronics, lights, whippers, brake booster and mainly HVAC (heating, ventilation, AC) systems.

2019 Tesla model S (TMS) have 100 kWh accumulators and optimized passive consumption, mainly thermal management of both compartments, and batteries. Due to this, a passive consumption on o route is in units of percent. Unfortunately, TMS and any other Tesla models are quite significant for everyday use. EPA measures [2] that TMS offer over 640 km of electric range weights over 2 tons, and its length nearly 5 meters makes them unfitting overcrowded cities, where is a huge part of the population worldwide. Nevertheless, these sizes of the battery have questionable greenhouse gas emission impact because its recoverability requires quite big mileage [1], [4]. Especially in states where is a significant part of electricity produced in coal power plants. In Europe, average citizen drives up to 40 km [3] per day, so there is no need for such a big range for daily needs.

On the other side of battery sizes are the triplets: Peugeot Ion, Citroen C Zero, and original Mitsubishi I-MiEV. Those cars designed in 2009 have a tiny battery up to 16 kWh. It weighs only 1080 kg, and it is 3.4 meters long. EPA range of this vehicle is about 100 km. The real range in this car is about 130 km, and the record is around 220 km per one charge. This car perfectly fits daily needs for everybody who have an electrical plug for charging the vehicle.

The huge disadvantage of this “small battery cars” is passive consumption. The car can use up to 15 kWh of stored electrical energy. The peak power of electrical heating is around 5 kW. So, there is a significant impact on the range in the winter. In some cases, the range of small battery vehicles can drop significantly [5]. There should be some impact in the night, when lights are on, or rain, when besides changing of rolling resistance, whippers and ventilation use are required. The aim of this paper is to measure the passive consumption of each electrical appliance in a battery electric vehicle.

2 Material and methods

Measurements were made on a 2012 Peugeot Ion with approximately 13.5 kWh of energy stored in traction battery and effective range around 120 km. This vehicle is susceptible to all deviation from standard journey conditions, in particular traffic jams and detours. Small consumption and small battery increase the importance of passive consumption.

There are two methods of measuring power for the auxiliary load. First is ohm method of measuring power on the 12V auxiliary battery; second is to use internal traction battery BMS for measurement information.

2.1 Ohm method

The first measurement was direct with the use of two multimeters—one for voltage, and another for current measurement. Firstly, the current monitor was clamp ammeter; unfortunately, its precision fluctuated significantly, and with other measurement errors, there were huge differences between the same measurements. Another test was run with shunt resistor. Results are summarized in the table 1.

2.2 BMS measurement method

The second measurement was read from BMS in traction battery via CAN communication reader. The results are in the table 2.

Differences between those two measurements are in the table 3.

3 Results

Measurements of those two methods are quite different because of the onboard charger, which has some losses while changing voltage from traction battery

Table 1: Measurement of appliances in Peugeot Ion via Ohm method.

Shunt 1.5 ohm	UI (mV)	U (V)	I (A)	P (W)
idle + auto vent	9.2	12.38	6.13	76
Parking lights	9.3	12.37	6.20	77
meeting lights	22.9	12.12	15.27	185
front fog lights	30.9	12.00	20.60	247
f+back fog lights	33.7	11.95	22.47	268
ventilation	15.2	12.24	10.13	124
max vent	18.7	12.17	12.47	152
max vent + light	41.8	11.84	27.87	330
idle	5.7	12.42	3.80	47
beep + interior light	6.4	12.42	4.27	53
brake light	8.4	12.38	5.60	69
int světlo	6.4	12.42	4.27	53
seat heat	9.0	12.36	6.00	74
audio	7.0	12.40	4.67	58
idle	6.4	12.41	4.27	53
Parking lights	7.1	12.40	4.73	59
meeting lights	20.2	12.16	13.47	164
+high beam lights	34.0	11.97	22.67	271
+front fog lights	44.5	11.85	29.67	352
+high beam lights	44.4	11.85	29.60	351
whipers	11.5	12.34	7.67	95
+windshield washer	12.3	12.30	8.20	101
back whiper	8.2	12.38	5.47	68
+windshield washer	10.6	12.37	7.07	87
avg emergency light	13.6	12.28	9.07	111

Table 2: Measurement of appliances in Peugeot Ion via tablet

Measurement	U1 (V)	U2 (V)	I1 (V)	I2 (V)	P1read (kW)	P2read (kW)	P1counted (W)	P2counted (W)	P1separate (W)	P2separate (W)	P12avg (W)
Without traction battery	357		0.70		0.25		250				
Traction battery + 12 V charging + daytime light	357		1.30		0.50		464				
Basal consumption (B)	357	317	1.00	1.00	0.40	0.30	357	317	357	317	337
B + daytime light	357	317	1.10	1.10	0.40	0.40	393	349	36	32	34
B + meeting lights	357	316	1.40	1.50	0.40	0.40	500	474	143	157	150
B + meeting + high beam lights	356	316	1.90	2.00	0.70	0.60	676	632	319	315	317
B + front fog lights	357	316	1.20	1.30	0.40	0.40	428	411	71	94	83
B + front + back fog lights	357	316	1.40	1.40	0.50	0.45	500	442	143	125	134
B + brake light	356	316	1.10	1.10	0.40	0.40	392	348	35	31	33
B + Emergency lights (avg)	356	316	1.20	1.25	0.45	0.40	427	395	70	78	74
B + Turning lights (avg)	356	316	1.10	1.15	0.40	0.35	392	363	35	46	41
B + Cabin light	356	316	1.05	1.05	0.40	0.30	374	332	17	15	16
B + Mix volume audio system	356	316	1.05	1.05	0.40	0.30	374	332	17	15	16
B + Cooling pump	357	316	1.20	1.30	0.40	0.40	428	411	71	94	83
B + Brake booster	357	316	1.80	1.80	0.70	0.60	643	569	286	252	269
B + "Auto" ventilation	357	316	1.10	1.15	0.40	0.40	393	363	36	46	41
B + Max: but one ventilation power	357	316	1.20	1.30	0.40	0.40	428	411	71	94	83
B + Maximal ventilation power	357	316	1.25	1.40	0.40	0.40	446	442	89	125	107
B + Boost ventilation power	357	316	1.30	1.70	0.50	0.40	536	537	179	220	199
B + AC max: + max: ventilation	356		4.20		1.40		1495	0	960		960
B + Mix heating	356		15.00		5.80		5340	0	4805		4805
B + Avg. Heating	356		13.70		439.00		4877	0	4342		4342
B + Front windshield ventilation (all HVAC) max:	356		15.00		5.30		5340	0	4983		4983
B + Front windshield ventilation (all HVAC) avg:	356		13.30		4.70		4735	0	4378		4378
B + Front wiper slow	355	316	1.15	1.15	0.40	0.35	408	363	51	46	49
B + Front wiper max:	356	316	1.25	1.20	0.40	0.40	445	379	88	62	75
B + Front wiper auto + splasher	356	316	1.15	1.35	0.40	0.40	409	427	52	110	81
B + Back wiper	356	316	1.05	1.05	0.40	0.30	374	332	17	15	16
B + Back wiper + splasher	356	316	1.15	1.20	0.40	0.40	409	379	52	62	57
B + Rear windshield heating	356	316	1.50	1.60	0.50	0.50	534	506	177	189	183
B + Drivers seat heating	356	316	1.10	1.10	0.40	0.35	392	348	35	31	33
B + Reverse + Brake	356	316	1.30	1.40	0.50	0.40	463	442	71	95	83
B + Drive + Brake	356	316	1.15	1.20	0.40	1.20	409	379	52	62	57
B + Neutral + Brake	356	316	1.10	1.10	0.40	1.10	392	348	35	31	33
B + 12V Battery charging	356	316	1.10	1.10	0.40	0.40	392	348	35	31	33

Table 3: Difference between measurements, and efficiency of on-board charger estimation.

Appliance	Ohm (W)	Tablet (W)	Ratio (%)
Meeting lights	114.0	142.8	0.80
High beam lights	221.0	319.4	0.69
Front fog lights	61.0	70.0	0.87
Braking lights	19.0	34.6	0.55
"Auto" ventilation	20.0	35.7	0.56
Boost ventilation	152.0	178.5	0.85
Front wiper slow	45.0	51.2	0.88
Front wiper auto + splasher	51.0	52.4	0.97
Back wiper + splasher	37.0	52.4	0.70
Drivers seat heating	24.0	34.6	0.69
Average			0.76

voltage (280 - 380 V) to 14.4 V. That efficiency varies with increasing power and its average is approximately 75 %. This means that for running appliances with an input power of 750 W, approximately 1000 W is drained from the traction battery. This means a 1 kWh each hour in use + active consumption for vehicle movement.

4 Discussion

In the picture 2 was measured real power of all the possible appliances in Peugeot Ion BEV. From this measurement could be concluded that in foggy weather could be passive consumption quite high because of using the heater (5 kW peak power) to heat air, AC (3 kW peak power) to dehumidify the air, ventilation to distribute air and some lights to increase safety on the road. That weather scenario means a significant increase in passive consumption from 0.4 kW to 1.2-1.4 kW and thru decrease range of BEV. The even worse situation is heavy snowing in the cold winter. Based on observation of appliances, passive consumption can raise to 5.48 kW each hour, and together with lower speed due to safety reasons and less amount of energy in traction battery due to low temperatures it has enormous, more than 50 % impact on a range available in this BEV.

With this knowledge, the importance of prediction of weather, day/nighttime driving, and passenger temperature habits grows. Combined with the prediction of the particular pathway with vertical distance, length, speeds, and traffic, the precise algorithm can be obtained to increase reliance in range information and widespread adoption of BEV and thru this more sustainable future.

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Optimal Control Problem Solving by Calculus of Variation

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Abstract. This article describes the use of calculus of variation for solving optimal control problem. This means the indirect method is used for this purpose. The main idea is to add co-states to original dynamic system state space description using calculus of variation. The new problem is specified as boundary value problem with the same number of differential equations and boundary condition. The solution for the transferred problem is calculated in Matlab. Whole method is applied to case study for illustration.

Keywords: Optimal Control Problem, Boundary Value Problem, Indirect Methods, Calculus of Variation, Inverted Pendulum

1 Introduction

The history of control theory is often connected with Scottish inventor James Watt and his mechanical governor controller for steam machine speed control [1], [2], however the need to control machines and processes is much older. For example, the just mentioned governor controller was originally used in windmills [3], [4]. When the wind was too strong and windmill shoves angular velocity too high, there was risk of damaging the milling stones by friction, reducing the quality of flour or even its ignition. Due to the controller the pressure between the stones was reduced (or they were totally push away from each other) in these conditions.

The need to control systems increased with development of industry. The first task was to stabilize the system and to keep the output controlled value equal to desired value (called setpoint). This task allows to linearize the controlled system at the single working point or some set of them and to use methods for linear system control. The basic and still used type of controller is PID [5].

The additional demands for increasing the control system efficiency and performance and for decreasing the production cost starts to appear with further industry development. Increase of computer technology performance made it possible to meet these requirements. A new branch of control theory has emerged – the modern control theory [6]. Its main task is to solve optimization problem – minimize or maximize specified cost function, which includes variety of demands.

It is possible to divide optimization problems into two types, static and dynamic. We are speaking about static optimization when the problem is connected with some steady state and we want to optimize some settings or parameters [7]. The result of optimization is not function of time. Dynamic optimization [8] is connected with time and dynamic changes. The result is control signal, which is time function.

This paper deals with optimal control problem solving by use of calculus of variation. This process is described on case study, which is swing up of inverted pendulum.

2 Optimal Control Problem

The other name for dynamic optimization is optimal control problem. As was mentioned before, we need to obtain control signal $u(t)$ for dynamic system represented by state space description (1). This paper will not deal with the situation where control signal is also function of system states, which leads to optimal controller synthesis. The resulting control signal will move the dynamic system from initial state to final state in finite time and at the same time minimize (or maximize) specified cost function. We denote this optimal control signal $u^*(t)$. The state variable waveforms obtained by applying optimal control to controlled dynamic system are called optimal state trajectories $\mathbf{x}^*(t)$. Note that vectors of values are denoted in bold.

$$\mathbf{x}'(t) = f(\mathbf{x}(t), u(t), t) \quad (1)$$

The cost function determines the required properties of optimal control $u^*(t)$. Generally, it is possible to specify any cost function, however there are several forms that are frequently used, for example for minimization of time, fuel, or energy needed for transfer dynamic system from initial state to final state. The equation of cost function general form is

$$J = S(\mathbf{x}(t_f), t_f) + \int_{t_0}^{t_f} V(\mathbf{x}(t), u(t), t) dt, \quad (2)$$

where t_0 and t_f specifies initial and final time. This form consists of two parts. First member of equation is called Mayer term and is used for penalization of final state. The second part is represented by integral and is called Lagrange term. It penalizes the whole control process. The form described by equation (2) is called Bolza term, it consist from Mayer and Lagrange term. It is good to know that cost function written in any form can be converted to each other form [9], [10].

The methods for solving optimal control problem can be classified into three main groups [11]:

- dynamic programing,
- direct methods
- indirect methods.

The last one approach of this list will be used in this paper and described below.

2.1 Indirect Methods

This approach uses the calculus of variation, or generally Pontryagin minimum principle [12], for conversion of optimal control problem to classical two point boundary value problem by adding co-states. If the original dynamic system is described by N state space equations, after the conversion we obtain the system described by $2N$ equations (N original equations and N for co-states). The boundary conditions are the same for original and new system, N for initial state and N for final state.

2.2 Calculus of Variation

Detailed description of calculus of variation can be found in [12], [13]. The main steps of this method are:

- Formulation of Hamiltonian function H from cost function (2) and state space description of dynamic system (1)

$$H = V(\mathbf{x}(t), u(t), t) + \mathbf{p}^T \mathbf{x}', \quad (3)$$

where V is Lagrange part of cost function and $\mathbf{p}$ are additional co-states.

- Derivation of optimal control signal expression from derivation of H (3) with respect to control signal u

$$\frac{\partial H}{\partial u} = 0 \rightarrow u^*. \quad (4)$$

- Preparation of new dynamic system with original state variables and co-states, substitution of optimal control expression to state space description

$$\mathbf{x}' = \frac{\partial H}{\partial \mathbf{p}}, \quad \mathbf{p}' = -\frac{\partial H}{\partial \mathbf{x}}. \quad (5)$$

- Solving the set of differential equations with specified initial and final conditions.
- Calculation of optimal control signal based on defined expression and results from previous step.

This process will be demonstrated on case study example.

3 Case Study: Inverted Pendulum Swing Up

The inverted pendulum on linear guidance system is very popular due to its properties. This system is strongly nonlinear, non-minimum phase and underactuated. That means there are more degrees of freedom (pendulum arm angle and cart position) than actuators (one actuator for moving with cart). The system consists of pendulum arm made by some shaft, which is at one end connected freely to cart. The actuator, basically DC motor, is used to move with the cart along linear guidance. This system is described by four state variables, which are pendulum arm angle x_1 (rad), pendulum angular velocity

x_2 (rad·s⁻¹), cart position x_3 (m) and cart velocity x_4 (m·s⁻¹). The control signal u is cart acceleration (m·s⁻²). Equations (6) - (9) show nonlinear state space description of inverted pendulum.

There are two primary tasks connected to inverted pendulum – stabilization of arm in upper nonstable equilibrium and transition between lower stable and upper unstable equilibrium called swing up. The second task is more complicated due to nonlinear character of system and stationary points located along the trajectories, which cannot be bypassed. The two degree of freedom control structure is used with advantage for this task due to division into feedforward and feedback part. The second part stabilizes the system along reference state trajectories. These are generated together with reference control signal by feedforward part. One of possible ways how to determine reference state trajectories and control signal will be discussed in next part of article – solving of optimal control problem. The resulting signals will be also optimal due to adding the request for control signal energy minimization (10).

The optimal control problem is generally specified by system dynamic represented by differential equations (6) - (9), selected cost function (10) and boundary conditions formed system state in initial time t_0 and final time t_f (11).

$$x_1' = x_2 \quad (6)$$

$$x_2' = \frac{3}{4} \cdot \frac{g}{l} \cdot \sin x_1 + \frac{3}{4} \cdot \frac{u}{l} \cdot \cos x_1 - b \cdot x_2 \quad (7)$$

$$x_3' = x_4 \quad (8)$$

$$x_4' = u \quad (9)$$

$$J = \frac{1}{2} \int_{t_0}^{t_f} u^2(t) dt \quad (10)$$

$$x(t_0) = [\pi \ 0 \ 0 \ 0]', \quad x(t_f) = [0 \ 0 \ 0 \ 0]' \quad (11)$$

The first step of solution is formulation of Hamiltonian (12) according to (3) and substitution of system dynamics (6) - (9).

$$H = \frac{1}{2} u^2 + p_1 x_1' + p_2 x_2' + p_3 x_3' + p_4 x_4' \quad (12)$$

$$H = \frac{1}{2} u^2 + p_1 x_2 + p_2 \left(\frac{3}{4} \cdot \frac{g}{l} \cdot \sin x_1 + \frac{3}{4} \cdot \frac{u}{l} \cdot \cos x_1 - b \cdot x_2 \right) + p_3 x_4 + p_4 u \quad (13)$$

The next step is minimization of Hamiltonian (13) with respect to control signal u according to (4). It is possible to derive optimal control signal u^* prescription (15) from equation (14). Note that for different cost function, for example with linear control signal dependence, the solution cannot be calculated by this method. See [14] for more information.

$$\frac{\partial H}{\partial u} = u + p_2 \cdot \frac{3}{4} \cdot \frac{1}{l} \cdot \cos x_1 + p_4 = 0 \quad (14)$$

$$u^* = -p_2 \cdot \frac{3}{4} \cdot \frac{1}{l} \cdot \cos x_1 - p_4 \quad (15)$$

Then, the new dynamic system description is determined by (5). That leads to adding of four differential equations with co-states (16) - (19) to original system state space description (6) - (9).

$$p'_1 = -\frac{\partial H}{\partial x_1} = -p_2 \left(\frac{3}{4} \cdot \frac{g}{l} \cdot \cos x_1 - \frac{3}{4} \cdot \frac{1}{l} \cdot u \cdot \sin x_1 \right) \quad (16)$$

$$p'_2 = -\frac{\partial H}{\partial x_2} = -p_1 + p_2 b \quad (17)$$

$$p'_3 = -\frac{\partial H}{\partial x_3} = 0 \quad (18)$$

$$p'_4 = -\frac{\partial H}{\partial x_4} = -p_3 \quad (19)$$

The control signal u in new system description (formed by eight differential equations) is substituted with prescription for optimal one (15). Obtained differential equations forms together with original boundary conditions (11) the two point boundary value problem, which can be solved in Matlab using function `bpv4c`. The state and co-state trajectories are results of this process. The last step of optimal control problem solving is determination of optimal control signal u^* from obtained trajectories and its prescription (15). The reference state trajectories from two point boundary value problem solution is also optimal state trajectories for original optimal control problem. The obtained optimal state trajectory $x_1^*(t)$ and optimal control signal $u^*(t)$ are shown for illustration at fig. 1.

Fig. 1. Optimal state trajectory $x_1^*(t)$ (left) and optimal control signal $u^*(t)$ (right)

4 Conclusion

This article describes one of the methods for optimal control problem solving based on calculus of variation. It can be classified as indirect method. The main idea of this approach is to transfer optimal control problem (N differential equations, $2N$ boundary conditions and cost function) to two point boundary value problem ($2N$ differential equations and $2N$ boundary conditions). The optimal control signal u^* is described with additional co-states. The difference compared to two point boundary value problem with free parameters (N differential equations, $2N$ boundary conditions and no cost

function) is that the prescription for control signal is based on cost function and system dynamics instead of expert choice. The resulting control signal and state trajectories are called optimal.

The calculus of variation can be generalized to Pontryagin minimum principle. It can be used for various tasks, with free time (t_f not specified), free end ($\mathbf{x}(t_f)$ not specified), constrained state variables or control signal, or cost function with specified Mayer part.

The described method was applied to solving swing up of inverted pendulum. The optimal trajectory for $x_1^*(t)$ (fig. 1 left) shows that pendulum arm starts with angle π (lower equilibrium) and ends with angle equal to 0, as requested. The optimal control signal $u^*(t)$ (fig. 1 right) starts and ends in nonzero values, because there were not specified any requirements. The same situation will occur when using many of optimal control problem solving toolboxes. The solution for this task is nontrivial.

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Vibration Measurement and Analysis of Hydraulic Shears

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Abstract. There was a request for the use of predictive maintenance of the hydraulic press. In agreement with the client, an initial task was created to apply predictive maintenance of a part of the hydraulic press, namely hydraulic shears. An initial measurement was performed using accelerometers located on the cutting edges of the hydraulic shears. This measurement revealed the amplitude of the measured signal and its frequency spectrum. Basic analysis of the cutting cycle of shears were performed. From the measured data, suggestions were made on how to reduce the size of the stored data for analysis. A design of a measuring device for use in continuous operation for continuous measurement was created. Further steps in the measurement were proposed to determine the change of acceleration based on the change in the state of the shears blade.

Keywords: Hydraulic Shears, Predictive Maintenance, Vibration Measurement, Fast Fourier Transform

1 Introduction

Predictive maintenance is a way how to prevent money loss in industry production. Unplanned machine shutdowns make companies lose profits [1]. Because of this money losses on November 10, 2019 at Brose Kopřivnice was performed the initial vibration measurement. This measurement was carried out by accelerometers on the blades of the hydraulic shears. The vibration signal was detected - amplitude to determine the range of the measuring element and the shape of the signal. Among the used mathematical methods, we find Fourier and Wavelet transformations, also with data preprocessing (signal extraction, vibration decomposition, RoI cutoff, etc.). These methods allow you to look at the individual frequencies contained in the signal, as well as at what frequency intervals are important information and what are not.

2 Vibration Measurement

For the first measurement was used external measurement instrument from Bruel&Kjaer company, specifically type Type 3050 Multi-purpose 6-channel input module on LAN-XI. This module was paired with five one-axis high speed accelerometers up to ± 100 g. Measurement frequency was 65.536 kHz. Vibration meas-

urement can determine mechanical state of the machine, typical state of bearings, shaft and stator[2], in this case it is state of the blades of shears. Sample rate for measurement should be high enough for further signal analysis. According to Nyquist theorem the sample rate should be at least two times bigger than the highest component of frequency spectrum[3].

From 1st measurement there is in total:

- 16 measurements after 20 seconds of scissors
- 5 measurements after 20 seconds of environment
- 1 test measurement to catch optimal measurement scenario

Measurement was done on 80% of scissors lifetime.

The measurement was carried out in approximately 80% of the life expectation of the shears. The lifetime of the shears depends on the adjustment and sharpening of the blades by maintenance staff and can vary in the range from 500 thousand to 1,5 million cuts. The blade is changed after 1 million cuts even if the blade is still capable of operation. Whether the blade is operable defines the appearance of the metal structure in cut and is determined by the operator using the microscope. Approximately 1 month passes before a new blade is replaced.

Position of accelerometers:

1. Horizontal (parallelly with direction of sliding plate) – upper blade
2. Vertical (parallelly with direction of cutting) – upper blade
3. Vertical – body of shears
4. Horizontal – lower blade
5. Vertical – lower blade

Fig. 1. The location of accelerometers on hydraulic shears

3 Data Visualization and Analysis

For a data visualization and signal analysis MATLAB was used. **Fig. 2** shows measured data from accelerometers. From the measured waveforms, the maximum amplitude value was determined to be approximately 850 ms^{-2} . The accelerometers must meet at least this range. This range can be reduced by placing accelerometer on shears body, but at a cost of changing frequency response. The cutting time is approximately 120 ms. The cutting period is 1.8 s, and when the stack of hydraulic press is full, the cutting is stopped. At full speed, the useful data is below 7 % of all amount of data. To lower the amount of stored data, it is necessary to incorporate triggering into longer measurements. There are 2 possible ways:

- HW trigger – Use of the control signal to trigger the cut. The cutting takes the same time, so the measurement time can be determined from the already measured data.
- SW trigger – Use of a buffer in which the measured data is constantly stored and overwritten. Once a measured value is exceeded, a defined number of samples would be taken back and stored together with the measured data for a defined period.

Fig. 2. Measured data

Signals 1 and 4 (blue and violet) are measured perpendicularly to the cutting direction – this can indicate change of blade clearance. Fourth signal is measured on the bottom blade and compared to first signal (measured on top blade) there is loss of transmission of vibration. Rest of the signals are measured parallelly to cutting direc-

tion. There is also loss of transmission of vibration (second vs. fifth and third signal). Frequency shift occurs, the biggest difference is with the signal measured on the body of shears. With bigger distance from blades, the bigger shift occurs.

Data from continuous measurement will be stored on limited data storage, so it is necessary to do such compression. Smaller amount of data will also allow other algorithms for predictive maintenance to run faster.

There was another measurement made without active shears, to determine the influence of hydraulic press on the measured signal. The ambient noise (mainly caused by hydraulic press) does not exceed value $1,5 \text{ ms}^{-2}$. FFT averaging will be used to suppress random states, that can occur.

Fig. 3 shows one side FFT of each accelerometer. Spectral components of these FFT signals are very different and there is need to make a comparison with different states of shears.

Fig. 3. One side FFT

We are also able to wirelessly divide the signal into its individual components using the wavelet packet decomposition method. Using this method, it is possible to obtain signal components in individual frequency ranges and determine where the frequency components of the signal are dominant for us and on which it is appropriate to concentrate in further analyzes.

If we measure the frequencies of 65.536 kHz, we get decomposition in the frequencies 0 Hz – 32768 Hz and 32768 Hz – 65536 Hz from the initial signal on the

second level. At each additional level, the original signal can be further decomposed and the individual intervals getting narrower. In the fifth layer we are already able to determine which components should be monitored and which are not. On this basis, either a comparison of individual measurements can be built or changes in this decomposition can be monitored.

4 Measurement System

4.1 Based on PLC

As part of continuous measurement, it is necessary to select parametrically and cost-effective accelerometers. Regarding the future deployment of the collection system based on the SIEMENS portfolio.

Basic idea is to use PLC S7 1200 with the SM 1281 CMS module, which can be connected to up to 4 accelerometers. The measured data can be stored in the module for a configurable time of 1-90 s and they can also be read from the PLC in addition to targeted sending to the server or cloud.

According to the basic analysis, the highest frequencies that can be considered useful are in frequency range to 12.5 kHz. These frequencies, however, occur on accelerometers that are directly placed on the shears. In practice, however, such an accelerometer cannot be placed due to the shear replacement and the press function. Therefore, a remote location is chosen, where vibrations are also captured at lower frequencies up to 10 kHz.

4.2 Based on NI USB Card

In this scenario, will be used a USB measuring card from NI. Specifically, model NI USB-4431, which has four IEPE inputs with a maximum sampling frequency of up to 102.4 kHz.

The basis of this measuring system will be a classic or industrial PC. This PC will be connected to NI USB card, which will be equipped with appropriate accelerometers. This will result as the basis for continuous measurement. For the functionality of this solution, it will be necessary to process the appropriate SW preferably in the LabView environment, which guarantees maximum speed of development. LabView also has a set of library functions with a mathematical tool for vibration processing. The results can be stored in both raw and processed form on the HDD.

5 Conclusion

To identify the specific useful components of the signal, further measurements will be required, preferably continuous. Minimal requirements for further analysis are 2 measurements:

- before end of service life of shears blades (approx. 1 million cuts)

- after changing the blades - sharpened, correctly adjusted

Second measurement will allow to use mathematical methods based on comparison, so it will be possible to monitor changes in signal (frequencies, amplitudes, etc.)

By means of these measurements it will be possible to determine in what frequency range the blunt or change of blade clearance occurs. Furthermore, using several mathematical procedures, it will be found out which of the methods is most suitable in terms of accuracy, speed, and amount of processed data.

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Blood Glucose Prediction: A Review of the Use of Neural Networks in Diabetes Melitus

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Abstract. The work deals with research on the use of neural networks (NN) for the prediction of blood glucose levels and methods using NN, dealing with the prediction of the disease and treatment of Diabetes Mellitus. The topic of the use of NN in this area is examined with regard to the focus of the dissertation. The first part of the work focuses on the prediction of blood glucose levels using both NN and other methods (CM and MPC models, AR and ARMA, fuzzy models). The second part of the work is focused on the prediction of DM disease with treatment options. Through a survey, we found that there are a number of methods based on NN, CM, AR and fuzzy models dealing with the issue. As the methods found are not listed in clinical practice, they cannot be objectively evaluated.

Keywords: Diabetes Mellitus, Glycaemic Prediction, Blood Glucose Prediction, Neural Network for Glycaemic Prediction.

1 Introduction

Measuring blood glucose levels in the human body is one of the important indicators of the state of the human body. Blood glucose (BG) is used as an indicator of the condition in Diabetes Mellitus, (DM). Laboratory tests and SELF monitoring methods (glucometers and continuous blood glucose meters (CGM)) are used in blood glucose measurements [1]. Today, the use of NN in continuous measurement with insulin therapy is beginning to be investigated. The methods presented in the present search, combined with the latest available technologies, can lead to better treatment management [2].

Upon closer study of the available publications, it is clear that the use of neural networks in a given area is divided into two parts, the first part is the prediction of glycaemic development and the second part is the prediction of the patient's health. An adaptive artificial neural network is used, which divides the input variables into areas: healthy and unhealthy. The estimation of the patient's condition is based on the attributes: current glucose concentration, pregnancy, blood pressure, subcutaneous fat thickness, serum Ins, BMI, history of DM [3].

The following chapters provide an overview of the searched publications focusing on neural networks focused on the prediction of blood glucose levels and Diabetes Mellitus with subsequent therapy. The search area was focused mainly on the period 2015-2020, searched in databases WoS, Scopus, Google Scholar.

2 Prediction of Blood Glucose Levels

Several approaches are used to predict blood glucose levels that are able to make accurate estimates of the glucose profile. These estimates also depend on the surrounding stimuli. Most current methods of BG prediction are based only on CGM signals, recently predictions based on information about administered insulin and physical activity are beginning to appear [4].

Two main methods are used to predict BG concentration. One is mathematical modelling (first order polynomial, variance of the autoregressive AR model), which uses only its previous value to determine the glucose concentration. In the other direction are different types of NNs [5].

2.1 Neural Networks in Various Modifications

Neural network approaches can model the nonlinear dynamics of glycaemic and are characterized by the processing of various input signals [6].

In the article [4] the authors developed a predictor consisting of the NN model and a polynomial extrapolation algorithm, used to describe nonlinear and linear components of glucose. In publication [7] NNs are used to identify glucose concentration dynamics by monitoring clinical data on glucose and insulin. A nonlinear NN model was developed, based on which an ad hoc model was designed for the feedback of glycaemic regulation by insulin delivery.

The use of the ANN approach to predict BG levels in DM1 was used in the publication [8]. Backpropagation neural networks are designed and trained using the Levenberg-Marquardt algorithm. In work [9] they use data from the CGM for train the forward NN. A window model is used to create and optimize an NN for each element in predicting previous BG values. Experiments have yielded results that suggest that ANN is accurate, adaptable and could be implemented in clinics.

The authors in [10] develop a system based on a deep learning algorithm. This system should be used to predict glucose using a multilayer convolution recurrent NN (CRNN). The proposed system has shown excellent prediction of BG levels in the in silico and clinical experiments. In study [11] Echo State NN (ESNN) is applied to the predictions of chaotic time series. In further research, the authors inserted data from CGM into optimized artificial neural networks (OANN) to predict BG in DM1. BG prediction can also be based on a jump neural network algorithm [12].

2.2 Compartment Models CM and MPC

Many attempts have also been made to develop closed-loop glucose regulators that provide estimates of insulin infusion rate. These glucose regulators are usually based

on model predictive control (MPC). According to a survey [13] linear and nonlinear MPC is one of the most popular approaches to feedback control. The authors focused on physiological models and analysis of signals from CGM in publication [14] using time series and predictive control of MPC. Compartmental models (CM) have been developed that simulate glucoregulatory processes. Because endocrine processes are complex and, in some cases, not fully explained, the proposed models can only work with a limited number of inputs [15].

2.3 Use of AR, ARMA

In publication [16] the authors develop a nonlinear autoregressive NN based on the use of a minimum number of data obtained from the continuous glucose monitoring sensor. Based on the glucose profile and physical activity, the authors built their linear ARMAX models in [17], which consisted of autoregressive (AR), Moving A Bever (MA) and external inputs (data from CGM, insulin, energy expenditure and galvanic skin response).

2.4 Hybrid Systems and Other Techniques

Hybrid systems use both data and physiological models to create a predictor of blood glucose levels. Models of food intake and insulin absorption are considered physiological models. The most popular alternatives for modelling food intake are the Dalla Man and Lehmann-Deutsch models. These are the Berger and Dall Man models for insulin absorption [13].

In publication [15] authors investigate the prediction of the glucose profile of a patient with DM1 based on the current glucose concentration and physical activity. Three models were created: FNN, SOM and a neuro-fuzzy network. The SOM model proved to be the best in testing. For example, in publication [18], they conceived the prediction of blood glucose levels using a multivariate regression problem. The regression support vector (SVR) was examined using subcutaneous glucose profile, plasma insulin concentration, appearance of meal derived glucose, and energy consumption during physical activity.

Fuzzy systems are also used. Article [19] presents the use of the Takagi Sugeno model for the development of an algorithm used to regulate and maintain blood glucose concentration. Because glucose is dependent on insulin, this relationship is described by a modified Bergman minimal model.

3 Prediction of DM and Treatment of the Disease

Neural networks are used to predict diabetes, among which FFANN stands out [20]. Another option is to use a multilayer neural network structure (MLNN). The system was trained using the Levenberg Marquardt algorithm and had a more accurate classification than other conventional networks [21]. Machine learning methods (vector support machine (SVM), decision tree (DT) or logistic regression) also deal with

the prediction of DM disease [22]. Principal component analysis (PCA) or neurofuzzy inference also offer possibilities [23].

In research [24], a model was developed to classify the level of control of patients with diabetes based on historical records. Uses Naïve Bayes, Logistic and J48 techniques. The proposed algorithm works with an accuracy of 74.4 % for the Logistic technique, 74.2 % for the Naïve Bayes technique and 73.5 % for J48.

One of the neural network prediction methods is based on Back propagation [25]. The output of the system offers options 0 or 1, where 0 means a healthy patient and 1 means a diabetic. As input parameters, 8 points were used: pregnancy, BMI, plasma glucose, blood pressure, fat thickness, family history of diabetes.

In an article [26], authors presented a method of diagnosing diabetes based on a classifier of a genetically optimized neural network. The basis of the method is the analysis of the main elements - components (PCA), neural networks (NN) and genetic algorithm (GA). The work uses the database Pima Indians Diabetes. The highest accuracy of prediction by the described system is 96.1 %.

The authors of the article [27] dealt with a prediction model based on data mining, the aim was to design a treatment plan for type II DM. The author used the J48 algorithm, and used 318 medical records in the experiment. Baseline control information showed that 59.1 % of the record was considered an oral hypoglycaemic agent, 35.5 % for insulin, and 5.3 % for diet. The research did not take into account patients with type 1 diabetes who could be included with other attributes.

4 Conclusion

The search shows that there are a plethora of ways to use neural networks. An important finding was that in the field of blood glucose measurement, neural networks are used both to predict the development of BG levels and to predict the disease itself DM.

It is not possible to say specifically which models or methods are the best and most optimal, as most of the proposed systems are not implemented in clinical practice and currently represent only basic research. However, the direction of research is clearly given, the first branch is the prediction of glucose concentration, which finds use in closed loops with an insulin pump. These systems are able to respond to the patient's needs. The second branch is the prediction of the disease itself based on several attributes.

The greatest benefit of neural networks is in the area of feedback and prediction of blood glucose levels in continuous measurement of blood glucose, as these systems in conjunction with an insulin pump replace the pancreas. Prediction of glucose concentration is therefore important with respect to the administration and determination of the exact amount of insulin. These systems may contribute to improving the quality of life of patients in the future.

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Node Control Optimization Using Neural Networks and Cloud Data: A Review

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Abstract. This work summarizes the research on the topic Optimization of node control using soft computing. In this case specifically using neural networks. The aim is to gain knowledge and experience in the field of node control using a neural network. Cloud-assisted Internet of Thing (CIoT) "is supported mainly due to the need to implement wireless sensor network (WSN) architectures. Thanks to rapid developments in technology, wireless autonomous networks and CIoT wireless sensor networks (WSN) can be used for environmental monitoring, road communication, driving assistance, weather forecasting, location, etc..... CIoT sensor nodes are deployed in uncontrolled regions, where human intervention is often difficult. Energy saving in these regions is a major design issue, as nodes cannot be replaced or, for example, revitalized. Optimization in WSN is an advanced task that requires more than one input constraint on which network operation depends.

Keywords: WSN, IoT, Neural networks, soft computing, management, control, cloud update, cloud control

1 Introduction

Neural networks are inspired by the biological networks of the neural structure of the human body. They use distributed, parallel processing of information when performing calculations. Knowledge is stored using individual links. To a network to be known as a neural, there must be the ability to learn [1].

The issue of "deep learning" methods, which is an increasingly powerful and popular tool for data analysis, has the potential to improve network traffic intelligently and efficiently. One of the critical issues is the accuracy of the method, where learning relies heavily on the integrity of the training set. Furthermore, the data collection process is relatively time consuming and complex, with the result that these methods may not meet the needs of time-sensitive applications. In addition, in smart grids, the predictions must be current, and they cannot wait for the initial data file that compiles them with data from all sensors. The traditional centralized data analysis structure

requires that the entire data set be uploaded to the cloud data center for analysis, which significantly increases network congestion [2,4].

2 Related work

The article [3] presents and gives an example of a model for a liquid state machine. The model uses the Spiking Neural network (SNN), which uses a single value to capture neural activations. The architecture is very similar to a biological network in the real world. In the model, "spikes" are used to communicate with other neurons. It determines the voltage of the neuron for the incoming signal, and when this voltage exceeds a predefined threshold value, an action potential of 1ms is sent. This whole process is called "spike".

The article [5] provides a complete overview of "Machine learning" methods for WSN, which includes comparisons with several types of neural networks. It summarizes possible application uses, detailed summaries, including a comparison of selected parameters (advantages, disadvantages, network life, statistical analysis and limitations). This is the period 2002-2013 and includes a detailed ML survey for WSN. Issues covered include localization, object tracking, routing, data clustering and aggregation, event detection, query processing, and MAC protocols as a functional challenge, while security, anomaly detection, fault node detection, and QoS as non-functional challenges.

According to the discussion in [6] the main benefit of this article is the optimization of the energy using "Machine Learning" techniques, specifically adaptive neural learning, which ensures that the network structure effectively reduces the total energy consumption of this experiment, thereby improving its overall life. Optimizing multi-objective tasks requires a complex decision architecture that generates higher communication overhead; whereas a low-level decision-making system would not be able to optimize energy. Both processes have an unbalanced impact on improving network performance. In this research, an adaptive neural learning approach through clustering has been introduced that minimizes overhead costs in CIoT, helping to maximize network life in an efficient manner.

This article describes the usage of neural networks in controller design. The application is used to control the rotor speed of a DC motor to follow a specific trajectory. The characteristics of the motor and its load characteristics are unknown. Unknown dynamics in the engine are "identified" by the LV in the training phase, and when this phase is completed, the ability of the proposed neural controller to track the required reference is evaluated. The effect of data length and data representation during the training phase is included to improve skills. The proposed neural network controller is analyzed, and the control unit was implemented and tested in a real DC motor of the control system. Finally, we make a comparison between LV and discrete PID controller. By implementing this work, the authors demonstrate the ability of LV to implement control algorithms using offline learning techniques.

This article [7] proposes a new method of adaptive tuning of a PID and neural network (PIDNN) based controller for a nonlinear process. The method uses an improved descent gradient method to modify the PIDNN parameters, where the stability of the edge nodes will be used to obtain high monitoring performance and robustness with respect to external load disturbance and parameter changes. The simulation results show the efficiency of the proposed algorithm in comparison with other well-known learning methods. To improve the convergent velocity and to prevent the capture of weights to the local optimum, an algorithm for initializing the neural network using the "swarm particle optimization (PSO)" method is used.

The work proposes an architecture for system control using PID and neural networks. The PID is cascaded with the neural network model. The error signal obtained as the difference between the device model and the required device output is used to adjust only the PID parameters. The neural network model uses a "feedforward" neural network to train masses and backpropagation. The simulation results show that the presented method is not only effective for monitoring the setpoint and the stability of the control system, but also effective for the robustness of the process.

Thesis [8] addresses mobile cloud computing (MCC) and "offloading" computationally intensive parts of a mobile application into the cloud. Machine learning techniques (also based on historical data) are designed to predict the performance of applications in various schemes. The work describes the training of the "backpropagation" network. It is several multilayer neural networks using historical records, where the first phase automatically predicts some mean parameters for each application run. Models have learned to share between different applications, neural networks can be shared, reducing data scatter.

Based on the thus predicted mean parameters and the topology of the application, the second phase begins. It deterministically calculates an estimate of the value of performance metrics. The deterministic algorithm can partially guarantee the accuracy of the prediction of the newly published application even without execution records. Access is evaluated through object recognition through the cloud and can accurately predict application performance and is resistant to data sparsity.

The work describes and offers three schemes, including the neural network architecture. The model learns and predicts and combines a neural network with a "resource-constrained critical path (RCPM)." The proposed architecture of the LV model is used for learning and predicting the execution time of the module.

Subsequent work from [9] presents a discussion on the issue of increasing the growth of cloud services, increasing the number of data centers in the EU and providing appropriate services for countless users, leading to the need to manage the energy and performance of founding nodes in data centers. Ensuring energy efficiency in these data centers is a major issue in cloud computing. Many optimization principles such as workload consolidation, device location, etc. - employ demands on the energy consumption of servers in data centers. In this work, a data-controlled prognostic system for a network frame using a neural network is solved. It is necessary to take

into account the power consumption of all components on the server outside the load of incoming requests and effectively predict it at any time in the future. The implementation of the model includes a general four-layer neural network.

The input to this network is a matrix, where m is the number of training cycles, n is the number of functions (server load, temperature, energy consumed by communication...). The input is applied to the input layer of the sensor nodes. Each node in the network is called a neuron. Each neuron adds products of mass coefficients and input data and implements a nonlinear function called neuron activation function. This is done in each layer to produce the output of the matrix $h\theta(x)$, which in our case is the assumed force. The size and number of neurons can vary based on the complexity of the system. There are four steps to training a neural network.

The author's article [10] summarizes the use of deep neural networks in data analysis and examines what type of data is needed for a hardware and architectural approach in different deployments in the implementation of deep neural networks. The sites discussed are in the cloud, peripherals, and endpoints. Covered architectural approaches include multi-core processors (central processing unit), multi-core processors (graphics processing unit), programmable gate arrays, and application-specific integrated circuits. The proposed classification in this article divides the existing solution into 12 different categories, arranged in two dimensions. The proposed classification allows a comparison of existing architectures, which are predominantly cloud, and expected future architectures, which are expected to be hybrid combinations of these architectures for IoT and WSN applications.

The author's work [11] proposes a neural network model for IoT congestion control using a PID controller and an "immune-hill-climbing" algorithm. IoT congestion management and computational complexity are a very important part of achieving a certain quality of service (QoS) in critical applications. Huge data and limited resources in the IoT and cloud system identify the real need for effective congestion control.

3 Conclusion

The aim of the research was to find out whether it is possible to use the Neural Network for control or Optimization of the Wireless Sensor Network node in the field of Internet of things. If the first goal were to be proven, the next part was to find a suitable method from a wide range of neural networks.

It is clear from the obtained materials that neural networks have a wide range of applications. Especially about data processing applications (eg LV on the cloud, processing of measured data, compression, etc.). However, in terms of the application of using a neural network to optimize node control, there is a lack of materials. By specifying the words for the search according to the given topic, I could not find almost anything, so the keywords were expanded by many more, which were based on the few publications found.

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Design of a Parking House Control System

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Abstract. This article deals with the design of a parking system control system. This topic is very popular nowadays as the world's capitals solve problems with a large number of parked cars. One of the possible solutions can be automated parking houses which together with the clever infrastructure of the metroloper can eliminate most of the problems. This article discusses the design of a parking house topology so that it can be integrated into these clever metropolitan infrastructures.

Keywords: Parking house, Smart city, Industry 4.0, Automation.

1 Introduction

Nowadays, automatic parking lots are already common, [1 - 8] there are several types and philosophies of parking in the world. However, these car parks are often inefficient in terms of parking time, bottlenecks (elevators) and possibly the number of automated robotic machines that can speed up parking or parking. In China, these car parks are being replaced by underground garages; there are many countries, especially large cities, where an effective automatic parking solution would solve problems with parking spaces, especially in densely built-up areas. In the last phase, there is an effort to store cars so as to maximize the use of space. The processing itself can basically be divided into three main directions:

1. Paternoster system - Probably one of the first automatic parking systems is the paternoster system. The first car park with this system was built in Paris in 1905. This system made 3 parking spaces the opportunity to park dozens of cars on the same area. However, there was still control by a man who had to control the entire system. The first fully automated system is the garage, which opened in 1951 in Washington, DC.

2. Browser and Pigeon Hole system - these systems are to some extent based on the paternoster system, but they are already full-fledged parking house systems. In the case of Pigeon Hole, or Czech Birdhouse, it was one platform that pushed the cars into the rack. This later gave birth to the Browser system, which brought this to the current form of most automated parking lots. The Browser system is today the most used system, where the car is placed in its place using a platform that runs on rails. To date, this system has been optimized for space efficiency.

3. Today, China is the biggest innovator in this sector. And for obvious reason, little space a lot of people and thus cars. The first concept, which already works in several installations, is the concept of a pallet, which parks cars in reserved places and thus complements normal conventional parking. However, there are already solutions for a complete car park with this technology. Furthermore, for several years now, carmakers have been trying to come up with a similar solution that they would implement in their cars. The latest venture in the industry is the addition of a third-dimensional pallet movement as such, namely the ability to bend the pallet with the car and thus reduce the space requirements. This concept was demonstrated in February 2019 in China.

2 Parking house control system

One of the main tasks of the control system is to operate the parking and unloading function. In order to implement this functionality, it is necessary for the system to contain elements and features that allow this. Since the main means of movement from vehicles are mobile robots that allow the movement of pallets on which vehicles are parked, there must be a communication interface for transmitting instructions for the movements of individual robots. This interface must be sufficiently robust and, due to the mobile nature of the robots, wireless. Only in this way can the unrestricted movement of robots around the parking house be ensured. The Zigbee interface was chosen as a suitable variant of the wireless interface. It is an industry standard which excels especially in resistance to interference with the possibility of transmission encryption, low energy consumption and the possibility of using a MASH topology, which in practice could improve the coverage of the entire parking house by a communication signal. Since the whole parking house will be built of reinforced concrete elements that largely block the transmission of wireless signals, it was decided during the design of the topology that wireless access points will be located on each floor of the parking house to ensure complete coverage of the communication signal. These access points make the wireless communication network accessible to the Ethernet network, which is used as a communication bus with the main control element of the control system (server).

Since for the parking process it is necessary not only to move the vehicles on pallets but also to transport these pallets by elevator and to control the gates through which the vehicles and robots are to pass. It is necessary that these elements can also be controlled via the Ethernet network or the selected Zigbee wireless communication interface.

The parking and parking itself is then operated from the server exclusively by sending control signals via the Ethernet network and indirectly via access points such as the Zigbee network.

As the main requirement for the parking house to be to serve the customer who wants to park or park the vehicle as quickly as possible, the layout of the floors was designed so that the cars are accessible while leaving as few pallet movements as possible. Nevertheless, it is necessary to further optimize the in-

dividual parking and parking steps, especially in connection with the sharing of some steps between several parking or parking requirements.

The optimization algorithm will use the computing power of the server, but since its development is part of this project, information on computational complexity is not available at this time. However, the assumption is that a typical mid-range server should suffice, and based on this assumption, a server was selected for the first tests of the control system.

The planning algorithm should include functionality that allows you to prepare parking the car for a certain time and also a learning part that will evaluate the daily habits of individual customers so that the cars that will most likely be parked are as close to the exit and it is possible to park in the smallest possible way.

As the parking house 1 will be equipped with a photovoltaic power plant and a battery energy storage, it is also necessary to evaluate its consumption in individual parts of the day. This, combined with the weather forecast and the parking house's consumption, will make it possible to minimize operating costs. This will be possible mainly due to the ability to evaluate whether a photovoltaic power plant will supply a sufficient amount of energy for operation on a given day, or whether it would be good to buy electricity in advance and store it in a battery. This feature will allow the purchase of the mentioned energy at the time of a low tariff and thus save costs associated with the operation. If there is a case that the photovoltaic power plant produces more energy during the day than is needed to operate the parking house, then it is possible to sell the excess energy back to the grid or to end customers through chargers for electric vehicles.

The entire control system is also connected to the Internet. This feature allows remote diagnostics and management of the parking house. Another advantage of this decision is also the possibility of communication of more parking houses with the superior system within Smart City 2. This will make it possible to evaluate the occupancy of parking capacities and to plan traffic flows through the city through intelligent traffic signs 3.

3 Results

This article describes the design of a parking house control system. During the design, the emphasis was mainly on the functionality of the sling house. By providing the necessary computing power for control algorithms. By building an industrial communication network for passing punks to parking robots. but also the security of the parking house, which is taken care of by camera and access systems both in the parking house and on separate robots. Last but not least, the possibility of integration into the network of smart cities was also considered. And a possible connection with industry 4.0. By building an industrial communication network for passing punks to parking robots. Construction of industrial communication networks for the transmission Pokuna parking robots.

Fig. 1: Proposed topology of the parking house and connection to the control system.

Fig. 2: Integration of parking garages into the Smart City concept.

Fig. 3: An example of interactive traffic signs showing the free number of parking spaces in individual urban areas

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Application Of Big Data Analysis In Smart Homes

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Abstract. This paper investigates the possibilities of big data analysis methods in smart homes environment and provides examples of application. In specifics it provides examples of expert systems application in power quality data analysis and use of statistical methods such as neural networks (Multilayer perceptron and radial basis function), liner regression and decision trees for the purpose of CO₂ predictions. The results of these implementations are published in multiple conference papers and journal articles.

1 Introduction

With the exponential increase in data collected from electrical devices, the importance of data analysis methods increases continuously. These data may be analyzed using variety of artificial intelligence (AI) techniques. Expert systems are the simplest form of artificial intelligence. These systems are most often used when there is only limited amount of data, adequate expert knowledge, and relevant threshold values available. The expert systems are the systems that emulate the humans decision-making ability. Expert knowledge is mainly defined and expressed by if-then rules. These rules may come as deductive inference (forward chaining) or adductive inference (backward chaining) [1]. The predictive analysis provides predictions about the future or otherwise unknown events. When a large amount of training data is available, the statistical methods are becoming more suitable [2-4]. The predictive analysis can be performed with many different statistical techniques such as predictive modelling, machine learning data mining. Predictive models are based on variables that are most likely to influence the outcome. These variables are also known as predictors [5]. There are many types of predictive models, such as neural networks and decision trees. Ahmad et al. compared different methods of predictive modelling for solar thermal energy systems such as random forest, extra trees, and regression trees [6].

This paper provides examples of expert systems application in power quality data analysis [7] and use of statistical methods such as neural networks (Multilayer perceptron and radial basis function), liner regression and decision trees for the purpose of CO₂ predictions. The results of these implementations are published in multiple conference papers and journal articles [8-14].

2 Application Of Optimized Deterministic Methods in Long-Term Power Quality

In this example of deterministic methods an application was developed using Visual basic (VB.net) language. The software structure was divided into six main sections as shown in the following figure (fig 1):

Fig. 1. Block diagram of the developed software

The inference engine of the software was divided into three stages. Multi-Stage processing allows optimization by reducing the required processing power and shortens the overall processing time. The Pre-processing stage includes verification, importing, combining, sorting the database, and handling missing data. Additionally, this stage flags the data intervals when the power quality recorder was disconnected or when the power system was switched off. This function was named “switched off intervals detections” (SWO). The processing stage starts with the calculation of minimum, maximum and the average. The processing continues by finding and clustering the abnormal data, thresholds were set according to the standard EN-50160:2010 [15]. The post processing stage further processes the abnormal data and creates an accurate result. After completing all algorithms, explanation system provides a detailed, understandable, and comprehensive report to the users. In comparison to typical existing solutions, the developed software holds the advantage of faster processing time, ability of dealing with missing data, automatically determining the unknown nominal values, flagging the data from SWO intervals, and providing more accurate analysis. The results obtained from experimental data showed that the software provides correct and accurate analysis, in both advanced and simplified form.

3 Application Of Statistical Methods For Prediction Of CO2 Within Smart Homes.

The section focuses in designing a methodology for processing data obtained from sensors through KNX and BACnet technologies which measured non-electrical quantities in a smart home environment. To predict CO2 levels from the measured indoor and outdoor temperatures and relative humidity, multiple statistical methods such as neural networks (Multilayer perceptron and radial basis function), liner regression (LR) and random trees(RT) were used. The accuracy of CO2 predictions from the processed data was compared and evaluated at various interval lengths. The Neural networks are one of the many ways to achieve predictive analysis. IBM SPSS Modeler offers multiple type of neural networks for predictive analysis (Radial basis function (RBF) and Multilayer perceptron (MLP)). The RBF network is a feed-forward network that requires supervised learning. Overall, there are three layers in RBF network: input layer, single hidden layer, and output layer. The MLP may contain more than one single layer. The measured values were taken by the indoor temperature sensor T_i ($^{\circ}\text{C}$) in an SHC room and relative humidity rH (%) outdoor temperature T_o ($^{\circ}\text{C}$). both RBF and MLP provided highly accurate results. However, the RBF provided held an advantage of faster training speed without a significant sacrifice in terms of accuracy. figure 2 shows the general concept of the purposed methods:

Fig. 2. Predictive analysis concept.

By reviewing the obtained results from LR, it becomes apparent that changing the algorithms of the models does not have any major impact on the results. Furthermore, day-long intervals showed significantly better accuracy. By summing up the tabulated and graphical results, it was concluded that the predictions obtained from this method would be accurate enough for the detection of presence. The prediction results included some inaccurate predictions. Therefore, it is not suitable for accurate CO2 concentration level predictions. The RT method showed significantly improved generalizations of CO2 concentration levels. Unlike the previous method, model settings affected the result noticeably. The general trend of the prediction pointed toward better accuracy with an increase in the number of trees. Specifically, the region between 10 and 18 trees appeared to be optimal for accurate predictions. Despite the fact the prediction waveform contained few minor inaccuracies and small noisy sections, it was still considered as a suitable method for both occupancy monitoring and accurate CO2 waveform predictions.

The MLP showed the best numerical characteristics. The visual investigation verified the good generalization of the trained models. All models and methods showed noisy predictions at late hours of the day. Nevertheless, these noise levels were reduced in MLP. Like the previous methods, the day-long training intervals were more accurate. Overall, the NN (MLP) proved to be the most accurate method for both occupancy monitoring and accurate CO₂ waveform predictions. In case of experiments using RBF, most accurate results were provided by experiments with the daily intervals (accuracy was about 99%) while the monthly intervals resulted in the least accurate results (accuracy was about 80%). Overall, RBF proved to be more than capable of predicting the CO₂ concentration values. By providing a live data asset to the IBM Cloud, the uploaded model can achieve near real-time prediction of CO₂ concentration values.

4 Publications List

1. Using the IBM SPSS SW tool with wavelet transformation for CO₂ prediction within IoT in Smart Home Care. Vanus J., Kubicek J., Gorjani O.M., Koziorek J. *Sensors* 2019, 19, 1407. doi: 10.3390/s19061407.
2. Novel Proposal for Prediction of CO₂ Course and Occupancy Recognition in Intelligent Buildings within IoT. Vanus J., Gorjani O.M., Bilik P. *Energies* 2019, 12, 4541; doi: 10.3390/en12234541
3. Application of Optimized Deterministic Methods in Long-term Power Quality. Gorjani O.M., Bilik P., Vanus J. In 2019 20th International Scientific Conference on Electric Power Engineering (EPE) 2019 May 15 (pp. 1-5). IEEE. DOI: 10.1109/EPE.2019.8777976
4. Prediction of CO₂ concentration in smart homes using IBM SPSS software tool. Gorjani, O.M., Vanus, J., Kubicek, J., Bilik, P. (2019), Proceedings of the 10th International Scientific Symposium on Electrical Power Engineering, ELEKTROENERGETIKA 2019, pp. 546-550. "
5. Power quality analysis of grid connected photovoltaic inverter (2019) Proceedings of the 10th International Scientific Symposium on Electrical Power Engineering, Bilik, P., Martinek, R., Vanus, J., Gorjani, O.M., Velicka, R., Koval, L. ELEKTROENERGETIKA 2019, pp. 444-447
6. Using Wavelet Transformation for Prediction CO₂ in Smart Home Care Within IoT for Monitor Activities of Daily Living. Vanus J, Krestanova A, Kubicek J, Gorjani O, Penhaker M, Oczka D. In International Conference on Computational Collective Intelligence 2019 Sep 4 (pp. 500-509). Springer, Cham. DOI: 10.1007/978-3-030-28374-2_43
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Comparison of SCG and ECG Heart Rate Monitoring in Laboratory Conditions

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Abstract. This paper introduces a verification of a novel low-cost modular measuring device based on seismocardiography and the transmission of the mechano-acoustic waves in closed acoustic tube. The system was compared with the ECG-based gold standard and the results prove that the proposed system is reliable and accurate. Acoustic tube parameters are measured and optimized for use in remote monitoring and can be utilized in the cardiac magnetic resonant imaging.

Keywords: Electrocardiography, Seismocardiography, cardiac monitoring, cardiac magnetic resonance imaging.

1 Introduction

Cardiac activity (CA) reflects the health state of a patient and thus its monitoring is among the most important diagnostic tools in the clinical practice. The CA can be divided based on the physical phenomenon it is based on: magnetoelectrical and mechano-acoustical. The electrical activity of the heart projects on the body surface as the changes of electrical potentials known as electrocardiogram (ECG). Another electrical CA monitoring technique is based on recording both magnitude and direction the electrical forces and thus forming a three-dimensional interpretation of the electrical CA is called vectorcardiogram (VCG). The electrical CA leads to contractions of the heart associated with its mechanic and acoustic activity [1]. The heart sounds can be sensed; the resulting waveform is known as phonocardiogram (PCG). Besides that, the graphical representation of the ballistic forces on the heart (leading to the repetitive motions of the body) is called ballistocardiography (BCG). Similarly, a method called seismocardiography (SCG) represents the local vibrations of the thorax wall.

This work describes a modular measuring device based on transmission of the sound waves in closed acoustic tube. Acoustic tube parameters are measured and optimized for use in remote monitoring, which is part of a project dealing with measurement of vital signs in magnetic resonance. The most prevalent technique for CA monitoring is based on ECG [2]. It is very liable source to monitor the heart rate (HR), a vital parameter in CA monitoring.

2 SCG Based Monitoring

Seismocardiography (SCG) is methods for studying the mechanical vibrations which are produced by cardiovascular activity. Common sensors used for SCG monitoring are accelerometers. They can measure acceleration in three axis and give complete information about the heart movement.

In this paper, we proposed a SCG monitoring method that relies on non-magnetic materials which do not affect MRI examination. The ECG monitoring is standard monitoring technique for triggering of MRI by AO. To successfully develop the adequate system, we must firstly understand relations of ECG and SGC signal measured by proposed setup.

The SCG-based detection system introduces delays into the system. The delay consists of displacement between the ECG and the SCG signal (R-AO interval in Fig. 1.), as well as the transmission delay of the SCG system.

Fig. 1. Relationship between SCG (upper waveform) ECG (lower waveform) cycles and their most important features (peaks and intervals) such as intraventricular blood movement (IM), aortic valve opening (AO) and isotonic contraction (IC)

3 Evaluation System

For the evaluation of the SCG based system quality, the ECG based system was used as the reference method (“gold standard”). The main parameter of the evaluation was the heart rate since it is vital both for diagnostic purposes and CMRI triggering and gating. The ECG measurements were performed by high performance and high accuracy biosignal amplifier g.USBamp. The ECG records were sensed by the limb leads. The whole system was controlled by means of LabVIEW environment. During the data acquisition, the patient was kept in a stable position on his back.

For the SCG measurements, the novel low-cost measurement system was used. The whole system consisted of four main parts and is depicted in Fig. 2. The main components used in construction of the proposed measuring setup are:

- Sensor head embedded in a belt,
- pneumatic tube,
- G.R.A.S microphone Type 40 PP
- DAQ card with NI 9234 module.

Fig. 2. Measuring setup for SCG monitoring; a) Sensor head embedded in a belt, b) Acoustic tube, c) Microphone, d) NI DAQ measuring module

4 Practical Issue

This chapter describes examination of measuring setup characteristic from point of acoustic interferences, propagation delay and signal distortion.

4.1 Acoustic Interferences

The first issue was a survey of the effect of acoustic interference on the measuring system. This effect occurs when the acoustic wave of the interfering signal (noise from motor, moving machine or speech e.g.) penetrates inside the acoustic tube. The wave energy is then divided between the pervading wave, the absorbed wave, and the reflected wave. This phenomenon is dependent on the surface, internal structure, material and frequency of the sound wave.

To verify damping properties of the acoustic tube, the measurement consisting two identical microphones and acoustic tube was performed. Microphones were placed inside and outside of the sealed acoustic tube, to record ambient noise and sound pervading into acoustic tube. The results of measured dumping were around 20 to 40 dB for frequencies up to 2.5 kHz. The measuring revealed decline of the acoustic tube dumping around 250 Hz, which was caused by resonance of measuring setup.

4.2 Propagation Delay

The measurement results showed that the propagation delay inside of the acoustic tube was around 35.66 milliseconds. The computed speed of propagation was calculated as 308.47 ms⁻¹, contrary to typical speed of sound around 346.13 ms⁻¹ for temperature 25° C. This value could be interpreted as an 11 % reduction in signal propagation speed due to influence of the different acoustic impedance in the closed acoustic tube.

4.3 Signal Distortion

In this section, we present an analysis of signal energy distribution in frequency spectrum. Most of the signal energy density was in the spectrum up to 40 Hz. The distortion in the propagated signal was classified only as minor in matter of changes in amplitude of spectral components. Contrary to original assumption of acoustic tube dumping properties, the signal spectral components were amplified in proximity to lower frequencies, precisely around 3 Hz.

5 Results

The core issue of this paper is to measure and analyze the differences in peak detection between ECG and SCG signal in laboratory conditions. The two signals were synchronously measured from the five patients with a total recording time of 3 hours. During the measurement, the patients were in the supine position, lying at their back.

As a sample record, a 200-second section was selected, containing all types of detected artifacts trough this study. The ECG signal was sampled at a frequency of 600 Hz and SCG signal was sampled at frequency 25 600 Hz and downsampled to 2 560 Hz. The computed time difference between the characteristic peak detected in the ECG signal (R-peak) and the characteristic peak in the SCG signal (IC-peak) corresponds to 122.8 millisecond. Adding the delay due to the transmission of the signal from the magnetic resonance room trough acoustic tube results in a time delay around 160 milliseconds.

5.1 Analyzation of the SCG signal

The visual representation of average SCG signal from sample recording is shown at Figure 3. Compared to typical SCG signal at Figure 1., the most significant peaks in our case are intraventricular blood movement (IM), aortic valve opening (AO) and isotonic contraction (IC).

Fig. 3. Normalized representation of measured SCG signal.

The detection algorithm has feature to force detection of positive or negative peaks based on operator input. In presented sample of measured signal can be seen (Fig. 4.), the negative peaks were selected for HR cycle detection. The negative peaks were stronger, but there was problem involving the instability of the characteristic signal features, namely, that IM peak could be detected instead of IC peak. This could happen due to characteristic peak amplitude fluctuation, due to changes in heart activity, slight movement of patient or loose sensor placement. In that case detecting algorithm can incorrectly select first suitable peak.

Fig. 4. Example of SCG signal with detection error.

Fig. 5. Statistical analysis comparison of ECG and SCG by Bland-Altman.

6 Conclusion

The results presented in this paper showed that the novel low-cost SCG-based system is suitable for the cardiac activity monitoring and its accuracy is comparable with the most prevalent method used in the clinical practice based on the ECG. Moreover, the method is also more resistant to the interference caused by the changes in the magnetic field and thus more appropriate for the use in the magnetic resonance scanner and for the needs of its triggering and gating [3].

According to Bland-Altman analysis at Figure 5., the sensor meets the requirements for monitoring cardiac activity. Errors in the presented data section are caused by a change in the amplitude ratio of the IM and IC signal, and consequently the selection of the wrong peak by the detection algorithm.

This system has these advantages over standard solution. It is resistant to electromagnetic interference, acoustic interference and can also be used during MRI examination. The main disadvantage is that the signal shape depends on many variables, such as the position and size of the measuring head, its position relative to the heart and surrounding tissue and bone structure. There may also be a general change in signal shape or a temporary change in amplitude of characteristic peaks during measurement.

In the next work, the peak selection algorithm must be improved. With the implementation of the self-tuning mechanism, it would be possible to set the peak detector to suit the patient's SCG (select a significant peak). This change should not only be used for offline analysis, but also for the algorithm used for triggering and continuous monitoring in MRI.

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Comparison of Two NLP Solvers Used in MPC

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Abstract. The paper deals with the design and implementation of a nonlinear model predictive control (NMPC). In this case, IPOPT is used as the NLP solver. A nonlinear system of three cascade-connected tanks was chosen for the case study. This option is also suitable because in the previous work the implementation was realized using the fmincon NLP solver. Finally, a comparison of control results using MPC with IPOPT and fmincon solver is presented.

Keywords: MPC, Optimal control, IPOPT, Dynamic optimization, Matlab

1 Introduction

This work extends the research in the field of design of modern control methods.[1] Modern methods have been developed since the 1960s, but their use in practice has been severely limited by insufficient computing power. Nowadays, this limitation is disappearing, and therefore it is possible to begin to expand theoretical knowledge into practice, and together with the implementation of these methods, there is room for their modernization.[2], [3] This paper presents the results obtained using the Modern Predictive Control (MPC) method. The use of this method is found mainly in the control of systems with multiple inputs and outputs (MIMO). The advantage of this method is the ability to work with strongly nonlinear systems, in which case it is a nonlinear MPC.[4], [5], [6]

The MPC algorithm is based on finding the optimal input over the length of the prediction horizon. Optimization methods are used for this purpose. Subsequently, the value of the first optimal action intervention is brought to the real system. The rest of the optimization values are discarded. In the next step, the prediction horizon is shifted and the optimization is performed again. In our case, we used IPOPT to find the optimal input. IPOPT is a software library for large scale nonlinear optimization of continuous systems. IPOPT is written in Fortran and C language and there is a toolbox which allows the implementation of IPOPT in Matlab [7], [8]

The fmincon library is implemented directly in Matlab and is used to find the minimum of a constrained nonlinear multivariable function. Problem definition and some use cases can be found in the documentation for this function.

MPC views IPOPT and fmincon as a solver of optimization problems.

2 IPOPT Implementation

IPOPT differs from `fmincon` mainly in that it needs to supply not only objective and constraint functions but also their first derivatives for its function. This greatly increases the complexity of implementing the problem, but also increases the speed of optimization.

In this case, the MPC will be used to control a nonlinear cascaded system of three tanks. The relationship between runoff and level in individual tanks is given by Toriceli's law. Nonlinear programming (NLP) was used to solve the problem. The direct transcription method was used to transform the task into the required format.[9], [10]

2.1 IPOPT options

Generally IPOPT offers many different options. For our purpose there were used only few of them.

General setting

Several things needed to be set up to solve our problem. The basic ones include the tolerance for which the calculation will take place. Then we set how detailed output we want to receive after each run.

Hessian options.

the most important setting is to switch on the internal Hessian calculation. We also have the option to choose which method will be used for its calculation.

Constraints on design variables.

This is a basic setting that is always needed. In our case, the technological limitation resulting from the height of the tanks was taken as the maximum. The logical limitation of the minimum level to zero was taken as a minimum.

Constraints limits.

Due to the use of the direct transcription method, the upper and lower limits are set to zero. This makes nonlinear constraints linear.

2.2 Functions handles

Before it is possible to call the optimization function itself, it is necessary to create several input function handles. These functions are:

- Objective
- Gradient
- Constraint
- Jacobian
- JacobianStructure

Objective function.

The objective function captures the goal of our optimization. the optimization cycle tries to minimize this function. In our case, the inflow, and the deviation between the current and setpoint for each condition are penalized. Individual increments are weighted using matrices Q and R.

Gradient function.

It is a vector of partial derivatives of an object function according to each design variable. In our case, it is a vector with 31 elements.

Constraint function.

Due to the use of the direct transcription method, this function contains the entire system dynamics. These are 96 values. These are 31 values for each state and 3 additional conditions capturing the initial value. The vector is constructed so that when the dynamics are met, the result is a zero vector.

Jacobian function.

Ipopt requires as output a matrix of partial derivatives of all constraint functions according to individual design variables. For our case, it is a matrix with 96 rows and 124 columns. It is clear from the definition of matrix assembly that most elements will be equal to zero. The size of the matrix is the main disadvantage of the direct transcription method. IPOPT is designed to handle thousands of design variables and similar constraints. For this reason, the resulting matrix of values must be prepared in sparse format. This format allows you to capture only non-zero elements in memory and thus significantly reduce the required memory.

Jacobian structure function

This function is an auxiliary function. Its output must again be a sparse matrix. This matrix is the same as the Jacobian matrix, only instead of non-zero elements they are ones.

3 Results

The result of this work is a graphical comparison of the effect of the solver used in the MPC algorithm. Comparison of two different solvers are presented. The MPC parameters such as the length of the prediction horizon, the weight matrices, etc. were chosen identical. For simulation purposes, the setpoint is constant with step changes. This course corresponds to a common scenario from practice. For clarity, the comparison is made over the course of the level of the second tank.

Fig. 1. Graph showing the water heights of second tank optimized by MPC with IPOPT solver

Fig. 2. Graph showing the water heights of second tank optimized by MPC with fmincon solver

Fig. 3. Graph showing the course of the optimal inflow found by MPC using fmincon and IPOPT solver

4 Conclusions

As you can see in **Fig. 1** and **Fig. 2**, the use of both solvers leads to an almost identical result. In either case, both solvers are well suited to the task at hand. Minor differences are probably due to other internal mathematical methods used in the solvers themselves.

Fig. 3 compares the proposed inflows for both solvers. As we can see, MPC proposes more aggressive action interventions when using the solver *fmincon*, the course of the level in **Fig. 1** and **Fig. 2** corresponds to this. To change this behavior, it would be possible to use the parameters of the cost function used in the MPC.

The result of the work is the verification that both compared solvers can be used for the solution, but for further work IPOPT will be preferred. This solver was chosen mainly because it is possible to implement it outside the Matlab environment.

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Wood classification and Imaging Inspection Systems

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Abstract. Forestry is undoubtedly crucial part of today's industry and automation of certain visual tasks could lead to significant increase of productivity and reduction of labor cost. Fault classification caused by human-nature mistakes, present during long visual inspection routine, like eye fatigue or lack of attention, could be reduced using vision inspection system. This article focuses on testing of state-of-the-art algorithms for wood type classification task.

Keywords: Wood Type Classification · Convolutional Neural Network · Machine Vision.

1 Introduction

Several papers regarding type of the wood and recognition system have been published. Great effort was made by Malaysian, Indonesian and Brazilian institutes, because of their significant wood industry potential. Their main motivation was based on illegal trade issues within their territory and articles mostly included datasets of tree cross-section cuts of exotic tree species. As a starting point and subject for case validation, CAIRO, publicly available dataset of macroscopic images, became popular among the researchers. [5, 10, 4, 2, 9, 6, 11–13]

Fig. 1. Samples from CAIRO dataset of Malaysian wood. [5].

Coloured and extensive dataset was released by Brazilian Institute University UFPR later on. Dataset includes 41 classes high-resolution pictures (3264 x 2448)

Fig. 2. Samples from UFPR dataset of Brazilian wood . [1].

taken by comercial camera DSC T20. It was used for case validation in numerous cases. [3, 2, 1]

UFPR dataset is extensive and publicly available. For these reasons is dataset suitable for objective evaluation and was used for following examination.

1.1 Dataset Preparation

Since, all 41 categories included different number of images and number of pictures per category in training process should be balanced, decomposition of dataset was derived from class with the least number of pictures. Total number of sliced pictures in catogories was ranging from 2960 to 7920. Consequently, 2500 pictures were randomly selected for training from every category and the rest of the images were used for final evaluation of algorithm performance stated in Table 1.

Table 1. Decomposition of dataset per single category

Process	No. images per class
Training	2250
Validation	250
Final Eavulation	450-5420

2 Used Method – Convolutional Neural Network (CNN)

Ever since CNN algorithm won ImageNet competiotion in 2012 [7], it is popularity increased rapidly. Nowadays, even greater challenges arose and with sufficient available computational resources, Convolutional Neural Networks represent revolutionary approach (see Fig. 3).

Convolutional Neural Network (CNN), is a modification of ANN, where instead of using standard perception layers, a convolution is used - max pooling layers, leading to a fully connected layers and output. There are many different types of architectures, but the main difference is that an input to this type of neural network, is a 2D array. The convolution operation is inherited from a frequency property of an image, and also together with max pooling can lead to

Fig. 3. Block diagram of convolutional neural network.

a reduction in transition from layer to layer. This is a valuable property for classification, because a huge number of inputs, can be reduced to a small number of outputs.

Following formula present feature map calculation. Input image is denoted by f and kernel by h . The indexes of rows and columns of the result matrix are marked with m and n respectively. [8]

$$G[m,n] = (f * h)[m,n] = \sum_j \sum_k h[j,k] f[m-j, n-k] \tag{1}$$

One of the modern approach in CNN includes a massive number of layers and parameters. These factors affect the training time and in order to train CNN from the scratch it takes a lot of time even when such computational resources as GPU are used.

3 Results

Hence, there is no possible way how to estimate Convolutional Neural Network architecture performance in various domain, potentially promising models were selected. These particular models are perceived as groundbreaking, because of their inovative structures within their architecture.

Table 2. Tested CNN architectures

Model	Inference time	Training time	Evaluation accuracy
	[s]	[hh:mm]	[%]
InceptionResNetV2	0.13	19:56	98.9
Xception	0.06	17:01	99.2
InceptionV3	0.1	9:56	98
ResNet50V2	0.06	9:45	97.3

Inference time regards to testing on PC with these parameters: Intel Xeon CPU 2.30 GHz, Nvidia Tesla K80 GPU

Fig. 4. Training of CNN.

4 Conclusion

Satisfactory accuracy ranging from 97.3 to 99.2 % was achieved by all tested models. Nevertheless, Xception network performed the best.

In comparison with all researched methods, the state-of-the-art CNN approach proved to be the suitable for this type of camera inspection task.

In addition, It is expected to achieve better results using majority voting method which is based on splitting image to multiple sections and evaluating sub-images individually. The most recognized category then represents the resulting one. This technique was successfully applied in several publications. [1, 7]

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Evaluation and Analysis of the Efficiency of a Segmentation Algorithm Based on Hybrid Methods for Blood Vessels Extraction

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Abstract. This paper deals with testing the settings of the parameters of a segmentation algorithm based on morphological operations and comparing these segmentation outputs against manually created gold standards using ROI (region of interest). Objective comparison was performed using objectification parameters structural similarity index (SSIM), mean square error (MSE) and correlation coefficient. Subsequently, the algorithm was also evaluated using the indicator quality accuracy (Acc). Also, the dependence of the segmentation efficiency on the image contrast, defined by the image quality parameter CNR (contrast to noise ratio), was investigated.

Keywords: RetCam3, retinopathy of prematurity, evaluation, objective parameters, segmentation, retinal blood vessels

1 Introduction

Segmentation of the retinal blood vessels is an important area in the field of ophthalmology [1, 2, 3]. Based on the extraction of the retinal blood vessels from retinal images, it is possible to analyze the vessels and veins in the retina of patients. Early analysis of the blood vessels allows ophthalmologist to early diagnosis, prognosis, treatment. [4] Untreated diseases can lead to blindness. The monitored diseases are: diabetic retinopathy, retinopathy of prematurity (ROP), atherosclerotic retinopathy, hemorrhage, age-related macular degradation (AMD), glaucoma, hypertension. [5-7] Tortuosity or curvature can be observed in the blood vessels. Tortuosity can be seen as a side symptom in people with high blood pressure, atherosclerosis and other diseases. However, it is a common manifestation of age and small deviations of curvature occur in the blood vessels in humans as well as animals. Due to the severity and clinical importance of retinal tortuosity, modern trends lead to the development of algorithms for vascular system segmentation from the retinal background to create a mathematical model that identifies areas of the blood vessels from other parts of the retinal area. [8,9,10] This paper deals with comparing proposed segmentation outputs against manually created gold standards using ROI (region of interest). The last step was to examine the dependence of segmentation efficiency on image contrast, defined by the image quality parameter CNR (contrast to noise ratio).

2 Related Works

Firstly, authors preprocessed of the retinal images with aim to highlight the retinal blood vessels and suppress unwanted noise and objects. [11, 12] After the segmentation procedures were applied.

One of the approaches to segmentation for retinal blood vessels are methods based on active contours such as Chan Vase, LBF (Local Binary Fitting), which describes the local image intensity with different deviations and diameters. [12]. Another approach is the level set segmentation method based on information about local clusters of regions that form an inhomogeneous image of the retina. [13] The approach of Chen et al. uses a combination of a level set function with selective binarization and Gaussian filtering in combination with LBF. With this combination, it is possible to work with low-contrast images. [12]

Pyramid multi-level segmentation is based on the fact that grayscale image data is represented by a combination of sampling operations and smoothing Gaussian filters. [15] Multi-level segmentation is suitable for structures with different width and length, that means it is suitable for the blood vessels. [14] The PCNN method is based on the fact that the pixels of the vascular system have the same intensity. The threshold value is dynamic for each pixel value. The advantage of PCNN is that postprocessing is not necessary, as the output is without noise. [15] Zhang et al. uses the so-called random forest classification in the application to retinal images. It is a method that creates multiple decision trees during the learning process and then determines the mode of the classes that are returned from each tree. [16]

3 Material and Methods

A segmentation algorithm based on morphological operations was tested on images from the private RetCam3 database. The data were obtained by the Center for Children with Visual Impairments in Ostrava. The images were taken with a RetCam3 camera with a resolution of 640x480 pixels for each image. 20 images were randomly selected from this database. Images have different image quality, contrast. In MATLAB, gold standards were created for selected images. These gold standards were created by manual segmentation using the ROI interface, which marked the main strains of the vascular system. After marking the blood vessels, the image was binarized and saved in jpeg format. Gold standards were created for testing the quality of the proposed segmentation algorithm.

In the second step, a segmentation algorithm based on morphological operations was applied to these 20 images. In the first step, the vascular system is segmented from other anatomical structures (e.g., an optical disk) and then a binary mask is formed. As part of the morphological preprocessing, the retinal blood vessels are highlighted, while the transitions of the bifurcation of the vessels are preserved. This part of the algorithm is based on the difference between the supremum and the infimum of the morphological opening operation, which is applied to the input image with two linear structural elements to strengthen the vessels and to remove unwanted anatomical structures (optical disk, choroidal vessels). Subsequently, a second derivative is applied, which serves to

further enhance the vasculature. In the next step, morphological filtering is applied to remove light parts from the images, which are not part of the vascular system. The last step is hysteresis thresholding, where two thresholds are set, namely the lower and upper threshold value. The final modification is skeletonization, which deletes unwanted small objects and identifies bifurcations and transitions of blood vessels, and fills holes and gaps in the binarized. The following parameters were set for the images: linear length of the structural element for vessel strengthening, linear length of the structural element for vessel removal, linear smoothing filter length, upper threshold, lower threshold, deleting objects smaller than (in pixels), filling holes smaller than (in pixels). Fig. 1. presents an example of input data, the gold standard and manual segmentation.

Fig. 1. Input data (A), Gold standard (B), Manual segmentation (C)

The last two parameters of deleting objects (skeletonization) and filling holes in the binarized image remained unchanged. For images, the length of the structural element was changed to strengthen the vessels and remove the vessels. The length of the smoothing filter was usually 9. For images, however, the lower threshold value of the image changed significantly.

4 Objective Evaluation of the Proposed Algorithm

It was necessary to use objectification parameters to objectively evaluate the similarity of segmented images to gold standards. The structural similarity index (SSIM), mean square error (MSE), was used from the objectification parameters to determine the similarity of two images (gold standard and image after manual segmentation), correlation coefficient. To determine the quality of the algorithm, the accuracy parameter (Acc) was calculated. The objective image quality parameter CNR (contrast noise to ratio) was used to determine the degree of contrast in the image.

Table 1 basic statistics of SSIM, MSE, correlation, Acc and CNR parameters. For each of these parameters, the median, mean, minimum and maximum values were determined.

Table 1. Basic statistics of used parameters

Parameter	SSIM [-]	MSE [-]	Correlation [-]	Acc [-]	CNR[-]
Median	0.91725	1243.35	0.644	0.981465	3.69005
Diameter	0.903275	1354.39246	0.63394	0.98033	3.71225
Maximum	0.9500	3.033×10^3	0.7617	0.98998	4.6743
Minimum	0.8060	654.5296	0.4498	0.95662	2.8369

The graphs below represent a graphical representation of the dependence of the SSIM parameters, the correlation coefficient and the accuracy on the CNR parameter. Fig. 2 represents a graph where the x-axis represents the CNR parameter. The CNR values are sorted from the lowest value to the highest, in order to better see the possible dependence of the vascular system segmentation efficiency on the contrast. Based on the correlation coefficient, this dependence is obvious. The accuracy of the algorithm has smaller deviations, so the contrast probably does not affect the quality of the algorithm. As for the SSIM parameter, the values here are around 0.92 of the value, while the effect of the CNR value on the SSIM value is evident at the lowest value and the highest value.

Fig. 2. Dependence of SSIM objectification parameters, correlation coefficient and accuracy quality indicator on CNR parameter

Fig. 3 represents the dependence of the objectification parameter MSE on the parameter CNR. This graph is separated from other parameters due to the fact that it has values in the order of thousands and other parameters in the order of units. Due to the better visibility of these parameter curves, the parameter was shown separately. In this graph, there are two peaks with the worst segmentation process result at CNR 3.07 and 3.32. These are images where there are higher numbers of fine choroidal vessels. These peaks are visible for all evaluation parameters (see Fig. 2). In addition to these two peaks, a decrease in the MSE parameter depending on the CNR can be observed, which means a more efficient segmentation process on more contrasting images.

Fig. 3. Dependence of the MSE parameter on the CNR parameter

5 Conclusion

Twenty images were randomly selected from the RetCam3 database. Gold standards have been created for these images in the MATLAB programming environment. The main blood vessels were manually marked using ROI (region of interest). Subsequently, the image was binarized and saved in jpeg format. In the next step, a segmentation method based on morphological operations was used, where a total of 7 different parameters are manually set. For images, the length of the structural element was changed to strengthen the vessels and remove the vessels. The length of the smoothing filter was usually 9. For images, the lower threshold value of the image is significantly lower. For objective evaluation of the similarity of the output segmented images to the gold standards, objectification parameters SSIM, MSE, correlation coefficient were used. An accuracy indicator was used to determine the quality of the segmentation algorithm. Subsequently, the CNR parameter was also calculated for each input image to determine the possible dependence of the effective vascular segmentation on the contrast image. According to the accuracy indicator (Acc) to determine the overall quality of the algorithms, the algorithm appears to be of good quality for detecting the vascular bed from retinal images. Its average value and median is 0.98 out of 20 tested. Based on the SSIM parameter, the segmentation of the retinal blood vessels to the gold standard appears rather good, as the mean value reaches 0.90 and the median value reaches 0.92.

Graphs were plotted to better orient the development of parameters depending on the CNR. Based on the correlation coefficient, the dependence on CNR is obvious. The accuracy of the algorithm has smaller deviations, so the contrast probably does not affect the quality of the algorithm. As for the SSIM parameter, the values here are around 0.92 of the value, where the lowest value and the highest value show the effect of the CNR value on the SSIM value.

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New Approaches to MRI Cardiac Triggering

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Abstract. Synchronization of the cardiac cycle is necessary during magnetic resonance imaging of the cardiovascular system for optimal representation and to achieve the highest image resolution and contrast. The gold standard of the cardiac function measurement is ECG signal, which, however, suffers from the effects of the magnetic field. The paper deals with new methods used for cardiac synchronization, especially sensing ballistocardiography (BCG) and seismocardiography (SCG) signals. It aims to summarize the scientific work of the student under the supervision of associate professor Radek Martinek.

Keywords: Cardiovascular Magnetic Resonance Imaging, MRI Triggering, Ballistocardiography, Seismocardiography

1 Introduction

Cardiovascular Magnetic Resonance Imaging (CMRI) is increasingly used to examine heart structure and function. Its non-invasive nature, together with its avoidance of ionizing radiation, allow for repeat, low risk, characterization of the myocardium and its associated components, throughout disease progression/regression. Triggering and gating devices and algorithms are necessary to ensure high temporal and spatial resolution of heart region. The task is to perform imaging during minimal movement of the heart and thorax, which causes motion artifacts, appearing as shadows or blurred contours on the image [1]. The principle of cardiac triggering is based on the detection of a change in signal of the heart (e.g., the R wave of ECG signal). Depending on the imaging being performed, detection of the R wave may initiate a series of evenly timed acquisitions across the R-to-R interval in order to reconstruct a cinematic image of cardiac systole and diastole. Alternatively, the R-wave may be used to define the time period of a single acquisition (e.g. end-systole or mid-diastole) [2]. Cardiac examinations are usually performed under respiratory quiescence, when the subjects hold their breath for the entire measurement period – from 6 to 25 seconds – to avoid respiratory movement artifact [1].

Since the ECG is considered as a gold standard for CMRI triggering, it suffers from many shortcomings. First, a magnetohydrodynamic effect occurs, when movement of electrically conductive blood adds an electrical current to the heart signal and affects the T wave of ECG signal, exceeding R wave and thus, causing R wave mis-

registration. Also, ECG electrodes are difficult to ensure proper electrode contact with the skin, demanding hair shaving and scrubbing off the skin surface, which complicates the exam and adds discomfort to the patient [2]. Furthermore, ECG measurements require some safety precautions due to the interaction of the ECG system with RF and gradient systems, since ECG, as a measurement with electrically active components, brings the risk of superficial heating of the patient's skin [3].

For all these reasons, more advanced methods of R wave detection and magnetohydrodynamic artifact suppression have been developed and used, however, these processing algorithms have unduly high computational requirements and are not today suitable for introducing into the medical practice. Therefore, new methods of triggering CMRI have been developed and are currently being studied. These methods are in general resistant to magnetohydrodynamic effect, as they are based on the non-electrical measurements, such as acoustic or mechanical manifestations of heart activity.

2 CMRI Triggering Methods

The literature survey was made in order to summarize the advantages and shortcomings of the individual triggering methods, currently being the subject of research. From conventional measurements of cardiac activity, vectorcardiography seemed to be good alternative to ECG thanks to its low affectability by magnetohydrodynamic effects, given by the differentiation of the magnetohydrodynamic artifact from the QRS loop, which occur in different orientation. However, this resistance is decreased in high-intensity fields [4], which are increasingly popular due to their positive effect on image quality [5]. Pulse wave measurement can be also used for the triggering purposes but it is not standardly used in clinical practice due to the high susceptibility to motion artifacts and long signal delay beside the real cardiac activity, which causes the acquisition start during the wrong heart phase [6].

In the literature, many types of alternative methods for cardiac triggering are described, such as self-gating, acoustic, accelerometric, ultrasonic or optical techniques. Most of alternative triggering methods have several common disadvantages. One is the absence of standardized sensor placement, as in the case of ECG. The location of the sensor highly depends on the specific patient and his body structure; some signals show very different waveforms when placed at diverse points of the chest. Therefore, research should also handle the possibilities of measurement without the complicated attachment of the sensor to the patient's body, such as sensors implemented in textiles or mats.

Another disadvantage is a delay of the signal, given by several attributes: a physiological delay between the R wave and the trigger point of alternative signal (first heart sound, J-wave, etc.), and other delays superimposed, caused by the transmission medium, electronics ensuring signal state and conversion to a digital signal, or filtration used to remove undesirable components. Such a delayed trigger signal may lag behind the ECG trigger for hundreds of milliseconds, collecting data from the wrong phase of

the cardiac cycle. Thus, suppression of the signal delay in some way, such as software customization, should be used.

The self-gating methods could solve the problems of sensor placement and signal delay versus ECG. Another advantage is the possibility of respiratory and cardiac gating altogether [7]. The motivation of this “double” triggering lies in a significant prolongation of the scan time and simultaneously in the shortening of the total examination time in cooperating patients. In case of patients unable to assist in breathing, respiratory synchronization is a necessity for a successful examination. However, shortcomings of self-gating techniques lie in the realization of synchronization itself. In general, these methods have low hardware requirements at the expense of the complexity of software, which processes MR data to generate a trigger signal.

Currently, acoustic and accelerometric triggering methods are most suitable to introduce into practice, providing safety and comfort for the patients and high resistance to artifacts caused by magnetic fields; efficiency of acoustic sensors has already been successfully tested at 7 T. However, their drawback is susceptibility of signal to interference caused by gradient coil switching, and accordingly, in the delay in signal transmission to the MR unit due to filtration [6, 8].

Other investigations, which are still in their infancy, such as optical or ultrasonic measurements, show high-quality heart rate calculations [9, 10], but some limitations have not yet proven their usability in medical practice: the optical method requires a very expensive evaluation unit, which could become more accessible over time, and inaccuracy in ultrasonic measurements of patients with cardiac disorders means a major complication in cardiac examinations [10].

3 Low-Cost Systems Based on SCG/BCG

In response to general problems arising with ECG measuring in MR environment, our research group implemented several prototypes of non-invasive and low-cost systems for measuring vital signs, especially cardiac activity, based on BCG and SCG signals. Both these signals sense the mechanical manifestation of the heart, expressing themselves as vibrations. The difference between these two methods is a source of these vibrations. It means, that BCG signal mainly reflects a pressure wave through the vessels, which occurs during the heart systole and blood ejection, and thus, small pressure fluctuations through the whole body. Thus, the BCG sensor requires a large contact area with patient's body. On the contrary, SCG signal measures the local vibrations of the patient's skin surface caused by movement of the heart in the chest area where the small SCG sensor is located. Also, SCG signal in general occurs at higher frequencies (up to 100 Hz) than BCG signal (up to 20 Hz).

3.1 SCG Triggering System

The SCG measuring system and the results obtained during MRI at 3T are described in [11]. Against the standard SCG measuring systems, based on the three-axis accelerometers, this system senses the signal in one vector perpendicular to the location of

the sensor fixed to the patient's chest using an elastic textile belt. The sensor is implemented into plastic funnel produced by the 3D printing method. The pressure modulated by the movement of the skin is transmitted to the microphone membrane outside the MR field via a sealed PVC acoustic tube (see Fig. 1). In this way, a closed acoustic environment is created, which is highly resistant to external vibrations and sounds.

The study proved that SCG system is independent on the effects of MR environment, in contrast with ECG. The accuracy of SCG peak detection was higher than 98 % in all 14 subjects, so the proposed system can be considered as the adequate alternative to conventional ECG measurement. Also, the authors tested the influence of motion artifacts on the signal. Only torso rotation and speaking have a significant effect on the peak detection, which was not registered during hand or head movements. However, disadvantage of the system is its attachment to the patient, which was very problematic especially in woman subjects. In general, the location of the sensor plays a crucial role, because the SCG signal is highly depended on the patient's body structure and differs when placed at diverse points of the chest.

Fig. 1. Schematic diagram of the SCG triggering system.

3.2 BCG Triggering System

Concerning the problems arising with the previous prototype [11], new BCG measuring pad is proposed in [12]. The closed pneumatic system with a deformable sensor consists of a tube or bellows of a nonmetallic and airtight material (polyvinyl chloride, polyurethane or silicone), a transmission line and a measuring apparatus located outside the MR field (see Fig. 2). The BCG signal, representing the cardiac activity, is the result of the small pressure changes in the gaseous medium filling a pneumatic system. The primary sensor version consists of a bed with a patient circuit along the entire length of the patient's body and a reference circuit outside the patient's body. The reference sensor is used for adaptive noise cancellation, reducing the vibrations transmitted by MR structure. In the study, the importance of the adaptive noise cancellation was verified.

Fig. 2. Installation of the BCG sensor in a magnetic resonance chamber - the bed embodiment: (1) sensor in the bed embodiment, (2) connector for linking to the transmission line, (3) measuring system, (4) MRI switching.

The results proved that the BCG signal captured by the new sensor can be used as a substitute for ECG signal during MRI with reliability of 97%. The diagnostic value of the resulting images was also confirmed by 10 radiologists, when BCG-triggered images reached similar or even better rating in comparison to conventional ECG and pulse oximetry. Based on the pre-clinical study conducted, it can be hypothesized that the proposed system has the ambition to shorten the examination time and also to increase patient comfort. These aspects are verified by the further study, currently in the preparation.

The last study proved that the pneumatic pad system helps to decrease an overall time of the examination; in the patient's preparation period, as well as during the MR sequences. It is caused by no need of the sensor or electrodes attachment and the correct peak detection, resulting in the minimum number of acquisitions repeated. Also, the pneumatic system reached good results in subjective evaluation by patients based on their feelings during the examination.

4 Conclusion and Future Work

The paper presented problematics of the vital sign monitoring and synchronization in MRI, and discussed advantages and leakages of several methods, which are currently subjects of research. The proposed alternative methods and their results were summarized with the aim to provide a basis for the further work of the student, which will focus on the sensor optimization (i.e. form, size and placement) with the aim to commercialize the proposed measuring system, and so, make a possibility to introduce it into medical practice. Other objective of the future work will be the implementation and testing of the signal processing methods and peak detection algorithms, which are key components of the cardiac triggering process.

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Dynamic Modelling of PEM Fuel Cells Stack System

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Abstract. In most modern methods of control system design, a critical part is the model, which describes with sufficient accuracy the behavior of the system. This article deals with the issue of modeling a fuel cell tank of the PEM type, which is the main part of the hydrogen technology laboratory. The fuel cell stack generates electrical energy through a chemical reaction of the incoming reactants. It is a highly temperature-dependent device. The efficiency of stack, apart from the temperature of the reactants and the environment, also depends on their partial pressure and humidity. For the correct operation of the device, the control system must ensure sufficient cooling with the cooling medium, flow, partial pressure and humidity of the reactants. For this reason, a dynamic model of fuel cell tank behavior has been created that can be used for hardware-in-the-loop applications to verify and test the functionality of the control algorithm.

Keywords: PEM fuel cell stack, modelling, dynamic behavior, electrochemistry.

1 Introduction

Over the last decades, fuel cell technology has been a very attractive field of science. The main reasons are zero emissions and environmental impacts, high electrical efficiency and low operating temperature (60 to 80 °C). Another factor is the large range of applications such as automotive or stationary power sources. The fuel cell system is a complex multiphysical device that covers three physical domains: electrical, thermal and fluidic [1 - 3].

For the purposes of testing and designing control using modern control methods, it is necessary to describe the behavior of the stack using a model. At present, the models can be divided into two categories. The first category of PEM fuel cell (Proton-Exchange Membrane) stack models can be described on the basis of analytical relationships and equations. Most of them describe steady state behavior and are used for static behavior analysis and component design. The second category represents a model based on experimental data and empirical relationships. Above all, these are models that do not use complex equations to describe the behavior: neural network, fuzzy or support vector machine. The dynamics model will help researchers of this technology to better understand the nonlinearities and internal relationships between the physical and chemical reactions of a PEM cell [4 - 8].

2 PEM Fuel Cell Stack Model

As mentioned above, a fuel cell stack is a device whose main product of the chemical reaction of the reactants entering the cells is direct electricity. By-products of the reaction are distilled water and heat, which needs to be removed from the cell. The reactants of PEM fuel cells are hydrogen and oxygen. The main parts of the fuel cells are the electrodes (anode and cathode) and the electrolyte, which in the case of the PEM type is formed by a polymer-exchange membrane.

The electrochemical reaction takes place on the surface of the catalyst at the interface between the electrodes and the membrane. Hydrogen is fed to the anode side in pure form. It is divided into two parts on the catalyst: protons and electrons. Protons travel through the membrane and electrons through electrically conductive electrodes through current collectors. It returns to the other side of the membrane via an external circuit. With the help of supplied oxygen (in pure form or in the form of air) from the cathode side, water is created on the other side of the membrane [9].

Model can be divided into three parts: the thermal model of stack, the fluidic model and electrical. Therefore, the fluidic model can be divided into the anode cathode model of fuel cell.

Fig. 1. Basic scheme of electrochemical reaction on PEM fuel cell [9]

2.1 Thermal Model

The temperature of the fuel cell stack is an important factor influencing their behavior. If the temperature is too high, the membrane dehydrates, which could lead to the destruction of the cell. If the temperature is too low, the reaction rate will decrease, thus reducing its efficiency. The temperature of the fuel cell is affected by the flow of the fuel cell, the temperature and flow of the reaction gases, the temperature and the flow of the cooling medium. The cell temperature can be calculated on the basis of the first law of thermodynamics (1) [4, 5, 9, 10]:

$$m_{stack} \cdot c_{p,stack} \cdot \frac{dT_{stack}}{dt} = \dot{Q}_{mass}^{in} - \dot{Q}_{mass}^{out} - \dot{Q}_{loss} + \dot{Q}_{react} \quad (1)$$

where m_{stack} is weight of the stack (kg), $c_{p,stack}$ is stack overall specific heat capacity (J/K), $\dot{Q}_{mass}^{in}$ is a heat entering the fuel cell stack, $\dot{Q}_{mass}^{out}$ is a heat leaving stack, $\dot{Q}_{loss}$ is a heat loss by conduction and convection and $\dot{Q}_{react}$ is heat generated by electrochemical reaction.

The heat entering the stack for hydrogen and humidified air as reactants can be expressed as (2):

$$\dot{Q}_{mass}^{in} = \dot{Q}_{H_2}^{in} + \dot{Q}_{air}^{in} + \dot{Q}_{C,H_2O}^{in} + \dot{Q}_{cool}^{in} \quad (2)$$

where $\dot{Q}_{H_2}^{in}$ is heat of entering hydrogen, $\dot{Q}_{air}^{in}$ is heat of entering air, $\dot{Q}_{C,H_2O}^{in}$ is heat of entering water vapor on the cathode side and $\dot{Q}_{cool}^{in}$ is heat of entering cooling medium.

The same equation applies for the leaving species. Derivation of the heat for different species can be calculated as (3):

$$\dot{Q}_j = \frac{W_j}{M_j} \cdot c_{p,j} \cdot (T_j - T_{amb}) \quad (3)$$

where W_j is weight flow rate (kg/s), M_j is molar weight (kg/mol), $c_{p,j}$ is molar heat capacity (J/kg.mol), T_j is temperature of species and T_{amb} is ambient temperature.

The heat loss is (4):

$$\dot{Q}_{loss} = h \cdot S_{stack} \cdot (T_{stack} - T_{amb}) \quad (4)$$

where h is the effective convection heat transfer coefficient (W/m².K) and S_{stack} is a surface area of fuel cells stack.

The heat generated by electrochemical reaction can be expressed as (5):

$$\dot{Q}_{react} = (\Delta H_{H_2O} - \Delta H_{H_2}) \cdot N \cdot \frac{I_{stack}}{2 \cdot F} - \Delta H_{O_2} \cdot N \cdot \frac{I_{stack}}{4 \cdot F} - U_{stack} \cdot I_{stack} \quad (5)$$

where ΔH_{H_2O} is enthalpy change of vapor (J/mol), ΔH_{H_2} is enthalpy change of hydrogen, ΔH_{O_2} is enthalpy change of oxygen, N is number of fuel cells in the stack, I_{stack} is stack current, F is Faraday's constant and U_{stack} is stack voltage.

2.2 Fluidic Model

Anode Side.

Pure dry hydrogen enters the electrochemical reaction (see below), which means the molar fraction $X_{H_2} = 1$. It also means that the partial pressure of hydrogen is equal to the pressure in the inlet of anode. According to the molar balance, the molar flow rate can be expressed as (6) [9, 10, 11]:

$$\frac{dN_{H_2}}{dt} = \dot{N}_{H_2}^{in} - \dot{N}_{H_2}^{out} - \dot{N}_{H_2}^{con} \quad (6)$$

where $\dot{N}_{H_2}^{in}$ is inlet molar flow rate (mol/s), $\dot{N}_{H_2}^{out}$ is outlet molar flow rate and $\dot{N}_{H_2}^{con}$ is molar flow rate of consumed hydrogen.

The molar flow rate of hydrogen can be calculated according to Faraday's law as (7):

$$\dot{N}_{H_2}^{in} = S_{H_2} \cdot \dot{N}_{H_2}^{con} = S_{H_2} \cdot \frac{I_{stack}}{2 \cdot F} \quad (7)$$

where S_{H_2} is stoichiometric ratio of hydrogen, which is defined as the ratio of hydrogen supplied to the amount of hydrogen consumed.

Cathode Side.

On the cathode side, oxygen enters the reaction, but not in pure form but in the form of humidified air. This results in a reduction in the molar fraction of oxygen, thus lowering the oxygen partial pressure. The molar flow rate equation for oxygen will be similar to (6). Differences are stoichiometric ratio of oxygen and oxygen consumed in reaction, which leads to different molar flow rate of oxygen (8):

$$\dot{N}_{O_2}^{in} = S_{O_2} \cdot \dot{N}_{O_2}^{con} = S_{O_2} \cdot \frac{I_{stack}}{4 \cdot F} \quad (8)$$

As mentioned above, the oxygen enters the reaction in form of humidified air, that means the molar flow rate of water and nitrogen has to be expressed (9, 10):

$$\frac{dN_{H_2O}^{cat}}{dt} = \dot{N}_{H_2O}^{cat,in} - \dot{N}_{H_2O}^{cat,out} + \dot{N}_{H_2O}^{gen} + \dot{N}_{H_2O}^{mem} \quad (9)$$

$$\frac{dN_{N_2}}{dt} = \dot{N}_{N_2}^{in} - \dot{N}_{N_2}^{out} \quad (10)$$

where $\dot{N}_{H_2O}^{gen}$ is molar flow rate of water generated as by-product of reaction and $\dot{N}_{H_2O}^{mem}$ is molar flow rate of water content in membrane.

The overall molar flux of each species at the cathode side can be expressed as (11 – 13):

$$n_{O_2} = \frac{\dot{N}_{O_2}^{in}}{N \cdot A} \quad (11)$$

$$n_{H_2O}^{cat} = \frac{\dot{N}_{H_2O}^{cat}}{N \cdot A} \quad (12)$$

$$n_{N_2} = \frac{\dot{N}_{N_2}^{in}}{N \cdot A} = \frac{0.79 \cdot \dot{N}_{O_2}^{in}}{0.21 \cdot N \cdot A} \quad (13)$$

where A is active area of electrode (m²).

To calculate the partial pressure of the oxygen, we need to express molar fraction of oxygen (14):

$$p_{O_2} = P_{air} \cdot X_{O_2} = P_{air} \cdot \frac{n_{O_2}}{n_{O_2} + n_{H_2O} + n_{N_2}} \quad (14)$$

2.3 Electrical Model

The main product of electrochemical reaction is electrical energy. This corresponds only to the part of the enthalpy that is directly converted into electricity. This enthalpy is called the Gibbs free energy and corresponds to the theoretical maximum potential of one fuel cell. The resulting stress on the cell depends, among other things, on the partial pressures of the reactants, which corresponds to the Nernst voltage (15):

$$E_{Nernst} = \frac{-\Delta G}{2 \cdot F} + \frac{R \cdot T_{stack}}{2 \cdot F} \cdot \ln(p_{H_2} \cdot \sqrt{p_{O_2}}) \quad (15)$$

where ΔG is Gibbs free energy.

The total voltage on the fuel cell is therefore equal to the difference of the maximum theoretical potential at a given pressure and temperature from the voltage losses (16,17):

$$E_{cell} = E_{Nernst} - E_{loss} \quad (16)$$

$$U_{stack} = N \cdot E_{cell} \quad (17)$$

where voltage losses are the sum of activation, concentration and ohmic losses (18).

$$E_{loss} = E_{act} + E_{con} + E_{ohm} \quad (18)$$

Activation Voltage Losses.

Another dynamic in the system is caused by double-layer effect. The activation over-voltage is expressed as follow:

$$\frac{dE_{act}}{dt} = \frac{I}{A \cdot C} - \frac{E_{act}}{R_a \cdot C} \quad (19)$$

where C is capacitance of the double-layer effect and R_a is equal to:

$$R_a = -\frac{A \cdot \eta_{act}}{I} \quad (20)$$

and

$$\eta_{act} = \frac{R \cdot T_{stack}}{\alpha \cdot F} \ln\left(\frac{i}{i_0}\right) \quad (21)$$

the α is charge transfer coefficient and i_0 is exchange current density.

Concentration Voltage Losses.

Losses due to mass transport of reactants are called concentration losses or concentration overpotential:

$$E_{con} = \frac{R \cdot T_{stack}}{2 \cdot F} \ln\left(\frac{i_L}{i_L - i}\right) \quad (22)$$

where i_L is limiting current density.

Ohmic Losses.

The highest resistance within the stack, or within the cell, is occupied by the resistivity of the membrane, the conductivity of which σ_{mem} depends on the humidity / degree of humidification λ . The ohmic losses are then:

$$E_{ohm} = \frac{\delta_{mem} \cdot I}{A \cdot \sigma_{mem}} \quad (23)$$

3 Conclusion

The issue of modeling the fuel cell stack is extensive and demanding. The model itself depends on a large number of internal parameters, which are difficult to measure or otherwise determine without cooperation with the manufacturer. The only way to fit the mathematical model correctly is to use measured data. Where, based on minimizing the deviation between the model and the measured data, the parameters can be fitted. The mathematical model was constructed, but unfortunately due to the closure of the laboratory, not enough data were measured to tune the parameters.

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Proposal of Electrogastrography Measurement Method based on the Spatial Biopotential Distribution

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Abstract. Even if the Electrogastrography is almost 100 years old method for measurement of stomach electrical activity, there is no defined standard for used electrodes and their placement. This paper deals with a proposal of electrodes placement based on evaluation of color maps of spectral power density calculated from non-invasive spatial measurement before and after food intake.

Keywords: Electrogastrography, gTec amplifier, biopotential distribution

1 Introduction

Electrogastrography is non-invasive method used for measurement of electrical activity of stomach. First measurement was made in 1922 by Professor Alvarez, but because of high demands on bioamplifier parameters required for measurement of these types of signals there were not big advance from that time. Electrical activity of stomach is very slow signal with frequency of 8.3-167 mHz and amplitude in microvolts. Physiological frequency on an empty stomach is around 0.05 Hz and is called normogastria. Frequencies below normogastria are called bradygastria and above are called tachygastria. [1–3]

2 Design and implementation

For acquirement of electrical signals, a spatial placement of electrodes was defined. Matrix of 15 electrodes placed over area around physiological position of stomach and one reference electrode placed on the right protrusion of the hip bone. Electrodes positions were defined in reference to skin reference points such as nipples, navel and xiphoid process. Placement of electrodes is visible on **Fig. 1**. Electrodes were labelled as A1-A15 and AR.

Fig. 1. Layout of electrodes for spatial measurement.

To find most suitable electrodes placement an experiment with measurement of electrical activity before and after food intake was made. There were 3 subjects included in experiment. Food used in the experiment was pizza of weight of 500 g.

Fig. 2. Distribution of power spectral density on an empty stomach.

To acquire signals, commercial bio-amplifier gUSBamp from gTec company was used. Device offers 16 measuring channels and resolution of measured signals in microvolts. Sampling frequency of 256 Hz was used, and signals were preprocessed using frequency filter of bandpass type with pass frequency range of 8.3-167 mHz.

3 Results

As it is visible on **Fig. 2**, on an empty stomach there is higher spectral power density distributed in area around electrodes A9 and A10, which corresponds with location of stomach pacemaker, as it is visible on **Fig. 4**. Other areas of stomach are less active.

Fig. 3. Distribution of power spectral density after food intake.

On **Fig. 3** there is shown a spectral power density after food intake. Activity is distributed over whole area of physiological stomach placement with highest spectral power density around electrodes A4 and A5, and lowest around electrodes A6 and A7. Numerical values of spectral power density are shown at **Table 1**.

Table 1. Medians of spectral power density (dB/Hz) after food intake.

A1	A2	A3	A4	A5
39.4	36.1	40.3	41.0	41.4
A6	A7	A8	A9	A10
32.5	34.3	37.5	37.6	39.4
A11	A12	A13	A14	A15
33.9	33.7	38.7	38.0	38.8

Move of activity centre from electrodes A9 and A10 to electrodes A4 and A5 is probably caused by stomach stretch after food intake. Increased activity in row of electrodes A11-A15 should not be credible, because it is near to intestines whose signals have similar frequencies as gastric one.

Fig. 4. Distribution of electrical potentials on gastric surface. [4]

4 Conclusion

Proposed electrodes placement consists of two measuring electrodes and one reference electrode. Layout was defined with possibility to measure in bipolar and unipolar setup thanks to preservation of reference electrode.

Electrodes positions are based on locations of highest and lowest spectral power density value, i.e. electrodes A4, A5 and A6, A7. Electrodes are placed in geometrical relation between reference points on body surface such as nipples, navel and xiphoid process. First measuring electrode is located in the middle between xiphoid process and navel. Second measuring electrode is located in intersection of line going from first electrode under angle of 30 degrees and vertical line intersecting left nipple.

Fig. 5. Proposed layout of electrodes.

Using proposed electrodes placement an experiment was done. During the experiment two measurements were carried out. One on an empty stomach and second after food intake. Testing food in this case were scrambled eggs. Signals were preprocessed using bandpass type frequency filter and, as visible on **Fig. 6**, presence of slow gastric waves is there evident. Signal rate on an empty stomach is approximately 3 cycles per minute and after food intake the rate increases to approximately 6 cycles per minute. Both rates are characteristic for electrical activity of stomach in such conditions, which proves ability of proposed electrodes placement to successfully measure electrogastrogram.

Fig. 6. Signals measured with proposed layout of electrodes.

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Multifrequency Bioimpedance Analysis of Human Calf Muscles

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Abstract. Electrical impedance of living tissues is dependent upon their structure and composition. Bioimpedance measurement is a simple and inexpensive method of determining body composition, measuring plethysmography or even studying the amount of muscle damage. This work focuses on human calf muscle bioimpedance measurement and identification of factors affecting the measured values. Electrical impedance and phase angle of peroneal muscles of both legs were measured in 30 healthy volunteers (15 male and 15 female), using frequencies between 30 and 90 kHz with a custom two-channel bioimpedance measurement device. No correlation between age or BMI and bioimpedance was found in this work. There was also no statistically significant difference between the values of right and left legs. There was however a statistically significant difference in medians of impedance and phase angle while sitting compared to standing. Across all frequencies, the impedance was higher while the subjects were sitting and the phase angle was lower in this position compared to standing. This study shows that bioimpedance measurement of calf muscles is influenced by leg position and the angle of the knee.

Keywords: Bioimpedance, Bioelectrical impedance, Electroimpedance myography

1 Introduction

Measurements of electrical impedance in living tissues is often referred to as bioimpedance measurement. Impedance is the ratio between voltage and corresponding current flowing through the tissue under test. Impedance of living tissues is dependent on frequency because of the capacitive character of cell membranes. AC current is used for measurement of bioimpedance in the frequency range between 100 Hz and 1 MHz with current amplitudes in the order of hundreds of micro amperes [1].

Bioimpedance is often used for body composition evaluation. This work focuses on the uses of measuring impedance of human muscles however. Measurement of muscle impedance, also known as electroimpedance myography, was studied for evaluation of progression in neurological disorders [2]. Bioimpedance is influenced by tissue swelling and changes in cell structures. Measurement of bioimpedance has also become widely used in the diagnosis of lymphedema, a condition characterized by increased

concentrations of extracellular fluid in the limb tissues [3]. Bioimpedance has also been proven to be able to detect swelling of the limb if the other healthy limb is used as control measurement site [4]. The method was also studied for the uses in assessing muscle damage after injuries [5] and rates of muscle contraction [6, 7]. This work focuses on evaluating of factors influencing the values of muscle impedance in healthy individuals.

2 **Materials and Methods**

Participants included in the study consisted of 15 women and 15 men ($n = 30$). Age and Body Mass Index were obtained from all participants. Impedance and phase angle were measured at 7 frequencies, starting at 30 kHz with steps of 10 up to 90 kHz. Measurements were taken once the participants were sitting down and also once again while they were standing. The instrument used for measuring of bioimpedance was custom-created, described in [8]. The device is capable of two-channel bioimpedance measurement, allowing for simultaneous measurement of both limbs at the same time. It uses bipolar bioimpedance measurement method, i.e. two electrodes placed on the sampled tissue.

The electrodes were placed on the skin of peroneal muscles of the volunteers with interelectrode distance of 10 cm. After the placement of electrodes, subjects would sit down for impedance and phase angle measurement. After one minute the subject would stand up for one more minute. The values used in this work are sampled impedance and phase angle averaged over one minute of measurement in each position.

Table 1. Participant characteristics

	Age (years)	BMI (kg/m ²)
Minimum	21	17.24
Median	23	22.48
Average	23.86	22.76
Maximum	28	32.89
Standard deviation	1.99	3.51
Skewness	0.36	0.70
Kurtosis	-0.90	0.94

Table 1 summarizes the characteristics of the participants in the sample file. Both age and BMI data are supposed to come from normal distribution, shown by Shapiro-Wilks test (p-values of 0.083 and 0.213 respectively).

2.1 Data processing

Before beginning hypothesis testing, the measured values of impedance and phase angle across all frequencies were tested for normality using the Shapiro Wilks test. Some groups of values showed $p\text{-value} < 0.05$ and therefore normal distribution of data was not assumed. All the hypothesis testing was done using nonparametric tests. Eight values were measured for each subject – impedance and phase angle of both legs in both standing and sitting position.

Figure 1 shows boxplots of the measured values of impedance for both legs (left leg is in the left column) in both positions, with standing in top row and sitting in bottom row. Figure 2 contains boxplots of the corresponding values of phase angle. The boxplots are graphed for sample size of 28, because 2 subjects were removed from data analysis. These 2 subjects were identified as outliers both in impedance and phase angle using the method of outer fences. As the boxplots show, there are still some outliers in the measured values, but these were considered to be caused by physiological variance and not to be an error in the measurement itself.

Fig. 1 Boxplots of impedance values

Fig. 2 Boxplots of phase angle values

2.2 Differences between left and right leg

The differences between left and right leg were evaluated using the Mann-Whitney U test for two independent data samples. The null hypothesis of this test assumes there is no difference in medians between the two samples.

2.3 Effect of leg position

The difference between sitting and standing was evaluated with the Wilcoxon signed rank test for paired data. This test ranks calculates the differences between each pair of data and assigns signed rank numbers to each difference. In this case the data are considered dependent because the same parameters are compared to each other, the only change is in the position of the legs.

2.4 Age and BMI correlation with impedance and phase angle

Considering the dependence of impedance upon body composition, the correlation of impedance and phase angle with age and BMI were tested. This was done using the Kendall correlation coefficient, because the data were not considered to come from a normal distribution

3 Results

The results of hypothesis testing showed no statistically significant differences between the impedance of left and right leg. The p-values of the Mann-Whitney U test were larger than 0.1 for all measured frequencies. P-values for phase angle difference between left and right leg were however all less than 0.001. This means the null hypothesis can be rejected and there is a statistically significant difference in phase angle between left and right leg.

Evaluation of leg position effect on the measured values showed that while the subjects were sitting, the impedance was higher and phase angle lower, than while standing. This effect appeared at all frequencies, as tested with Wilcoxon ranked sum test (all p-values < 0.001).

Fig. 3 Scatter plots of Impedance and Phase angle correlated with BMI (on the left) and age (on the right)

Figure 3 shows scatterplots of impedance and phase angle versus age and BMI. Only left leg at frequency 50 kHz is shown in the graphs. As can be seen from the graphs, there is no correlation between age and BMI and bioimpedance values. Table 2 contains the values of Kendall correlation coefficient, showing no correlation.

Table 2. Kendall correlation coefficients for age and BMI and bioimpedance values for left leg at 50 kHz in sitting position

	Impedance	Phase angle
Age	0.028	-0.125
BMI	0.203	-0.086

4 Conclusion

According to the results of this work, bioimpedance measurements of the calf muscles could be successful in differentiating between different knee angle positions. Therefore, it is important to measure bioimpedance always in the same position, if the results are to be compared.

There was no significant difference in medians between the left and right leg measurements in the studied group. No significant correlation was found between age or BMI and bioimpedance or phase angle.

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Test Measurement of TEG for Power Supply in Energy Harvesting Applications

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Abstract. This article discusses the possibilities of using selected TEG cells and DC-DC converters in energy harvesting to power equipment with low energy requirements for operation. These results are based on experimental measurements of the load characteristics of both the TEG cells themselves and TEG cells in connection with DC-DC converters intended for use in energy harvesting.

Keywords: TEG, DC/DC, Harvesting.

1 Introduction

As part of laboratory measurements, were tested two converters in a three different output voltage settings. The converters used are hereinafter referred to as DC-DC1, DC-DC2 and DC-DC3, as shown in Table. 1. The power source for DC-DC converters are TEG cells, when 2xTEG4 and 2xTEC1 cells were tested. To test the power supply capacity of individual TEG cells, a laboratory system for regulating the temperature difference on the used TEG cells was created. The laboratory system is described in more detail in the following text. The load characteristics of the outputs of the TEG cells themselves were measured, followed by the load characteristics of the output from the DC-DC converter in connection with each mentioned DC-DC converter.

Many studies have addressed the use of TEG energy as an alternative source, for example [1], [2], [3], [4], [5]. These sources can be used both to power low-power devices, such as flow meters, for which the work described here has been performed. However, more energy-intensive solutions are no exception; with a correctly chosen DC-DC system, TEG can be used for powering even modern telephones, which is what the work deals with [3].

The purpose of the measurement was to determine the suitability of the usable configuration of the TEG cell and DC-DC converter for use in powering devices with low energy requirements. One of the possible devices is SOC (System on Chip) with external peripherals, which will be powered from the supercapacitor most of the time. The task of the TEG cell together with the DC-DC converter is therefore to supply the

supercapacitor. Such a device may thus have specific requirements for operation in a low-energy mode, especially if a large-capacity capacitor is present on the load. For these required specifics, it was necessary to measure the load characteristic in order to be able to test the TEG and DC-DC configuration within the applicability in the application of the device power supply. Each of the measured characteristics was measured for the range of temperature difference on the TEG cell from 1 K to 10 K in steps of 1 K. The mentioned temperature range was chosen within the specification of the project related to the possibility of energy harvesting using TEG cells and the above equipment.

In addition to the connection with a used supercapacitor with a selected capacity of 1 F, the load power characteristics were also measured when using a purely resistive load and when using a combination of a 470 μ F capacitor with a resistive load in the DC-DC converter connection.

Table 1. Used DC-DC converters

DC-DC Converter	Output Voltage Settings	Converter Tag in Text
EM 8900 + EM 8502	2.6 V	DC-DC1
LTC 3108	2.35 V	DC-DC2
LTC 3108	3.3 V	DC-DC3

Table 2. Used DC-DC converters

TEG Cell Tag in Text	TEG Cell Type
TEG1	TEG-127020
TEG2	TEG-127009
TEG3	TES1-12703
TEG4	TES1-12704
TEC1	TEC1-127060
2xTEG4	Two serial TES1-12704
2xTEC1	Two serial TEC1-127060

2 Measuring System

The temperature sensors are located in the middle of the heatsink so that they fit directly on the cell to be measured as is on Fig.1. The measurement system is similar with system used in [2]. The individual sensors are connected to a digital multimeter, which is set to measure resistance using four wires. This connection reduces the error caused by the resistance of the wires. The measured data is transferred to a PC, specifically to an application running on LabVIEW, using the GPIB bus like is shown on Fig. 1. The voltage from this D / A converter is the control voltage for the current source to which a power resistor is connected, which together with the control transis-

tor is located on one of the heatsinks, their power ensures heating of one of the heatsinks between which the cell is connected.

Fig. 1. Used measuring system

For proper operation, it was necessary to select the appropriate parameters of the components of the associated circuits of the converter DC-DC2 and DC-DC3, specifically type LTC3108, namely capacitor C according to the formulas:

$$f = \frac{1}{2\pi\sqrt{L_{sek}C}} \quad (1)$$

$$C = \frac{1}{(2\pi f)^2 L_{sek}} \quad (2)$$

$$C = \frac{1}{(2\pi \cdot 32 \cdot 10^3)^2 \cdot 75 \cdot 10^{-3}} = 329.8 \text{ pF} \rightarrow 0.33 \text{ nF} \quad (3)$$

After the temperature drop on the cell is constant, the measurement of its load characteristic or the characteristic of the entire connection begins with the DC-DC converter.

3 Measurement Results

In the logarithmic power characteristics of Fig. 2 and Fig. 3, the values of the power provided by the inverter at the set resistive loads are plotted. An important parameter for each of the load characteristics is the temperature difference on the TEG cell used. The Fig. 2 series of images plots the load characteristics when the 470 μ F capacitor is used, the Fig. 3 image series the load characteristics when the 1F supercapacitor is used. From the mentioned TEG articles in the Table 2, after initial measurements, serial combinations of two TEG cells, ie 2xTEG4 and 2xTEC1, were selected.

Fig. 2. Logarithmic load power characteristic with 470µF capacitor used, measured at a temperature difference dT - within the entire measuring. The best output power is measured with 2xTEG4_260 and 2xTEC1_330
a) on $dT=4$ K, b) on $dT=7$ K, c) on $dT=10$ K

The Fig. 3 show the characteristics for a temperature difference of 2 K, 5 K, 10 K. The characteristics of the configurations that provided, with a 1F supercapacitor under load, a stable output is shown. Stable output was achieved only when using the DC-DC1 converter. Two curves are plotted on each graph. One when using a TEG cell 2xTEG4 (blue), the other for a TEG cell 2xTEC1.

Fig. 3. Logarithmic load power characteristic with 1F capacitor used, measured at a temperature difference dT - within the entire measuring
a) on $dT=2$ K, b) on $dT=5$ K, c) on $dT=10$ K

As can be seen from the characteristics in the above Fig. 3 graphs, the performance characteristics of the 2xTEG4 cell achieve a greater range of possible load characteristics, as well as larger outputs provided. The values of the provided power are comparable depending on the temperature difference with the used TEG cell 2xTEG4 in the range of load resistance 100 Ω to 100 kΩ.

The DC-DC1 converter was set for an output voltage of 2.6 V. From the above characteristics of Fig.3, it is clear that the used DC-DC1 converter is capable of pow-

ering a load with a 1F supercapacitor installed when using TEG cell 2xTEG4 and 2xTEC1. When using 2xTEG4 but stably within a wider range of load resistance.

Table 3. Values of voltage on output of DC-DC1 with 2xTEC1

R [ohm]	Temperature difference [K]									
	1	2	3	4	5	6	7	8	9	10
70 k		2	1.23	1.2	1.24	1.2	1.25	1.21	1.27	2.43
60 k		2.4	2.39	1.2	1.2	1.2	1.2	1.2	1.26	2.4
50 k		2.2	2.29	1.24	1.2	1.2	1.2	1.24	1.25	2
40 k			2.2	2.4	1.1	1.1	1	1.23	1.2	1.4
30 k				2.2	1	1.3		1.2	1.2	1.7

Data in Table 3. describes the output behavior of a DC-DC converter powered by a TEG cell 2xTEC1. As can be seen after comparing the color-coded areas, increasing the capacity of the capacitive member reduces the usability areas (marked in green) for the selected power supply application. In the case of a capacity increased to level 1 F, physically represented by a supercapacitor connected to a DC-DC converter DC-DC1, the usable area of stable voltage output and sufficient supply power is the area at temperature difference at 2xTEC1 from 2 K to 4 K, measured at load resistance from 30 kΩ to 60 kΩ.

Table 4. Values of voltage on output of DC-DC1 with 2xTEG4

R [ohm]	Temperature difference [K]									
	1	2	3	4	5	6	7	8	9	10
70 k	2.337	2.425	2.428	2.432	2.432	2.432	2.432	2.433	2.433	2.433
60 k	2.337	2.425	2.429	2.431	2.432	2.433	2.432	2.433	2.433	2.433
50 k	2.334	2.425	2.429	2.432	2.432	2.433	2.433	2.433	2.433	2.434
8 k	2.242	2.424	2.427	2.429	2.429	2.43	2.43	2.431	2.431	2.431
7 k	0.041	2.424	2.426	2.429	2.429	2.429	2.43	2.43	2.43	2.43
300		2.23	2.245	2.235	2.236	2.252	2.251	2.246	2.237	2.255
200		2.143	2.154	2.133	2.144	2.161	2.161	2.156	2.133	2.166

Data in Table 4. describes the case when the capacity is increased to the level of 1 F, physically represented by a supercapacitor connected to a DC-DC converter DC-DC1, in the usable area of stable voltage output and sufficient supply power is the area at temperature difference at 2xTEG4 from 1 K to 10 K, measured at load resistance from 300 Ω to 60 k Ω . From the stated range of usable area, however, the required supply requirements at a temperature difference of 1 K are achieved only within the range of load resistance from 8 k Ω to 50 k Ω .

Conclusion

The best performance results with DC-DC2 and DC-DC3 converters were achieved by using a load resistance around 10 k Ω , TEG cell 2xTEC1 at a temperature difference on TEG cells from 7 K. In comparison, when using DC-DC3 in conjunction with TEG cell 2xTEG4 were achieved the worst performance characteristics across the tested temperature differences on the TEG cells. In the case of the resulting power loads using the DC-DC1 converter, stable measurement results were achieved from a load resistance of 10 k Ω upwards, across the entire temperature difference on TEG cells 4 - 10 K. The resulting power load characteristics of DC-DC1 take on similar waveforms, larger mutual deviations, regardless of the used TEG cell.

In connection with DC-DC and TEG cell, the configuration of DC-DC1 and 2xTEG4 described in more detail with the microcontroller as load was tested. Realized full operation partly was in energy-saving mode. In the operation, when were powered in addition to the microcontroller and input and output peripherals, was achieved at a temperature difference of 3 K. From experimental measurements it was found that to ensure the power of the selected application the temperature difference on the applied TEG cells is just 3 K. For a higher temperature difference on the TEG cells, the functionality of the device on the load of the power supply element consisting of a TEG cell with a DC-DC converter was further confirmed.

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Application of Advanced Signal Processing Methods for the Purpose of Vital Signs Monitoring in Car Seats: An Overview

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Abstract. The paper focuses on a thorough summary of existing methods of measuring vital functions, which are primarily integrated into car seats. All methods of monitoring vital signs integrated in car seats are based on the analysis and processing of biomedical data, they are prone to various disorders and the occurrence of artifacts that should be removed. Analysis of biomedical data, which can include vital signs, is a very challenging task. The main goal of this paper is to summarize already existing methods in order to monitor vital signs in vehicles / car seats. The paper aims to summarize the results of the student's scientific work under the supervision of associate professor Radek Martinek.

Keywords: Vital Signs Monitoring, Sensors, Car Seats, Signal Processing Methods.

1 Introduction

For safety reasons, drivers are always warned to stay alert - no matter what the situation on the road. Even a brief diversion of attention can affect the whole journey and in fact lead to accidents. An increased number of vehicles leads to an increased number of accidents. Therefore, many scientists are currently working on different warning systems that can measure different vital signs of a driver in order to monitor his alertness [1; 2; 3; 4; 5].

One of the most effective means of detecting and analyzing the expected development of the state of alertness and attention of the human factor is the processing of the electromagnetic field emitted by a large number of nerve pathways in the brain. Other biological signals can also be used for this purpose - for example, the frequency of eyelid flicker, hand vibration, electrical resistance, skin temperature and facial expression. Existing systems cannot predict this state because they only detect the current state [1; 6]. Table 1 provides an overview of the most common sensor-based methods.

Type of sensor	Principle
car seats	sensors mounted in the seats, which monitor the driver's condition by measuring vital signs, such as: capacitive electrocardiography (cECG), ballistocardiography (BCG), seismocardiography (SCG) or all at once.
steering wheel	cECG or photoplethysmography (PPG) monitoring via conductive systems located on the steering wheel, which monitor the driver's condition while driving.
front camera	monitors the driver's face and evaluates signs of fatigue, such as inter alia frequent blinking, eyes closing - or head dropping.
back camera	monitors horizontal and vertical traffic signs, detects lane deviations and traffic restrictions. In cooperation with the front camera, it traces the driver's view and determines, whether he has registered the vertical traffic sign with the view. It detects time of collision with an obstacle in front of the vehicle.
helmet	is included in a test phase and monitors the driver's condition through the electroencephalography (EEG) monitoring.

Table 1. Overview table of sensor-based methods.

The very fundamental division of sensors for monitoring the driver's condition is based on their location. From the driver's point of view and his comfort, it is absolutely important that he is connected to the measuring device while driving. If so, the driver must place the sensors or probes on his body and have them mounted all the way. The disadvantage of this approach compared to contactless sensors is that the signals interfere with the driver's operation [1; 7; 8; 9].

The student's work primarily deals with sensors integrated in the car seat, but there will also be a detailed overview of the most current and popular methods for monitoring vital signs in cars (eg. camera systems, steering wheel sensors). Figure 1 shows the location of the sensors in the car seat.

Figure 1. Location of sensors in the car seat.

2 Results of Literature Survey

Contactless sensors are the future of measuring vital signs in car seats. Based on modern signal and image processing methods, a number of technologies will be implemented in intelligent cars [10]. This can work, for example, by stopping the car in the event of asthma, a heart attack or other negative medical condition. If the system integrated in the intelligent car detects a bad driver condition, it does not allow driving. In addition, if the system detects that the driver has consumed alcohol, drugs or other addictive substances, the system will not allow driving again. If the system diagnoses a heart attack, it calls the emergency services. Because modern cars will be equipped with location information and, of course, a communication interface, it will be easier for medical services to track the driver of this vehicle. Modern systems will also be able to feel emotions, so the system will alert the driver that he is not in good shape to drive. In the future, in-car sensors may also become part of a larger telemedicine system - mentoring patients' health [11]. People in the car spend a lot of time in a relatively quiet position, so it is possible to watch them while the driver is sitting.

Driving a vehicle generates a lot of interference in terms of measured quantities, such as BCG, ECG, etc. The signal can be negatively affected by noise and interference from several sources, including the senior himself. The main challenge of using different vital signs monitoring sensors mounted in car seats is motion artifacts, which can be generated either by body movement or vibrations coming from the road [12], and these can be reduced by introducing various sophisticated filtration methods. Another problem that future manufacturers of such devices will have to face is the ethical aspects of such monitoring methods [13].

3 Conclusion and Future Work

Monitoring vital signs in car seats is not a frequently discussed topic, so it is important to focus on this part. The aim of future research is to obtain satisfactory results during measurements, which would be used in practice.

At present, the area of interest of the student gets into the issue of measuring vital functions in a car seat. Many artifacts will occur during the measurement and should be eliminated. The authors are currently finalizing a research publication on this topic.

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The Review of Phasor Measurement Unit Actual State

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Abstract. This article presents a view of the current state of monitoring systems in electric power network. There are discussed Phasor Measurement Units like more accurate synchronous measuring system of power changes. There is discussed different approach to hardware and software solutions. This article is focused on low cost realization of PMU device. In conclusion problems of low cost solutions are discussed.

Keywords: Phasor Measurement Unit, synchrophasor, dynamic power changes, electric power network, low-cost solution

1 Introduction

With the increasing degree of electrification and thus the utilization of the transmission power system, the need for accurate monitoring of the current state of the network increases. Monitoring of the electricity flows and quality is essential to ensure the proper functioning of the grid, because electricity cannot be stored in higher amounts effectively. As much energy the consumers currently need, so this amount must be produced by power plants. The goal of accurate monitoring is to prevent incidents such as Blackout USA 2003, to eliminate power outages and related damage. In 2003, insufficient monitoring of the parameters of the transmission system became apparent, which withstood a strong overload for an hour and a half due to a fault in the 1 measuring system, as result the failure initiated a chain reaction of power outages in much of the USA. It took 2 days to sequentially restart the electrical system (Barron 2003). Conventional SCADA (System Control and Data Acquisition) measuring systems calculate the current state of the network from aggregated values of voltages and currents at important points of the power supply network. These systems are unable to capture rapid changes during transients. An improved power grid monitoring system (such as a phasor measurement system) could prevent the above-mentioned problems (Krishna 2014, s2-3). An example of the complexity of the power grid is shown in Figure1. The upper part of 220 and 400 kV represents the transmission network - direct connection of power plants and the main monitoring area ,

the lower part of the distribution network - connection of main transformer stations and final consumers, including backup interconnection lines (Galetka 2016, s1-2).

Fig. 1. Electric power network

1.1 Phasor Measurement Unit

In 1992 they released a fully functional prototype of a special device for accurate (synchronous) measurement in electric power network. The measurement results represent information about the amplitude and phase of the measured AC signal, the so-called phasor (phase vector). The device specifically for this type of measurement is called a Phasor Measurement Unit (PMU). In order to be able to compare the phasors with each other, it is necessary to ensure synchronous data acquisition. The instantaneous values of amplitude and phase (vectors) of voltage and current in the supply network are marked with a time stamp. These vectors with the corresponding timestamp are called "synchrophasors". The power supply line itself changes the parameters of the AC signal (Figure Fig.2). By monitoring the changes in the synchrophases, it is possible to infer changes in the consumption or supply of energy and to respond appropriately to these changes.

Fig. 2. Synchro phasors in power grid

2 Low Cost Realization

Finished PMU devices available on the market usually come as a complement to other technology of monitoring or control of the electricity system. Due to the branching of the supply network, it is not financially possible to place PMU devices to each generator / transformer or consumption point, but they are used at selected substations. Because the quality of network state monitoring depends on the number of installed PMUs, commercial companies and academics are trying to develop low-cost equipment with sufficient measurement accuracy (low cost version of PMU). These cheaper devices would allow a wider deployment of PMU technology and increase efficiency by using the maximum available power transmission capacity in the power grid. However, there is a dilemma with low-cost devices, we have only limited computing power of the processor and a cheaper version of the input part of the HW measuring chain achieves lower accuracy. It is therefore necessary to choose the right area where costs can be reduced and where not. In the next chapters, the low cost solutions of PMU units, mainly from the academic sphere, will be described.

2.1 CompactRIO PMU

Researchers from the National Institute of Technology (NIT), India have come up with the possibility of implementing the general architecture of the PMU on the CompactRIO (cRIO) platform Figure 3. The cRIO platform has a powerful processor, real-time operating system and user programmable fpga chip for fast computing and data transfer from module measuring cards. These cards can be freely exchanged (C Series modules). In the case of the cRIO controller, this is not a completely low cost solution, because the cost of the HW itself is high, however, this platform allows testing the effectiveness of computational algorithms necessary for cheaper computing units of lower performance. The controller performs the needful computations and estimates frequency, rate of change of frequency, voltage and current phasors using the discrete fourier transform (DFT) algorithms. Additionally, it generates a time-tag with the help of a PLL control circuit to time stamp these estimates. This time tagging sets apart the synchrophasor from a phasor. The one pulse per second (PPS) signal provided by the GPS satellites coincides with all other received pulses on earth which makes synchronization possible. As testing algorithms recursive and nonrecursive DFT were used in phasor calculations.

Fig. 3. cRIO measurement system

2.2 Open PMU v1

The OpenPMU is organisation of international team dealing with open source cheap but still very accurate PMU devices. This version consists of standard laboratory components like universal National Instruments measurement card USB6009 as front end and standard Windows PC for computations and data formatting. All the magic happened in LabVIEW development environment using proprietary toolkits. Software part is heavily modified cRIO PMU project. As a computation unit here worked Acer Aspire Revo mini PC. Output of this project came out like DIY manual for building your own PMU device using similar components. Open PMU organisation make also their open source software components for building and testing PMU devices.

2.3 μ PMU

Realization of PMU device using cheaper and newer MyRIO universal measurement card. This device work similar to previous cRIO but without interchangeable modules. This unit have fixed equipment so it's cheaper but it is still enough for PMU purposes. MyRIO have ARM Cortex A9 CPU with user programmable FPGA only analog and digital I/O are fixed, also communication interface is fixed to USB and wifi connection possibilities. Key μ PMU features include high sampling frequency of 10 kS/s, user selectable phasor output rate, LCD to show live data to user, and battery backup supply to allow continuous operations up to one hour during grid instabilities. Furthermore, the cost of producing a unit is really cheap so it is suitable for wide-spread. Base the computation unit and information display with power supply backed up show Figure 4.

Fig. 4. μ PMU main internal parts

2.4 Open PMU v2

The same organisation group of OpenPMU developed their next generation PMU device. It is the most compact and cheapest realization of PMU device. Unit is based

on Beaglebone board which is cheap one desk computer like Raspberry PI but more powerful. Board is using ARM Cortex A8 CPU. They designed their own data acquisition board like universal expansion board for this computer but with all hardware necessary for synchrophasor measurement. Software of this device is build like user selectable modules for the best fit. Because of open source is easy to make and connect your own software modules or change the actual one. The main computation unit and set with expansion board show Figure 5.

Fig. 5. Open PMU v2 a) main unit b) with expansion measurement board

2.5 Arduino PMU

This project is really interesting behaviour. Developer use the cheapest low power one desk computer and build yourself all the necessary hardware components. Computer is Arduino Due with ARM Cortex-M3 CPU 32 bit architecture and 84MHz crystal oscillator. Because of so low computing power, author use one computer for data acquisition and calculations, next one for data communication (sending results to superior system), another one for displaying processing values. An integrated 12 bit AD-converter with 0-3.3V range is working on 3200 Samples/s.

Fig. 6. Arduino PMU

3 Conclusion

As you can compare, higher price devices have more possibilities and robust hardware construction. Cheaper voltage and current transducers have less accuracy, some types brings into the measurement additional phase and amplitude error heavily depending on frequency. Cheaper computation unit bring less power resulting in software light weightig necessity. Small comparison of devices shows Tab 1. With approximately price in Czech crown (czk) of device, number of voltage (V) and current (I) inputs construction details and 1 channel sampling speed – slower device, lower data acquisition speed.

Table 1. Low cost comparison

	cRIO	OpenPMU v1	μPMU	OpenPMU v2	Arduino
Approximate price	150000,-	22400,-	7900,-	2300,-*	7800,-
Number of inputs	3V 3I	3V	1V	3V	3V
Project details	no	yes	no	yes	yes
1 channel sampling	50kS/s	6,4kS/s	10kS/s	12,8kS/s	3,2kS/s

*- without power interface

4 Results

This work make review on actual open source PMU projects. There is big dependence on price for some system and its capabilities. All low cost solutions are taking the way of using cheaper computer with extremely light weighted software solution so after completion no big changes are possible. In this article I have to sort the most interesting low cost solutions by capabilities and it result by price.

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Monitoring the Condition of the Protective Fence above the Railway Track Praha-Zbraslav

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Abstract. The paper deals with the description of the development and implementation of a complex monitoring system, which is used to monitor the condition of the protective fence installed above the railway track. The protective fence is used to capture falling rocks and other material from the slope above the track. In doing so, it fulfills a protective safety function against possible danger of passing trains from falling rocks. In a critical case, human health could also be endangered. The monitoring system is based on the use of accelerometer wireless sensors that are located at defined locations on the fence in the MESH network. IQRF technology is used. The data transfer is carried out using the GSM gateway to the SQL database. SW Grafana is used for data visualization.

Keywords: Accelerometers, Asynchronous, Discrete measurements, Event systems, Environmental stability, Failure detection, Measuring transducers, MEMS sensors, Railways, Solar cells

1 Introduction

Not only in the Czech Republic but also abroad there is a large number of rock formations whose damage directly threatens objects or traffic on the roads located under these formations. For these reasons, the stability of many such rock formations is ensured by means of retaining steel networks and/or dynamic barriers.

Another equally important element of roads protection is the use of gabion walls, which are special iron cages filled with stones. These cages are tied together. Their primary purpose is to prevent slopes from sliding. Even these slopes need to be monitored. For this purpose, special sensors called load anchor cells are used.

Generally, two basic protection systems are used to rehabilitate rock formations. The first one is the use of high-strength steel network, where the damaged rock mass is covered with this network.

The second method is based on installing dynamic barriers (fences). Mainly this is a special construction of the fence, where a special twin-screw mesh is drawn between the fence rods. This is further reinforced by the use of steel ropes at their edges.

At present, there is no comprehensive monitoring system that informs the network administrator about whether they have been broken, or just capturing a certain amount of fallen rocks. Checking these retaining networks and barriers is done only at a given time. [1]

2 Measurement System

2.1 Accelerometer Sensor

The STM LIS2DW12 accelerometer was selected. LIS2DW12 is the new 3-axis high-performance 14-bit accelerometer with an ultra-low-power design. The LIS2DW12 has 16-bit output resolution and can be set to prioritize low power consumption less than $1\mu\text{A}$ or low-noise performance down to $90\mu\text{g}/\sqrt{\text{Hz}}$ with five settings in either mode. Thanks to its measurement accuracy and flexibility, the LIS2DW12 is particularly suitable for next-gen applications from healthcare, fitness and gaming to industrial sensing and environmental monitoring. The LIS2DW12 has user-selectable full scales of $\pm 2\text{g}/\pm 4\text{g}/\pm 8\text{g}/\pm 16\text{g}$ and is capable of measuring accelerations with output data rates from 1.6 Hz to 1600 Hz. [2]

2.2 Network Coordinator / GSM Gateway

A commercial IQRG/GSM Gateway GW-GSM-02A was used, see Fig. 1. The gateway sends the measured data to the cloud, which offers a communication interface for further data processing. [3], [4]

- Interface between IQRG and GSM networks
- Connectivity to Internet via GPRS
- GSM quad band 850 MHz, 900 MHz, 1800 MHz and 1900 MHz
- Datalogger mode
- Dedicated to IQRG Cloud only

Fig. 1. GSM gateway

2.3 Wireless Sensor

The wireless fence protection sensor is based on the LIS2DW12 sensor described above. The block diagram of the sensor is shown in Fig. 2. The sensor communicates via the IIC bus with the IQRF module. At the same time, the interrupt output is connected to the wake up pin of the IQRF module. This functionality is for alarm states. Powering the IQRF module is primarily using LiPol battery. This is recharged via the PV module and the MPTT circuit. Charge status information is transmitted via charge and fault pins.

Fig. 2. The block scheme of measurement node

In FIG. 3 it is possible to see a prototype sensor comprising the application of a protective layer.

Fig. 3. The prototype of measurement sensor node

The monitoring system described above was installed on the Praha-Zbraslav site above the railway track near the train station. The view of the overall site is shown in Fig. 4.

Fig. 4. The area of interest

The 4 pieces of accelerometric sensors were installed on the protective fences. Along with them, the network coordinator / GSM gateway was installed in a special cabinet, together with the necessary electronics, which supplies the GSM gateway with a lead-acid battery and recharges the battery using a solar panel and a charging regulator. The location of the sensor at the location is shown in Fig. 5.

Fig. 5. The placement of sensor

The graph (Fig. 6) shows the accelerometer data from one sensor for all its axes. The data shows how the protective fence moved in all three axes due to falling stones. To evaluate alarm states, a vector sum is performed in all axes, which should be equal to one. In case of the impact of rocks or rock massif onto the protective fence, this value is exceeded and this is detected as an alarm condition. The limit at which this alarm condition is detected can be set remotely for each axis, depending on the sensor installation conditions.

Fig. 6. Accelerometric data from sensor 4

3 Conclusion

The paper dealt with the description of the design and implementation of an autonomous monitoring system for detecting the change in the status of protective fences installed mainly above line structures and serving for the protection of these structures and their operation against falling rocks and other materials. The system is based on accelerometer sensors that are located at defined locations on the fences. A network of sensors in the MESH topology is created on the monitored area and communicates with the network coordinator using the IQRF wireless technology. Data is sent via GSM gateway to cloud and then to MySQL database. In the pilot project, alarm conditions were also tested, when the sensor sends an asynchronous packet after exceeding the set threshold.

4 Publications where the results have been published

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Filtering VCG Records Using Wavelet Transform

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Abstract.

Vectorcardiography as an alternative form of a 12-lead ECG that provides us with an expanded view of the electrical activity of the heart. During the measurement of the biological signal, the interfering components of the signal are also recorded, which need to be filtered out in a suitable manner. A wavelet transform with a total of 5 different waves and 6 levels of decomposition was used for filtration. From the results of correlation and MSE, the sym4 wavelet can be considered the most suitable for selection for filtration using the wavelet transform.

Keywords: Vectorcardiography, VCG, Wavelet filtration, ECG, Myocardial infarction

1 Introduction

Nowadays, electrocardiography is one of the most extensive procedure used in clinical practice to diagnose cardiovascular disease. Electrocardiogram is considered the gold standard for the diagnosis of electrical activity of the heart. A surface ECG is usually obtained by recording the potential difference between electrodes located on the surface of the skin. The most commonly used clinical ECG system is a 12-lead ECG, which monitors basic cardiac electrical activity from 12 different measurement angles [1].

In 1956, E. Frank proposed a new lead system called vectorcardiography (VCG), which captures the electrical activities of the heart in the form of spatial vectors. It is a 3-lead VCG system and is observed along three orthogonal planes X, Y, Z on the body (frontal, transversal and sagittal) and shows cardiac electrical activities in space and time [2].

VCG signals are not commonly used in medical practice as are 12-lead ECGs because VCG interpretation is not commonly taught and requires specialized knowledge of the spatiotemporal degradation of cardiac vectors. Therefore, an alternative form of deriving VCG from a commonly measured 12-lead ECG was proposed [3]. The first consideration on the transformation of individual leakage systems was presented by the authors in [2]. Transformation methods for the derivation of ECG and VCG leads are

an integral part of obtaining further beneficial information from the measurement of electrical activity of the heart [4, 5].

In wavelet transform, a signal is expressed as a linear combination of the sum of the product of the wavelet coefficients and mother wavelet. A family of the mother wavelet have the energy spectrum concentrated around the low frequencies like the ECG signal [6]. Therefore, the wave better resembling the QRS complex of the ECG signal. In practice, a wavelet transform (DWT) is used to analyze the ECG signal $x[n]$ at different scales. In discrete wavelet transform (DWT), for analyzing both the low and high frequency components in $x[n]$, it is passed through a low-pass and high-pass filters. This process results in a set of approximate (a_x) and detail (d_x) coefficients. Thus, DWT decomposes the signal into approximate and detail information [7, 8, 9, 10].

During the measurement of biological signals, there is also a recording of interfering components, which can distort the desired signal. Therefore, it is necessary to remove these interfering components from the signal before further data processing. In this work we analyze the effect of wavelet transform in the form of signal filtering on VCG data.

2 Materials and Methods

2.1 Patients Records

In this work, VCG records from the PTB diagnostic database were used, which were recorded from healthy volunteers and patients with various heart diseases at the Cardiology Department of the Benjamin Franklin University Clinic in Berlin, Germany. The individual records of this database consist of 15 simultaneously recorded signals: a conventional 12-lead ECG and 3-lead Frank's orthogonal system (VCG). The signals were acquired for 2 minutes with a 16-bit resolution in the range of ± 16.384 mV and sampled at a sampling frequency of 1 kHz. The Physikalisch - Technische Bundesanstalt database contains records from 294 subjects with different diagnoses. For the purposes of this project, only records diagnosed with myocardial infarction were selected from this database.

2.2 Wavelet Filtration

Matlab 2018b software with built-in `wden` function using wavelet toolbox was used for signal filtering. The fixed parameters of the function were the setting of the universal threshold ' $sqtwolog$ ' set to $\sqrt{2 \ln(length(x))}$, the type of thresholding ' s ' representing soft thresholding and the Multiplicative scaling of the threshold ' mln ' representing the scaling by estimating the noise level dependent on the level. The main parameters of the function were the setting of the decomposition level and the type of wavelet used. Possible usable waves are orthogonal wavelets belonging to the *haar*, *dbN*, *fkN*, *coifN* and *symN* families. Useful waves belonging to the biorthogonal group are *biorNr.Nd* or *rbioNd.Nr* [11, 12].

2.3 Evaluation Parameters

The mean square error (MSE) compares two records based on similarity or, conversely, difference. To evaluate the effect of individual levels of decomposition, we compare the MSE between the original signal and the filtered signal for all types of waves. The unit is the square of the unit of the measured quantity. The closer the result is to zero, the more similar or identical the records. The equation for calculating the mean square error is determined by the relation (1).

$$MSE = \frac{1}{n} \sum_{i=1}^n (V_i - oV_i)^2 \quad (1)$$

where V_i is the original measured value of the vectorcardiography, oV_i is the filtered record and n is the length of the record.

Correlation indicates the relationship between two records or variables. It is often used in statistics when looking for a linear relationship between records. The correlation coefficient has no unit and its value is in the range -1 to 1. If the correlation value is 0, then there is no relationship between the two variables. If the value is -1, it means indirect linearity between records. The value of correlation 1 then means direct linearity, ie similarity between the evaluated records. The equation for calculating the correlation coefficient is given by equation (2) [13].

$$R = \frac{\sum (V_i \cdot oV_i)}{\sqrt{\sum V_i^2 \sum oV_i^2}} \quad (2)$$

3 Results

Total of 29 patient records with a diagnosis of myocardial infarction were used. Three orthogonal leads (X, Y, Z) measured by the Frank lead system were selected from each record. Vectorcardiographic recordings were filtered using five different waves and six levels of degradation. Sym4, sym3, db4, coif4 and fk14 waves were used. For each wavelet and for each level of decomposition in the individual leads, the mean square errors and correlation coefficients between the filtered and the original record were calculated. Correlation coefficients for individual leads are shown in the figures below. In the table 1 are shown MSE values for sym4 wave, which achieved the best results.

Table 1. MSE for sym4 wave

Level	MSE X (mV) ²	MSE Y (mV) ²	MSE Z (mV) ²
1	1.775 · 10 ⁻⁶	8.138 · 10 ⁻⁶	1.805 · 10 ⁻⁶
2	5.438 · 10 ⁻⁶	2.673 · 10 ⁻⁵	6.433 · 10 ⁻⁶
3	1.371 · 10 ⁻⁵	6.026 · 10 ⁻⁵	1.701 · 10 ⁻⁵
4	4.050 · 10 ⁻⁵	1.560 · 10 ⁻⁴	4.366 · 10 ⁻⁵
5	1.152 · 10 ⁻⁴	2.570 · 10 ⁻⁴	1.113 · 10 ⁻⁴
6	9.039 · 10 ⁻⁴	1.100 · 10 ⁻³	1.300 · 10 ⁻³

Fig. 1. Linear graph of correlation coefficients for individual levels of decomposition for lead X

Fig. 2. Linear graph of correlation coefficients for individual levels of decomposition for lead Y

Fig. 3. Linear graph of correlation coefficients for individual levels of decomposition for lead Z

4 Conclusion

The issue of this project dealt with the application of wavelet transform in the form of filtering on vectorcardiographic records. A total of five different waves with six level decompositions for each wave were used. In each level of decomposition for individual waveforms, the mean square errors and correlation coefficients were calculated as statistical indicators for the filtered records. Only six levels of degradation were intentionally used, as diagnostic information was already lost at the sixth level. The types of waveforms for filtering were selected with respect to similarity to VCG data, in order to maintain the required signal frequencies.

From the MSE results, it can be observed that the largest deviations for all types of waves occur in the Y lead and only minimal deviations in the X and Z leads. The waveforms that reached the smallest MSE values in the first three levels of decomposition and can be used to filter VCG recordings are sym4, coif4 and fk14 waveforms. The fk14 wavelet reached the lowest MSE values in the first three levels of decomposition than the most commonly used wavelet for sym4 filtering. However, at higher levels there is a significant deterioration. At higher levels, the MSE also begins to differ between the sym4 and coif4 waveforms, where the error rate for the coif4 waveform in the X-lead becomes more noticeable.

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Astronomical Time Series Classification using Artificial Neural Networks

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Abstract. Time series analysis is a growing issue in multiple fields of science. One of the most common task is looking for hidden periods in time series data sets. In this work, we have chosen large astronomical time series collection from Kepler K2 project and analyzed possible approaches for hidden periods search and their classification. Since these data sets are generally large, we were looking for some automated solution based on artificial neural networks that requires some data pre-processing. This work therefore brings a brief overview of possible solutions for looking for hidden periods in astronomical time series with use of pure artificial neural networks or together with more conventional statistical approaches - mainly from a data pre-processing and its visualization point of view.

Keywords: artificial neural networks, classification, time series, big data

1 Introduction

Time series are in general discrete sequences of quantity values measured in time. In astronomy, it is usually flux or magnitude on one axis and Julian date on the other axis. These time series comes from multiple observational devices and observatories designed for e.g. variable stars detection, stellar system analysis or extra-solar planets discoveries. Finding periods in these time series is therefore crucial for further research in this area. Since we are talking about large amount of data growing exponentially during last years, we are facing a big data issues, where fast handling and analysis of these amount of data is mandatory.

2 State of the Art

Most literature on time series classification assumes that [1] copious amounts of perfectly aligned atomic patterns can be obtained, the patterns are all of equal length and every item that we attempt to classify belongs to exactly one

of our well-defined classes. Based on these assumptions, the best machine learning approach for time series classification is usually Nearest Neighbour algorithm with the relatively expensive Dynamic Time Warping as the distance measure [2]. But all these assumptions are challenging in astronomical time series since they greatly vary in lengths, periods, noisiness and are without clear borders. In [3] authors concludes LSTM as another state-of-the-art technique for this task.

2.1 Time Series Classification Algorithms

Today, different kinds of (deep) neural networks are used for time series analysis [3]. We can start for example with basic **Multi-layer Perceptron (MLP)** - a traditional ANN for classification purposes. ANNs described further in this section can be considered as enhancements of this model. Another favourite ANN is **Long Short-term Memory (LSTM)** that deals with the major drawback of conventional ANNs such as MLP: its inability to react based on previous inputs, leading to a development of Recurrent Neural Network (RNN) [5] that introduces to MLP an internal memory with previous state of hidden layer. LSTM [6] deals with a major drawback of RNN: vanishing and exploding gradients [7] [8]. It seems that noisy time series are quite a challenge for LSTM and RNN in general. Possible solution to this can be inspired by [9], where the authors used a conversion into a symbolic representation with a self-organizing map. Another type of ANN is **Convolutional and Fully-convolutional Neural Network (CNN and FCN)**. Traditional pattern recognition usually requires to implement and fine-tune some data pre-processing [10]. The advantage of CNN is that it requires only minimal modification of the original data before classification and its typical usage includes time series classification [10]. Fully-convolutional neural networks (FCN) performs well in fields of time series classification [3]. This kind of network does not require neither massive data pre-processing nor "feature engineering". Even more, it can itself be used as a tool for significant attributes extraction [3]. Last, but not least is the **LSTM Fully-convolutional Neural Network**. Authors in [3] comes with a new type of ANN called LSTM Fully-convolutional Neural Network (LSTM-FCNN). They suggest to extend the FCN by LSTM module. Authors states that their solution significantly improves the performance of FCN with just a small increase of model size. They also states that it requires minimal data pre-processing and conclude that LSTM-FCNN is superior to current models. We can also consider other ANNs, such as **Multi-scale Convolutional Neural Networks (MCNN)** which performance is (in general) heavily dependent on time series data pre-processing and optimization of huge amount of hyperparameters. Another option could be **ResNet** that does not require any either deep data pre-processing or "feature engineering" [3].

2.2 Known Methods for Time Series Data Pre-processing

Time series, images and even records of human speech usually consists of huge amount of data. If we attempt to classify them using a traditional backpropagation algorithm without attribute extraction, we would face overfitting [10].

In this work, we focus on **significant attributes extraction** that reduces the dimensionality of the original data by extracting only significant attributes. These can be various types of statistical attributes or even more complex types such as periodograms or generated images. According to [3], other often used methods are **Fully-convolutional Neural Network** as a method for significant attribute extraction. In [4], authors also mention **Dynamic time series wrapping** and **Shapelet transformation** as a way of time series pre-processing.

3 Kepler K2 Data Set

We tested our approaches on Kepler K2 data set provided by NASA and containing thousands of real astronomical time series. Data from K2 mission are publicly available [12] [13] and well documented [14] [15]. In this work we are interested in Kepler K2 light curves containing flux of individual objects in time. For these data, Kepler K2 also provides official catalogue of confirmed variable objects that we can utilize. Based on sampling frequency, we distinguish **2 cadency groups**: *long* with 1765.5s (29.4min) and *short* with 58.89s. We can obtain about 40000 light curves with length up to 1300 measurements.

4 Experiments and Results

Our primary goal is to find the best light curves classifier at least for binary classification (the light curve is of variable object or not). Various combinations of following pre-processing methods were performed: balancing data sets, cutting light curves to equal length, mixing data, generating periodograms, Fourier transformation and other means of feature extraction as means of dimensionality reduction. During our experiments we discovered that the original data set may not provide clear examples of time series of variable and non-variable stars. This led to a poor accuracy and we were therefore looking for a way how to distinguish these time series by means of significant attributes extraction. We tested the usability of extracted attributes by visualization using Sammon mapping [16] in order to visualize extracted features, hoping to see clear clusters with variable and non-variable time series. Such set of attributes could be then used for classification using ANN.

Experiments were performed with several ANNs and various data pre-processing. We started with MLP containing 3 hidden layers: 16 neurons in input, 34 neurons in first hidden, 16 in second hidden and 64 in third hidden layer. Results are depicted in Tab. 1. The best activation function turned out to be Selu that achieved 0.66 accuracy. Then we attempted to improve the accuracy by generating so-called **periodograms** created by conventional statistical analysis. Results can be seen in Tab. 1 and shows no significant improvement of accuracy. We also attempted to establish some **custom activation functions** listed in Tab. 1 (raw light curves were used). As last experiment with MLP, we attempted to use our own activation functions with Kepler K2 light curves processed by **Fourier transformation**. Results are listed in Tab. 1. We achieved similar results with

Fig. 1: Sammon mapping: 500 epochs, time series length: 1200-1225. Attr.: stand. dev., variance, min, max, mean, sum val., median, abs. sum of changes, agg. autocorr., arithmetic coeff., binned entropy, energy ratio, agg. FFT val., first loc. of min/max, mult. max values, index mass quant., linear trend etc. Or processed by FT or min-max normalization.

Cosine transformation. We then continued with **Convolutional Network**, where all data from K2 data set were normalized by min-max normalization, we run 5000 epochs with learning rate 0.005 and following network configuration: two convolutional layers with sigmoid activation function, window size of 7 and 6 (or 12) filters, each followed by pooling layer and with output layer with sigmoid activation function. Results are depicted in Tab. 2. We also attempted to extract various statistical markers in order to distinguish variable and non-variable objects. To verify this, Sammon projection was used (see Fig. 1). The experiment so far confirms that the original data does not contain clusters and we will need to focus on domain-specific details of the data.

5 Conclusion

Unfortunately, we did not get the accuracy over 65% using our current data pre-processing methods. Changing ANN types or their parameters seems to have very little effect at results although we can see a positive affect of some activation functions. We believe that the major issue is improper data pre-processing that is unable to clearly distinguish variable and non-variable lightcurves for machine learning. One of the reasons might be the length of each light curve that is used as a feature vector. Therefore, we were (and still are) looking for better way of **dimensionality reduction using significant attributes extraction**. Based on ideas in [17], we expect that e.g. selecting n greatest or lowest **DFT coefficients** could be the way how to achieve this. By doing so, we should get a

Table 1: MLP classification results for K2 data.

K2 data with no feature extraction			
Activation function	Precision	Recall	Accuracy
Sigmoid	0.98	0.53	0.56
Hyperbolic tangent	0.72	0.61	0.64
Relu	0.67	0.60	0.61
Elu	0.64	0.63	0.63
Selu	0.78	0.62	0.66
Soft plus	0.82	0.58	0.62
Soft sign	0.64	0.58	0.60
Harp sigmoid	0.98	0.49	0.48
Linear	0.73	0.61	0.63
K2 data converted to periodograms			
Activation function	Precision	Recall	Accuracy
Sigmoid	1.00	0.49	0.49
Hyperbolic tangent	0.51	0.71	0.66
Relu	0.54	0.70	0.65
Elu	0.63	0.65	0.65
Selu	0.65	0.61	0.62
Soft plus	0.80	0.61	0.65
Soft sign	0.56	0.67	0.64
Harp sigmoid	0.00	0.00	0.50
Linear	0.61	0.65	0.64
K2 using own activation functions			
Activation function	Precision	Recall	Accuracy
$\tanh(0.1 \cdot x)$	0	0	0.45
$\tanh(0.3 \cdot x)$	0.05	0.53	0.45
$\tanh(0.5 \cdot x)$	0.52	0.66	0.59
$\tanh(x)$	0.72	0.68	0.66
$\tanh(1.5 \cdot x)$	0.68	0.68	0.65
$\tanh(2 \cdot x)$	0.71	0.67	0.65
K2 data, own activation function and Fourier transformation			
Activation function	Precision	Recall	Accuracy
$\tanh(1.1 \cdot x)$	0.68	0.64	0.64
$\tanh(1.4 \cdot x)$	0.75	0.65	0.67
$\tanh(1.5 \cdot x)$	0.74	0.65	0.66
$\tanh(1.7 \cdot x)$	0.68	0.61	0.61
$\tanh(2 \cdot x)$	0.72	0.63	0.63

Table 2: Results of CNN classification for Kepler K2 data with different count of light curves and measurements in each time series (cutted to this length).

Light curves	Length	Precision	Acc.	Recall
500	800	0.65	0.65	0.65
7502	1300	0.65	0.64	0.64
500	400	0.64	0.62	0.63

fixed-sized feature vector more suitable for machine learning. In future, we plan to focus on the data in a more domain-specific way: try to distinguish concrete variability types from non-variable objects instead of all variables together. Then identify the best-performing classifiers and attempt to find better ones by means of **evolutionary algorithms**.

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Integration of natural deduction and resolution method into Transparent intensional logic

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Abstract. In this article, I summarize what I have been working on during the last academic year. I was working on the integration of the natural deduction and the resolution method into the system of Transparent intensional logic (TIL). For the resulting proof calculi of TIL, it is crucial to integrate logical deduction rules, rules for λ -conversions, special technical rules typical for TIL, and semantic rules for natural language.

Keywords: natural language processing; Transparent Intensional Logic; TIL; natural deduction; general resolution method

1 Introduction

Natural language processing and computational linguistics are the research areas that are increasingly gaining interest. These areas have more in common with logic than it might seem at first sight. There are large corpora of textual data that we want to formalize and then apply formal proof methods to obtain information deduced from these texts. For this purpose, we need hyperintensional logic such as TIL, because in the rich semantics of natural language there are hyperintensional contexts where the object of predication is the meaning of another expression. In this case, intensional analysis leads to the paradox of logical-mathematical omniscience or idiocy. To this end, we use Tichý's Transparent intensional logic (TIL), a *hyperintensional, typed λ -calculus of partial functions with procedural semantics* ([11], [5]). TIL λ -terms encode structured abstract procedures (*constructions*) that produce objects (if any) that are denoted by the term.

Natural language sentences are automatically formalized in the form of TIL constructions using *The Normal Translation Algorithm* [10]. We use these constructions as a knowledge base for the TIL inference machine.

There are two approaches to building up an inference machine for TIL that we discuss in this paper. First, the system of natural deduction, second, the general resolution method. These systems were initially designed for the first-order logic. We show adaptation of these methods for the purposes of TIL and natural-language processing.

The important issue to deal with is the integration of special rules rooted in the rich semantics of natural language into a standard proof calculus so that we can de-

duce relevant analytic consequences of natural language sentences. These rules include, for example, rules dealing with property modifiers or rules for *factive attitudes* like knowing, regretting, being sorry that, and so on. These kinds of verbs presuppose that the embedded clause denotes a true proposition. If F is the meaning of a factivum (for example it can be the verb “to regret”) then from $F(x, C)$ (“ x regrets that C ”) or from $\neg F(x, C)$ (“ x does not regret that C ”) we can derive the truth of C . In addition to these semantic rules, there are special technical rules of TIL like λ -conversions, rules for performing *substitution method*, elimination of the property *True* of propositions, and so on.

Using two case studies, I am going to illustrate how to integrate such special rules into the system of natural deduction and resolution method within TIL. Section 2 demonstrates reasoning with factive propositional attitudes by means of natural deduction. Section 3 deals with the same example using the resolution method. Concluding remarks can be found in Section 4.

2 Natural Deduction in TIL

In TIL we use the classical system of natural deduction in the sequent form ([8], [3]). A similar approach was implemented in the classical typed λ -calculus by Gordon and Melham [1]. TIL differs from the standard, simply typed λ -calculi by the fact that in addition to extensional and intensional contexts TIL deals also with *hyperintensional contexts*. If TIL construction occurs in a hyperintensional context, then the construction itself is an object of predication and we say that the construction is *displayed*. Natural deduction rules in TIL are in general applicable to constructions that produce truth values and do not occur in displayed mode. The rules follow the general pattern of natural deduction and are thus introduced in I/E pairs. Rules for introduction and elimination of *propositional connectives* are standard. *Quantifiers* in TIL are not special symbols; rather, they are *functions* applicable to classes of objects. Again, there are introduction and elimination rules for both quantifiers. Additionally, special rules of quantification *into* a hyperintensional context are specified and they consist in the application of the *substitution method*.

Here is an example of the derivation in TIL using an adjusted natural deduction system.¹

Consider the following text in natural language:

The Mayor of Ostrava regrets that the President of TUO does not know (yet) that he (the President of TUO) will go to Brussels. The President of TUO is prof. Snášel.

Assuming the above, we would like to find out whether prof. Snášel goes to Brussels. Hence, we want to answer the question „*Will prof. Snášel go to Brussels?*“

¹ This example is a simplified version of the example presented in [3].

First, we formalize the sentences from the above scenario and the question using TIL:

Types: *Brussels*/ι; *President*(-of TUO), *Mayor*(-of Ostrava)/ι_{τω}; *Go*/(οι)_{τω}; *Regret*, *Know*/(οι*_n)_{τω}; *he*/*₁ → ι.

Knowledge base:

A: $\lambda w \lambda t [{}^0\text{Regret}_{wt} {}^0\text{Mayor}_{wt} {}^0[\lambda w \lambda t \neg[{}^0\text{Know}_{wt} {}^0\text{President}_{wt}$
 $[{}^0\text{Sub} [{}^0\text{Tr} {}^0\text{President}_{wt}] {}^0\text{he} {}^0[\lambda w \lambda t [{}^0\text{Go}_{wt} \text{he} {}^0\text{Brussels}]]]]]$

B: $\lambda w \lambda t [{}^0\text{President}_{wt} = {}^0\text{Snašel}]$

Question:²

Q: $\lambda w \lambda t [{}^0\text{Go}_{wt} {}^0\text{Snašel} {}^0\text{Brussels}]$

Our question is a simple *Yes/No question* and to answer it we have to find out if the corresponding construction can be derived from the knowledge base using deduction rules plus special rules of TIL and natural language semantics.

This example demonstrates the *top-down derivation* from the hyperintensional level of the complement of regretting/not knowing that “he will go to Brussels” to the extensional level of Snašel’s going to Brussels. For this purpose, we apply the rules for factive attitudes plus the rule for *True-Elimination*. They are $(x \rightarrow \iota, c \rightarrow *_n, {}^2c \rightarrow \circ_{\tau\omega}; p \rightarrow \circ_{\tau\omega}; \text{True}/(\circ\circ_{\tau\omega})_{\tau\omega})$:

(F1) $[{}^0\text{Regret}_{wt} x c] \vdash [{}^0\text{True}_{wt} {}^2c]$
 (F2) $\neg[{}^0\text{Know}_{wt} x c] \vdash [{}^0\text{True}_{wt} {}^2c]$
 (True-E) $[{}^0\text{True}_{wt} p] \vdash p_{wt}$

For technical reasons, we also need the rule of ²⁰-elimination, a simple technical adjustment, which holds for any construction *C* that is typed to *v*-construct a non-procedural object of a type of order 1.

(²⁰-E) ${}^{20}C = C$

The last technical device we need is Leibniz’s law of substitution of identicals (its specification for TIL can be found in [6] and [9]) and a proper evaluation of functions *Sub* and *Tr* according to their definitions. The special rules can be simply added to the set of logical inference rules and used together in the derivation process. Here is the derivation:³

² In TIL we formalize questions in the same way as their declarative counterparts.

³ In the proof we omit first and last steps, which are an elimination and introduction of the left-most $\lambda w \lambda t$. At steps 5 and 12 we use the *restricted* β -reduction that is valid in the logic of partial functions [7].

1.	$[^0\text{Regret}_{wt} \text{ } ^0\text{Mayor}_{wt} \text{ } ^0[\lambda w \lambda t \neg[^0\text{Know}_{wt} \text{ } ^0\text{President}_{wt} \text{ } ^0\text{Sub } [^0\text{Tr } ^0\text{President}_{wt}] \text{ } ^0\text{he } ^0[\lambda w \lambda t [^0\text{Go}_{wt} \text{ } \text{he } ^0\text{Brussels}]]]]]]]$	$\emptyset$
2.	$[^0\text{President}_{wt} = ^0\text{Snasel}]$	$\emptyset$
3.	$[^0\text{True}_{wt} \text{ } ^{20}[\lambda w \lambda t \neg[^0\text{Know}_{wt} \text{ } ^0\text{President}_{wt} \text{ } ^0\text{Sub } [^0\text{Tr } ^0\text{President}_{wt}] \text{ } ^0\text{he } ^0[\lambda w \lambda t [^0\text{Go}_{wt} \text{ } \text{he } ^0\text{Brussels}]]]]]]]$	1, F1
4.	$^{20}[\lambda w \lambda t \neg[^0\text{Know}_{wt} \text{ } ^0\text{President}_{wt} \text{ } ^0\text{Sub } [^0\text{Tr } ^0\text{President}_{wt}] \text{ } ^0\text{he } ^0[\lambda w \lambda t [^0\text{Go}_{wt} \text{ } \text{he } ^0\text{Brussels}]]]]]]_{wt}$	3, True – E
5.	$[\lambda w \lambda t \neg[^0\text{Know}_{wt} \text{ } ^0\text{President}_{wt} \text{ } ^0\text{Sub } [^0\text{Tr } ^0\text{President}_{wt}] \text{ } ^0\text{he } ^0[\lambda w \lambda t [^0\text{Go}_{wt} \text{ } \text{he } ^0\text{Brussels}]]]]]]_{wt}$	4, ²⁰ -E
6.	$\neg[^0\text{Know}_{wt} \text{ } ^0\text{President}_{wt} \text{ } ^0\text{Sub } [^0\text{Tr } ^0\text{President}_{wt}] \text{ } ^0\text{he } ^0[\lambda w \lambda t [^0\text{Go}_{wt} \text{ } \text{he } ^0\text{Brussels}]]]]]$	5, β -r
7.	$[^0\text{True}_{wt} \text{ } ^2[^0\text{Sub } [^0\text{Tr } ^0\text{President}_{wt}] \text{ } ^0\text{he } ^0[\lambda w \lambda t [^0\text{Go}_{wt} \text{ } \text{he } ^0\text{Brussels}]]]]]$	6, F2
8.	$^2[^0\text{Sub } [^0\text{Tr } ^0\text{President}_{wt}] \text{ } ^0\text{he } ^0[\lambda w \lambda t [^0\text{Go}_{wt} \text{ } \text{he } ^0\text{Brussels}]]]]_{wt}$	7, True – E
9.	$^2[^0\text{Sub } [^0\text{Tr } ^0\text{Snasel}] \text{ } ^0\text{he } ^0[\lambda w \lambda t [^0\text{Go}_{wt} \text{ } \text{he } ^0\text{Brussels}]]]]_{wt}$	8,2, SI
10.	$^2[^0\text{Sub } ^{00}\text{Snasel } ^0\text{he } ^0[\lambda w \lambda t [^0\text{Go}_{wt} \text{ } \text{he } ^0\text{Brussels}]]]]_{wt}$	9, Tr
11.	$^{20}[\lambda w \lambda t [^0\text{Go}_{wt} \text{ } ^0\text{Snasel } ^0\text{Brussels}]]_{wt}$	10, Sub
12.	$[\lambda w \lambda t [^0\text{Go}_{wt} \text{ } ^0\text{Snasel } ^0\text{Brussels}]]_{wt}$	11, ²⁰ -E
13.	$[^0\text{Go}_{wt} \text{ } ^0\text{Snasel } ^0\text{Brussels}]$	12, β -r

Since we proved that premises entail that Snášel is going to Brussels, the answer to the question Q is YES.

3 Resolution method in TIL

The integration of the resolution method with the special rules was initially presented in [4], where the authors proposed the application of the rules together with Skolemization prior to the resolution process. This approach was further revised and modified to integrate the application of the special rules with the resolution process [2]. Here I present the same example as above, this time solved by means of the adjusted resolution method.

Knowledge base and question remain the same as in the previous example with the addition of following special rules:

- F1: $[^0\text{Regret}_{wt} \text{ } x \text{ } c] \supset [^0\text{True}_{wt} \text{ } ^2c]$
 F2: $\neg[^0\text{Know}_{wt} \text{ } x \text{ } c] \supset [^0\text{True}_{wt} \text{ } ^2c]$
 T: $[^0\text{True}_{wt} \text{ } p] \supset p_{wt}$

The knowledge base after the conversion into the Skolem clausal form and negation of the question:

- A: $[^0\text{Regret}_{wt} \text{ } ^0\text{Mayor}_{wt} \text{ } ^0[\lambda w \lambda t \neg[^0\text{Know}_{wt} \text{ } ^0\text{President}_{wt} \text{ } ^0\text{Sub } [^0\text{Tr } ^0\text{President}_{wt}] \text{ } ^0\text{he } ^0[\lambda w \lambda t [^0\text{Go}_{wt} \text{ } \text{he } ^0\text{Brussels}]]]]]]]$
 B: $[^0\text{President}_{wt} = ^0\text{Snasel}]$
 F1: $\neg[^0\text{Regret}_{wt} \text{ } x \text{ } c] \vee [^0\text{True}_{wt} \text{ } ^2c]$

$$\begin{aligned} \text{F2: } & [{}^0\text{Know}_{wt} y d] \vee [{}^0\text{True}_{wt} {}^2d] \\ \text{T: } & \neg[{}^0\text{True}_{wt} p] \vee p_{wt} \\ \text{Q: } & \neg[{}^0\text{Go}_{wt} {}^0\text{Snasel} {}^0\text{Brussels}] \end{aligned}$$

At this point, we can proceed to the application of the resolution and rules. After two applications of the resolution rule, we will get the following construction:

$$\text{R2: } {}^{20}[\lambda w \lambda t \rightarrow [{}^0\textit{Know}_{wt} {}^0\textit{President}_{wt} [{}^0\textit{Sub} [{}^0\textit{Tr} [{}^0\textit{President}_{wt}] {}^0\textit{he} {}^0[\lambda w \lambda t [{}^0\textit{Go}_{wt} \textit{he} {}^0\textit{Brussels}]]]]]]_{wt}$$

By applying restricted β -reduction and 20 -elimination to R2 we obtain:

$$\neg [{}^0Know_{wt} {}^0President_{wt} [{}^0Sub [{}^0Tr {}^0President_{wt}] {}^0he {}^0[\lambda w \lambda t [{}^0Go_{wt} he {}^0Brussels]]]]]$$

that can eventually be unified with F2:

[illegible]

To evaluate the substitution, we make use of the clause B and Leibniz's law:

$$\begin{array}{ll}
2^0[{}^0Sub\ [{}^0Tr\ {}^0President]_{wt}] \ 0he\ 0[\lambda w\lambda t\ [{}^0Go_{wt}\ he\ 0Brussels]]]_{wt} = & \text{R4, B} \\
2^0[{}^0Sub\ [{}^0Tr\ {}^0Snael] \ 0he\ 0[\lambda w\lambda t\ [{}^0Go_{wt}\ he\ 0Brussels]]]_{wt} = & \text{Sub, Tr} \\
2^0[\lambda w\lambda t\ [{}^0Go_{wt}\ {}^0Snael\ 0Brussels]]]_{wt} = & 2^0\text{-elimination, restricted } \beta\text{-reduction} \\
[{}^0Go_{wt}\ {}^0Snael\ 0Brussels] &
\end{array}$$

As a result, we obtained an adjusted clause:

$$\begin{array}{l} \text{R4': } [{}^0Go_{wt} \ {}^0Snasel \ {}^0Brussels] \\ \text{R5: } \# \end{array} \quad (\text{R4'} + \text{Q})$$

We obtained the empty clause, hence the answer to the question Q is YES.

4 Conclusion

In this paper, we presented two ways of building up an inference machine in TIL where it is necessary to integrate special technical rules of TIL and rules from natural language semantics. The first system is the natural deduction, where we can easily add special rules and use them together with classic natural deduction rules in the derivation process. In the second system, the general resolution method, the situation becomes more complicated. There is only one inference rule used (the resolution rule) and the rest of deduction rules is incorporated within the transfer into the Skolem clausal form and unification. The main issue was, where and how to incorporate special rules into the resolution method. We solved this problem by adding the most of the special inference rules in their implicative form into the knowledge base, whilst special rules based on the equivalence of constructions (β -reduction, 20 -elimination,

evaluation of *Sub* and *Tr* functions, Leibniz's law) are applied during the resolution process to adjust clauses before unification. Future research will concentrate on deriving answers to Wh-questions in both systems and their comparison.

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An approach for multi-objective optimization problem

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Abstract. Optimal problems are attracting more and more researchers to pay attention to minimization or maximization of various fields. There are many types of classification of optimal problems, such as constrained or unconstrained; single-objective or multiobjective optimization problems, etc. Unlike single objective optimization, there are multiple under-optimized objective functions, these objectives under consideration conflict with each other. Sometimes, optimizing a particular solution towards a single objective can cause unacceptable results with regard to the other objectives. Most of the multi-objective optimization algorithms try to divide the candidate solutions into a different front, as the first front solutions are considered as Pareto front solutions. While in large multi-objective problems, it is easier for solutions to be non-dominated with each other. In this paper, we try to use a trade-off value for a solution as the evaluation criteria instead of the front number. With this value, a solution with more good objective values is in a better chance of being selected for generating the offsprings. Meanwhile, we propose a new algorithm combining trade-off value and genetic algorithm.

Keywords: Multi-objective optimization · genetic algorithm · crowding distance.

1 Introduction

When addressing Multi-objective optimization (MOO) problem [1] [2], the solving methods are mainly classified in these three types [6] 1. the analytical method or numerical method, 2. methods with a priori articulation of preferences, methods with a posteriori articulation of preferences, and methods with no articulation of preferences. 3. Pareto-based method and decomposition-based method.

The analytical method needs strict mathematical proofs and derivation to get an exact solution, except for the decision variables and objective variables this basic information should be clear, the problem characteristics are also involved [3] [5]. While many realistic problems are managed as a black box problem, the above conditions are hard to be satisfied. Thus, a numerical method, which works with appropriate iteration formulas, is designed for a multi-objective problem. A numerical method usually starts with a set of given initial positions and generates the next iteration positions according to the objective formula. During a series of iterations run, it needs the decision and objective variables feedbacks from the objective problem. With the iteration times grow, this method

gets the approximate solution. As the required information for solving multi-objective optimization problem is small, many realistic optimization problems could match. As well as, intelligent numerical methods, as one sort of heuristic search algorithm, are widely researched and used.

The other type to consolidate and relate seemingly different methods is based on user' preferences for multi-objective optimization. Preference is represented as a decision-makers opinion concerning targets in the decision space. There are three major categories: methods with a priori articulation of preferences, methods with a posteriori articulation of preferences, and methods with no articulation of preferences. Before running the optimization algorithm, the user specifies the relative importance of the objective functions or desired goals, which indicate a priori articulation of preferences method. To reflect the users' preferences, those parameters coefficients, exponents, constraint limits, etc. are usually involved to denote a completely optimal solution set.

2 Multi-objective optimization algorithm

In this section, an approach for multi-objective optimization problems will be introduced. This approach combines the population ranking technique based on a trade-off value with the genetic algorithm together. Genetic algorithm is one of the methods in the evolutionary class, which repeatedly modifies a population of individuals represented a solution with the help of crossover and mutation operations. Usually, before the modification to the population, a selection step is taken to distinguish the optimal or inferior individual. Generally, the relative optimal individuals run through the crossover operation as the parents to generate the offspring, while the offspring will replace the other half of relative inferior individuals. Many strategies are proposed to show how to select the parents or how to improve the selection quality of the parents.

One of the popular approaches to the multi-objective optimization problem is NSGA-II [4], which also has a fast non-dominated sorting strategy. But there is a flaw in NSGA-II that it works not very well in solving a big number of objectives problems. In this regard, with the fixed size of population to this problem, more individuals are non-dominated solutions, since the individual preservation strategy is conducted based on non-dominated condition, the solutions may not move towards Pareto-optimal region. In NSGA-II algorithm, non-dominated solutions are ranking the same order without the crowding distance. While, in our approach, we count the better objective value number for a solution to all solutions, then to rank the solutions. In other words, if a solutions which have the best of all objectives than the rest, this solution is ranked first. The trade-off value computation process is as, first sort all the objective, then do the summation of the sequence order of a solution in all objective list. Next rank the population based on the trade-off value. Our approach replaces the trade-off value to the evaluation criteria instead of the basic fitness function value. This trade-off value can majorly reflect the degree to which individuals are superior or inferior, due to the definition of this value, which is the summation of the objective value's

position order number in all objectives. This is to say, if a solution has many good objective values, then its value gets bigger. To those solutions with many relatively better objective values or those with rare extremely superior values, they can be preserved as the parents in a big possibility. The genes inherited from the parents constitute the offspring, all in all, this value based ranking criteria can sort the good individuals out from the population.

Now, we will introduce the multi-objective optimization algorithm based on the trade-off value and genetic algorithm step by step. Algo. 1 is the pseudocode of this algorithm, and Table is the relevant symbol annotation.

Algorithm 1: A mutiobjective optimization algorithm

Input: $P, N, Max_{it}, L = \emptyset, OffP = \emptyset, it = 0$
Output: L

```

1 initial  $P$ ;
2 while  $it \leq Max_{it}$  do
3   for  $i = 1$  to  $\frac{N}{2}$  do
4     if  $L = \emptyset$  or  $rand \leq 0.5$  then
5       Parents  $\leftarrow P$ ;
6     else
7       Parents  $\leftarrow L$ ;
8     end
9     Offsprings  $\leftarrow$  SBXCrossover(Parents);
10    PolynomialMutation(Offsprings);
11    Evaluation(Offsprings);
12    OffP.add(Offsprings);
13     $it+ = 2$ ;
14  end
15  Uset = Union(OffP,  $P$ );
16   $L.elite(OffP)$ ;
17  Calculate Trade[Uset];
18   $P =$  Trade.sorting(Uset);
19  OffP =  $\emptyset$ 
20 end

```

The process of our algorithm is:

Step 1. Initial the population of P (Line 1). And each individual represents a solution to a multi-objective optimization problem. $OffP$ is a set of offspring generated by parents, and its initial status is $OffP = \emptyset$. L is also a set of solutions that are non-dominated and the maximum size of L is N , which number is the final required solution amount. For population P , each individual's values are normally determined initially by random, and subsequently by evolution.

Step 2. The selection of parents (Line 4-8), which are used to produce the next generation population. The parents are from two sets P or L with the same probability. The set L preserves the non-dominated solutions during the running of an algorithm, the chosen ones from L more likely produce good solutions. At the same time, for adding the chance to exploit a random area solution, the set

Table 1. Symbols annotation for Algorithm ??

Symbols	Annotations
P	The population of individuals (solutions).
N	The size of the population.
Max_{it}	A threshold value restricts the maximum running times
L	A set of individuals with maximum size N holds optimal non-dominated solutions
$OffP$	The population of offspring generated by P .
$Trade[]$	$Trade[]$ is array, each value is a summation for all objectives' position standing of one solution.
$rand$	A random value. $0 < rand < 1$
Parents	Individuals selected for generating offspring.
Offsprings	Individuals generated by Parents.
$\leftarrow$	A symbol for where an object comes from.
$.add$	An operation of adding elements to a set.
$.elite$	Elite preservation operation.
Union	An operation of combination of two sets.
$Trade.sorting(*)$	The sorting operation to the set $*$.
$\emptyset$	An empty set symbol.

P is also used. While, the population P is picked by trade-off value ranking, so the individuals from P are not strictly random and worse.

Step 3. Crossover operation (Line 9). A way to stochastically produce new individuals from an existing population. Traditionally the individual keeps genetic information represented by a bit array, and a bit called 'crossover point' is randomly picked from both parents. The two offspring carrying genetic information from parents by swapping the bits to the right or left of crossover point. As the individuals are coded in real numbers in our simulation, we choose a simulated binary crossover (SBX) operator. SBX operator uses two parents and creates two offspring, a parameter named a distribution index is used which decides the distance between the offspring and the parents, whether it is close to or away from each other. There are two properties of the SBX operator with one-point crossover, average property and spread factor property (the ratio of the spread of offspring points to that of the parent points). They interpret as the average values of the encoded parameter is the same before and after the crossover operation, the probability of occurrence of spread factor around equal 1 is more likely than any other spread factor value.

Step 4. Mutation operation (Line 10). A variation operator assists the population to maintain diversity in the search space. Bit-coded GAs operator attempted to mutate every bit with a probability independently, while when it comes to the real-valued variables, the flaws of using a Bit-coded GAs come up. One of the reasons was the artificial discreteness associated with the coding mechanism and the second was the biasedness of mutated solutions towards certain parts of the search space [7]. Polynomial mutation (PLM) operator is suggested with a user defined parameter η_m , this operator is adopted in our simulation. Poly-

nomial mutation works as its name, there is polynomial to perturb a solution and generate a new variable value in the vicinity of its original. The author of PLM operator made a theoretical study and found that parameter η_m induces $\mathcal{O}(V_u - V_d)/\eta_m$ perturbation effect in a variable, where V_u and V_d are upper and lower bounds of this variable. A Java implementation of PLM algorithm is provided by the jMetal framework and used in our experiments.

Step 5. Evaluation operation (Line 11). Trade-off value is the summation of objective values position order number, which has the reflection of the inferior or superior comparison among individuals to some extent. Trade-off values are used to rank the population. If an individual has a big value then its rank in the population is also high. On the contrary, the last rank one individual in the population, its value must be the smallest. The user should be aware that which objective values are to be minimized or maximized. Then the Trade-off values can be generated.

Step 6. Elite population preservation (Line 16). A set L holds the non-dominated solutions generated during the running process. When the size of non-dominated solutions exceeds the maximum number, the set L needs to be pruned, where their crowding distance is assigned and compared. The one with the worst crowding distance value will be removed. The process of crowding distance assignment is: Firstly individuals are sorted in each objective domain (objective function values order), the first and the last individuals in the order are assigned an infinity crowding distance. Secondly, for the rest of the individuals, locate the different two closest neighbor individuals in the rank, then calculate the crowding distance value based on the equation 1.

$$I[i]_{distance} = I[i]_{distance} + \frac{I[i+1].m - I[i-1].m}{f_m^{max} - f_m^{min}} \quad (1)$$

Where in the Equation 1, $I[i]_{distance}$ is the crowding distance of individual i_{th} , the initial value of it is 0. $I[i].m$ is the objective function value corresponding. And f_m^{max} and f_m^{min} are the biggest and the smallest objective function values in respective objective function domain. Figure 1 shows the illustration of calculating and results.

Fig. 1. An example of calculating crowding distance

Step 7. A ranking process (Line 17-18). The ranking is a process to evaluate and to sort the population based on the trade-off values. $Uset$ is a twice size of population P , and now we want to choose the half population of $Uset$ to replace

the original population P . First, the Trade[$Uset$] are calculated, then sorting the $Uset$ based on their trade-off values. Next, The first half of the entries are assigned as the population P .

Step 8. Terminal operation check (Line 2,20). When the evaluation time reaches the maximum number, stop running and output the results. Otherwise, go back to Step 2.

3 Conclusion

In this paper, we propose a new algorithm which combines the trade-off value and genetic algorithm for solving the multi-objective optimization problem. This trade-off value can majorly reflect the degree to which individuals are superior or inferior. With the fixed size of the population to a multi-objective problem, more individuals are non-dominated solutions, if the individual preservation strategy is conducted based on trade-off values instead of a non-dominated condition, the better individuals will be kept. Meanwhile, we also adopt the crowding distance evaluation to get rid of some bad individuals. In the next work, we will do the experiments, to see where we could improve our work.

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Natural gas consumption forecasting from big data collection

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Abstract. This paper presents current state of our research related to solving natural gas consumption forecasting tasks. We have performed literature review of existing related works. With insights gained from this process, we created state of the art dataset. We have proved its high usability with first machine learning based experiment. Full dataset will be published after submission of our complete research paper.

Keywords: gas consumption prediction, big data, machine learning

1 Introduction

Natural gas consumption forecasting tools gained significant importance in recent decades. There were multiple reasons for this. Natural gas is considered to be the cleanest of all fossil fuels. Air pollution and CO₂ emissions produced during the utilization of any fuel are important factors influencing the decision-making process.

Some of the researchers, like Soldo [11] and Tamba et al. [15], created literature review studies. These offer an overview of available methods at a given date, which we can consider as a form of research baseline. These reviews include an algorithms performance and precision overview useful to the new researchers trying to get into this field. During cross-method comparisons, they often encounter hurdles created by different metrics, forecasting horizons and input data used in the individual works. That means that a simple evaluation of outcomes against each other is not a trivial task and sometimes can be even impossible, as stated by Tamba et al. [15]. To our best knowledge, no large dataset was made publicly available after research for other researchers to use it with their own methods and directly compare the outcomes of the research. We perceive that as a huge challenge that we faced ourselves at the starting point of our work. This is why we have decided to change this and make this research field more accessible to newcomers by publishing a new publicly available dataset. Dataset will be published after research with release of our complete paper.

2 State of the art

2.1 Dataset features

Reviews performed by Soldo [11] and Tamba et al. [15] narrowed our selection of follow-up articles. We have compared entry insights gained from those articles with data sources available to us. Two key factors resulted from this comparison. First of them was focus on the gas network data level. This level is common for forecasting tools used by larger distribution companies because it resembles their scope of operations. In some countries division of the market follows regions of such country. This creates the option to enrich the dataset with economic statistics of each area from the state census. The second key factor was the hourly data frequency. There were previously reported interesting trends during different times of the day by Soldo [12]. If these high-frequency data can be obtained, it will enable the exploration of more previously undiscovered trends.

The first stage of our review was focused on weather data. It was confirmed that weather data and especially air temperature are crucial for the precision of forecasts. Taspinar et al. [16] and Czech Energetic Regulatory office [4] confirmed that the addition of ambient temperature and cloud cover data is beneficial. It was also described that prediction models could benefit from the discovery of heating breaking point value. If the temperature rises for a specified amount of time over this value, consumers will then turn off their heaters and consumption drops. This enables the division of prediction models into two modes - heating and non-heating season, as described by Brown and Matin [2]. The heating season is specified by law for many countries.

Buildings tend to have thermal memory, which introduces delays in observed consumption changes. These were found to be repetitive and can be forecasted if temperature and solar radiation data are included in the model, as recommended by Soldo [12].

Urbanization and economic factors were also successfully used in prediction models. It was also discovered that a growing urbanization rate usually boosts consumption while higher age of consumers leads to lower demand. The growing density of urbanization also seems to decrease the consumption of studied areas.

The gas stock market usually uses a so-called gas day for trades - 24 hour period starting at 6 a.m. of each day.

We have gathered data for all of these previously mentioned features and included them in our dataset.

2.2 Forecasting methods

The first approaches used in forecasting were based on the approximation principles, mainly the Hubbert curve model [6]. The main works that used this approach were [5, 10, 7] and many others.

Later statistical methods have become very popular in this research field. These methods are very popular even these days. Balestra and Nerlove [1] used a statistical model estimation for gas demand modeling, according to the known

time-series of demands. They have developed a dynamic model that predicts the demand on the market for natural gas. Vondracek et al. [18] developed a statistical model that utilizes the non-linear regression for prediction of the gas consumption for small commercial and individual customers.

Another large group of applied algorithms is the application of Artificial neural networks. Suykens et al. [13] have developed a non-linear model of the Belgian gas consumption with utilization of the weather and market data about oil prices. Khotanzad et al. [9] prepared a two-stage model that combines regular feed-forward neural networks and functional link neural networks on the first level and nine different mixing strategies on the second level. A combination of classical and fuzzy neural networks was developed by Viet and Mańdziuk [17]. This approach was tested on weekly data with short, middle and long term forecasting horizons. Another application of the hourly based data was performed by Szoplik [14], who efficiently used Multi-layer perceptron on the gas consumption enriched with the weather data. For a more detailed overview from early history until 2010, please see the excellent survey from Soldo [11].

3 Dataset

3.1 Data preparation and local environment

With the knowledge gained from our literature survey, we have started our search for data. Our country Czech Republic is located in central Europe. All four weather seasons are there equally represented. That makes our country suitable for discovering season-related trends in data, as stated by Janda and Kourilek [8].

The distribution of natural gas in the Czech Republic is operated by three network operators. All of them are customers of one major cross-border pipeline operator, which operates 3,820 km of pipelines. The Czech Republic has small own natural gas sources, which can cover about 2% of its yearly consumption. Remaining demanded volume must be imported from other countries. Around 75% of imported gas comes from Russian sources. There are eight gas storage facilities in the Czech Republic. Their capacity can cover about a third of total year consumption and is usually used for balancing unexpected outages in international import and surges of demand caused by surprise temperature drops.

Peak demand of 9.8 billion m³ was reached in 2001. At the end of 2018, there were approximately 2.9 million end customers. From this number, 92% were households. However, they consumed only 27.8% of the whole demand. It was clear that we need to find data from the region where are all types of customers are represented. That is why we acquired and used data from the Prague distribution network.

3.2 Prepared dataset

Our dataset covers six whole years from January 1, 2013 to December 31, 2018. All data features are available at an hourly frequency. The whole dataset is

composed of 52,584 data points. These data points were assembled from three main components.

The first component was created from consumption data. Prague is the capital city of the Czech Republic and its distribution network consisted of 422,926 customers [4] in 2018. Total consumption was 3.82 billion m³. Residential sector included 381,914 households (33.3% of consumption). Industrial sector consisted from 177 big (24.8% of consumption), 39,175 medium (18.9% of consumption) and 1,652 small customers (21.9% of consumption). Missing remainder to 100% were operational losses that occurred during distribution, e.g., pipeline leak. The heating season in the Czech Republic is from September 1 to May 31. Usually, it is required for the heating season to begin that the temperature drops below +13°C for two consecutive days, and no warming is forecasted for the next days. The heating season usually represents about 70% - 75% of the whole year's consumption.

The second component includes weather variables. We have used data from the Prague LKPR airport weather station. Airports are required to periodically issue METAR (aerodrome routine meteorological report) information. Those reports are archived and preserved for a long time.

The third component representing economic features are natural gas price data. We have obtained price data from the Czech energy regulation office and included them in the dataset.

4 First experiment

The purpose of the experiment described in this section is to validate the usability of the created dataset. Our results are preliminary, and further development of our forecasting method will follow.

4.1 Experiment setup

We have used numerical covariate time series of consumption variable as exogenous input variables in the forecasting models. Nominal features were not included in the preprocessed dataset to mitigate the curse of the dimensionality risk originating from the need of using multiple lagged values as features to incorporate time dependency of the data into the machine learning models. Outliers in the consumption variable were detected with the interquartile range method with respect to the month. Only short sequences of missing values were found in exogenous variables. They were imputed with the linear interpolation. Consumption variable was the only exception because it contained sequences of missing values with length up to 24 consecutive values. Due to this fact, the separate model was created where missing data points were replaced by substituted values. This model used the Random forest algorithm for the missing consumption forecasting and current hour, day in the year, day of the week, month, temperature and trend obtained from the STL decomposition as input features. This model was able to successfully forecast current gas consumption

with mean MAPE of 5.36 % based on the 10-fold cross-validation results. Thus it was used over the interpolation methods.

4.2 Direct approach with single model

The first step in the preprocessing pipeline was reducing the gas consumption time dependency and extraction of it as additional features. The current value is heavily dependant on the prior values as we can judge from the strong autocorrelation of the consumption time series. Daily and half-daily seasonal patterns with peaks at lag numbers, which are multiplies of the number 24, respectively 12, corresponding to the hours in a day are apparent from the autocorrelation plot. We did a first-order seasonal differencing of the time series with a lag of 24 to reduce part of the time dependency with respect to the forecast horizon and autocorrelation values. The second step was the decomposition of the differenced time series into additive components. STL (Seasonal and Trend decomposition using Loess) [3] was used for this purpose, which decomposed the time series into trend, periodic and residual component. Consumption did not follow any deterministic trend, so finally, the trend component was merged with the residual one. The Augmented Dickey-Fuller test for the unit root of the merged time series was done to check if the stationarity expectations were met. We rejected the null hypothesis at the significance level of 5% with the $p-value \ll 0.05$ and took the stationarity expectation as fulfilled. The final step was the transformation of the time series to the form suitable for the single model forecasting. As mentioned before, the last known value for the next 24-hour forecast horizon is midnight of the previous day. The final step of preprocessing consisted of applying the difference between the current value and the consumption at the last midnight for every value in the time series. Time series transformed in this way served as the forecasted variable for the algorithms. Predicted values were finally obtained by reversing the whole process and used for computation of all evaluation metrics.

Table 1. Machine learning approach results from the daily perspective. RF indicates the Random forest algorithm, LGB the Light gradient boosting algorithm.

Approach	Alg.	MAE	MSE	MAPE	SMAPE	GDMAPE	R2
Direct	SM RF	10.67e+04	2.75e+10	4.75	4.73	4.63	0.991
	LGB	10.00e+04	2.45e+10	4.55	4.52	4.49	0.992

5 Conclusion and further research

We have performed detailed literature review and gained key insights from it. We have prepared state of the art big dataset and proved its usability by first machine learning experiment. These results created baseline for our future development of forecasting method.

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Community detection in networks using clustering methods and graph's distance metric

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Abstract. One of the important tasks in network analysis is community detection. Communities represent densely connected groups of nodes in comparison to rest of the network and can be used for further network analysis. Many different methods have been proposed in literature and various criteria has been optimised. In this work we propose new method for detecting communities that use various distance metrics in graphs and combine them with standard clustering algorithms. One of used metric is closed trail distance, which is able to capture a higher degree of connectivity between nodes. The proposed methods are evaluated on artificial networks generated by Lancichinetti-Fortunato-Radicchi benchmark. The results of new and state of the art methods are compared and evaluated.

Keywords: Community detection · Clustering methods · Closed trail distance

1 Introduction

For the study of relationships between objects, it can be beneficial to represent data in the form of graphs and utilize network analysis tools. Community detection is one of the possible tasks in network analysis. If different objects are connected more frequently among themselves in comparison to the rest of the network, then these objects (nodes) forms a community.

Because the exact definition of the community is not known[2], there are several methods solving community detection tasks in the way of optimization of specific criteria. One of the frequently used algorithms is the Louvain method, based on finding communities with the best modularity[1].

The modularity optimization approach is not always suitable for the analysis. Therefore we explore methods based on a different idea. One can use Infomap, which leverages random walks in a graph. But there may be some other useful properties in graphs.

In recent work Closed Trail distance (*CT* distance)[6], metric for expressing distance between two nodes in graph, has been introduced for reflecting cyclical

dependencies between objects. In later work we used $k - CT$ components derived from CT distance to define clustering and closure coefficients in graphs [5]. Experimental results of coefficients showed ability to separate different types of network and express relationship of real word network to Barabási-Albert and Watts-Strogatz models.

2 Description of proposed methods

For leveraging benefits of CT distance for community detection we have proposed combining clustering algorithms together with CT distance and Shortest Path distance (SP distance). Two different approaches are introduced and described in following sections.

2.1 Using graph distances and hierarchical clustering for community detection in graphs

This method relies on hierarchical agglomerative algorithms [4] to group nodes (graph objects) to clusters by using SP or CT metric from graph. These clusters are then represented as communities in network.

Due to using custom distance metrics we were restricted with using hierarchical clustering with basic linkage types - single, complete and average.

For all clustering algorithms used in this paper was number of clusters input parameter. There are multiple method for choosing the best number of clusters. We have decided to use silhouette score as selecting criteria. Silhouette score is higher when close nodes belong to the same community. Another option is to measure the quality of created communities using modularity or performance [2].

2.2 Clustering algorithms in vector space generated from distance matrix

This method take graph's distance matrix as new vector space and employ various methods of clustering algorithms for calculating communities in graphs.

Because we are treating distance matrix as new vector space we are able to use usual distance metrics (such as Euclidean and Manhattan) in clustering algorithms. In later section of this paper you can see numerous results of using K-Means, K-Medians and Hierarchical agglomerative clustering.

Vector space for well-known Zachary's Karate club network is shown on Figure 1. In this illustration you can also see result of K-Means clustering algorithm, silhouette coefficient suggested use of 2 or 3 clusters depending on selected clustering method.

Fig. 1: Visualization of vector space formed from Zachary's network distance matrix. Shape of points represent ground truth communities in network [2]. Color marks clustering result for K-Means algorithm with $k = 2$. PCA was used for dimension reduction of vector space to 2 dimensions.

3 Empirical results

For evaluating quality of community detection we have calculated and compared Normalized Mutual Information (NMI) for graphs with ground truth communities generated using LFR benchmark. Various parameters value was experienced with and for each parameters configuration 10 different network realizations was generated and results are represented as mean value over these realizations.

To compare the results, selected state of the art algorithms were used, namely Fastgreedy, Infomap, Label propagation and Louvain. Their description is given in [7].

3.1 LFR benchmark

To generate networks with ground truth communities we have used LFR framework [3]. Graphs generated by this framework follow power-law degree distribution and also in community size. Mixing parameter μ describe ratio of external node's degree (count of inter community edges) and node's degree.

For empirical study we have generated graphs with 1000 nodes, power law coefficients 2.1 for degree distribution and 1.1 for community size distribution. Average degree of nodes was 20 and maximum degree was 100. Mixing parameter μ was from range $\langle 0.1, 0.8 \rangle$

3.2 Parameter selection

One of the important parameters in both algorithms is the number of clusters in the data clustering algorithms. A possible measure of the quality of clustering algorithms is the Silhouette score. When using a clustering algorithm to

detect communities, it is possible to use measures to determine the quality of communities, the two measures used here are modularity and performance.

The results comparing the quality of individual measures when selecting a parameter of the clustering algorithm can be seen in the Figure 2. The evaluation measure is NMI, which expresses the correctness of the inclusion of nodes in communities in comparison with ground truth communities. As selected measure in later experiments was selected performance.

Fig. 2: Comparison of the dependence of strategies for parameter selection to NMI in the hierarchical clustering algorithm with average linkage. The relationship is compared for all proposed community detection methods. The selected measure for further experiments is performance.

3.3 Hierarchical clustering and graph distances

The first proposed strategy use graph distances in combination with hierarchical clustering. For networks generated by the LFR framework, calculations were performed using SP and CT distance in combination with the average and complete linkage approach in hierarchical clustering.

The quality of the acquired communities is compared with the state of the art algorithms in the Figure 3. When comparing the graph distance, better results were obtained with CT distance. Average linkage yields better results

Fig. 3: Comparison of the quality detected in comparison with ground truth communities. The proposed methods are represented by a solid line, the dotted line shows the result for known community detection algorithms. The quality values of the NMI detection communities are compared for a different parameter of the LFR benchmark indicating the ratio of edges outside the community.

than complete linkage. A comparison of the quality of the communities using CT distance and selected algorithms revealed a comparable quality of the result as with the Fastgreedy algorithm, but a quality comparable to the Louvain algorithm was not achieved.

3.4 Clustering in vector space

The second proposed method is based on using graph distances to create a new vector space and employing clustering algorithms to detect communities. This section presents the results for use of Hierarchical agglomerative clustering with complete, average and ward linkage or algorithms belonging to a representative clustering method, specifically K-Means and K-Medians.

Both SP and CT distances for vector space creation were compared and the results are shown in Figure 4. When comparing the used distance, the results are slightly better for vector space based on CT distances. When gradually comparing the results of the proposed method with state of the art methods optimizing modularity, the proposed method achieved better results than the Fastgreedy method and worse than the Louvain algorithm. The other 2 reference algorithms were Label propagation and Infomap, which show slightly better results for networks with a lower ratio of edges outside the community, with increasing ratio the proposed method achieves better results.

4 Conclusion and further research

New methods for community detection using graph distances and clustering algorithms have been proposed. Experiments using the LFR benchmark for network generation were performed.

Fig. 4: Comparison of vector space-based methods with selected community detection algorithms. The proposed methods (marked by a solid line) are based on vector space containing graph distances and clustering algorithms.

When comparing the two proposed approaches, the advantages of using CT distance were obvious. The method based on the creation of vector space using graph distances achieved better results. The quality of the detected communities was also compared with the state of the art algorithms and, especially using the vector space method, competitive results were achieved.

Further work should verify the use of the proposed methods for real world network. Among other issues deserving further work is the stability of hierarchical clustering, which could be influenced using the Fiedler vector during preprocessing.

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Multi-services systems monitoring

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Abstract. Complexity of information systems is still rising due to modernisation of old infrastructures, higher performance requirements and scalability. All these changes have big impact on environment heterogeneity where components, relations, and their unexpected cooperation and dynamic can cause serious problems. To be able to understand such complex information system, techniques like process mining and discovery are used. Processes give possibility to detect errors which are difficult to evaluate in a real time. Aim of this paper is to provide a solution to evaluate the quality of processes conducted by the system in real-time. Provided processes data are usable for system visualisation in real time and all routines this system shall cover. Monitored services are critical parts which provide all necessary data which are processed by monitoring layer of information system. This paper also briefly covers the problem of data normalisation, streaming and batch processing which is important for model creation and further validations. Because merging of real-time streamed data and batch data is necessary **lambda architecture** was utilized in this work. Graphical representation of the system can be envisioned as a directed graph with services as its nodes and communication between services as its edges. Graphical solution cover real time system visualisation and also visualisation of predictions evaluated to particular state.

Keywords: Docker, Python, Linux, Spark, Flink, Kafka, Markov chain

1 Introduction

The prevalence of web services used for (sub)system integration has become a big topic nowadays [9]. All kinds of services which are responsible for specific domains. All data send to these services in different formats and also protocols. To avoid business services direct integration problems additional layer for integration has been introduced [1]. In this paper system functionalities based on services cooperation are important. Services are tightly connected with processes this monitored system covers. This additional integration layer which is aware of services communication in cooperation with monitoring can provide very clear insight how system works.

High availability, fail overs and dynamic scaling in big systems brings another level of complexity even though it is not directly connected with services. For

services monitoring the system, complexity makes no difference from processes perspective of view. These problems put us on path which is described in this paper. The most important thing is to gather the data from all services. Co-existence of monitoring is necessary for system definition and its fault analysis. "While building a fault-free system of such complexity is unrealistic, it is very desirable to have effective fault detection and isolation methods in operational system management" [9].

For better understanding and modelling the complex system it is necessary to mine service data, especially the logged call data between services. To easily understand the system Markov chain model [6] was selected. Model itself is later used for system visualisation. It is also used for process prediction based on near-real-time streamed data.

2 Complexity of system

All interconnected services in system define it's behaviour. With increasing number of services, system complexity raises [4]. Complexity is proven in cases of system failures because everyone is searching for root cause this error was caused. This negative feedback can be sometimes viable before it happens.

Patterns based on business processes any system is covering. Most common symptoms like slowly increasing number of erroneous processes can suggest further problems which can be caused by decreasing amount of resources (like connection pools ...) for example. All necessary resources are important for services which are backbone of complex systems nowadays.

2.1 Processes, services, activities and events

Processes mirrored to the information systems which fully obey and supplement such processes create a big interconnected network of service calls. Complete service calls can be understood as traces via whole system. Each trace then corresponds to the appropriate process this information system covers.

Each invocation of service is initiated by another service in this information system. High level view of services interactions, provides introspection for processes which is the critical part in process analysis. More about services definition in relation to processes can be found also [here](#). Each process is composed from activities. But from monitoring point of view activities are attracted to processes. Monitored services produce events (Fig. 1). Specific event is caught and grouped as request and response. This events sending and those monitoring is important for further investigation.

3 Process discovery

However, this approach has often resulted in discrepancies between the actual business processes and the ones as perceived by designers [7] therefore, very often,

Fig. 1. Services relations

the initial design of a process model is incomplete, subjective, and at a too high level. Instead of starting with an explicit process design, process discovery aims at extracting process knowledge from "process execution logs".

3.1 Terminology

While a lot of process discovery concepts are taken from graph theory, it uses a bit different terminology. Event is a single occurrence of a process, and it has following attributes¹:

- **Process ID** - It is the main ID which connects Activities into one process.
- **Activity** - Name of a single activity in the process.
- **Activity instance ID** - ID of a single instance of a activity.
- **Timestamp** - Timestamp of the event.

3.2 Events gathering and distributing

Raw data from logs are not suitable for processing. Before model creation or predictions it is necessary preprocess data. This is better described in chapter ?? about preprocessing. What is more important that the normalised logged events flowing through monitoring needs to be splitted for batches events computation and for streamed real time normalised events. This kind of architecture is know as lambda architecture[5].

3.3 The model

Model of the system processes is consisted of three components: Markov chain, evaluation of transition time and absolute number of observed transitions. The table contains 4 columns, the first and the second represent transitions (From-To), third and forth represent time interval (Minimum Time and Maximum Time) (Tab. 1).

¹ There are more attributes, only the relevant ones are mentioned

Table 1. An example of the model

From	To	Minimum time	Maximum time
A	C	1	4
START	A	-1	-1
C	END	-1	-1

4 Realisation

Environment which is fully virtualised in **Docker**. This brings possibility to test and run the solution locally. It is also possible to utilize **Docker-swarm** and spread the environment over multiple computers.

Whole environment is also compound to fully support distributed computing [8]. This kind of approach fully supports paradigm of command and conquer paradigm [3].

Model (see 3.3) is persisted as table structure into database. This model is further utilised for graphical output. Based on this model graphical representation is constructed as described in chapter 4.3.

4.1 Architecture

As was mentioned in previous chapter all components (Fig. 2) chosen for this solution fully support distributed computing and together make the environment scalable and highly available.

Fig. 2. Components architecture

Components:

- **Spark** - analytical engine for stream and batch processing
- **Flink** - streaming platform used for preprocessing in this work
- **Kafka** - message broker supporting publish subscribe behaviour
- **Postgre** - database used for persisting of model or batch data

4.2 Use of model and predictions

Basic scenarios how this solution covers model creation and traces predictions. They consist of these steps:

- Model creation - Batch part
 1. Events gathering preprocessing, normalisation and labeling
 2. Model construction based on preprocessed events
 3. Model persist
- Traces prediction - Stream part
 1. Normalise and label streamed events
 2. Do predictions for streamed events based on model
 3. Compare reality with prediction
 4. Persist false marked trace

Added value of this model is easy visualisation (Fig. 3) and clear understanding which processes are important during run time of system.

Traces prediction and comparison with real time traces provides possibility to see if any of trace is not as expected compared to prediction. Visualisation of such negative traces also brings another added value related to this solution.

4.3 Visualisation

To understand modeled system from database table is not possible. To be able to see all calls and present them in understandable way. We graphically (Fig. 3) represent the model (Tab. 1) as directed graph [2].

Fig. 3. Detail of graphical model representation

Whole rendering where each row from model represents each edge in graph is constructed by javascript `vis.js` framework inside `grafana` application. Vertexes in columns which are proportionally sized according to those maximum times.

False traces which are marked negatively based on model prediction are also important and need to be visualised. This visualisation gives insight to monitored processes from high level of perspective which is a crucial part of system understanding and monitoring in cases of failures or malfunctioning on business level.

5 Summary

This research is going to be published on INCOS 2020 conference. This kind of solution is based on Markov Chain algorithm that can be replaced or combined with another algorithms. Current work is tested for small chunks of data which also do not cover the performance problems that can come when there is large amount of events.

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Detection of Anomalies During Car Driving Based on Singular Value Decomposition

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Abstract. This work introduces a model using the singular value decomposition (SVD) to anomaly detection during car driving. The driver is influenced by many factors during driving as fatigue, telephoning, radio tuning, etc. These factors could change the quality of driving. Unexpected situations may arise during driving as stroke, heart attack, intensive (asthmatic) cough, etc. These factors and situations are the motivation to develop a model for anomaly detection for safer driving. This was achieved by using timestamps while computing SVD for the description and approximation of the skeletal joints trajectory. The anomaly was detected by Isolation Forest.

Keywords: Activity feature · human action · SVD · anomaly · Isolation Forest

1 Introduction

Human activities are one of the important as well as interesting topics in computer vision and image analysis. The motivation of the works [1, 5] is the fact that the discipline can be potentially used in many fields (medical applications, public surveillance, or even in entertainment and sport).

Many vehicles are equipped with cameras that monitor driver's fatigue. The fatigue and driver's actions while driving cause car accidents. This is what motivated the development of the systems that monitor a driver's activity aiming for personal and external security. For this purpose, RGB cameras can be used. The cameras are cheap, can be small and they are easily integrated into the interior of the car.

The skeleton poses captured from each frame of RGB images can then be used for recognition of human activities and behavioral analysis of the driver. In some cases, the use of depth sensors is not appropriate (e.g. in specific environmental conditions or surroundings) and a conventional camera is needed. This could be the case for an interior car environment, when, for example, the lights of the oncoming car disturb the function of depth sensors. The skeleton can be captured from images, for instance, using OpenPose [2].

The driver's behaviour could be a challenge to analyse. The challenges, for example, are unexpected situations, behaviours about which the data is difficult

to obtain and the driver's numerous dangerous behaviours. The best way is to focus on the normal and correct behaviour of the driver during driving and then recognize the anomalies. Thus it opens a door to a new field of anomaly detection discipline.

The rest of the paper is organised as follows. In Section 2 the details of proposed method are stated. The experimental results are reported in Section 3. The conclusion can be found in Section 4.

2 Proposed method

The proposed work is based on previous work [1] which focused on recognition of human activity based on singular value decomposition. The main idea of the proposed method for anomaly detection during car driving is based on an approximation of skeletal joints trajectories using singular value decomposition (SVD) and using Isolation Forest[4] for anomaly detection. The matrix containing left singular vectors is neglected due to its various sizes for each activity. The time information is lost if the SVD is applied to the data in a classical way and subsequently the left-singular vectors are neglected. The time information context is created by using two approaches. The first approach how to keep the time information is to calculate SVD on each part of a given activity. The second approach is to insert the time information directly into the matrix, that is used for SVD.

The classical skeleton of each frame which describe the actual pose is created by OpenPose [2] from RGB frames of video. Therefore, the pose features called 3D Joint Positions [6], which is slightly modified, was selected. In this work, the name of this modified features set is called pose features. The individual pose feature is denoted by $d_{i,t}$, where i is the index of pose feature, and t is the frame number. For each joint j in a specific frame t , the pairwise relative position features are extracted by taking the difference between the coordinates position $J_{j,t}$ of the joint j_1 and the coordinates position of j_2 :

$$d_{i,t} = p_{j_1,j_2,t} = J_{j_1,t} - J_{j_2,t} \mid j_1 < j_2. \quad (1)$$

The dimension of the pose feature $d_{i,t}$ (i.e. the directional vector) is D where D is as large as the expected joint $J_{j,t}$ coordinate dimension (2D or 3D). These features are rotation invariant and hold information about relative joint position to each other independent of the global location. This ensures that the activity recognition is invariant on the rotation of the skeleton.

The first intuitive approach how to keep the time information is to divide the data into several parts. This principle is commonly used in statistics, where SVD is calculated for a given time span (e.g. one year). In our case, the first suitable solution to get more local time intervals, is to create a hierarchical time pyramid of the time intervals. The whole time interval is used by the first level of the pyramid. In each consequent level, the main interval is divided into several overlapping smaller sub-intervals. At each additional level, the sub-interval size

Fig. 1. The division of the activity timeline a into a few parts b , c , and d .

is reduced by half, and the overlap between two sub-intervals is the half of their length. This process is shown in Figure 1.

The second approach is to create timestamps which are then used for SVD computation. These timestamps provide certain consistency of data, such as data order, even with the occasional complete loss of information about the location of the joints. Every skeleton frame in the temporal part has a timestamp acquired from this formula:

$$\tau_t = \frac{N}{t - t_b} * c, \quad (2)$$

where N is the length of the part sequence, t is the actual index of the sequence frame, t_b is the index of the beginning of the part sequence and c is a regulation coefficient of the step size of the time-line (default is 1).

The singular value decomposition (SVD) $A = USV^T$ is used for a trajectory approximation of the pose feature for every temporal part. The angles of the fitted planes and the variance are used for description and approximation of the trajectory. The features extraction for every temporal parts of each pose feature $d_{i,t}$ and temporal information τ_t is used for creating the matrix A as follows.

$$A_{i,b,e} = \begin{bmatrix} d_{i,b,1} & \cdots & d_{i,b,D} & \tau_b \\ d_{i,b+1,1} & \cdots & d_{i,b+1,D} & \tau_{b+1} \\ \vdots & \vdots & \vdots & \vdots \\ d_{i,e,1} & \cdots & d_{i,e,D} & \tau_e \end{bmatrix}, \quad (3)$$

where i is the identifier of pose feature, b and e are the indices of the beginning and the end of the temporal part.

The variance values contained on the diagonal of the matrix S obtained via SVD is subsequently converted to a unit vector s , which is one of the features for recognition. The orthonormal vectors from the right singular matrix V^T represent fitted planes to data from the matrix A . The matrix V^T can be used as the next feature for the recognition, because it is the representation of fitted planes and contains duplicate values. The use of angles has proved useful in this work. Conversion to angles is done by:

$$V_{\alpha_r} = \arctan \left(\frac{\sqrt{\sum_{k=1}^4 V_{k,r}^2 - V_{r,r}^2}}{V_{r,r}} \right), \quad (4)$$

where the index $r \in \{1...D\}$ selects the orthonormal vector that is presented in the r -th row of the matrix V^T , and $k \in \{1...D\}$ is an element index of this vector.

The next characteristic of the trajectory curve is the centroid C_i . The centroid C_i is computed for i -th pose feature of each specific time interval. The final feature vector for a specific time interval and a specific pose feature index looks as:

$$a_i = (s_1, ..., s_D, V_{\alpha_1}, ..., V_{\alpha_D}, C_{i,1}, ..., C_{i,D}) \quad (5)$$

All these subset feature vectors are concatenated into one and subsequently used for recognition. In our case, the recognition is done by Isolation Forest[4].

3 Experiments

In this section, we evaluate the proposed method using our proposed dataset where the RGB wide angle camera is used for data collection. The proposed dataset contains 7 video sequences with different lengths. These videos were collected during real car driving and have 8 FPS and 1280×720 resolution. The longest video consists of 48 186 frames and the shortest consists of 952 frames. Each video sequence is accompanied by a text file that contains information about the location of the anomalies and the type of anomaly. Video samples are shown in Figure 2. The dataset contains the following anomaly types: cough, scratching, gestures, periphery control, telephoning and texting, fatigue, drinking, sneezing, relaxing, waiting and unspecified activities.

Fig. 2. Sample frames from proposed dataset (from left): (i) without anomaly, (ii) with anomaly - drinking.

The skeletal joints locations were generated by OpenPose[2] from 4 video sequences. First three video sequences are used for training and the fourth is used for testing. If no skeleton is generated by OpenPose[2] for a specific frame, then the last known skeleton data is used. The legs are not used for experiments, because they are not visible.

The sub-sequences are generated from the dataset via a sliding window. Sizes of sliding windows are 40, 80 and 120 frames and step size is 10 frames. The training sub-sequences do not contain any anomalies, anomalous sub-sequences are

skipped. The testing sub-sequences contain the same number of sub-sequences with and without anomalies. The testing sub-sequences without anomalies are selected randomly. The testing sub-sequence contains the whole anomaly or contains only an anomaly or no anomaly. The sub-sequence acceptance process performed by sliding window is shown in Figure 3.

Fig. 3. Accepted testing sub-sequence. Green rectangles represent sliding windows and red rectangles represent anomalies.

The test of accuracies based on the size of the sliding window is presented in Table 1. The test is performed by three sliding windows of different sizes (40, 80, 120) and each test is repeated 100 times. Three level time pyramid decomposition and the constant $c = 1$ are used for generating timestamps for the experiment. The Isolation Forest [4] uses 40 estimators and 0.08 contamination ratio.

Table 1. The test of accuracies is based on the size of the sliding window. Each test is repeated 100 times.

Size of sliding window	Accuracy (%)			
	Lowest	Average	Median	Highest
120	66.13	76.35	76.61	83.87
80	62.5	76.85	77.08	84.38
40	57.93	68.95	69.21	84.15

4 Conclusion and future work

This work has been demonstrated on a RGB video dataset and presents whether the driver’s behaviour is normal or some anomaly has been detected. One previous work that focused on human activity recognition was used for this purpose. The method for the description of space-time data uses SVD decomposition of matrix A which contains joints coordinates and timestamps. For better time information preservation the sequences were divided into individual time parts by using the temporal pyramid decomposition. The features that describes the

driver's motion during driving are evaluated by Isolation Forest[4] for anomaly detection. The experiments confirmed that this principle is usable for anomaly detection. The monitoring of the driver's behaviour is an interesting area of future work. It would be interesting to try the proposed features by using Extending Isolation Forest [3] and/or eventually create features by using variance autoencoder. The proposed dataset will be extended to new subjects.

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High-Dimensional Text dimensionality Reduction by Stacked-Random Projection

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Abstract. This study focuses on high-dimensional data, which are characterized by sparsity, redundancy, and high computational complexity. In this study, we propose a stacked-random projection dimensionality reduction framework. The framework is validated using 20-newsgroups high-dimensional data set. The experimental results show that this framework can improve the performance of dimensionality reduction algorithm significantly.

1 Introduction

In this era of Big Data, there have been considerable advances in data storage and retrieval techniques across many different fields, namely data mining and machine learning. Most of these data are high-dimensional, some with even more than 10,000 dimensions, a feature which poses great challenges in terms of data retrieval, classification and understanding. These challenges increase the complexity and cost of information collection, storage and processing, and impede decision-making [1, 2, 3]. High-dimensional data tends to be affected by the "Curse of Dimensionality", a concept which was first proposed by Richard Bellman [4] in his discussion of the optimization problem. The so-called curse occurs when the volume of the higher-dimensional space increases exponentially as the number of dimensions increases. Therefore, it is necessary to reduce the number of dimensions of the high-dimensional data in order to extract the low-dimensional features of the data, and also to eliminate the redundancy and noise of the high-dimensional data.

When random projection is used to transform the original high-dimensional data into low-dimensional data, this not only reduces the computational complexity of the learning algorithm, but also maintains the approximate high-probability distance between the original data. Xie, et al. [5] and Mahmoud Nabil [6] have provided reviews of existing research findings on the random projection method. Papadimitriou et al. [7] combined random projection with Latent Semantic Indexing (LSI) for literature classification. LSI is an effective method to solve literature classification problems, but the calculation overhead of high-dimensional data makes this method invalid for large data sets. Using random projection can reduce the dimension of high dimensional data to an extent that LSI can process, which significantly reduces the

computing overheads. Li et al. [8] combined random projection with Expectation-Maximization to analyze geometric objects for object recognition. Kaski [9] applied random projection and Self Organizing Map for the organization of a document system. The results showed that the performance of random projection was almost the same as that of PCA and similar to that of the original index. Bingham and Mannila et al. [10] compared the performance of several dimensionality reduction methods in image and text processing tasks. The results showed that the random projection does not only guaranteed the same original distance, but also achieves the same accuracy as that of PCA in a shorter time. Zhao et al. [11] proposed the Stacked Semi-Random Projection (SSRP) method, whereby the generated subspace has a 30% improvement in classification accuracy compared with the produced using Random Projection.

In the study herein, we propose a deep random projection framework, named stacked-random projection (SRP), which incorporates random projection as its core stacking element. We use SRP to reduce the dimension of the high-dimensional text feature vectors, and compare with random projection. The experimental results show that the SRP dimensionality reduction framework is an effective dimensionality reduction method which can significantly improve the dimensionality reduction performance.

2 Stacked-Random Projection

The basic idea of random projection is to choose a random hyper plane to map original variables into a low-dimensional space. In 1948, Johnson and Lindenstrauss proposed a theorem, nowadays termed the Johnson-Lindenstrauss lemma (JL) [12]. JL lemma is the theoretical basis of random projection, which guarantees that the subspace errors generated by random projection are controllable. The JL lemma states that for any $0 < \varepsilon < 1$, and any integer n , let k be a positive integer such that

$$k \geq \left(\frac{\varepsilon^2}{2} - \frac{\varepsilon^3}{3} \right)^{-1} \ln n \quad (1)$$

Then for any n -point set V in $\mathbf{R}^d$, there is a map $f: \mathbf{R}^d \rightarrow \mathbf{R}^k$, such that for all $u, v \in V$,

$$(1 - \varepsilon) \|u - v\|^2 \leq \|f(u) - f(v)\|^2 \leq (1 + \varepsilon) \|u - v\|^2 \quad (2)$$

It indicates that by using random projection, the original high-dimensional data is reduced to low-dimensional data, and the distance between the original data is maintained approximately with a high probability. According to the Johnson-Lindenstrauss lemma, it would require at least 6515 dimensions to project 2,000 samples without too much distortion ($\varepsilon=0.1$), regardless of the feature vector dimensions of the original data set. Thousands of dimensions are still high-dimensional data for the following step such as classification or clustering.

A Stacked Auto-Encoder (SAE) is composed of a set of auto-encoder connections which is a deep architecture that has been successfully used to learn hidden features of input data. SAE uses a greedy layer-wise pre-trained learning network. Inspired by SAE, we propose a deep random projection framework, named stacked-random

projection (SRP), which incorporates random projection as its core stacking element. An SRP with k layers uses the input data as the first layer, and the output of the l^{th} ($l < k$) layer is taken as the $(l+1)$ layer input. In this way, a group of random projections can be combined layer by layer in a stack.

The main idea of the SRP dimensionality reduction method based on the high-dimensional text feature vector can be illustrated by means of taking the 20-newsgroups data set as an example (further details are provided in Section 3 below). First, the data set is subjected to tokenization, stop-words removal and TF-IDF in order to obtain the feature vector of the text, the feature dimension of the 20-newsgroups dataset was found to be 130,107. Then, a 4-layer SRP is constructed, this process is shown in the Figure 1. Thus, the dimensionality reduction process from high dimensionality to low dimensionality is completed. A graphic illustration of our proposed SRP is provided in the Figure 2.

Fig.1. The SRP dimensionality reduction process for the 20-newsgroups data set. The 4-layer SRP realizes the dimensionality reduction, using the random projection method from 130,107 down to 10,000, down to 5,000, down to 1,000 and down to 100.

Fig.2. Architecture of Stacked-Random Projection.

3 Experimental Results and Analysis

Two datasets were used in the experiment. One is the BBC news dataset [13]: a total of 2,225 text files on five topical areas published on the BBC news website. Text documents were arranged into folders containing five labels: business, entertainment, politics, sports, and technology. The other dataset consists of data sourced from 20-newsgroups [14], it is a collection of approximately 20,000 newsgroup documents, partitioned evenly across the 20 different newsgroups. Following tokenization, stop-

words removal and TF-IDF, the feature dimension of the BBC news dataset is 11,227 and that of the 20-newsgroups dataset is 130,107.

We compared the dimensionality reduction performance of Principal Component Analysis (PCA), Multiple Dimensional Scaling (MDS), random projection (RP), and stacked-random projection (SRP). To correctly compare the performance of these dimensionality reduction methods, we experimentally reduced the feature vector of BBC news dataset and 20-newsgroups dataset to 2000, 500, and 100. Table 1 shows the run time (Time), mean ratio of distances (projected/original) (Ratio), and the standard deviation of ratio of distances (projected/original) (Standard deviation). As shown in Table 1, RP and SRP greatly shorten the run time of dimension reduction compared with PCA and MDS. We can see that for low values of dimension, the distribution the distortion is controlled and the distances are well preserved by the SRP.

Table 1. The run time, ratio, and standard deviation of each dimension reduction method reduce dimension to 2000, 500 and 100.

		Dimension=2000			Dimension=500			Dimension=100		
		Time (s)	Ratio	Standard deviation	Time (s)	Ratio	Standard deviation	Time (s)	Ratio	Standard deviation
BBC	PCA	30.52	1.00	0.02	15.16	0.57	0.09	4.99	0.23	0.09
	MDS	57.99	1.00	0.02	28.67	1.00	0.07	15.47	1.00	0.07
	RP	1.12	1.00	0.04	0.56	1.00	0.08	0.41	1.01	0.18
	SRP	2.87	1.00	0.05	2.38	1.00	0.07	2.27	1.00	0.12
20- News groups	PCA	24.87	1.00	0.00	13.35	1.00	0.08	4.20	1.00	0.10
	MDS	65.27	1.00	0.02	44.74	1.00	0.03	23.13	0.99	0.06
	RP	0.10	0.99	0.06	0.46	1.00	0.12	0.31	0.99	0.28
	SRP	3.33	1.00	0.05	2.85	1.00	0.07	2.72	1.00	0.15

4 Conclusions

This study proposes a stacked-random projection dimension reduction framework based on deep networks. In our experiment, we compared SRP with PCA, MDS and random projection, multiple evaluation metrics showed that SRP maintained an effective balance between running time and distance before and after dimension reduction. The results show that the stacked-random projection dimensionality reduction framework is an effective dimensionality reduction method which can significantly improve the dimensionality reduction performance.

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Finding the first eigenpair of p -Laplacian using inverse iteration method

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Abstract. In this paper, we present an approach and an efficient numerical method for finding the first eigenpair (λ_1, φ_1) of the p -Laplace operator. The core of the method is solving the corresponding Poisson equation. We formulate an analytical background for such problem and introduce the gradient method for finding the solution. Then we deal with the eigenvalue problem with p -Laplacian. We introduce the inverse iteration algorithm as an efficient method for computing the first eigenvalue. Consequently, we use the introduced method for finding the first eigenvalue of p -Laplacian for a given domain and various values of p .

Keywords: p -Laplacian operator, quasilinear elliptic PDE, eigenvalues, inverse iteration method, gradient method

1 Motivation

Part of our recent research is focused on the following Dirichlet boundary value problem

$$\begin{cases} -\Delta_p u = \lambda_1 |u|^{p-2} u + g(u) - h(x) & \text{in } \Omega, \\ u = 0 & \text{on } \partial\Omega, \end{cases} \quad (1)$$

where $p \in (\frac{4}{3}, 4)$,

$$\Delta_p u := \operatorname{div}(|\nabla u|^{p-2} \nabla u), \quad (2)$$

$\Omega \subset \mathbb{R}^N$ is a bounded domain with a Lipschitz boundary, $N \geq 1$, $p > 1$, $g : \mathbb{R} \rightarrow \mathbb{R}$ is continuous, $h \in L^{p'}(\Omega)$, $p' = \frac{p}{p-1}$ and λ_1 is the first eigenvalue of the operator $-\Delta_p$. Note that if we take $p = 2$, then (2) turns into a classical Laplace operator Δ .

We know that (see for example [1]) that

$$\lambda_1 = \min \left\{ \int_{\Omega} |\nabla u|^p \, dx : u \in W_0^{1,p}(\Omega), \int_{\Omega} |u|^p \, dx = 1 \right\},$$

λ_1 is simple and isolated and there exists a unique positive eigenfunction $\varphi_1 \in W_0^{1,p}(\Omega)$.

It can be shown that weak solutions of (1) correspond to the critical points of the functional

$$J(u) = \frac{1}{p} \int_{\Omega} |\nabla u|^p \, dx - \frac{\lambda_1}{p} \int_{\Omega} |u|^p \, dx - \int_{\Omega} G(u) \, dx + \int_{\Omega} hu \, dx,$$

where

$$G(t) = \int_0^t g(r) \, dr.$$

In [1] and [2], it is shown that, under certain assumptions, the problem (1) has a nontrivial weak solution.

The main goal of this paper is to present a technique and an efficient numerical method for finding the value λ_1 for the given domain. The core of the method is solving the corresponding Poisson equation. Section 2 gives an analytical background and introduces the gradient method for finding the solution. In Section 3, we deal with the eigenvalue problem with p -Laplacian. We present the inverse iteration algorithm as an efficient method for computing the first eigenvalue. In Section 4, we use the introduced method for finding the first eigenvalue of p -Laplacian.

2 Poisson equation with p -Laplacian

Let us first deal with the following type of boundary value problem

$$\begin{cases} -\Delta_p u = f(x) & \text{in } \Omega, \\ u = 0 & \text{on } \partial\Omega, \end{cases} \quad (3)$$

where $1 < p < \infty$, $N \geq 1$, $\Omega \subset \mathbb{R}^2$ is a bounded domain with a Lipschitz boundary and f depends only on x .

We are interested in finding weak solution of the problem (3), in other words finding a function $u \in W_0^{1,p}(\Omega)$ so that for all $v \in W_0^{1,p}(\Omega)$

$$\int_{\Omega} |\nabla u|^{p-2} \nabla u \nabla v \, dx - \int_{\Omega} f v \, dx = 0.$$

Define the following functional

$$J(u) := \frac{1}{p} \int_{\Omega} |\nabla u|^p \, dx - \int_{\Omega} f u \, dx. \quad (4)$$

It can be shown that

$$J \in C^1(W_0^{1,p}(\Omega), \mathbb{R})$$

and

$$\langle J'(u), v \rangle = \int_{\Omega} |\nabla u|^{p-2} \nabla u \nabla v \, dx - \int_{\Omega} f v \, dx.$$

It is clear that weak solutions of the problem (3) correspond to critical points of J . For

$$\|u\|_p := \|u\|_{1,p,0} = \left(\int_{\Omega} |\nabla u|^p dx \right)^{\frac{1}{p}}$$

is a norm on $W_0^{1,p}(\Omega)$, we can write

$$J(u) = \frac{1}{p} \|u\|_p^p - \int_{\Omega} f u dx.$$

Note that the norm is lower semicontinuous. Moreover, the second term is a linear functional. We can show that J is also lower semicontinuous and coercive. We can now formulate the following theorem.

Theorem 1. *There exists $u \in W_0^{1,p}(\Omega)$ satisfying*

$$J(u) = \min_{v \in W_0^{1,p}(\Omega)} J(v).$$

The proof is based on coercivity and lower semicontinuity of J . It can be also shown that the solution is unique. The proofs and more detailed steps can be found in my dissertation thesis that is currently in progress.

2.1 Gradient method

For a numerical computation, we use the steepest descent algorithm for the p -Laplacian. The algorithm and its variants and convergence results are introduced in [3]. The problem of finding the descent direction was also described in [8]. The most challenging part of the algorithm is finding the descent direction. The process of finding such direction will be described in detail in my dissertation thesis. To improve the performance of the algorithm, we applied a preconditioner suggested in [3].

3 Computing the first eigenpair of p -Laplacian

For future research, we need to compute eigenvalues of the p -Laplace operator, i.e. the real numbers λ for which the problem

$$\begin{cases} -\Delta_p u = \lambda |u|^{p-2} u & \text{in } \Omega, \\ u = 0 & \text{on } \partial\Omega \end{cases} \quad (5)$$

has at least one nontrivial solution. If we consider the problem (5) in one dimension, all eigenvalues can be computed using an analytical formula (see [4]). The one-dimensional problem appears to be a good starting point for the further research.

For the higher dimensions, the situation is more complicated. To compute eigenfunctions and eigenvalues of $-\Delta_p u$, we need to solve the problem (5) and we only reduce on the first eigenpair.

3.1 Inverse iteration algorithm

To compute the first eigenpair (λ_1, φ_1) , we use the inverse iteration method with normalization introduced in [5]. In the beginning, we chose q close to p so that $q < p$ and solve

$$\begin{cases} -\Delta_p v_0 = 1 & \text{in } \Omega, \\ v_0 = 0 & \text{on } \partial\Omega, \end{cases} \quad (6)$$

In every step, we use the previous solution to construct the right-hand side of the current problem.

$$\begin{cases} -\Delta_p v_{m+1} = \left(\frac{v_m}{\|v_m\|_\infty} \right) & \text{in } \Omega, \\ \varphi_{m+1} = 0 & \text{on } \partial\Omega. \end{cases} \quad (7)$$

Note that the right-hand side does not depend on v_{m+1} . For this reason, we can solve the problem (7) using techniques introduced in Section 2.

After a prescribed number of iterations, we get the first eigenpair in the following way

$$\lambda_p = \frac{1}{\|v_{m+1}\|_\infty^{p-1}}, \quad \varphi_{m+1} = \frac{v_{m+1}}{\|v_{m+1}\|_\infty}.$$

For more detailed information about the algorithm and its convergence, see [5].

4 Results

In this section, we compute the first eigenvalues of the p -Laplace operator for various values of p using the algorithms introduced above. We choose $\Omega = [0, \pi] \times [0, \pi]$ and to approximate the functions from $W_0^{1,p}(\Omega)$, we use the finite-element discretization with equidistant nodes and a discretization step h , right-angled triangles and piecewise linear basis functions. In the inverse iteration algorithm, the number of iterations was set to $nI = 10$. As the experiments have shown, this number is enough for the method to guarantee the desired precision. The value q was chosen as $p - 10^{-9}$ and the precision of the gradient method was taken as $\varepsilon = 10^{-3}$. In Table 1, we can see the results for various values of p .

In the figures 1, we can see the first eigenfunctions for various values of p .

5 Conclusion

In the paper, we introduced an efficient numerical method for finding the first eigenvalue of the p -Laplacian on the given domain. The core of the method is solving the corresponding Poisson equation. In Section 2, we present the problem including the analytical background and introduce the numerical method for finding the solution. Section 3 is dedicated to the eigenvalue problem with p -Laplacian. We present the inverse iteration algorithm as an efficient method for computing the first eigenvalue. In Section 4, we use the introduced method for

p	λ_1	p	λ_1
$\frac{3}{2}$	1.807656	$\frac{7}{3}$	2.039247
$\frac{5}{3}$	1.892489	$\frac{5}{2}$	2.067240
$\frac{11}{6}$	1.959229	$\frac{8}{3}$	2.052869
2	1.993696	$\frac{17}{6}$	2.047935
$\frac{13}{6}$	2.034230	3	2.030305

Table 1: Results for $\Omega = [0, \pi] \times [0, \pi]$, $h = \frac{\pi}{64}$

Fig. 1: First eigenfunction of the two-dimensional problem

finding the first eigenvalue of p -Laplacian for a given two-dimensional domain and various values of p . Eigenvalues play a crucial role in solving several problems

with saddle point geometry. In the future, we will build on this research and proceed to saddle point problems of the type (1).

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Mixed formulation of the log-transformed permeability in the stochastic Galerkin formulation of the Darcy flow problem

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Abstract. This contribution outlines how to reformulate the Darcy flow problem with the log-transformed permeability field so that new formulation does not contain logarithmic transform. This is very important in the stochastic Galerkin method, where we need separable formulation. Separable formulation generally allows us to build the system of equations in the sparse and condense form. Another part of this contribution is an outline of the use of a reduced basis method for such a problem.

Keywords: stochastic Galerkin method · mixed formulation · log-transformed permeability.

1 Introduction

This contribution extends the results of the use of a reduced basis (RB) method for the stochastic Galerkin method (SGM) used on elliptic problems presented in [1]. It uses the idea of the reformulation of the problem presented in [2] and combines it with the reduced basis approach to the mixed problems presented in [3].

2 Deterministic problem setting

We assume the Darcy flow problem on the domain with Lipschitz boundary $\Omega \subset \mathbb{R}^n$

$$\begin{cases} -\operatorname{div}(-k(x)\nabla u(x)) = f(x), & x \in \Omega \\ u(x) = u_0(x), & x \in \Gamma_D, \\ -k(x)\frac{\partial u}{\partial n}(x) = g(x), & x \in \Gamma_N \end{cases} \quad (1)$$

with the differentiable permeability field in the form $k(x) = e^{a(x)}$, i.e. $a(x)$ should be at least $C_1(\Omega)$.

Our aim is to transform the problem to get rid of the exponential transformation of the data $a(x)$. This is motivated by the stochastic Galerkin method, where the random field material function $a(x, \mathbf{Z})$ is usually assumed separable $a(x, \mathbf{Z}) = \sum_{i=1}^M a_i(x) \varphi_i(\mathbf{Z})$, and we need to preserve this property for the whole problem (which exponential transform violates).

First, we divide the original problem (1) into two sub-problems using the superposition principle. Solution of (1) $u(x) = u_1(x) + u_2(x)$, where u_1 is the solution of the problem with $f = 0$ and $g = 0$ and u_2 is the solution of the problem with $u_0 = 0$.

Next, we use the derivation product rule and the substitution $u_2(x) = e^{-a(x)} \tilde{u}_2(x)$ to obtain the following formulations

$$\begin{cases} -\nabla a \cdot \nabla u_1 - \Delta u_1 = 0, & x \in \Omega \\ u_1 = u_0, & x \in \Gamma_D \\ -\frac{\partial u_1}{\partial n} = 0, & x \in \Gamma_N \end{cases}, \begin{cases} \operatorname{div}(\nabla a \tilde{u}_2 - \nabla \tilde{u}_2) = f, & x \in \Omega \\ \tilde{u}_2 = 0, & x \in \Gamma_D \\ \frac{\partial a}{\partial n} \tilde{u}_2 - \frac{\partial \tilde{u}_2}{\partial n} = g, & x \in \Gamma_N \end{cases}. \quad (2)$$

Now, the solution to the original problem is $u(x) = u_1(x) + e^{-a(x)} \tilde{u}_2(x)$.

Using the relations $q_1(x) = -\nabla u_1(x)$ and $q_2(x) = \nabla a(x) \tilde{u}_2(x) - \nabla \tilde{u}_2(x)$ for problems in (2), we get the following mixed formulations

$$\begin{cases} q_1 + \nabla u_1 = 0, & x \in \Omega \\ \nabla a \cdot q_1 + \operatorname{div}(q_1) = 0, & x \in \Omega \\ u_1 = u_0, & x \in \Gamma_D \\ q_1 \cdot n = 0, & x \in \Gamma_N \end{cases}, \begin{cases} q_2 - \nabla a \tilde{u}_2 + \nabla \tilde{u}_2 = 0 & x \in \Omega \\ \operatorname{div}(q_2) = f, & x \in \Omega \\ \tilde{u}_2 = 0, & x \in \Gamma_D \\ q_2 \cdot n = g, & x \in \Gamma_N \end{cases}. \quad (3)$$

Using the spaces $U := H_{\operatorname{div}}(\Omega)$, $P := L_2(\Omega)$, $U_0 := \{v \in U : v \cdot n = 0 \text{ on } \Gamma_N\}$ and $U_N := \{v \in U : v \cdot n = g \text{ on } \Gamma_N\}$ and bilinear and linear forms

$$\begin{aligned} m : U \times U &\rightarrow \mathbb{R} : m(q, v) = \int_{\Omega} qv, \\ b : U \times P &\rightarrow \mathbb{R} : b(q, p) = - \int_{\Omega} p \operatorname{div}(q), \\ c : U \times P &\rightarrow \mathbb{R} : c(q, p) = - \int_{\Omega} p (\nabla a \cdot q), \\ F : P &\rightarrow \mathbb{R} : F(p) = - \int_{\Omega} pf, \\ G : U &\rightarrow \mathbb{R} : G(q) = - \int_{\Gamma_D} u_0(q \cdot n), \end{aligned}$$

we can formulate the weak forms of the transformed problems (3)

$$\begin{cases} \text{Find } u_1 \in P, q_1 \in U_0 : \\ m(q_1, v) + b(v, u_1) = G(v), \quad \forall v \in U_0 \text{ and} \\ b(q_1, p) + c(q_1, p) = 0, \quad \forall p \in P \end{cases} \quad (4)$$

$$\begin{cases} \text{Find } \tilde{u}_2 \in P, q_2 \in U_N : \\ m(q_2, v) + b(v, \tilde{u}_2) + c(v, \tilde{u}_2) = 0, & \forall v \in U_0. \\ b(q_2, p) = F(p), & \forall p \in P \end{cases} \quad (5)$$

2.1 Discretization

We assume a discretization $U_h \subset U$ and $P_h \subset P$ which satisfy inf-sup conditions. Moreover, we assume corresponding spaces U_{0h} and U_{Nh} .

Using the basis functions $v_i \in U_{0h}$ and $p_i \in P_h$ in bilinear and linear operators and using an element of $g_h \in U_{Nh}$, we obtain the following matrices and vectors $[M]_{i,j} = m(v_j, v_i)$, $[B]_{i,j} = b(v_j, p_i)$, $[C]_{i,j} = c(v_j, p_i)$, $[\overline{M}_N]_i = m(g_h, v_i)$, $[\overline{B}_N]_i = b(g_h, p_i)$, $[\overline{F}]_i = F(p_i)$ and $[\overline{G}]_i = G(q_i)$.

Now, assuming discretized approximations of the solutions $\bar{u}_1, \bar{q}_1, \bar{u}_2, \bar{q}_2$ of $u_1, q_1, \tilde{u}_2, q_2$, the matrix form of the problems (4) and (5) are

$$\begin{bmatrix} M & B^T \\ B + C & \end{bmatrix} \times \begin{bmatrix} \bar{q}_1 \\ \bar{u}_1 \end{bmatrix} = \begin{bmatrix} \overline{G} \end{bmatrix} \quad \text{and} \quad \begin{bmatrix} M & B^T + C^T \\ B & \end{bmatrix} \times \begin{bmatrix} \bar{q}_2 \\ \bar{u}_2 \end{bmatrix} = \begin{bmatrix} -\overline{M}_N \\ \overline{F} - \overline{B}_N \end{bmatrix}.$$

The final discretized approximation of the solution is then $u_h(x) = u_{1h}(x) + e^{-a(x)} \tilde{u}_{2h}(x)$ and $q_h(x) = e^{a(x)} q_{1h}(x) + q_{2h}(x)$.

3 Stochastic problem

The problems (4) and (5) have almost identical procedure of solution. Therefore, we now focus only on one of the sub-problems. Let the material field a be in the separable form $a(x, \mathbf{Z}) = \sum_{i=1}^M a_i(x) g_i(\mathbf{Z})$, where $\mathbf{Z} \in \mathbb{R}^n$ is a vector of random variables. Then the first problem in (2) takes the form

$$\begin{cases} q(x, \mathbf{Z}) + \nabla_x u(x, \mathbf{Z}) = 0, & x \in \Omega, \mathbf{Z} \in \mathbb{R}^n, \\ \nabla_x a(x, \mathbf{Z}) \cdot q(x, \mathbf{Z}) + \text{div}_x(q(x, \mathbf{Z})) = 0, & x \in \Omega, \mathbf{Z} \in \mathbb{R}^n, \\ u(x, \mathbf{Z}) = u_0(x), & x \in \Gamma_D, \mathbf{Z} \in \mathbb{R}^n, \\ q(x, \mathbf{Z}) \cdot n = 0, & x \in \Gamma_N, \mathbf{Z} \in \mathbb{R}^n. \end{cases} \quad (6)$$

We will look for the solution in the following spaces

$$\tilde{U} := U \otimes L_{\text{dFZ}}(\mathbb{R}^n) = H_{\text{div}}(\Omega) \otimes L_{\text{dFZ}}(\mathbb{R}^n),$$

$$\tilde{P} := P \otimes L_{\text{dFZ}}(\mathbb{R}^n) = L_2(\Omega) \otimes L_{\text{dFZ}}(\mathbb{R}^n).$$

Due to separable nature of the spaces we will assume basis functions in the form

$$\tilde{U} \ni v_{i,j}(x, \mathbf{Z}) = v_i(x) \psi_j(\mathbf{Z}), v_i(x) \in U, \psi_j(\mathbf{Z}) \in L_{\text{dFZ}}(\mathbb{R}^n),$$

$$\tilde{P} \ni p_{i,j}(x, \mathbf{Z}) = p_i(x) \psi_j(\mathbf{Z}), p_i(x) \in P, \psi_j(\mathbf{Z}) \in L_{\text{dFZ}}(\mathbb{R}^n).$$

The bilinear and linear forms arising in the weak form of the problem (6) then take the form

$$\begin{aligned}\tilde{m} : \tilde{U} \times \tilde{U} &\rightarrow \mathbb{R} : \tilde{m}(q\psi, v\varphi) = \int_{\mathbb{R}^n} \psi \varphi \, dF\mathbf{Z} \int_{\Omega} q \cdot v \, dx, \\ \tilde{b} : \tilde{U} \times \tilde{P} &\rightarrow \mathbb{R} : \tilde{b}(q\psi, p\varphi) = - \int_{\mathbb{R}^n} \psi \varphi \, dF\mathbf{Z} \int_{\Omega} p \operatorname{div}_x(q) \, dx, \\ \tilde{c} : \tilde{U} \times \tilde{P} &\rightarrow \mathbb{R} : \tilde{c}(q\psi, p\varphi) = - \sum_{i=1}^M \int_{\mathbb{R}^n} g_i \psi \varphi \, dF\mathbf{Z} \int_{\Omega} p (\nabla_x a_i \cdot q) \, dx, \\ \tilde{G} : \tilde{U} &\rightarrow \mathbb{R} : \tilde{G}(q\psi) = - \int_{\mathbb{R}^n} \psi \, dF\mathbf{Z} \int_{\Gamma_D} u_0(q \cdot n) \, dx.\end{aligned}$$

3.1 Discretization

We assume the same discretization of $\{v_i\} \subset U$ and $\{p_i\} \subset P$ as before (satisfying inf-sup condition of the deterministic case, or moreover satisfying inf-sup condition for any value of $\mathbf{Z}$). And additionally, we assume the discretization of $\{\psi_i\} \subset L_{dF\mathbf{Z}}(\mathbb{R}^n)$ in the form of orthonormal polynomials (so called polynomial chaos with respect to the distribution of $\mathbf{Z}$).

The resulting spaces $\tilde{U}_h = \{v_i\} \times \{\psi_i\}$, $\tilde{P}_h = \{p_i\} \times \{\psi_i\}$ are the tensor products of discretizations on physical domain (U, P) and discretization on stochastic domain $L_{dF\mathbf{Z}}(\mathbb{R}^n)$.

Due to the separable nature of linear and bilinear forms and the basis functions combined with the orthonormality of the base $\{\psi_i\}$, the out-coming matrices have the following structure

$$\tilde{M} = M \otimes I, \quad \tilde{B} = B \otimes I, \quad \tilde{C} = \sum_{m=1}^M C_m \otimes G_m, \quad \tilde{\overline{G}} = \overline{G} \otimes e_1,$$

where

$$[C_m]_{i,j} := - \int_{\Omega} p_i (\nabla_x a_m \cdot v_j) \, dx, \quad [G_m]_{i,j} := \int_{\mathbb{R}^n} g_m \psi_i \psi_j \, dF\mathbf{Z}.$$

4 Reduced basis method

Even with the matrices condensed into a separable form (sum of Kronecker products) the solution of the SGM system is very expensive. Therefore, we seek for some reduced basis $(\tilde{U}_R, \tilde{P}_R) \subset (\tilde{U}_h, \tilde{P}_h)$ which will be much smaller but still descriptive enough.

The tensor structure of the spaces $\tilde{U}_h = U_h \times \{\psi_i\}$, $\tilde{P}_h = P_h \times \{\psi_i\}$ gives us the opportunity to choose only one of the dimension (physical/stochastic)

of the problem which will be reduced. In all standard cases, the dimension of the physical discretization will be much larger than the stochastic one (finite elements/polynomials) and therefore we choose to find the reduced basis $(U_R, P_R) \subset (U_h, P_h)$. The whole reduced basis will then be in the form $\tilde{U}_R = U_R \times \{\psi_i\}$, $\tilde{P}_R = P_R \times \{\psi_i\}$.

The simple procedure of obtaining basis vectors for (U_R, P_R) is to sample the random vector $\mathbf{Z}$ and calculate corresponding deterministic problems. If we assume n samples of $\mathbf{Z} : \{Z_1, \dots, Z_n\}$, we obtain two sets of vectors $U_R = \{q_1, \dots, q_n\}$ and $P_R = \{u_1, \dots, u_n\}$ corresponding to the deterministic solutions with material fields $a(x, Z_i)$.

4.1 Augmentation of the basis U via supremizer functions

The bases $U_R = \{q_1, \dots, q_n\}$ and $P_R = \{u_1, \dots, u_n\}$ cannot be used directly for the reduced solution because they do not provide discrete inf-sup condition. To overcome this problem we need to enhance the basis U_R .

Because our problem is generalized saddle point problem (non-symmetric), we need these inf-sup conditions to be fulfilled

$$(\exists \beta_1 > 0) (\forall p \in P_r) : \sup_{v \in U_R} \frac{b(v, p)}{\|v\|_{H_{\text{div}}}} \geq \beta_1 \|p\|_{L^2}$$

and

$$(\exists \beta_2 > 0) (\forall p \in P_r) : \sup_{v \in U_R} \frac{c_j(v, p)}{\|v\|_{H_{\text{div}}}} \geq \beta_2 \|p\|_{L^2}.$$

We assume that the original full discretization (U_h, P_h) fulfilled these conditions. Therefore, we can assure the inf-sup condition of the reduced basis via augmenting the basis U_R with supremizer functions. The supremizer functions are defined as

$$v_i^1 = \arg \sup_{v \in U_h} \frac{b(v, p_i)}{\|v\|_{H_{\text{div}}}}, \forall p_i \in P_R$$

and

$$v_{i,j}^2 = \arg \sup_{v \in U_h} \frac{c_j(v, p_i)}{\|v\|_{H_{\text{div}}}}, \forall p_i \in P_R.$$

The solutions of these maximization problems can be obtain by solving the following linear equations

$$(M + D) \bar{v}_i^1 = B^T p_i$$

and

$$(M + D) \bar{v}_{i,j}^2 = (B^T + C_j^T) p_i,$$

where D is discretization of

$$d(q, v) = \int_{\Omega} \text{div}(q) \text{div}(v)$$

and therefore $(M + D)$ is a discrete representation of H_{div} norm.

Lastly, when we have a suitable reduced basis $(\tilde{U}_R, \tilde{P}_R)$, we need to estimate its quality. The simple indicator of its quality will be the residual of the reduced solution. In this case, the error - the residual of the RB will be comparable to the solution of the full problem using some iterative method.

This can be used to formularize adaptive schemes of the reduced basis construction. This topic is thoroughly discussed in [1].

5 Conclusions

We outlined the procedure for an efficient solution of the stochastic Darcy flow problem with log-transformed material in the mixed formulation. This generally incorporates the solution of two very similar problems to incorporate both Dirichlet boundary and source terms (Neumann boundary and forcing term).

The solution to each of these problems is computationally feasible due to the use of the reduced basis method. The basic scheme outlined here can be efficiently combined with the adaptive schemes introduced in [1] (most importantly using the deflation inside iterative solvers).

The concrete iterations of the reduced basis are strongly dependent on the problem tested. The extensive tests of this problem for the elliptic problems can be found in [1].

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Bayesian identification of material parameters in infinite dimension

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Abstract. The main topic of this paper is the Bayesian approach to inverse problems with infinite-dimensional parameters and finite dimensional observations. As a typical representative of this class of problems, an inverse problem governed by a boundary value problem with the material in the form of a Gaussian random field is considered. The aim of the Bayesian inversion is to find the posterior probability distribution of the unknown parameter which, in this case, is infinite-dimensional. Practical computational methods only allow the solution of a finite-dimensional approximation of this problem. However, the Bayesian inverse approach can also be formulated in the infinite-dimensional setting. Formulating the problem as infinite-dimensional helps studying the desirable convergence of the approximated finite-dimensional problem solution to the theoretical solution of the original problem when refining the approximation.

Keywords: Bayesian inversion · Gaussian random field · material identification · posterior sampling.

1 Introduction

This paper focuses on the solution of stochastic material identification problems governed by a boundary value problem on a physical domain D . The unknown material is a real function $u \in L^2(D)$; therefore, the problem is naturally infinite-dimensional. The aim is to describe the probability distribution of u based on observed data, called posterior distribution. In computational practice, u is approximated using a finite-dimensional basis and the inverse problem is solved using the standard Bayesian approach. However, for theoretical purposes, it is also possible to adapt the Bayesian approach to infinite-dimensional setting and define the posterior probability measure of the original $L^2(D)$ -valued random variable u .

2 Problem setting

Consider a stochastic inverse problem of finding a probabilistic description of input parameters to a mathematical model based on the following knowledge:

1. noisy observed data, i.e. outputs of the mathematical model corrupted by observational noise,
2. probability distribution of the observational noise,
3. preliminary information independent of the observed data in the form of the prior distribution of the unknown parameters.

We consider observed data $y \in \mathbb{R}^m$ in the form

$$y = G(u) + \eta, \quad (1)$$

where $G : X \rightarrow \mathbb{R}^m$ is the governing mathematical model called observation operator, $u \in X$ is the unknown input to this observation operator, and $\eta \in \mathbb{R}^m$ is the observational noise with known probability distribution. The aim is to find the posterior probability density function of the random variable u using the Bayesian approach.

In practical applications, $X = \mathbb{R}^n$ is typically considered; the Bayesian inversion in finite-dimensional setting forms a well-established framework. However, in many cases, the input $u \in X$ is naturally infinite-dimensional and it is beneficial to study the problem first in the infinite-dimensional setting before considering a discretized version of the problem. The aim is then to find the conditional distribution μ^y of $u|y$. A typical case in which X is an infinite dimensional space arises for example when considering a boundary value problem with the material in the form of a Gaussian random field, as considered in author's publication [5].

3 Gaussian random field material

Let $(\Omega, \mathcal{F}, \mathbb{P})$ be a probability space. Consider a set $D \subset \mathbb{R}^d$, $d \in \{2, 3\}$. Further consider a Gaussian random field (GRF) $\{u(x) : x \in D\}$ with a constant mean function

$$\mathbb{E}[u(x)] = \mu(x) = m_0$$

(independent of x) and the covariance function

$$\text{Cov}(u(x), u(y)) = c(x, y) = \sigma^2 \exp\left(-\frac{\|x - y\|_2}{l}\right)$$

for each $x, y \in D$. Here σ^2 is the variance of the GRF and l is its correlation length. Since $\mu(x)$ is a constant function and the covariance depends only on the distance of x and y , the resulting GRF is stationary and isotropic. The dependence of u on $\omega \in \Omega$ is often suppressed; however, in fact, $u : D \times \Omega \rightarrow \mathbb{R}$.

For $X = L^2(D)$, the GRF can be viewed as a Gaussian measure $\mathcal{N}(m_0, \mathcal{C})$ on $(X, \mathcal{B}(X))$ with the covariance operator

$$(\mathcal{C}\phi)(x) = \int_D c(x, y) \phi(y) \, dy, \quad x \in D,$$

i.e $u \in L^2(\Omega, L^2(D))$, see [1]. Therefore, u can be written in the form of the Karhunen-Loève expansion

$$u(x, \omega) = \mu(x) + \sum_{j=1}^{\infty} \sqrt{\lambda_j} \phi_j(x) \xi_j(\omega), \quad (2)$$

where (λ_j, ϕ_j) are the eigenvalues and eigenfunctions of the operator $\mathcal{C}$, $\lambda_1 \geq \lambda_2 \geq \dots \geq 0$, and ξ_j are independent Gaussian random variables such that $\xi_j \sim N(0, 1)$, see [2].

4 Bayesian inversion in infinite dimension

Before deriving the Bayes' theorem for separable Banach spaces according to [3], recall first the Radon-Nicodym theorem.

Theorem 1. *Consider two measures μ and ν on a measurable space $(X, \mathcal{F})$. If μ is absolutely continuous with respect to ν and ν is σ -finite then there exists ν -measurable function $\frac{d\mu}{d\nu} : X \rightarrow [0, \infty]$ such that, for all ν -measurable sets $A \in \mathcal{F}$, $\mu(A) = \int_A \frac{d\mu}{d\nu}(x) d\nu(x)$.*

The function $\frac{d\mu}{d\nu}$ from Theorem 1 is called the *Radon-Nikodym derivative* of μ with respect to ν or simply the *density* of μ with respect to ν . Note that the Radon-Nikodym derivative of a measure on $(\mathbb{R}^n, \mathcal{B}(\mathbb{R}^n))$ with respect to the Lebesgue measure is called the probability density function.

Consider the prior measure $\mu_0 = \mathcal{N}(m_0, \mathcal{C})$ defined above. Further assume the Gaussian observational noise with zero mean, i.e. $\eta \sim \mathcal{N}(0, \Sigma)$. According to (1), $y|u \sim \mathcal{N}(G(u), \Sigma)$. Denoting $\mathbb{Q}_0 = \mathcal{N}(0, \Sigma)$ and $\mathbb{Q}_u = \mathcal{N}(G(u), \Sigma)$, we can write

$$\frac{d\mathbb{Q}_u}{d\mathbb{Q}_0}(y) = \exp(-\Phi(u; y)),$$

where $\Phi(u; y) = \frac{1}{2}(y - G(u))^T \Sigma^{-1}(y - G(u))$, for details see [3].

Assume that Φ is measurable with respect to the measure $\nu_0(du, dy) = \mu_0(du) \mathbb{Q}_0(dy)$. The joint random variable (u, y) is distributed according to

$$\nu(du, dy) = \mu_0(du) \mathbb{Q}_u(dy).$$

It can be simply shown that $\nu(A, B) = \int_{A \times B} \frac{d\mathbb{Q}_u}{d\mathbb{Q}_0}(y) \nu_0(du, dy)$; therefore,

$$\frac{d\nu}{d\nu_0}(y) = \exp(-\Phi(u; y)).$$

The density of the desired distribution μ^y of $u|y$ is now obtained by conditioning:

$$\frac{d\mu^y}{d\mu_0}(u) = \frac{1}{Z} \exp(-\Phi(u; y)), \quad (3)$$

where $Z = \int_X \exp(-\Phi(u; y)) \mu_0(du) > 0$.

Obtaining the formula (3) for the posterior measure is just the beginning of solving the stochastic inverse problem. In finite dimension, information about the posterior distribution is typically obtained via Markov chain Monte Carlo sampling methods such as the Metropolis-Hastings (MH) algorithm. In infinite dimension, it is also possible to construct MH methods, see [4]. The purpose of MCMC methods for infinite dimensional setting is rather theoretical; however, it is supported by the philosophy that it is beneficial to establish a well-defined sampling method as a limit of finite-dimensional sampling methods for approximated inverse problem resulting from representing u in a finite-dimensional basis, see [1]. The approximation resulting from the use of a numerical method for the solution of the underlying boundary value problem is also discussed in [1].

5 Model problem

Consider an observation operator G governed by the boundary value problem

$$\begin{aligned} -\operatorname{div}(\exp(u) \nabla p) &= 0 \text{ in } D \subset \mathbb{R}^2, \\ p &= 0 \text{ on } \Gamma_0, \\ p &= 1 \text{ on } \Gamma_1, \\ -k \nabla p \cdot n &= 0 \text{ on } \partial D \setminus (\Gamma_0 \cup \Gamma_1). \end{aligned} \tag{4}$$

Assume that the parts Γ_0 and Γ_1 of the boundary are divided into m sub-parts S_i , $i \in \{1, \dots, m\}$. Observed data are $y_i = \int_{S_i} -k \nabla p \cdot n ds$ as in [6]. This defines the observation operator $G : L^2(D) \rightarrow \mathbb{R}^m$; input to G is a function $u \in L^2(D)$ and the output is the vector $y = (y_1, \dots, y_m)^T$.

As outlined above, for the practical computation, it is necessary to represent u in a finite-dimensional basis. A natural finite-dimensional approximation results from approximating the KL expansion (2) by its truncation

$$u(x, \omega) \approx u_n(x, \omega) = \mu(x) + \sum_{j=1}^n \sqrt{\lambda_j} \phi_j(x) \xi_j(\omega),$$

i.e. u_n is a random field with mean $\mu(x)$ and covariance function

$$c_n(x, y) = \sum_{j=1}^n \sqrt{\lambda_j} \phi_j(x) \phi_j(y).$$

Mean μ , the eigenvalues λ_j and the eigenfunctions ϕ_j are given; therefore, the randomness is only in ξ_j . For a given $n \in \mathbb{N}$, the unknown input to this inverse problem is the $\mathbb{R}^n$ -valued random variable $\xi = (\xi_1, \dots, \xi_n)$ and the prior distribution is simply $\xi \sim \mathcal{N}(0, I_n)$, where I_n denotes the identity matrix of size n . In this simplified form, the problem becomes a standard Bayesian inversion for a real valued random variable as explained e.g. in [5].

In the numerical experiments, we consider the following parameters

of the observation operator: $D = (0, 1) \times (0, 1)$, $\Gamma_0 = (0, 1) \times \{0\}$, $\Gamma_1 = (0, 1) \times \{1\}$, $m = 10$, $S_i = (\frac{i-1}{9}, \frac{i}{9}) \times \{0\}$ for $i \in \{1, \dots, 9\}$, $S_{10} = \Gamma_1$,
of the prior distribution: $m_0 = 0$, $\sigma = 1$, $l = 0.1$, $n = 24$,
of the noise: $\Sigma = 0.05 \cdot I_m$.

A vector of simulated observed data y was extracted from a sample solution shown in Fig. 1 (right) that was obtained for the material sample in Fig. 1 (left). It was corrupted by observational noise.

Fig. 1. Material sample used to simulate the observed data y (left) and the corresponding solution of the boundary value problem (4) - function p (right)

Fig. 2. Estimated posterior mean (left) and standard deviation (right)

The computational realization of the Bayesian inversion consists in posterior sampling using Markov chain Monte Carlo (MCMC) methods and post-

processing of obtained samples. Specifically, the delayed-acceptance Metropolis-Hastings algorithm with the acceleration using a polynomial surrogate model was used. The MCMC methods are out of the main topic of this paper; however, details of this algorithm can be found in author's previous papers [8,9] and discussions on the analysis of the sampling process in [6,7].

Figure 2 shows the estimation of posterior mean and standard deviation calculated from obtained samples. Note that the standard deviation is significantly lower near the boundary part Γ_0 which provided most of the observations.

6 Conclusions

The paper outlined the Bayesian approach for infinite-dimensional random variables and described a model problem of identifying a material parameter in the form of a Gaussian random field. As indicated above, related considerations focus on studying the difference between the theoretical solution of the original problem and the solution of the approximated finite dimensional problem and the convergence properties with respect to refinements of the approximation. Author's current research also includes studying MCMC sampling methods in infinite dimension.

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MPRGP with Projected Conjugate Gradient Expansion and Fallback

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Abstract The standard expansion in MPRGP algorithm uses a projected line search in the free gradient direction with a fixed step length. Such a scheme is often too slow to identify the active set, requiring a large number of expansions. The authors recently proposed expanding the active set by projecting the optimal step for the unconstrained minimization. While the new scheme usually achieves large speedups of up to 4.7, we observed that it could also slow down the algorithm up to 0.77 of the original run time. To mitigate this issue, we propose a cheap fallback strategy for the projected CG expansion step, that either increases the speedup or at least recovers the performance of the original algorithm.

1 Introduction

Quadratic programming (QP) problems with bound or box constraints can be solved by the MPRGP (Modified Proportioning with Reduced Gradient Projections) algorithm developed by Dostál [5,6], which belongs among the active set based methods. The algorithm has been proven to enjoy an R-linear rate of convergence given by the bound on the spectrum of the Hessian matrix. In each iteration, MPRGP performs one of three types of steps - unconstrained minimization, expansion, and proportioning. The unconstrained minimization is typically performed by a conjugate gradient (CG) [7] step, and we will assume this for the rest of the article. The active set is expanded by the expansion step, which consists of a maximal feasible unconstrained minimization, in our case a partial CG step to the bound/box, followed by a feasible fixed step length line search. Finally, a proportioning step, which is designed to reduce the active set, consists of a steepest descent step in the direction of a chopped gradient.

The authors introduced in [8] expansion using a full CG step with the result projected back into the feasible set. This projected CG step has been shown to significantly speed-up the algorithm in almost all benchmarks. However, in some cases, we observed a slight slow-down. To mitigate the issue, we propose a fallback strategy that rejects the projected CG step and does instead the expansion step of the original algorithm when a certain fallback criterion is satisfied.

The paper is divided as follows. Section 2 briefly describes the MPRGP algorithm. In Section 3 we discuss the projected CG step expansion. Our fallback

strategy is presented in Section 4. The numerical experiments are presented in Section 5. Finally, we draw our conclusions in Section 6.

2 The MPRGP Algorithm

MPRGP [6] represents an efficient algorithm for the solution of convex QP with box constraints, i.e. for minimizing quadratic functional subject to constraints

$$\arg \min_{\mathbf{x}} f(\mathbf{x}) = \arg \min_{\mathbf{x}} \frac{1}{2} \mathbf{x}^T \mathbf{A} \mathbf{x} - \mathbf{x}^T \mathbf{b} \quad \text{s.t.} \quad \mathbf{l} \leq \mathbf{x} \leq \mathbf{u}, \quad (1)$$

where $f(\mathbf{x})$ is the cost function, $\mathbf{A} \in \mathbb{R}^{n \times n}$ is positive semi-definite Hessian, $\mathbf{x}$ is the solution, $\mathbf{b}$ is the right hand side, $\mathbf{l}$ and $\mathbf{u}$ is the lower respectively the upper bound.

To describe the algorithm we first have to define a gradient splitting. Let $\mathbf{g} = \mathbf{A} \mathbf{x} - \mathbf{b}$ be the gradient. Then we can define a component-wise (for $j \in \{1, 2, \dots, n\}$) gradient splitting which is computed after each gradient evaluation. The free gradient is defined as

$$g_j^f = \begin{cases} 0 & \text{if } x_j = l_j \text{ or } x_j = u_j, \\ g_j & \text{otherwise.} \end{cases}$$

A step in the free gradient direction can expand the active set (defined as $\{j : x_j = l_j \vee x_j = u_j\}$), but cannot reduce it.

The chopped gradient is defined as

$$g_j^c = \begin{cases} 0 & \text{if } l_j < x_j < u_j, \\ \min(g_j, 0) & \text{if } x_j = l_j, \\ \max(g_j, 0) & \text{if } x_j = u_j. \end{cases}$$

A step in the direction opposite to $\mathbf{g}^c$ may reduce the active set, but cannot expand it.

The next ingredient is the projection onto the feasible set Ω which is defined as

$$[P_\Omega(\mathbf{x})]_j = \min(u_j, \max(l_j, x_j)).$$

Finally, the projected gradient is defined as $\mathbf{g}^P = \mathbf{g}^f + \mathbf{g}^c$. Its norm decrease is the natural stopping criterion of the algorithm.

The algorithm proceeds by checking if the current iterate is proportional, i.e.

$$\|\mathbf{g}_k^c\| \leq \Gamma \|\mathbf{g}_k^f\|, \quad \Gamma > 0.$$

If satisfied, we do a CG step with a maximal step length that keeps the next iterate in the feasible set. If the CG step length had to be shortened, instead of completing the CG step, we proceed with a projected fixed step length in the direction of the free gradient. If the current iterate is not proportional, we do the proportioning step which consists of the steepest descent step in the chopped gradient direction. See [8] for an in-depth discussion of each step.

Figure 1. Projected CG step illustration after the first unconstrained CG step. The grey part is the feasible set bounded by the horizontal line. The ellipses are the cost function contour lines. The right black point on the horizontal line is the solution. [4]

3 Expansion by Projected CG Step

The conjugate gradient step is one of the best steps we can take to minimize the cost function. Therefore, the natural idea is to replace the fixed step length expansion with a full conjugate gradient step with the subsequent projection into the feasible set. See [8] for the actual implementation.

However, in some cases, this projected CG step can lead to an increase in the cost function. In [4], Section 6.2, the authors illustrate by Figure 1 the situation when increase in the cost function happens. Clearly, the CG step finds the unconstrained minimizer of the cost function, but the subsequent projection onto the feasible set puts us on a higher contour line, i.e. increases the value of the cost function. In this case the standard expansion would put us closer to solution.

4 Expansion by Projected CG Step with Fallback

As discussed in the previous section, the projected CG step can increase the cost function value. This increase can indeed happen in practice as illustrated by convergence plot (Fig. 2) for Diabetes benchmark described in Section 5. We can observe a large increase in the cost function value after the projected CG expansion step in the 28th iteration.

We can make the decrease of cost function monotone again by rejecting the projected CG step when the cost function increases and instead do the fixed step length expansion. We choose the step length $\bar{\alpha} = \|\mathbf{A}\|^{-1}$ as it guarantees largest cost function decrease among the fixed step lengths. We call this variant *fallback 1*.

Note that from the point of the overall convergence, it may be better to allow the cost function to increase occasionally. Especially when the increase is small. Therefore, we propose criterion *fallback 2* which does the fallback step only when the condition of *fallback 1* is satisfied, and the next step would be the proportioning step.

The fallback variant of the algorithm is illustrated in Algorithm 1.

Figure 2. Convergence plot for Diabetes benchmark with projected CG expansion.

5 Numerical Experiments

Machine learning employing support vector machines (SVMs) for classification [3] is used as benchmarks. Convergence on three publicly available datasets is tested, namely Australian, Diabetes, and Ionosphere downloaded from LIBSVM dataset webpage [1].

We use the no-bias SVM formulation with l_1 hinge-loss function and with $C = 1$. Therefore we solve the dual QP formulation with box constraints [3].

Since this is a classification application, there are very low requirements on the accuracy of the underlying solver, and typically it is enough to set the relative tolerance of MPRGP to 10^{-1} [9]. However, to make the differences between the algorithms more pronounced, we set the relative tolerance to 10^{-4} . Other parameters include the proportionality parameter $\Gamma = 1$ and fixed step length for standard expansion $\bar{\alpha} = 1.9\|A\|^{-1}$. We used $\bar{\alpha} = \|A\|^{-1}$ for the fallback expansion step length as it guarantees the best decrease of cost function among the fixed step lengths [6].

The initial guess is set just under the upper bound (each component is set to $1 - 100\epsilon_m$, where $\epsilon_m \approx 2.2e-16$ is the machine epsilon).

The tests were computed using PERMON toolbox [2] - the algorithm variants are implemented in PermonQP, while SVMs are implemented in the PermonSVM module.

The results for each tested variant and dataset are presented in Table 5.

The most time-consuming operation of the algorithm is overwhelmingly the number of Hessian multiplications [8]. We can notice that the projected CG

Algorithm 1: MPRGP with projected CG step and fallback

Input: A , $x_0 \in \Omega$, b , $\Gamma > 0$, $\bar{\alpha} \in (0, 2\|A\|^{-1}]$

- 1 $g_0 = Ax_0 - b$, $p_0 = g_0^f$, $k = 0$
- 2 **while** $\|g_k^P\|$ is not small:
- 3 **if** $\|g_k^c\| \leq \Gamma\|g_k^f\|$:
- 4 $\alpha_k^{feas} = \max\{\alpha : x_k - \alpha p_k \in \Omega\}$
- 5 $\alpha_k^{cg} = g_k^T p_k / p_k^T A p_k$
- 6 $x_{k+1} = x_k - \alpha_k^{cg} p_k$
- 7 **if** $\alpha_k^{cg} \leq \alpha_k^{feas}$:
- 8 $g_{k+1} = g_k - \alpha_k^{cg} A p_k$
- 9 $\beta_k = p_k^T A g_{k+1}^f / p_k^T A p_k$
- 10 $p_{k+1} = g_{k+1}^f - \beta_k p_k$
- 11 **else:**
- 12 $x_{k+1} = P_\Omega(x_{k+1})$
- 13 $g_{k+1} = Ax_{k+1} - b$
- 14 **if** *fallback*:
- 15 $x_{k+\frac{1}{2}} = x_k - \alpha_k^{feas} p_k$
- 16 $g_{k+\frac{1}{2}} = g_k - \alpha_k^{feas} A p_k$
- 17 $x_{k+1} = P_\Omega\left(x_{k+\frac{1}{2}} - \bar{\alpha} g_{k+\frac{1}{2}}^f\right)$
- 18 $g_{k+1} = Ax_{k+1} - b$
- 19 $p_{k+1} = g_{k+1}^f$
- 20 **else:**
- 21 $\alpha_k^{cg} = g_k^T g_k^c / (g_k^c)^T A g_k^c$
- 22 $x_{k+1} = x_k - \alpha_k^{cg} g_k^c$
- 23 $g_{k+1} = g_k - \alpha_k^{cg} A g_k^c$
- 24 $p_{k+1} = g_{k+1}^f$
- 25 $k = k + 1$

Output: x_k

variant significantly improves on this metric compared to the standard fixed step length expansion, except in the case of *diabetes* benchmark. The *fallback 1* improves the performance compared to *projCG* variant except for *ionosphere* benchmark. This is specifically targeted by the *fallback 2* strategy which recovers the performance of *projCG* while even further improves the performance for the *australian* benchmark.

6 Conclusion

We presented two fallback variants of the projected CG expansion step used in MPRGP algorithm. These variants, and the second one especially, fixed the deficiencies of the project CG variant and reduced the number of Hessian multiplications compared to the original MPRGP algorithm by a factor of up to 3.8.

Dataset	Exp. Type	Hess. mult.	CG	Exp.	Prop.	Cost inc.	Fall.
australian	fixed	4567	1134	1704	24	423	0
australian	projCG	3571	565	1455	95	127	0
australian	fallback 1	3298	1015	1014	36	218	218
australian	fallback 2	2160	747	662	32	74	56
diabetes	fixed	1108	124	491	1	18	0
diabetes	projCG	1439	113	627	71	109	0
diabetes	fallback 1	292	84	96	1	14	14
diabetes	fallback 2	292	84	96	1	14	14
ionosphere	fixed	628	149	237	4	8	0
ionosphere	projCG	265	104	78	4	6	0
ionosphere	fallback 1	320	109	89	5	27	27
ionosphere	fallback 2	277	104	78	5	13	11

Table 1. Comparison of numbers of each step for different variants of the algorithms. The table also includes the number of cost function increases.

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Randomization of the Initial Guess in the Constrained Optimization on Grassmann Manifolds

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Abstract. The paper presents effects of the usage of a randomized initial guess in the quadratically constrained optimization, where the feasible sets correspond to Grassmann Manifolds. As an example of the application, we have chosen the Electronic Structure Calculations based on the Hartree-Fock Approximation and the Kohn-Sham Theory. The test calculations consist of finding the potential curves of diatomic molecules. Our results are given by the Inexact Restoration Method which is a local optimizer suitable for such a class of problems. The randomization of the initial guess may be understood as the first step towards the development of global optimization methods.

Keywords: Quadratically Constrained Optimization · Inexact Restoration Method · Initial Guess · Electronic Structure Calculations

1 Introduction

Electronic Structure Calculations based on the Hartree-Fock (HF) or Kohn-Sham (KS) theories belong to computationally challenging tasks [1]. Among the biggest problems we can name, for example, high computational costs, problems with convergence of standard solvers based on the SCF iteration for solving the discretized Nonlinear Eigenvalue Problem (NEVP) or the correctness of the results. We are usually interested in the lowest possible (Ground State) energy of a given system of electrons and nuclei. However, there are higher energies that are also solutions of the NEVP. Thus, they can be returned by standard numerical methods with no evidence they do not represent the Ground State. The NEVP can be also reformulated to the constrained optimization problem which corresponds to the direct energy minimization under a selected basis. Here, the feasible sets correspond to Grassmann Manifolds. We are interested in the development of optimization methods suitable for such problems. As a starting point, we have selected a local optimization method called the Inexact Restoration Method (IRM) which has been originally tested on the HF Equation [2]. Our development goes towards the KS Equations with a more complicated

structure. The second direction of our research is the development of global optimizers partially based on the ideas of the IRM. One of the prerequisite is the ability of an efficient generation of random points on the feasible set. This paper brings an overview of the studied optimization problem and the effect of the randomization. Also, it gives a brief insight into results of our calculations.

2 Optimization Problem on the Grassmann Manifold

The set of all K -dimensional linear subspaces of an N -dimensional vector space $\mathbb{V}$ is known as the Grassmann Manifold $Gr(K, \mathbb{V})$ [3]. As an example of $\mathbb{V}$ which is also of our interest, we should mention an Euclidean vector space $\mathbb{R}^N$ with $N \geq K$. It is useful to define a quantity representing an element from $Gr(K, \mathbb{R}^N)$. Given a K -dimensional subspace $\mathbb{W}$, one may consider a set of vectors aligned as columns of matrix $\mathbf{C} \in \mathbb{R}^{N \times K}$ as its representative. However, it is easy to prove that such a representation is not unique (at least any permutation of columns represents the same subspace). As a unique representation we may choose an orthogonal projection matrix $\mathbf{X} \in \mathbb{R}^{N \times N}$ which can be calculated as $\mathbf{X} = \mathbf{C}\mathbf{C}^T$. In fact, the set of all orthogonal projection matrices (onto K dimensional subspaces of $\mathbb{R}^N$) is fully determined by the following three equations:

$$\mathbf{X} = \mathbf{X}^T, \quad (1)$$

$$\mathbf{X}\mathbf{X} = \mathbf{X}, \quad (2)$$

$$\text{Trace}(\mathbf{X}) = K. \quad (3)$$

The set of such matrices can serve as a feasible set Ω in constrained optimization problems given as

$$\min_{\mathbf{X} \in \Omega} f(\mathbf{X}), \quad (4)$$

where $f : \mathbb{R}^{N \times N} \mapsto \mathbb{R}$ is a real multivariate function. If we write equations (1), (2), (3) elementwise, we can see that Ω is given by a set of quadratic and linear equations. Due to this fact, special optimization methods have to be utilized. The IRM is a gradient-based iterative procedure suitable for a such class of problems. It is based on a repetition of two alternating steps:

1. **Calculation of the descent direction and optimization within the tangent set** - Given an iterate $\mathbf{Y}_k \in \Omega$ an optimal descent direction has to be found. One of possible choices is the gradient descent one. Next, the projection of the direction to the tangent set $S_\Omega(\mathbf{Y}_k)$ which, in the case of $Gr(K, \mathbb{R}^N)$, is defined as

$$S_\Omega(\mathbf{Y}) = \{\mathbf{E} \in \mathbb{R}^{K \times K} | \mathbf{E} = \mathbf{E}^T \wedge \mathbf{Y}\mathbf{E} + \mathbf{E}\mathbf{Y} - \mathbf{E} = \mathbf{0}\} \quad (5)$$

has to be calculated. The next iteration is given as $\mathbf{X}_{k+1} = \mathbf{Y}_k + t_k \mathbf{E}_k$, where step length $\mathbf{E}_k$ in the tangent descent direction is determined using an optimization procedure within $S_\Omega(\mathbf{Y}_k)$ (e.g. linesearch methods). In a neighborhood of $\mathbf{Y}_k$ the points of the tangent set are very close to Ω but they does not belong to it. The same holds for the next iterate $\mathbf{X}_{k+1}$.

2. **Restoration Phase** - Given an iterate $\mathbf{X}_{k+1}$ which does not belong to Ω , the restoration phase calculates its projection $\mathbf{Y}_{k+1} = P_{\Omega}(\mathbf{X}_{k+1})$. In the case of $Gr(K, \mathbb{R}^N)$, this projection can be obtained in two ways. First, this can be done by calculating the spectral decomposition of $\mathbf{X}_{k+1}$ and modifying the resulting matrices[2]. Secondly, due to specific spectral properties of $\mathbf{X}_{k+1}$, it can be performed iteratively using a Newton-like Method which is also known as McWeeny purification procedure [4].

We should notice, that IRM is generally a local minimizer. It means that it converges to a local minimum for which the initial guess belongs to its basin of attraction. This can be seen as a complication when we are interested in the finding the global minimum.

3 Electronic Structure Problem

Electronic Structure Calculations belong to the class of problems leading to the optimization problem described above. Here, the objective function has the following form

$$f(\mathbf{X}) = E\left(\mathbf{M}^{-\frac{1}{2}}\mathbf{X}\mathbf{M}^{-\frac{1}{2}}\right) \quad (6)$$

where function E depends on the selected method:

- HF Equation:

$$E^{\text{HF}}(\mathbf{Z}) = \text{Trace}[2\mathbf{H}\mathbf{Z} + (\mathbf{J}(\mathbf{Z}) + \mathbf{K}(\mathbf{Z}))\mathbf{Z}], \quad (7)$$

- KS Equation:

$$E^{\text{KS}}(\mathbf{Z}) = \text{Trace}[2\mathbf{H}\mathbf{Z} + \mathbf{J}(\mathbf{Z})\mathbf{Z}] + E_{\text{xc}}[\mathbf{Z}]. \quad (8)$$

Matrix $\mathbf{H} \in \mathbb{R}^{N \times N}$ represents the kinetic energy and the potential describing interaction between electrons and nuclei. Functions $\mathbf{J}, \mathbf{K} : \mathbb{R}^{N \times N} \mapsto \mathbb{R}^{N \times N}$ are linear and represent Coulomb and exchange interactions. Exchange-correlation function $E_{\text{xc}} : \mathbb{R}^{N \times N} \mapsto \mathbb{R}$ is generally non-linear. In the first case, function f is quadratic, in the second case, it is more general due to the presence of the exchange-correlation term $E_{\text{xc}}[\mathbf{Z}]$ [1]. For a given set of fixed atomic nuclei (which fully determines the nuclear potential) we are interested in the lowest possible (Ground State) energy of the electron shell which correspond to the global minimum of f (subject to mentioned eq. constraints). By varying the positions of the nuclei we obtain the energy surfaces which serve as a tool for describing structures of molecules. In the case of the diatomic molecules, these surfaces are reduced to potential curves. For finding such a curve we have to sample the inter-nuclear distance and solve our optimization problem for each configuration. As there may exist several local minima of f (for a given configuration), the result strongly depends on the initial guess. The standard initial guess is given by solution of the generalized eigenvalue problem without interelectronic interactions, i.e.

$$\mathbf{M}^{-\frac{1}{2}}\tilde{\mathbf{F}}\mathbf{M}^{-\frac{1}{2}}\mathbf{C} = \mathbf{C}\mathbf{A} \quad (9)$$

with eigenvectors represented by matrix $\mathbf{C} \in \mathbb{R}^{N \times K}$ with orthonormal columns, diagonal matrix $\mathbf{\Lambda} \in \mathbb{R}^{K \times K}$ containing K lowest eigenvalues and $\tilde{\mathbf{F}} = \mathbf{H}$. The initial matrix $\mathbf{X}_0$ is then calculated as $\mathbf{X}_0 = \mathbf{C}\mathbf{C}^T$. In the case of the randomized initial guess a random set of K orthonormal vectors has to be generated. This can be done in two steps. First, a random set of K unit vectors is generated. The easiest way of their generating is to pick matrix $\tilde{\mathbf{C}} \in \mathbb{R}^{N \times K}$ of random numbers from the normal distribution $\mathcal{N}(0, 1)$. If we normalize the columns of $\tilde{\mathbf{C}}$, such vectors are uniformly distributed on the unit hypersphere (in other words, such a distribution is rotationally symmetric). As a second step, the columns of $\tilde{\mathbf{C}}$ have to be orthogonalized. There exist several ways of the orthonormalization:

- QR decomposition

$$\tilde{\mathbf{C}} = \mathbf{Q}\mathbf{R} \quad (10)$$

with orthonormal matrix $\mathbf{Q} \in \mathbb{R}^{N \times K}$ and upper triangular matrix $\mathbf{R} \in \mathbb{R}^{K \times K}$. Then $\mathbf{C} := \mathbf{Q}$.

- Singular Value Decomposition

$$\tilde{\mathbf{C}} = \mathbf{U}\mathbf{S}\mathbf{V}^T \quad (11)$$

with orthonormal matrices $\mathbf{U} \in \mathbb{R}^{N \times K}$, $\mathbf{V} \in \mathbb{R}^{K \times K}$ and diagonal matrix $\mathbf{S} \in \mathbb{R}^{K \times K}$. Then $\mathbf{C} := \mathbf{U}$.

- Löwdin Orthonormalization

$$\mathbf{C} = \tilde{\mathbf{C}} \left(\tilde{\mathbf{C}}^T \tilde{\mathbf{C}} \right)^{-\frac{1}{2}} \quad (12)$$

which has the property of a minimizing the difference between the original and orthonormalized vectors in the sense of the least squares.

In the following figures we may see the results of the calculation of the potential curve of Be_2 molecule (both figures use the atomic units). The system is described by the KS Equation, where our modified version of IRM has been used [5]. Fig. 1 shows the calculated energies for internuclear distances between 2 and 14 a. u. Evidently, the standard initial guess belongs to a basin of attraction of a wrong minimum at short distances. This fact is undesirable if we want to find the Ground State potential curve. In the close distances we have also tried to employ the randomized initial guess. We have performed tens of runs to see the effect of the randomization. The result is the IRM has found the right minimum in the vast majority of cases. As an example (Fig. 2), we attach a comparison of iterative histories of the error of the energy for selected internuclear distance $r = 3.55$ a. u. We may see that IRM rapidly falls to a non-global minimum while using the standard initial guess. Although the randomized initial guess may lead to much more iterations (in addition, the number of iterations may vary dramatically), it is much more robust in the sense of the correctness of the results.

Fig. 1. Potential curve of Be_2 molecule

Fig. 2. Iterative history for $r = 3.55 \text{ a.u.}$

4 Conclusions and Outlooks

Currently we have submitted one paper [5] with a modified version of IRM which has been adapted for the usage with the KS Equations. We present a comparison of the algorithm with standard methods based on SCF iteration. Here, we have presented a part of results focused on the initial guess randomization. Our numerical experiments shown that, in the sense of the robustness, the random

initial guess may be advantageous compared to the standard one used commonly in the Electronic Structure Calculation libraries. However, we should stress that randomization itself is not almighty. There is no guarantee, that such a point does not belong to the basin of attraction of a non-global minimum. Currently, our research is focused on the global optimization strategies based on the Swarm Intelligence [6]. Such methods can be understood either as direct global optimizers or as preprocessing tools for the exploration of the feasible set to find a point that is close to the global minimum. Such a point is then used as an initial guess for a local optimizer (e. g. an IRM based one) with usually better local convergence properties.

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Nonadiabatic molecular dynamics

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Abstract. Main topic of my work is nonadiabatic molecular dynamics calculations. A full quantum description of the most chemical processes is still and will be for many years computationally unavailable, therefore many simplifications have to be made in investigation of chemical reactions. In nonadiabatic molecular dynamics nuclei are treated as classical objects while electrons are treated quantum mechanically. Within my work I have developed a package of programs called MULTIDYN3.0, which have been implemented using FORTRAN language. In the core of MULTIDYN3.0 multistep and Runge-Kutta methods for integration of ordinary differential equations (i.e. equations of motion) are implemented. Quantum behavior of electrons are modeled with help of external quantum chemistry program for ab initio calculations, for example MOLPRO [2]. There are two approaches to nonadiabatic simulations. In the first one the ab initio calculations are performed on the fly during the integration of equation of motions. In the second approach potential energy surfaces and other quantities required in evaluation of equations of motion are first calculated on some appropriately chosen grid of points of configuration space. These ab initio data can be fitted using neural networks. For this purpose I have also implemented a package for creating and training of neural networks called NEURON4DYN.

Keywords: molecular dynamics, ab initio calculations, potential energy surfaces

1 Equations of motion

In the following text coordinates of electrons will be denoted by $\mathbf{r}$ and coordinates of atomic nucleus by $\mathbf{R}$. The total quantum mechanical Hamiltonian of a system can be written as [1]

$$\begin{aligned}\mathcal{H} &= -\frac{\hbar^2}{2} \sum_{\alpha} M_{\alpha}^{-1} \nabla_{R_{\alpha}}^2 - \frac{\hbar^2}{2} \sum_{\beta} m_{\beta}^{-1} \nabla_{r_{\beta}}^2 + V_{rR}(\mathbf{r}, \mathbf{R}) \\ &= -\frac{\hbar^2}{2} \sum_{\alpha} M_{\alpha}^{-1} \nabla_{R_{\alpha}}^2 + \mathcal{H}_r(\mathbf{r}, \mathbf{R}).\end{aligned}\tag{1}$$

M_{α} denotes mass of atomic nucleus α and m_{β} is mass of electron β . Term $V_{rR}(\mathbf{r}, \mathbf{R})$ is a potential energy and include all interparticle interactions, i. e.

electron-electron repulsion, nucleus-nucleus repulsion, nucleus-electron attraction, spin-orbit interactions, etc. $\mathcal{H}(\mathbf{r}, \mathbf{R})$ is electronic Hamiltonian, i.e. Hamiltonian that governs the motion of electrons when nuclei are at fixed positions $\mathbf{R}$.

In the semiclassical approximation atomic nuclei are treated classically and are described by a classical Hamilton equations of motion

$$\begin{aligned}\frac{d\mathbf{P}_\alpha}{dt} &= -\frac{\partial H_R}{\partial \mathbf{R}_\alpha} = \mathbf{F}_\alpha, \\ \frac{d\mathbf{R}_\alpha}{dt} &= \frac{\partial H_R}{\partial \mathbf{P}_\alpha} = \frac{\mathbf{P}_\alpha}{M_\alpha}.\end{aligned}\tag{2}$$

$\mathbf{P}_\alpha$ denotes momentum of nucleus α , H_R is Hamilton function for classical system of atoms, F_α is force acting on atom α . Electrons are described by time dependent Schrödinger equation

$$\mathcal{H}_r(\mathbf{r}, \mathbf{R}(\mathbf{t}))\phi(\mathbf{r}, t) = i\hbar \frac{\partial}{\partial t}\phi(\mathbf{r}, t).\tag{3}$$

Where $\phi(\mathbf{r}, t)$ is electronic wave function. This wave function can be expanded using a complete orthonormal set (Schauder basis) on the Hilbert state space of electrons $\phi_j(\mathbf{r}, \mathbf{R})$:

$$\phi(\mathbf{r}, t) = \sum_j c_j(t)\phi_j(\mathbf{r}, \mathbf{R}).\tag{4}$$

In general, functions $\phi_j(\mathbf{r}, \mathbf{R})$ are orthonormal with respect to integration over coordinate space of electrons

$$\int \phi_i(\mathbf{r}, \mathbf{R})\phi_j(\mathbf{r}, \mathbf{R})d\mathbf{r} = \delta_{ij},\tag{5}$$

where δ_{ij} is the Kronecker delta function. There are also defined the following matrix elements:

$$H_{ij} = \int \phi_i(\mathbf{r}, \mathbf{R})\mathcal{H}_r(\mathbf{r}, \mathbf{R})\phi_j(\mathbf{r}, \mathbf{R})d\mathbf{r} = H_{ji}(\mathbf{R}),\tag{6}$$

$$\mathbf{d}_{ij}^\alpha(\mathbf{R}) = \int \{\phi_i(\mathbf{r}, \mathbf{R})[\nabla_{R_\alpha}\phi_j(\mathbf{r}, \mathbf{R})]\}d\mathbf{r},\tag{7}$$

$$D_{ij}^\alpha(\mathbf{R}) = - \int \{\phi_i(\mathbf{r}, \mathbf{R})[\nabla_{R_\alpha}^2\phi_j(\mathbf{r}, \mathbf{R})]\}d\mathbf{r}.\tag{8}$$

Each of these matrix elements depends on the coordinates of atomic nuclei $\mathbf{R}$. $\mathbf{d}_{ij}(\mathbf{R})$ and $D_{ij}(\mathbf{R})$ are called nonadiabatic coupling vector and nonadiabatic coupling elements.

In this paper $\phi_j(\mathbf{r}, \mathbf{R})$ will denote adiabatic, in literature also known as Born-Oppenheimer, basis functions. Electronic wave function can be then written as

$$\phi(\mathbf{r}, t) = \sum_j c_j(t)\phi_j(\mathbf{r}, \mathbf{R}).\tag{9}$$

Where c_j denotes adiabatic amplitude of state j and $|c_j|^2$ gives probability of finding system in adiabatic state j . The adiabatic wave functions are defined as eigenfunctions of $\mathcal{H}(\mathbf{r}, \mathbf{R})$ for given positions $\mathbf{R}$ of nuclei

$$\mathcal{H}(\mathbf{r}, \mathbf{R})\phi_j(\mathbf{r}, \mathbf{R}) = \varepsilon_j(\mathbf{R})\phi_j(\mathbf{r}, \mathbf{R}), \quad (10)$$

where $\varepsilon_j(\mathbf{R})$ is a potential energy surface of adiabatic state j . This equation is also known as stationary Schrödinger equation.

If expansion 9 of electronic wave function is inserted into Schrödinger equation of motion for electrons 3, multiplied from left by $\phi_i(\mathbf{r}, \mathbf{R})$ and integrated over the space of electrons coordinates $\mathbf{r}$, the following equations are obtained

$$\dot{c}_j = -\frac{i}{\hbar}\varepsilon_j c_j - \sum_{i\alpha} c_i \dot{\mathbf{R}}_\alpha \mathbf{d}_{ji}^\alpha(\mathbf{R}). \quad (11)$$

Forces which act on atoms can be obtained using Hellmann-Feynman [3] theorem

$$\mathbf{F}_\alpha = -\langle \phi | \nabla_\alpha \mathcal{H}_r | \phi \rangle, \quad (12)$$

which gives

$$\mathbf{F}_\alpha = -\sum_i |c_i|^2 \nabla_\alpha \varepsilon_i + \sum_{i \neq j} c_i^* c_j (\varepsilon_j - \varepsilon_i) \mathbf{d}_{ji}^\alpha. \quad (13)$$

The first term in equation (13) is weighted average of forces of all adiabatic states and the second term takes into account quantum forces resulting from nonadiabatic transitions in the electronic subsystem.

2 Potential energy surfaces of $[\text{N}_2\text{He}]^+$ complex

Recently I am examining $[\text{N}_2\text{He}]^+$ system. There are two goals. The first goal is to calculate differential cross section of $\text{N}_2^+ + \text{He}$ reaction initially in the lowest electronic state with possible interactions with the lowest state. In the second goal I want to examine and simulate interaction of $\text{N}_2 + \text{He}^+$ system. Ab initio calculations are performing using MOLPRO software package using complete active space self consistent field (CASSCF) method [4]. One disadvantage of this method is the presence of discontinuities in potential energy surfaces when a state that is not included in the state averaging crosses with one that is [5]. On figure 1 we can see potential curves of $[\text{N}_2/\text{He}]^+$ of 6-th to 10-th states with symmetry A' when helium atom approach to the center of nitrogen diatom while there distance is set to 2.08 Bohr , which correspond to equilibrium position of diatom N_2 . From Mulliken charge analysis we can see, that at large distance we have neutral nitrogen with charged helium when the complex is in the 7-th A' state.

Fig. 1. Potential energy curves of 6-th to 10-th A' state of $[N_2/He]^+$ complex, $|NN| = 2.08\text{Bohr}$

Fig. 2. Mulliken population analysis $[N_2/He]^+$ complex for $|NN| = 2.08\text{Bohr}$. At large distance, charge is on Helium atom when the system is in the 7-th A' state.

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2-phase Volume Segmentation Exploiting Null-Spaces of Graph Laplacians

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Abstract. Spectral clustering is widely studied clustering technique, which exploits null-spaces of the graph-Laplacian operators, with applications ranging from genomics to computer vision. In this contribution, we study their capability to capture of mesh geometries such that the related problem is formulated as 2-phase volume segmentation.

Keywords: 2-phase Segmentation; Graph Laplacian; VQ; MS-regularizator;

1 Introduction

In this contribution, we present a part of an ongoing research focused on 2-phase volume image segmentation using specific spectral properties of Laplacians. We cooperate on this research with Bulgarian Academy of Sciences, in particular with Stanislav Harizanov and Svetozar Margenov, and prepare journal paper as well as software written in Python and also C.

Essential idea is based on modified minimization of the Mumford-Shah functional [4] as a minimization of a quadratic term on a general open set $\Omega_g \setminus B$ such that:

$$u^*, B^* = \arg \min_{u, B} \beta \int_{\Omega_g \setminus B} [\nabla u(x, y)]^2 dS, \quad (1)$$

where $u \in C_{loc}^1$ represents a solution of a segmentation problem, B describes boundaries among objects, i.e., particularly meaningful clusters, $\beta \in \mathbb{R}$ is a tuning parameter that a value is problem depended. Unlike Mumford-Shah regularizator, a minimization of border length is not considered in (1). It allows capturing highly non-convex shapes efficiently, which is fundamental nature of volume 2-phase segmentation of porous media. The minimization problem (1) can be straightforwardly formulated the as an eigenproblem of the graph Laplacian $\mathbf{LX} = \mathbf{XA}$, where eigenvalues belong to a spectrum of the lowest magnitude associated with the operator $\mathbf{L}$. From the spectral graph theory point of view, these eigenvectors are related to indicator vectors of connected components of similarity graph G , which are embedded into real-value domain. Typically, vector quantification techniques such as k-means or k-means++ are exploited for reconstructing discreteness of these vectors. On the other hand, we can also consider spectral clustering as a technique for outperforming vector quantification techniques mentioned above for non-convex clusters.

2 Vector Quantification: k-means type algorithms

Vector quantification (VQ) is a collection of coding techniques that are practically used for lossy data correction and compression. It seeks a representative codevector of a cluster, thus it can be directly used as a prototype-based clustering. For a fixed number of prototypes k , it corresponds to the well-known clustering methods of k -means type that is based on an idea of minimizing intra-cluster compactness.

The standard k -means [2] belongs to partitional clustering techniques. It means, it decomposes the training set $X = \{\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_m\}$, where $\mathbf{x}_j \in \mathbb{R}^n$, into a set of clusters $S = \{S_1, S_2, \dots, S_k\}$, in which clusters are mutually disjoint and satisfy: $S = \bigcup_{i=1}^k S_i$, where $\text{card}(S_i) \geq 1$.

Let us define a clustering using a mapping $\phi : \{1, \dots, m\} \rightarrow \{1, \dots, k\}$. We can then determine an optimal representative $\mu_j \in \mathbb{R}^n$ (centroid) related to samples belonging to the cluster j as follows:

$$\mu_j(\phi) = \arg \min_{\mu} \sum_{i=1}^m d(\mathbf{x}_i, \mu) I(\phi(i) = j), \quad (2)$$

where $d : \mathbb{R}^n \times \mathbb{R}^n \rightarrow \mathbb{R}$ is a similarity measure and I denotes an index set. If d represents squared L_2 distance, then μ_j becomes a mean of samples that are assigned to cluster j^1 using the mapping ϕ . Then, the algorithm reduces within-cluster variance $\text{Var}(\phi) = \sum_{i=1}^m d(\mathbf{x}_i, \mu_{\phi(i)}(\phi))$. Formally, it determines the set of clusters S so that the residual sum of squares (RSS) is being minimized:

$$S^* = \arg \min_S \sum_{i=1}^k \sum_{\mathbf{x} \in S_i} \|\mathbf{x} - \mu_i\|^2 = \arg \min_S \sum_{i=1}^k \text{card}(S_i) \text{Var } S_i. \quad (3)$$

Standard stochastic solver used for the k -means problem (3) is called the Lloyd-Forgy algorithm. It is based on an iterative refinement technique such that it proceeds by alternating between two steps, namely assignment and update. At first, algorithm chooses initial centroids randomly. Then, it assigns each sample $\mathbf{x}_j$ to a cluster that squared distance to its centroid is minimal. Afterwards, it computes new centroids μ_j of the actual clusters. The algorithm converges when the largest centroid displacement is less than small ε .

Unfortunately, this Lloyd-Forgy algorithm does not guarantee convergence to a global optimum. And worse, it may fail to converge to a local minimum in some cases, and the algorithm yields a partial optimal solution in the Karush-Kuhn-Tucker point of an objective function (3). Despite these facts, its simplicity and convergence rate (superpolynomial with factor $2^{\Omega(\sqrt{n})}$) are getting the algorithm very attractive. In 2007, David Arthur and Sergei Vassilvitskii proposed a technique called k -means++ [1] for improving randomised seeding of an initial guess. It is based on an adjustment by uniformly random initialization at probability distribution so that a probability of a particular sample is proportional to distance to the nearest mean. Using this modification, solution returned by a minimizer is at most worse by factor $8(\ln(k) + 2)$ [1] than an optimal solution.

¹ Cluster forms the convex-shaped Voronoi cell that μ_j is geometric centre.

3 Spectral clustering

A bottom line of the spectral clustering methods² is geometrically based on assumption that the training set X is sampled from the Riemannian manifold Ω containing multiple connected components forming non-overlapping parts of the domain. In a traditional approach related to spectral clustering, vectors belonging to the training set X are projected onto the null space $\text{Null}(\mathbf{L})$ of the differential operator $\mathbf{L}$. Laplacian operators are used, and a dimension of their null space is equal to $\dim \text{Null}(\mathbf{L}) = \alpha(\Omega)$, i.e. an algebraic connectivity of the manifold Ω . More precisely, an algebraic connectivity associated with the underlying (similarity) graph $G = [V, E]$ capturing geometry of Ω .

While k -means-type algorithms minimize a within-cluster variance, an aim of the spectral clustering is maximizing internal cluster connectivity that a cluster represents connected components of the similarity graph G .

In practical applications, similarity level s_{kl} between vertices v_k and v_l representing training samples $\mathbf{x}_k, \mathbf{x}_l \in X$, respectively, is commonly modelled using RBF function such that $s_{kl} = \exp\left(-\frac{\|\mathbf{x}_k - \mathbf{x}_l\|}{2\sigma^2}\right)$, where the free parameter σ is standard deviation. Firstly, let consider the standard minimal k -cut problem:

$$A_1^*, \dots, A_k^* = \underset{A_1, \dots, A_k}{\operatorname{argmin}} \operatorname{cut}(A_1, A_2, \dots, A_k). \quad (4)$$

Since similarity between two vertices is inversely proportional to distance between them and the minimal cut (4) increases with the number of edges between the partitions, it often tends to the trivial cut separating individual vertex from the rest of the graph in practice.

The way to exclude these singleton solutions is to explicitly require that the clusters should be sufficiently large by considering their internal cluster connectivity. Hagen and Kahng introduced such technique, which is called RatioCut. It is defined as a fraction of a graph cut and cardinalities of connected components:

$$\operatorname{RatioCut}(A_1, A_2, \dots, A_k) = \sum_{i=1}^k \frac{\operatorname{cut}(A_i, A_i^c)}{\operatorname{card}(A_i)}, \quad (5)$$

where A_i^c denotes the complement of the partition A_i . Let us introduce the characteristic vector $\mathbf{u} \in \mathbb{R}^m$ of the component A_i . For simplicity, we efficiently define its j -th entry as follows $\mathbf{u}_j = \frac{1}{\sqrt{\operatorname{card}(A_i)}}$ if $v_j \in A_i$, 0 otherwise. Then, we can rewrite (5) using $\mathbf{u}$:

$$\sum_{i=1}^k \mathbf{u}_i^T \mathbf{L} \mathbf{u}_i = \sum_{i=1}^k (\mathbf{U}^T \mathbf{L} \mathbf{U})_{ii} = \operatorname{Tr}(\mathbf{U}^T \mathbf{L} \mathbf{U}), \quad (6)$$

where $\operatorname{Tr}(\mathbf{L})$ is a trace of the unnormalized Laplacian defined as $\mathbf{L} = \mathbf{W} - \mathbf{D}$. The matrix $\mathbf{D}$ is a diagonal matrix, which consists of degrees of vertices V on main diagonal. $\mathbf{W}$ is adjacency matrix of the graph G .

² In the image processing communities, the spectral clustering is also known as segmentation-based object categorization.

By relaxing minimization (6) and exploiting the Rayleigh-Ritz theorem, we can see the solution of minimizing (6) is given by a matrix containing the first k eigenvectors of the Laplacian matrix $\mathbf{L}$ as its columns. These eigenvectors represent indicator vectors embedded into a real-value domain and can use vector quantification technique, discussed in Section 2, for reconstructing them. This approach leads to the unnormalized spectral clustering presented in [3].

Another typically used way how to deal with singleton partitions produced by (4) is exploiting disassociation measure called the normalized cut:

$$\text{Ncut}(A_1, A_2, \dots, A_k) = \sum_{i=1}^k \frac{\text{cut}(A_i, A_i^c)}{\text{vol}(A_i)}, \quad (7)$$

where $\text{vol}(A_i) = \sum_{u \in A_i, t \in V} w_{u,t}$ is volume of partition A_i .

Further, we can define characteristic vector for the NCut formulation (7) as in the previous case analogously, and rewrite (7) as trace minimization problem then. Following relaxation and exploitation of the Rayleigh-Ritz theorem lead to generalized eigenproblem $\mathbf{L}\mathbf{x} = \lambda\mathbf{D}\mathbf{x}$. This formulation is commonly used as transformed into a form of standard eigenproblem of symmetric normalized Laplacian $L_{\text{sym}} = \mathbf{D}^{-\frac{1}{2}}\mathbf{L}\mathbf{D}^{-\frac{1}{2}}$.

However, the training vectors X projected into $\text{Null}(\mathbf{L}_{\text{sym}})$ are proportional to square roots of degrees corresponding to vertices V in this case. Consequently, the new coordinates of the training vectors X in $\text{Null}(\mathbf{L}_{\text{sym}})$ could be in different ranges. The standard approach is normalizing them by L_2 norm. Afterwards, we can apply vector quantification techniques for reconstructing indicator vectors of connected components. This approach is called the normalized spectral clustering and was firstly presented by Shi and Malik [5].

4 Benchmarks

We compare two presented spectral clustering algorithms in following numerical experiments. We mainly analyze how precisely they are capable to capture geometries of input meshes, see Figure 1. For this, we formulate the problem as 2-phase volume segmentation such that input data consists of 2 materials, particularly an air and a solid. While spectral clustering provides regularization of noisy data implicitly³, we do not deal with meshes corrupted by random noise. This simple setting helps us just focus on object geometries, their representations in null spaces of related Laplacians, and we can straightforwardly compare clustering results with ground truth by means of the Hamming distance $\|\cdot\|_H$.

To obtain more precise results, we set relative tolerance for Krylov-Schur eigensolver to $1e-8$, attempts for restarting k-means to 10, and initial guesses produced by k-means++. Number of clusters k was 2. Relative tolerance for the k-means solver is not required to be small. Therefore, it was set to 0.1. The input data are sufficiently large to obtain a solution in reasonable time on 1

³ Regularization properties arises from the Mumford and Shah regularization.

MPI process. The dimensions of the Laplacian matrices for both input datasets are 274,625. Therefore, we do not deal with possible non-determinism arising from parallel computations, and we can set as ideal benchmarking conditions as possible. The similarity is modelled by using RBF function such that we incorporate 6, 18 and 26 local neighbours of actual voxel (denoted as $\#neighbours$ in Table 1), and σ_{max} is maximal value of standard deviation associated with RBF function for that $\dim \text{Null}(\mathbf{L}) > 1$. In Table 1, we also reported a number of iterations needed for convergence of eigensolver, residual sum of squares (RSS) related to k-means, and $\|\cdot\|_H$ between obtained results and ground truth.

Fig. 1. From left: visualizations of mesh geometries related to ball and bone dataset.

Analysing achieved results presented in Table 1, we can see both algorithms detected $\dim \text{Null}(\mathbf{L})$ equal to a number of materials in the order of the ball dataset correctly and achieved results corresponds to ground truth, i.e. Hamming distance between them is 0. Increasing the size of the neighbourhood, σ_{max} and the number of iterations needed for converging eigensolver decreases almost for all settings. This is a consequence of a few dependent facts. By increasing the size of the neighbourhood, more voxels are incorporated there, and we need to filter out voxels from different groups more precisely, i.e. decreasing σ_{max} . It leads to possible better capturing of mesh geometry, i.e. maximizing internal cluster connectivity and minimizing intra-cluster variance, and, from the spectral properties of the operators, better separating zero eigenvalues from rest of the spectra causing quicker convergence rate of the eigensolver. Further, eigenvectors of L_{sym} are proportional to $\sqrt{\deg V}$ and normalization using L_2 norm just fit them to unit sphere. However, this proportionality is preserved by such normalization. This causes the order of magnitude smaller intra-cluster variance, appearing as higher RSS than in case of unnormalized spectral clustering. Probably, we could achieve better convergence rate and intra-cluster variance (smaller RSS) by means of decreasing standard deviation σ in order to the normalized spectral clustering, where $\#neighbours$ equals to 26.

Looking at results related to the bone dataset, we can see that the unnormalized spectral clustering provides worse results than the normalized version. Moreover, eigensolver did not converge in order to the unnormalized spectral clustering for 6 neighbours setting. It is a consequence that RatioCut minimizes the graph cut and simultaneously maximizes cardinality of desired components since NCut is proportional to the volume of the components. Therefore, normalized spectral clustering could outperform unnormalized version and provide a better quality solution in the sense of higher compactness and a smaller number

of components, when degrees of vertices differ a lot. Note that the unnormalized spectral clustering separates small parts of air material in this case.

Table 1. Achived results associated with unnormalized and normalized spectral clustering on bone and ball datasets (Figure 1).

dataset	spectral clustering	#neighbours	σ_{max}	dim Null($\mathbf{L}$)	#iters.	RSS	$\ \cdot\ _H$
ball	unnormalized	6	0.22	2	122	4.89e-7	0
	unnormalized	18	0.19	2	69	2.10e-6	0
	unnormalized	26	0.18	2	65	2.43e-6	0
	normalized	6	0.21	2	125	0.13	0
	normalized	18	0.20	2	66	0.16	0
	normalized	26	0.20	2	69	0.5	0
bone	unnormalized	6	—	—	—	—	—
	unnormalized	18	0.125	5	167	3.0	211, 539
	unnormalized	26	0.125	3	119	1.0	0
	normalized	6	0.130	4	287	124.3	0
	normalized	18	0.130	2	104	0.4	0
	normalized	26	0.130	2	93	0.6	0

5 Conclusion and future work

In this contribution, we focused on two clustering algorithms, which exploit null-spaces of Laplacian operators. Namely, they are unnormalized and normalized spectral clustering. We analyzed the ability of these algorithms to capture object geometries in null-spaces of these operators as the problem of 2-phase volume segmentation. From the presented theory and achieved results, we can conclude that the unnormalized spectral clustering is more suitable for input data containing reasonable large underlying clusters. On the other hand, better results are achieved by the normalized version. In our future work, we will focus on a segmentation of object corrupted by noise and meshes containing tens of millions points.

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Parallel finite element method of transient piezo-acoustic problem

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Abstract. In this paper we are dealing with the acoustic wave propagation. The motivation of this work is the oil level measurement in the ultrasonic sensor, which is often used in the automotive industry. The mathematical model of the piezoelectric level sensor includes the modeling of elastoelectric waves in the piezoelectric element, the modeling of acoustic waves in the fluid and the interaction of the two models. This work includes parallel implementation of FEM acoustic.

Keywords: transient piezoelectricity, piezo-acoustic coupled problem, finite element method, parallel implementation

1 Transient piezoelectricity problem

Mechanical deformation of some materials, e.g. quartz, gives rise to electrical field. Conversely, when voltage is applied to the piezoelectric material, it undergoes a mechanical distortion. Completing Maxwell's equations of electrostatics and equations of elasticity by the direct and the inverse piezoelectric effect gives the piezoelectric equations. The formulation of the piezoelectric problem is presented in [1], [3].

Let us consider a 3-dimensional computational domain Ω with a Lipschitz boundary and the time interval $T := (0, \tau)$. The displacement vector field $\mathbf{u}(\mathbf{x}, t)$ and the potential scalar field $\phi(\mathbf{x}, t)$ are governed by

$$\begin{aligned} \rho \mathbf{u}_{tt} - \operatorname{div} \boldsymbol{\sigma} &= \mathbf{0}, \quad \boldsymbol{\sigma} = c^E \boldsymbol{\varepsilon}(\mathbf{u}) + e^T \nabla \phi, \\ \operatorname{div} \mathbf{D} &= 0, \quad \mathbf{D} = e \boldsymbol{\varepsilon}(\mathbf{u}) - \epsilon \nabla \phi, \end{aligned} \tag{1}$$
$$\begin{aligned} \mathbf{u} &= \mathbf{u}_\Gamma \quad \text{on } \Gamma_u, \quad \boldsymbol{\sigma} \cdot \mathbf{n} = \boldsymbol{\sigma}_n \quad \text{on } \Gamma_\sigma, \quad \Gamma_u \cup \Gamma_\sigma = \partial\Omega, \\ \phi &= \phi_\Gamma \quad \text{on } \Gamma_\phi, \quad \mathbf{D} \cdot \mathbf{n} = D_n \quad \text{on } \Gamma_D, \quad \Gamma_\phi \cup \Gamma_D = \partial\Omega, \\ \mathbf{u}(\mathbf{x}, 0) &= \mathbf{u}_0(\mathbf{x}), \quad \mathbf{u}_t(\mathbf{x}, 0) = \dot{\mathbf{u}}_0(\mathbf{x}). \end{aligned}$$

The high-order tensors c^E, e, ϵ in Eq. (1) contain elastic stiffness constants, the piezoelectric stress constants and the electric permittivities for constant mechanical strain according to piezoelectric material, respectively.

For the purpose of weak form we consider Sobolev spaces:

$$\mathbf{V} := \{\mathbf{v} \in \mathbf{H}^1(\Omega) := (H^1(\Omega))^d \mid T_{\Gamma_u}(\mathbf{v}) = 0\},$$

$$\Pi := \{\varphi \in H^1(\Omega) \mid T_{\Gamma_\phi}(\varphi) = 0\}.$$

Additionally, set

$$\mathbf{V}_{\Gamma_u} := \varepsilon_{\Gamma_u} \mathbf{u}_\Gamma + \mathbf{V} \quad \text{and} \quad \Pi_{\Gamma_\phi} := \varepsilon_{\Gamma_\phi} \phi_\Gamma + \Pi,$$

where $\varepsilon_\Gamma : H^{\frac{1}{2}}(\Gamma) \rightarrow H^1(\Omega)$ is extension operator.

Thus, we are able to state the variational formulation of Eq. (1) (see [2], [5])

$$\left\{ \begin{array}{l} \text{find } \mathbf{u} \in L^2(T; \mathbf{V}_{\Gamma_u}) \text{ and } \phi \in L^2(T; \Pi_{\Gamma_\phi}) \text{ with} \\ \mathbf{u}_{,t} \in L^2(T; \mathbf{L}^2(\Omega)), \mathbf{u}_{,tt} \in L^2(T; \mathbf{V}') \text{ such that} \\ \\ \int_{\Omega} \rho \mathbf{u}_{,tt} \cdot \mathbf{v} \, d\Omega + \int_{\Omega} C^E \varepsilon(\mathbf{u}) : \varepsilon(\mathbf{v}) \, d\Omega + \int_{\Omega} E^T \varepsilon(\mathbf{v}) \cdot \nabla \phi \, d\Omega = \\ \qquad \qquad \qquad = \int_{\Gamma_\sigma} \boldsymbol{\sigma}_n \cdot \mathbf{T}_{\Gamma_\sigma}(\mathbf{v}) \, d\Gamma, \quad \forall \mathbf{v} \in \mathbf{V} \\ \\ \int_{\Omega} E \varepsilon(\mathbf{u}) \cdot \nabla \varphi \, d\Omega - \int_{\Omega} \epsilon \nabla \phi \cdot \nabla \varphi = \int_{\Gamma_D} D_n T_{\Gamma_D}(\varphi) \, d\Gamma, \quad \forall \varphi \in \Pi \end{array} \right. \quad (2)$$

After discretization Ω and approximation $\mathbf{V}, \Pi$ by a finite element method, we obtain the following linear system

$$\begin{pmatrix} M & 0 \\ 0 & 0 \end{pmatrix} \begin{pmatrix} \bar{u}_{tt} \\ \bar{\phi}_{tt} \end{pmatrix} + \begin{pmatrix} K & B^T \\ B & -A \end{pmatrix} \begin{pmatrix} \bar{u} \\ \bar{\phi} \end{pmatrix} = \begin{pmatrix} f \\ g \end{pmatrix}. \quad (3)$$

2 Piezo - acoustic coupled problem

The numerical simulation of coupled piezoelectricity-acoustic problems demands consideration of the coupling conditions at the interface Γ_{pf} . At each point of the interface Γ_{pf} , the normal components of both the mechanical velocity in the solid and the acoustic particle velocity in the fluid have to coincide. The fluid causes a certain pressure load on the solid at the interface. This pressure load corresponds to the mechanical stress acting perpendicular to the surface of the solid. These conditions are incorporated as appropriate boundary conditions in the PDEs. The relation between the velocity potential ψ and the acoustic pressure p in the fluid is given as

$$p(\mathbf{x}, t) = \rho_f \frac{\partial \psi}{\partial t}(\mathbf{x}, t).$$

Let us assume that deformations are the only source for the acoustic field Ω_f and the boundary conditions at the outer boundary of Ω_f are zero. The weak form of the coupled problem reads to

$$\left\{ \begin{array}{l} \text{find } \mathbf{u} \in L^2(T; \mathbf{V}_{\Gamma_u}), \phi \in L^2(T; \Pi_{\Gamma_\phi}) \text{ and } \psi \in L^2(T; H^1(\Omega_f)) \text{ with} \\ \mathbf{u}_{,t} \in L^2(T; \mathbf{L}^2(\Omega)), \mathbf{u}_{,tt} \in L^2(T; \mathbf{V}') \text{ such that} \\ \\ \int_{\Omega_p} \rho_p \mathbf{u}_{tt} \cdot \mathbf{v} \, d\Omega + \int_{\Omega_p} C^E \varepsilon(\mathbf{u}) : \varepsilon(\mathbf{v}) \, d\Omega + \int_{\Omega_p} E^T \varepsilon(\mathbf{v}) \cdot \nabla \phi \, d\Omega = \\ \qquad \qquad \qquad = \int_{\Gamma_{pf}} \psi_t (\mathbf{v} \cdot \mathbf{n}) \, d\Gamma, \quad \forall \mathbf{v} \in \mathbf{V} \\ \\ \int_{\Omega_p} E \varepsilon(\mathbf{u}) \cdot \nabla \phi \, d\Omega - \int_{\Omega_p} \epsilon \nabla \phi \cdot \nabla \phi \, d\Omega = 0, \quad \forall \phi \in \Pi \\ \\ \int_{\Omega_f} \frac{1}{c_f^2} \psi_{tt} \eta \, d\Omega + \int_{\Omega_f} \nabla \psi \nabla \eta \, d\Omega = \int_{\Gamma_{pf}} (\mathbf{u}_t \cdot \mathbf{n}) \eta \, d\Gamma, \quad \forall \eta \in H^1(\Omega_f). \end{array} \right. \quad (4)$$

After discretization $\Omega = \Omega_p \cup \Omega_f$ by the finite element, we obtain the following linear system

$$\underbrace{\begin{pmatrix} M_p & 0 & \\ 0 & 0 & 0 \\ 0 & 0 & M_f \end{pmatrix}}_{\mathbb{M}} \underbrace{\begin{pmatrix} \bar{u}_{tt} \\ \bar{\phi}_{tt}^H \\ \bar{\psi}_{tt} \end{pmatrix}}_{x_{tt}} - \underbrace{\begin{pmatrix} 0 & 0 & C^T \\ 0 & 0 & 0 \\ C & 0 & 0 \end{pmatrix}}_{\mathbb{C}} \underbrace{\begin{pmatrix} \bar{u}_t \\ \bar{\phi}_t^H \\ \bar{\psi}_t \end{pmatrix}}_{x_t} + \underbrace{\begin{pmatrix} K & B^T & 0 \\ B & -A_p & 0 \\ 0 & 0 & A_f \end{pmatrix}}_{\mathbb{K}} \underbrace{\begin{pmatrix} \bar{u} \\ \bar{\phi}^H \\ \bar{\psi} \end{pmatrix}}_x = \underbrace{\begin{pmatrix} -\tilde{B}^T \\ \tilde{A}_p \\ 0 \end{pmatrix}}_z \phi^P(t). \quad (5)$$

The matrices M_p , M_f , C , K , B , A_p , A_f are the discretizations of the bilinear forms on the left-hand sides of (4) and $\phi = \phi^P + \phi^H$. To conduct a transient analysis we can apply the Newmark scheme (see [4]), where at each time step we

- compute predictor step

$$\begin{aligned} \hat{x} &= x^{(i)} + \Delta t x_t^{(i)} + \frac{(\Delta t)^2}{4} x_{tt}^{(i)}, \\ \hat{x}_t &= x_t^{(i)} + \frac{\Delta t}{2} x_{tt}^{(i)} \end{aligned}$$

- solve algebraic system of equations

$$\left(\mathbb{M} - \frac{\Delta t}{2} \mathbb{C} + \frac{(\Delta t)^2}{4} \mathbb{K} \right) x_{tt}^{(i+1)} = z^{(i+1)} + \mathbb{C} \hat{x}_t - \mathbb{K} \hat{x} \quad (6)$$

- perform corrector step

$$\begin{aligned} x^{(i+1)} &= \hat{x} + \frac{(\Delta t)^2}{4} x_{tt}^{(i+1)}, \\ x_t^{(i+1)} &= \hat{x}_t + \frac{\Delta t}{2} x_{tt}^{(i+1)}. \end{aligned}$$

3 Numerical example

We deal with simulation of the piezo-acoustic sensor of the oil level in the axial symmetry. The geometry contains piezo disk (radius $r_p = 2$ mm; thickness $t_p = 1$ mm) made of the piezoceramic material PZT-5H. The domain Ω_f consists of plastic (density $\rho_p = 900$ kg/m³; speed of sound $c_p = 1950$ m/s), water ($\rho_w = 1000$ kg/m³, $c_w = 1498$ m/s) and air ($\rho_a = 1.225$ kg/m³, $c_a = 343$ m/s). Figure 1 shows 2-D axial geometry with the appropriate boundaries.

Fig. 1: Geometry of the piezo-acoustic problem.

The mechanical displacements $(u_r)_r$ along the z -axis and the mechanical displacements $(u_r)_z$ along the r -axis have to be zero. The voltage signal $\phi_I(t) := 3.3K(\sin(\omega t)e^{-2ft})$ with $f = 1$ MHz and $K = \sin(\text{atan}(\pi))e^{-\frac{\text{atan}(\pi)}{2}}$. The propagation of the acoustic wave is shown in Figure 2. The axisymmetric computational grid comprises 21120 squares.

4 Parallel implementation of FEM acoustic

The time-iteration matrix (implicit Newmark scheme) is mass dominant. We solve (6) by the conjugate gradients (CG) method with the diagonal preconditioning. The domain Ω is decomposed into N nonoverlapping subdomains, each of which is associated to exactly one concurrent process. This induces a nonoverlapping distribution of matrices. On the other hand, vectors are distributed with overlaps in the sense that DOFs on interfaces are shared among the adjacent processes. That gives rise to communication. The CG method is running on each process locally up to three instructions per iteration - one action of the system matrix and two dot-products.

The communication proceeds as follows:

Fig. 2: Example of the propagation of acoustic wave in axial symmetry.

- Distributed matrix-vector product $\mathbf{s} := \mathbf{A} \cdot \mathbf{p}$
 - Compute local contribution $\bar{\mathbf{s}}_i := \mathbf{A}_i \cdot \mathbf{p}_i$ in parallel. The result is correct up to the interface DOFs.
 - Send (nonblocking) interface restrictions (corrections) of $\bar{\mathbf{s}}_i$ to neighbours.
 - Receive (nonblocking) the corrections from neighbours and add them to $\bar{\mathbf{s}}_i$.
- Distributed dot-product $\beta := \mathbf{s} \cdot \mathbf{p}$

Each process knows a globally nonoverlapping mask $\mathbf{M}_i$ (ownership) of the globally overlapping interface DOFs.

 - Apply the mask to the vectors $\tilde{\mathbf{p}}_i := (\mathbf{p}_i)_{\mathbf{M}_i}$.
 - Compute the local dot-product $\beta_i := \bar{\mathbf{s}}_i \cdot \tilde{\mathbf{p}}_i$.
 - The result $\beta = \sum_{i=1}^N \beta_i$ is gained by the all-to-all communication with a singlevalued message per process.

We study the convergence of the acoustic wave. The computational domain is the cylinder with radius 8 mm and height 35 mm. The geometry contains the plastic cylinder with radius 3 mm, height 30 mm, thickness of plastic 1 mm, plastic reference situated at a height of 18 mm. The acoustic wave is excited by Neumann boundary condition (without piezo disk) with the same signal as above. In 3 the acoustic wave on the z -axis for $t = 2.5 \mu\text{s}$ is shown (it travels about 4 mm). In the case of 2D axisymmetric discretization we obtain the convergence

(oscillations are lost) for the discretization step $h = 0.05$ mm. The sufficient discretization in 3D case requires 202 mil. degrees of freedom ($h = 0.036$ mm).

Fig. 3: Convergence of the acoustic wave.

5 Future work

In the future we would like to apply this problem to examples arising from the industry. Eventually, we would like to introduce hysteresis. In 09/2019 some results related to the analysis of piezo-acoustic FEM was presented in the conference Modelling 2019 in Olomouc.

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Classification algorithms and compositional data

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Abstract. Compositional data represent quantitative information about parts of some whole. Due to the related special mathematical properties, the statistical analysis of compositional data, including analysis with machine learning algorithms, requires development of appropriate techniques. In this paper, the concept of compositional data is summarized and the relationship of their mathematical properties and the application of classification algorithms is described. The paper aims to establish important technical and mathematical background which will eventually lead to new modifications of well-known classification algorithms towards their application on compositional data.

Keywords: compositional data, classification algorithms, affine equivariance, random forests

1 Motivation

Our previous research focused on the application of variable selection methods and classification algorithms on mixed data, especially the mixed data which arise in medical research. Recently, the research has been extended on the application of the algorithms on the compositional data. The term compositional data refers to datasets containing only relative information. In practice, the compositional data occur when the quantitative description of parts of some whole is of interest. They occur for example in biology, geology, medical sciences or social sciences and their nature implies the need for careful approach to the statistical analysis. Consequently, modification of classification algorithms (or generally machine learning algorithms) is currently discussed topic.

Firstly, the paper focuses on the mathematical background of the compositional data analysis. To understand the concept of compositional data is vital for subsequent assessment of suitability of well-known classification algorithms, or machine learning algorithms in general. Then, the paper directly focuses on the particular difficulties which are connected with several widely-used classification algorithms.

2 The concept of compositional data

Compositional data are multivariate data which contain strictly relative information, in other words, they quantitatively describe parts of some whole. The only relevant information is then hidden in ratios between compositional parts. Commonly, compositions are in a form of percentages, proportions or concentrations, following mathematical theory was drawn mainly from [1,2,10]. The cited sources also include the original work of John Aitchison who played a key role in compositional data research.

A D -part composition is defined as a D -dimensional positive vector $\mathbf{x} = [x_1, x_2, \dots, x_D]$. The sample space of D -part compositions is a D -simplex

$$S^D = \left\{ \mathbf{x} = [x_1, x_2, \dots, x_D], x_i > 0, i = 1, \dots, D, \sum_{i=1}^D x_i = \kappa \right\}, \quad (1)$$

where κ is the sum of parts of a composition, usually, its value is 1 or 100 because it gives us convenient interpretation of compositions with proportions or percentages. Actually, in real-world problems, the constant κ can be any positive number (e.g. when working with concentrations in $\mu\text{g}/\text{m}^3$), which is not an issue thanks to the *scale invariance* principle. In this context, we can define closure operator C that scales elements of a D -part composition $\mathbf{x}$ to a D -part composition with the desired sum of parts κ

$$C(\mathbf{x}) = \left[\frac{\kappa x_1}{\sum_{i=1}^D x_i}, \dots, \frac{\kappa x_D}{\sum_{i=1}^D x_i} \right]. \quad (2)$$

The next important principle is the *permutation invariance*. This principle assures that the conclusions derived from the analysis do not depend on the order of the parts in compositions. The third principle is the *subcompositional coherence* which guarantees the scale invariance for all possible subcompositions and the independence of the analysis of a particular subcomposition on the parts excluded from the subcomposition. The described principles can be perceived as vital requirements without which the analysis could result in misleading results.

Aitchison defined following operations - perturbation, powering and the inner product as

$$\mathbf{x} \oplus \mathbf{y} = C(x_1 y_1, \dots, x_D y_D), \quad (3)$$

$$\alpha \odot \mathbf{x} = C(x_1^\alpha, \dots, x_D^\alpha), \quad (4)$$

$$\langle \mathbf{x}, \mathbf{y} \rangle_A = \frac{1}{D} \sum_{i < j} \ln \frac{x_i}{x_j} \ln \frac{y_i}{y_j}, \quad (5)$$

with $\mathbf{x}, \mathbf{y} \in S^D$, $\alpha \in \mathbb{R}$ and the closure operator C . Above defined operations lead to the systematization of the theory under the name - *the Aitchison geometry on the simplex*. The simplex with perturbation and powering is a $(D-1)$ -dimensional vector space. The inner product (with associated norm and distance) can be used

to obtain $(D - 1)$ -dimensional Euclidean space structure on the simplex, more details are available in [1, 2, 10, 11]. Finally, the key question, which perfectly reflects research goals of compositional data analysts, is whether standard statistical methods, which assume that the sample space is $\mathbb{R}^D$, are appropriate for data with different sample space, i.e., S^D .

2.1 Working in coordinates

Before Aitchison's work, a common approach was through simple ratios of compositional parts or their log-ratios. This aimed to determine some appropriate transformation from S^D to real space. Aitchison then defined pairwise log-ratio transformation (pwlr : $S^D \rightarrow \mathbb{R}^{D(D-1)/2}$), centred log-ratio transformation (clr : $S^D \rightarrow \mathbb{R}^D$) and additive log-ratio transformation (alr : $S^D \rightarrow \mathbb{R}^{D-1}$) as

$$\text{pwlr}(\mathbf{x}) = \left\{ \ln \frac{x_i}{x_j}, i < j, i = 1, \dots, D, j = 1, \dots, D \right\}, \quad (6)$$

$$\text{clr}(\mathbf{x}) = \ln \left[\frac{x_1}{g(\mathbf{x})}, \dots, \frac{x_D}{g(\mathbf{x})} \right], \text{ with } g(\mathbf{x}) = \left(\prod_{i=1}^D x_i \right)^{1/D}, \quad (7)$$

$$\text{alr}(\mathbf{x}) = \ln \left[\frac{x_1}{x_D}, \dots, \frac{x_{D-1}}{x_D} \right]. \quad (8)$$

However, there are several problems with above defined transformations. The pwlr transformation is characterized by the presence of redundancies and high dimensionality. The alr transformation violates the permutation invariance, which is not an issue for the clr transformation but its application results in a singular covariance matrix and violation of the subcompositional coherence. However, it does not mean that the transformations are useless, e.g. the clr transformation is widely-used in the context of the principal component analysis and the pwlr transformation is often mentioned in connection with modifications of variable selection methods for compositional data [7].

The isometric log-ratio transformation (ilr : $S^D \rightarrow \mathbb{R}^{D-1}$) [5] takes desired properties from the clr transformation (isometry, i.e., it preserves distances) and simultaneously solves its disadvantageous properties (singular covariance matrix). The ilr transformation came from the recognition that compositions can be represented by their coordinates in the simplex with a suitable orthonormal basis. The ilr transformation can be chosen as $\mathbf{z} = [z_1, \dots, z_{D-1}] = \text{ilr}(\mathbf{x})$, with

$$z_i = \sqrt{\frac{D-i}{D-i+1}} \ln \frac{x_i}{\sqrt[D-i]{\prod_{j=i+1}^D x_j}}, i = 1, \dots, D-1. \quad (9)$$

Finally, the principle of working in coordinates states that the standard statistical methods should be applied on the coordinates and, if necessary, the results are transformed back to the simplex. All described transformations can be used but carefully, and with consideration of all connected properties.

3 Classification algorithms

In terms of classification, it is important to discuss where the problem is with compositional data in a role of exploratory (input) variables. At first, it may seem that using compositions as input variables (or their transformation) should not be a problem but many algorithms give different predictions with different log-ratio transformations and so inconsistent results. In other words, we can say that they are not affine equivariant. The affine equivariance property assures that the analysis is immune to changes in input coordinates and it is a crucial and desirable property of methods which consequently assures consistent behaviour and consistent results.

Regression models have a traditional position in the context of classification algorithms. There are plenty of studies investigating the affine equivariance property of different regression estimators or applications of regression models on compositional data (e.g. [3, 6, 8, 15]). Therefore, our focus aims to other classification methods.

Authors in [4] investigated the performance of the random forests on the data from the National Geochemical Survey of Australia. They pointed out that due to the mechanism of tree-based methods, they cannot generally be affine equivariant. They applied the random forests algorithm on the original compositions, pwlrs, clr and ilr coordinates and on a set of all original compositions with all possible log-ratios. In this application, the pwlrs out-performed other options but as the authors highlighted, it can not be generalized to other classification algorithms. The random forests algorithm can deal with the high dimensionality of the pwlrs and so this choice seems like the most appropriate.

Despite this, we believe that there is a room for improvement. We are inspired by [14] where authors suggested the random forests with conditional inference trees. In the same spirit, we would like to modify the process of the random selection of exploratory variables in the sense of making better use of the co-dependency of compositions. The key can be in the variable selection algorithm for compositional data which was proposed in [7] whose modification could be built in the random forests algorithm.

Few final remarks are pointed to the artificial neural networks which are indispensable in the field of machine learning. Authors in [4] highlighted that the neural networks can not be generally considered as affine equivariant. From our available literature, it seems that the combination of neural networks and compositional data is a rather secondary topic. Perhaps, due to the fact that the interpretation of the neural networks' "black box" itself is questionable, the investigation of their behaviour for different transformations of compositional data might be considered as unpopular.

4 Conclusion

This paper provided important technical and mathematical background of the compositional data analysis whose understanding is necessary for following

modification of well-known classification algorithms. The principles of the compositional data analysis were summarized. Also, the importance of the affine equivariance property was described.

For future work, we would like to continue in the research related to classification algorithms and the medical data analysis which is the crucial supporting part of the prepared dissertation, so far, five articles have been published related to this topic [9, 12, 13, 16, 17]. Articles related to the application of classification algorithms in compositional data analysis are in preparation in cooperation with the Department of Mathematical Analysis and Applications of Mathematics and the Department of Geology of the Faculty of Science, Palacký University Olomouc.

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Graph Theory in Sport Tournaments Scheduling

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Abstract. This work is a summary of my results achieved during academic year 2019/2020. My research during this academic year was focused on topics related to the use of graph theory in scheduling of sport tournaments. The main aim of this research is to provide methods of fair scheduling of incomplete tournaments. Incomplete tournaments are such tournaments that the number of rounds played in the tournament is not large enough to ensure that participants can play each other. Natural condition in this type of tournaments is that strength of opponents of each participant of the tournament should be similar to the strength of opponents of other participants. This can be modeled in graph theory in such way that every participant is represented by a vertex and every match between two participants is represented by an edge between corresponding vertices. Several features of graph theory can be used while solving this problem. For instance edge coloring can be used to divide matches into rounds and vertex labeling can be used to describe the strength of each participant.

Keywords: handicap graph, labeling, tournament

1 Introduction

In graph theory a tournament is usually defined as an orientation of a complete graph. It can be used to describe the results of a round robin tournament. Every participant of the tournament is represented by a vertex. If the match between participants u and v resulted as the victory of u , then the edge between vertices u and v is oriented from u to v .

Round robin tournaments are usual for certain sports. Standard definition of a tournament is suitable to describe for example the results of curling tournaments. First phase of world championships and other curling tournaments is usually played in the round robin system. Moreover the result of a curling match cannot be a draw and the final score of a match is not important, only number of wins and loses is counted in the table. But generally the definition is not suitable for most sports. There must be precisely one edge between u and v and this edge must be directed either as uv (from u to v) or vu (from v to u), so if the match can possibly end with a draw, then it is impossible to describe the result in the graph without changing the definition of a tournament.

On the other hand tournaments as defined in graph theory are quite useless for the problem of scheduling sport tournaments and some other concepts of the graph theory can be used in the scheduling. In scheduling, we do not know the results of matches yet. But we would like to ensure fair conditions for all participants. When we think about it, it is not easy to describe, when the conditions are fair. For instance we should ensure that some participant will not have a series of matches against strong opponents and then a series of matches against weaker opponents while other participant will have alternating matches against stronger and weaker opponents. Also several other problems should be avoided. If there are not equal conditions in a match (for instance in chess match white has an advantage of the first move, in football matches home team has an advantage of home stadium etc.) we should ensure that all participant will have an advantage in the half of matches.

When we examine incomplete tournaments, that means tournaments in which every participant meets only certain number of other participants, some additional requirements occur. Of course, if we want the incomplete tournament to be fair, the strength of opponents of participant A should be similar to the strength of opponents of participant B . At least if the strength of A and B is comparable.

Results achieved during academic year 2019/2020 are presented in next sections of this text.

2 Edge Coloring of Handicap Cubic Graphs

My work on the topic of edge coloring of handicap cubic graphs is joint work with Petr Kovář and Tomáš Michna and is built on previous works of Petr Kovář et al. ([1], [2], [3]). Some results presented in [1] were improved.

Handicap graphs belong to less known topics of graph theory, so the definition of handicap graph is recalled here.

Definition 1. Let $G = (V, E)$ be a graph. Handicap labeling of G is a bijection $f : V \rightarrow \{1, 2, \dots, |V|\}$ for which there exists an integer l such that for every v in V the weight $w(v) = \sum_{u \in N(v)} f(u) = l + f(v)$, where $N(v)$ is the neighborhood of vertex v . Graph G with handicap labeling f is a handicap graph.

Thus a graph G on n vertices is handicap graph if and only if all numbers $1, \dots, n$ are used as vertex labels and for every vertex i its weight $w(i)$, given by the sum of labels of all neighbors of vertex i , is equal to the label $f(i)$ plus a constant l (while l is the same for every i).

Handicap graphs are among labeled graphs, which can be used in scheduling of incomplete tournaments. Handicap cubic graphs can be used to schedule tournaments in which every participant plays three matches. Generally in handicap graphs we can approach to fair conditions for all participants when we fulfill several requirements. Handicap graph should be connected to ensure that there will not be separate group of better or worse participants, which will play together and will not meet any of other participants. The other condition is to get the best possible edge coloring – ideally coloring with k colors for k -regular graph to

ensure that there will be k rounds and each participant will play in each round. Now the question for cubic graphs is: for which number of vertices n it is possible to create handicap cubic graph, that is edge 3-colorable and connected?

From previous work of Petr Kovář et al. [1] it is known that there exists such handicap cubic graph for $n = 8$, $n = 16$, $n = 24$, $n = 32$ and $n = 34$. For all other $n < 35$ no such graph exists. For higher numbers of vertices it is shown (with given construction) that there exists such graph also for all following $n \equiv 0 \pmod{8}$ [1]. From parity principle it is clear that for any odd n such graph does not exist.

Our follow-up work showed that for every even $n > 30$ there exists 3-regular connected handicap cubic graph colorable by 3 colors and we also know how to construct such graph for every even $n > 30$. So when we combine together results from [1] with our new results, we can summarize it in the following theorem.

Theorem 1. *There exists a 3-edge-colorable connected handicap cubic graph $G = (V, E)$ iff the number of vertices of G is 8, 16, 24 or any even number greater than 30.*

3 Making Connected Graphs from Disconnected Graphs

Other part of my research is trying to solve the following problem: we have a disconnected graph $G_1 = (V, E_1)$ with some labeling f . Note that G_1 can be a subgraph of another graph G on more vertices, so labels in G_1 do not have to be exactly numbers $1, \dots, |V|$. Can we transform G_1 into graph $G_2 = (V, E_2)$ which is connected and labels and weights of each vertex are the same as in G_1 ? If yes, how? For lots of graphs it is impossible. For certain graphs it is possible, but it is difficult to find the construction that can be used to transform G_1 into G_2 . Work on the easiest possibility of transformation, transformations of 2-regular subgraphs, is already in progress with certain outcome.

I created a function in Matlab which can find 2-regular graphs which are suitable to be transformed to a different 2-regular graph. When such suitable 2-regular graph H is a subgraph of some disconnected graph G_1 , then the transformation into graph G_2 can be made and possibly G_2 will be connected (however this is not guaranteed, it depends on properties of G_1 and H).

The results were already obtained for cycles on at most 10 vertices. The result is that there exist cycles on 9 vertices which can be transformed into a different cycle on 9 vertices with no changes of labels such that weights of all vertices remain unchanged. But for other numbers of vertices to 10 such single cycle does not exist. However, the result on 9 vertices is not useful, because when we transform single cycle into a different cycle on the same vertices, then the connectivity of a graph is unchanged. Transformation between single cycle and more cycles of shorter length would be more interesting. Currently we know that a collection of cycles C_4 can be transformed into another collection of cycles C_4 , which can be useful in some graphs.

Theorem 2. *Let $G_1 = (V, E_1)$ be a 2-regular graph and $|V| \leq 10$. If G_1 is a single cycle, it can be transformed into another 2-regular $G_2 = (V, E_2)$ with the same label and weight of each vertex only in the case that $|V| = 9$. Furthermore for labels of vertices along the cycle $v_1, v_2, \dots, v_9$ the following equation system must be fulfilled:*

$$\begin{aligned} v_1 + v_8 &= v_5 + v_7 \\ v_2 + v_9 &= v_5 + v_6 \\ v_3 + v_5 &= v_8 + v_9 \\ v_4 + v_6 &= v_7 + v_9. \end{aligned}$$

Figure 1 illustrates how a cycle on 9 vertices can be transformed into a different cycle on 9 vertices with the same label and weight of each vertex.

Fig. 1. Transformation of cycle C_9 .

4 Conclusion

During academic year 2019/2020 I focused on the topics related to the scheduling of sport tournaments. Some previous results were extended in cooperation with Petr Kovář and Tomáš Michna, however these improvements are not published yet in an article. The other part of this WOFEX article on transformations of disconnected graphs should be included in my Ph.D. thesis which I write nowadays. The progress of this research is not very substantial yet, but some research regarding 2-regular subgraphs is already done.

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Determination of Spam over Internet Telephony detection parameters

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Abstract. In this paper the most suitable parameters were determined to discover the behavior patterns between SPIT call and the regular calling VoIP user. These parameters were consequently used to model an innovative approach to SPIT detection in Internet Telephony using the elements of artificial intelligence. For this purpose, data from various sources were collected and processed, especially from mobile phone users and the VoIP provider.

Keywords: analysis, SPIT, spam, telemarketer, VoIP

1 Introduction

This paper is devoted to data processing and its preparation for integration into machine learning algorithms. Since we are convinced that every participant in the telecommunications chain, like in real life, manages a set of learning patterns, it is necessary to determine these distinguishing features from the various datasets.

You will be familiarized with all datasets that were obtained from different sources in different formats. This data had to be processed to the unified form, to find individual parameters that distinguish a regular user from a spammer in a VoIP network and then bring the results on the input of machine learning algorithms. The following subchapters will present the complete procedure of the determination process of individual parameters where different statistical and data mining methods were used.

2 Regular user Call Detail Records

As you probably know, nowadays it is not a simple matter, or in some cases, it is almost impossible to keep or gather Call Detail Records (CDR) according to the laws or recent GDPR regulation. I did not want to work with randomly generated CDR records, I had to somehow gather the records by myself. Subsequently, I found the solution by asking for call logs directly from my family, friends, colleagues and also some random people who were willing to help me.

I took advantage of the possibility that each phone stores its CDR records in the phone memory from where they can be extracted with the free download application for Android phones or with the purchase of special software for downloading data from iOS phones. In total, I managed to get 36 CDR records from people who made or received 26328 phone calls in total.

Subsequently, I managed to obtain two quite comprehensive datasets that were free to download from the Internet from the crawled website, which we processed into the form I required. First of all, I obtained data that were part of the studies project at the University of Strathclyde (UoS) [2]. This dataset was gathered by social sensor software (Nodobo), developed for Android phones. The telephone subscriber database consists of data that has been extracted from a total of 27 mobile phones. This dataset of mobile phone usage consists of 13035 CDR records.

The last dataset [1] I were able to get was a set of CDR records, that consist of detailed call records from 342 mobile phones that were recorded over the period of one month. These 342 users together recorded 33726 calls over the mentioned period.

3 Telemarketer CDR records

As I mentioned before, to obtain data from VoIP providers is a very difficult matter nowadays. However, we managed to get two datasets from the VoIP provider, which provides its services to the vendors selling their products by phone calls.

The first dataset is a set of CDR telephone records that were made by 47 telemarketers for the period of May 2018. This file contains a total of 109776 telephone calls.

The next dataset contains a total of 596855 CDR records, which were made by 125 call center employees for the period from February 2019 to May 2019, a total period of three months.

4 Data processing

After processing all data, I created profiles of individual users, which were consequently subjected to statistical and data mining methods. In the following lines, we will look at the average profiles of the telemarketer and regular users of the telecommunication chain. In Table 1, you can see a comparison of the behavioral parameters of both types of users. These are average statistics that show us how a participant behaves within a one day.

The processed data shows that the average telemarketer records 180.58 calls per day. This number of calls is 43.41 times higher than the average number of calls made by an average user, who averages 4.16 calls per day. The average number of incoming calls for an average telemarketer is only 5 % of the total number of calls. Outgoing calls (95 %) account for the bulk of his efforts to sell

as many products over the phone as possible. In the case of an ordinary user, the ratio of incoming and outgoing calls is almost equal, where the number of incoming calls is 49 % of all calls, and the proportion of outgoing calls is 51 %.

Table 1: Average day statistics comparison (SPIT/Regular)

Investigated variable	SPIT	Regular
Call count	180.58	4.16
Incoming calls	9.62 (5 %)	2.04 (49 %)
Outgoing calls	171.94 (95 %)	2.12 (51 %)
Answered calls	92.25 (51 %)	3.89 (93.5 %)
Not answered calls	88.33 (49 %)	0.27 (6.5 %)
Incoming answered	3.61 (37.5 %)	1.92 (94.1 %)
Outgoing answered	89.06 (52 %)	1.97 (92.9 %)
Incoming not answered	6.01 (62.5 %)	0.12 (0.06 %)
Outgoing not answered	82.89 (48.2 %)	0.15 (0.07 %)
Average duration	93.45	132.4
Incoming calls average duration	89.71	135.27
Outgoing calls average duration	97.19	129.53
Incoming calls unique numbers	122.17 (6.5 %)	18.25 (49.6%)
Outgoing calls unique numbers	1768.22 (93.5 %)	18.57 (50.4%)

Another significant difference between user statistics confirms the ratio of received and missed calls. The probability of a successful telemarketer call is only 51 %. For a typical user, this probability is up to 93.5 %. The probability of receiving an incoming call is also much higher for a regular user (94.4 %) than for a phone vendor (37.5 %). The called party is more likely to answer the call to an ordinary subscriber (92.9 %) than a telemarketer whose success rate is 52 %.

We will now focus on the average call time. The average telemarketer call time is 93.45 seconds. An average phone user has an average time of 132.4 seconds, which means that an average call lasts 1.42 times longer from the SPIT user.

Another parameter examined is the number of unique phone numbers that were recorded in the CDR records of each user. It will be another significant parameter in the classification of individual users, as the difference between the individual values is very noticeable. The unique incoming/outgoing telephone numbers ratio is 0.07 for a telemarketer. This is because the telemarketer is calling a huge number of new numbers for sale purpose. In the case of an ordinary user, the value of this ratio is 0.5, since it maintains telecommunications relations only with a specific range of familiar telephone numbers.

Subsequently, the number of calls was statistically analyzed at each time interval of the day. I assume that since this is the call center data, many of the salespeople's calls will be time-bounded. Since it is a company employing people,

we should be able to determine the working hours of individual employee profiles from the analyzed data.

Based on other statistics, I found out, that the average telemarketer will make most calls between 6 AM - 6 PM, (Fig. 2) which signifies 12 hours of work. The amount of calls after 6 PM rapidly converges to zero, which indicates that the shift ends. A slight decrease in the number of calls can also be noticed by 12 PM, which probably symbolizes a lunch break. Individual employee profiles differ, from the data obtained, it is possible to determine whether he is a potential part-time worker or full-time worker.

There is a slight increase in the number of calls up to the evening hours for the average user. At the time (6 PM) where the telemarketer calls drop, the normal user is increasing the call frequency.

Fig. 1: Average call count in specific hours (Regular)

Fig. 2: Average call type count in specific hours (SPIT)

Similarly to the previous case, when a caller makes more calls during the day and relatively less at night, we assume that callers show different call behavior patterns on weekdays and weekends. The results of the statistical analysis for each day of the week are shown in Figure 3. From the processed SPIT data, it

is evident that the number of calls does not fluctuate much on weekdays, but the number of weekend calls is only 0.4 %, unlike a regular user, whose weekend calls account for an average of 17% of total calls.

Fig. 3: Comparison of average call count in specific days

In Figure 5, the number of not answered calls also confirms the absence of call center employees at work. During the working week, the successful call ratio is 49.19 %, while during the weekend, the successful call ratio is only 8.3

In terms of incoming and outgoing calls (Fig 6., Fig 7.), The SPIT user is characterized by a huge difference in making many outgoing calls at the expense of a low number of incoming calls. For a regular user, the ratio of these values is balanced on a daily basis.

Fig. 4: Answered (Regular)

Fig. 5: Answered (SPIT)

Fig. 6: In/Outgoing (Regular)

Fig. 7: In/Outgoing (SPIT)

5 Conclusion

This paper partially deals with the main research interest of my dissertation thesis that applies machine learning algorithms to SPIT detection. Many research papers dealing with SPIT detection are not based on real data and are mainly dedicated to one particular way to solve, suppress, and possibly to avoid the SPIT attack.

My future dissertation thesis only deals with real gathered data. These data in different formats were gathered, processed and analyzed from various sources as VoIP provider, data collected from my honeypots, data from the mobile devices of people using mobile network services as well as data from multiple sources that were available online. This part of the thesis describes the data processing and its preparation for integration into machine learning algorithms. In future thesis, which I'm going to defend this year, I describe more parameters to reach high accuracy innovative detection mechanism.

6 Awards

Dean's appreciation for his results in Ph.D. study 2019

Publications

1. Behan, L., J. Rozhon, and M. Voznak. 2019. "Implementation of a VoIP Simulation Network by using Stochastic Process Methods.". doi:10.1109/DS-RT47707.2019.8958656.

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Optimized IoT Architecture Based on Fog Computing: An Overview

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Abstract. Over the years, computing paradigms have evolved from distributed and grid to cloud computing that has become a common approach in the Internet of Things (IoT) area. However, cloud computing has certain disadvantages that allow the emergence of new computing paradigms, such as fog computing. The main reasons to engage fog computing are location-awareness and support of time-sensitive applications. These features are significant for many applications, especially in IoT filed. The main aim of this study is to design an optimized IoT network architecture supporting the fog computing paradigm.

Keywords: computing paradigms; Internet of Things; LPWAN; LoRaWAN; fog computing; network architecture

1 Introduction

Although the concept of interconnecting computers and networks together in a manner to monitor and control devices has existed for decades, the Internet of Things (IoT) area is becoming increasingly popular in recent years. Considerable popularity of this area is due to novel technologies and market trends that allow the interconnection of more devices, which can be smaller, simpler, and less expensive at the same time [1]. With this expansion of the IoT field and unique requirements of the IoT devices, the development of new technologies aiming at achieving as low energy consumption as possible while maintaining a certain quality of transmission. The choice of appropriate technology for a particular application is important activity for any IoT deployment. For example, Low-Power Wide-Area Network (LPWAN) technologies are designed to enable long-distance wireless communication with the lowest power consumption. Devices designated for this kind of network technology are mainly placed in a difficult to access area and are powered by a battery. LPWAN technologies are primarily designed to transfer a small amount of data at once, and they include technologies such as LoRa, SigFox, or NB-IoT. The LoRaWAN is an open standard, and it allows us to build private networks [2]. For comparison, Sigfox [3] and NB-IoT is managed by a network operator. These network technologies implement a cloud computing paradigm that has several drawbacks, and it is not sufficient for some IoT use cases.

The paper is structured as follows: firstly, we briefly describe LPWAN technologies in the introductory part, the second section provides an overview of the LPWAN architectures. The section number three includes an explanation of the purposed optimized network architectures. Finally, the forth section summarizes our conclusions.

2 LPWAN Architectures

In this subsection, different network architectures are discussed to show the actual state of the area.

2.1 Cloud Computing Based Architecture

The cloud computing paradigm offers resources (e.g., computing, storage, services, and applications) over the Internet. It provides three service models - SaaS (Software as a Service), IaaS (Infrastructure as a Service) and PaaS (Platform as a Service). The benefits of cloud computing are reduced management efforts, on-demand resource allocation, convenience, and flexible pricing based on usage of services (pay-as-you-go) [4]. In the field of LPWA networks, this is the most common approach, which is not always appropriate. The fundamental limitation is a considerable physical distance between the cloud service and end-device, which increases the average network latency and jitter, and causes location-unawareness. Therefore, cloud computing is inappropriate for time-sensitive applications, such as many smart city applications, healthcare applications, or vehicular networks.

2.2 Edge Computing Based Architecture

The edge computing based architecture tries to eliminate the weakness of high latency. This elimination is achieved by transferring computing power closer to the end-device - to the edge of the network. Edge is a term representing an intermediate element between a data source and a cloud. The main idea of edge computing is to perform computation in the closer physical distance to data providers. Especially the data providers in IoT or M2M area (in most cases, a variety of sensors) generates a huge amount of data per a short period [5]. The edge computing approach enables saving bandwidth and computational time, which is crucial in such applications where sending that amount of data to the cloud service would be impossible.

2.3 Fog Computing Based Architecture

The concept of fog computing was introduced by Cisco Systems in 2012. Similar to edge computing, the fog computing paradigm brings computation and storage closer to the end-node with the benefit of low latency, high bandwidth, and location-awareness [6]. The name fog is an analogy to the mentioned lower

proximity to the data source, which we can define as cloud closer to the ground. Typical for fog computing is a cooperation with the cloud. In this manner, tasks requiring low latency or location-aware can be processed at the edge of the network, while the cloud connection can be used for more complex tasks or as storage for historical data. Key differences between edge and fog computing are [7]:

- Fog computing cooperates with the cloud, whereas edge computing exclude such cooperation
- Fog computing works with hierarchical architecture, whereas edge computing tends to consists of a small number of layers
- Fog includes computation, networking, storage, control, and acceleration, whereas edge commonly offers only computation

3 Network Architecture

First of all, very important is the design of the IoT network architecture as it will affect the overall properties offered to end-nodes. Because the resulted architecture will support fog computing, it will have three-layer architecture [8]. Generally, the lowest layer includes IoT end-nodes, which are intended to collect information from a surrounding environment. The higher layer is called the fog layer and includes fog-nodes that will be designed for autonomous decision making according to the processed data. The highest level is named the cloud layer, and as a name suggests, it will include a cloud server as an addition to the fog-nodes. The general three-layer architecture can be seen in Figure 1

Fig. 1. Three-layer fog computing architecture

As the network architecture will correspond to the fog computing paradigm, some properties must be preserved:

- Location-awareness - due to the closer proximity to end-nodes, the network can react to different end-nodes needs and adapt to their requirements.
- Efficiency - is given by the full cooperation between the fog and the cloud layer. If necessary, the computation, as well as storage, can be transferred from the fog layer to the cloud layer and vice versa. This transfer can happen in many situations, such as unavailable resources
- Lower latency - the main advantage of fog computing. The lower latency can be achieved by processing at the network edge and can be used to add support for time-sensitive applications, such as alarming systems or health monitoring systems

The LoRaWAN enables the creation of private networks and, thanks to its openness, allows modifications of the network architecture [9]. The standard LoRaWAN network architecture consists of the following components [2]:

- Gateway - serves as a bridge between the low power LoRaWAN network and high bandwidth IP network like Ethernet, Wi-Fi, or Cellular. The gateway works as an entry point to the network for end-nodes, converts their RF packets to IP packets, and relays them.
- Network server - manages the network, filters redundant received packets, performs security checks and controls adaptive data rate, etc. It serves as an interface to the application server.
- Application server - a final destination for the data. It determines what to do with the received data, for example, store them in a database and visualize in certain web application.

According to the above LoRaWAN standard network architecture, from the end-nodes point of view, the gateway is the closest part of the architecture, and it only works as a passive part of the network from the perspective of data processing and computing. It just takes the data, transforms them into the form suitable for subsequent transmission and processing, and forwards them to the network server. The application server is located somewhere in the Internet and solves all the data processing, computing, and storage. The network architecture corresponds to the cloud computing paradigm scheme.

The main idea of this study is to take the LoRaWAN basic elements and transform them into the fog computing paradigm supporting architecture. To fulfill this requirement, several changes must be realized. The main challenge is payload encryption, which is done as end-to-end. That means a gateway itself does not have access to the decrypted data, and because of that, data storage and processing are impossible. One solution could be integrating the network server and application server into every gateway. The other solution could be the involvement of the master-slave approach, where slave gateways would work as standard LoRaWAN gateway and transfer all traffic to the master gateway. Master gateway would integrate network and application server to decrypt payload and control data processing by the slave gateways. However, a solution

could also be a negotiation between gateway and application server during the first communication with an end-device and then storing the necessary keys in the secured database located on the gateway. In this manner, request from a gateway to the application server would be executed only at first communication with end-device or in case of need. Thereby, the interaction with the application server would be lowered to the minimum. Because there is not only one solution to this problem, the choice of appropriate network architecture design is a crucial task, and it needs to be compared in simulations.

4 Conclusions

While cloud computing does not inherently meet conditions to support time-sensitive applications and location-awareness, the fog computing paradigm uses a different approach. Instead of concentrating all the computing power and storage into the cloud layer, it inserts an intermediate layer called the fog. In this paper, we introduced different approaches for the optimized IoT network architecture. The architecture design corresponds to the fog computing paradigm. Like that, it includes not only the cloud layer but also the fog layer with appropriate computational and storage resources.

5 Publications

Part of the study described above was published as part of my rigorous thesis. Another publication: Jalowiczor, J., Gresak, E., Rezac, F., Rozhon, J., Safarik, J.: Development and deployment of the main parts of LoRaWAN private network. *Autonomous Systems: Sensors, Processing, and Security for Vehicles and Infrastructure*, 2019.

6 Participation in research projects

Modular Open Source Secure Mobile Communication, The National Cyber and Information Security Authority (NÚKIB), 2019 – 2021, junior researcher (04/2020 – still active).

Reg. No. VI20172020079 – Secure Gateway for the Internet of Things (SIoT), Ministry of the Interior within program Security research for needs of the Czech Republic, 2017 - 2020, my position: junior researcher (10/2017 – 03/2020).

Reg. No. CZ.01.1.02/0.0/0.0/16_084/0009815 –Development of Industrial Sensors and Extension of IoT Services Portfolio, Ministry of Industry within program APLIKACE III., 2017 - 2020, my position: junior researcher (10/2019 – 03/2020).

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Measurements of Changes of the Energy Propagation in SM Splitters due to High-Power and Gamma Radiation Load

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Abstract: In the article, ageing degradation processes on photonic splitters (1:2) are studied. One splitter is loaded by gamma radiation (^{60}Co) and the other by high-power load (stepped Er^{3+} amplifier). An evaluation is performed by BP109-IR device through an energy propagation of mode LP₀₁ and its parameters FWHM_{eff} and MFD_{eff} . Each splitter branch was placed at 0 and 1 cm from the mobile head of the BP109-IR and then the parameters were measured. Both measured splitters have the same split ratios, but their measured values are different, therefore it is technologically impossible to produce splitters with the same parameters, which implies that the effect of degradation mechanisms will be different.

Keywords: ageing, FWHM_{eff} , gamma radiation, LP₀₁, MFD_{eff} , power.

1 Introduction

Photonic components have been deployed to the communications area for a long time. In recent years, there is seen a very rapid increase in the use of optical components for different industries, and this provides new challenges. One of the industries where optical components (optical fibers, amplifiers, couplers, etc.) are used, are nuclear power plants, where they play a dual role, namely high data communication and sensing (monitoring of physical quantities). These optical components are installed near radioactive areas, so it is necessary to monitor the photonic components with regard to increased radiation. Ageing of these components can break lossless communication or damage optical sensors. Accelerated ageing of optical splitters 1:2 (90/10) that will be exposure to gamma radiation (^{60}Co) and by the help of high power (2-stage Er^{3+} amplifier) it can be simulated a quality and endurance in time domain. Gamma radiation exposure is one way how to monitor the accelerated ageing and its effects on components. The power load and simulation test the effect of high pulse powers, which enter optical components. In the following sections of the article, methods of

accelerated ageing of the optical splitters (1:2) by high-power load and gamma radiation are described [1-4].

2 Measurement method and ageing of optical splitters

This article is focused on parameters FWHM_{eff} and MFDeff of energy propagation in mode LP01 in SM optical splitters. Two SFT-S35-01x02-10 CM1-NPC-NPC splitters with split ratio 10 (first branch)/90 (second branch) were measured and compared.

2.1 High-power load

The splitter (optokon1) was loaded using a three-stage fiber optic system based on EDFA amplification fibers. Further information on the constructed amplifier can be found in the publication. A measured splitter was connected to the output of the last EDFA amplifier. This splitter was high-power loaded for 67 hours.

2.2 Gamma radiation load

A synthetic radioactive isotope of cobalt ⁶⁰Co with a half-life of 5.2714 years was used for experimental load of the passive optical components. It is produced artificially by activating neutrons of the ⁵⁹Co isotope. The splitters were in the upper part of the shaft and the shaft itself was in the underground tunnel. In the lower part of the shaft, there is a jack for the source material, which irradiate the inserted samples. The source material ⁶⁰Co emits 1.17 MeV and 1.33 MeV gamma rays. The total activity of the source was approximately 2 TBq and the dose rate depends on the sample position to the source. The source was placed in the center of the circle during the irradiation and the samples on circumference. The measured splitter was loaded by 28.4 kGy.

2.3 Evaluation of high-power load

Graphs with values before and after the high-power load are seen in this section, see Fig. 1. The x-axis shows the load. The values of the new (non-loaded) splitter for the first and other branch are on the left side and the values after 67 hours load are on the right side. On the y-axis, there is the effective MFDeff or the effective FWHM_{eff}. For each parameter, there is a graph for the polarimeter head distance of 0 or 1 cm from the scanned sample. A light source was a laser with the wavelength 1309.25 nm.

Fig. 1. Results after measurement of high-power load of splitter *optokon1* for MFD_{eff} and FWHM_{eff} .

After 67 hours of high-power load, the both parameters FWHM_{eff} and MFD_{eff} increased on both scanned axes. The increase on these axes was different in each branch. In the first branch, where 10% of the power is transmitted, the parameter value on the scanned x-axis has increased more than on the y-axis. On the other hand, it is opposite in the other branch, so there is a larger increase on the scanned y-axis than on the x-axis. At a head distance of 1 cm, the increase in the first branch was less than in distance of 0 cm, but in the other branch the increase of 1 cm was greater than in distance of 0 cm.

2.4 Evaluation of Gamma radiation load

There is the measurement of the splitter *optokon2*, which was loaded by gamma radiation. For comparison, the graphs from measurements at both 0 and 1 cm distances for the 1309.25 nm wavelength are presented. In each graph, see Fig. 2, the value of the unloaded splitter is on the left side and value after load 28.4 kGy on the right side on the x-axis. The MFD_{eff} and FWHM_{eff} values for both output branches are displayed on the y-axis.

Fig. 2. Results after measurement of radiation load of splitter *optokon2* for MFD_{eff} and FWHM_{eff} .

3 Conclusion

The *optokon1* splitter before high-power load, the output branch (which transmits 90% of the power) has the FWHM_{eff} and MFD_{eff} parameters of 100 or more μm larger than the first output branch. At the distance of 1 cm, this difference was below 100 μm . The all values increased after 67 hours of high-power load. For both branches at a distance of 0 cm, the values increased approximately the same, i.e. around 50 μm . At a distance of 1 cm, there is already a difference on the other branch, in which the values grew higher by more than 100 μm for FWHM_{eff} and 150 μm or more for MFD_{eff} . In the *optokon2* splitter, there is also a difference in the pre-load condition that the other branch has values slightly larger than the first branch. After that, the splitter was exposed to the gamma radiation dose of 28.4 kGy, all values dropped. With a 1309.25 nm wavelength source used, the values in the first branch (10% power passes) were dropped more than the MFD_{eff} measurements at 0 cm each, where the parameter in the other branch dropped more. From these results, it is clear that each kind of load on the splitters has a different effect on its properties.

Acknowledgement

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LoRaWAN Infrastructure for Hydro-meteorological Sensors

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Abstract. The paper proposes infrastructure for hydro-meteorological sensors. This experiment was focused on Smart Metering and Smart City domain in the Baltic sea. The communication was working with LoRa technology. The paper aims to develop functional units to deploy the whole ecosystem end-nodes, infrastructure, and applications. The project was done during a professional internship at the University of Klaipeda.

Keywords: WAN, LoRa, Infrastructure, experiment, internship, IoT

1 Introduction

We developed communication systems consisting of sensors that require the proper design to achieve more efficient signal propagation. A comprehensive communication infrastructure complemented these sensors. This concept reflects the needs of modern communication systems.

Data was transmitted wirelessly via LoRa technology to achieve the lowest power consumption at a low cost. It ensures communication over a long distance [1–6]. LoRa operates on the unlicensed band and offers high noise endurance. Modulations are based on the spreading factor principle.

2 Infrastructure

The article describes the development and implementation of a complete ecosystem. We developed the infrastructure on two gateways and five hydrometeorological sensors. Low energy microcontrollers ATmega and wireless module supporting LoRa technology were used in our experiments [7–9].

Figure 1 describes the backend systems of The Things Network. Are responsible for routing Internet of Things data between devices and applications. IoT (Internet of Things) network requires gateways as a bridge between specific radio protocols and the Internet. The Things Network is positioned between the gateways and the applications and takes care of these routing and processing steps.

Fig. 1. Network Architecture [10]

The gateway was designed for outdoor use. We placed it in the industrial box with IP65 protection, including Lightning Arrester and OverVoltage protection, to ensure sufficient protection from harsh environmental phenomena.

The network server was based on internal infrastructure. The network server’s main objective is to remove records duplication and process received frames by each gateway. The Fig. 2 visualizes how the ChirpStack LoRaWAN Network Server components are connected.

Fig. 2. ChirpStack architecture [11]

The application server was used for data visualization. It was a necessary part of the LoRaWAN infrastructure and used for the decryption of application payloads.

3 The goals

The goal internship objective was the development of sensor systems in IoT areas for use in a closed ecosystem. The preferred solution was to build internal infrastructure on a closed network. We did not use the third-party cloud solution.

We realized the multifunction system for wireless meteorology monitoring enabling data acquisition from the sensor. We collected data from the wind speed sensor, wind direction sensor, rainfall sensor, relative humidity sensor, temperature sensor, pressure sensor, light intensity sensor, UV index sensor, and thunderstorm detection sensor.

4 Knowledge & skills

We used modern technology and created an innovative product based on modern technological procedures. During the development of the product, we gained general knowledge about the design and realization of LoRaWAN system. We have identified complex problems and gained related information and skills during development. We have demonstrated our ability to think analytically, understand, and process a wealth of scientific and technical information.

5 Conclusion

We successfully implemented a functional LoRaWAN infrastructure at the Klaipeda University campus. Two LoRaWAN Gateways have been integrated at the campus to form a bridge between devices and the Network Server.

The Network server is based on its internal infrastructure. Therefore there is no need to communicate with a third parties cloud solution. The Application Server provides a web-interface and APIs for the management of users, organizations, applications, gateways, and devices. Test Sensors are based on Adafruit Feather 32u4 development board with LoRaWAN RFM95 wireless chip. The sensor is used for measuring the coverage of LoRAWAN technology in the field.

The weather station is based on Moteino Mega development board with LoRaWAN RFM95 wireless module. It measures weather conditions. The weather stations have integrated sensors to measure temperature, relative humidity, barometric pressure, wind direction, light intensity, and UV index.

The station's external mechanical parts were printed on a 3D printer with a particular filament for outdoor overhead. The electronic circuits were milled on a PCB milling machine. We developed a cross-platform web application created specifically for the weather station. The application provides data in graphical form and displays it in real-time using the MQTT protocol. The web application

is based on Angular, which is a TypeScript-based open-source web application framework.

6 Acknowledgment

The research received support from the Erasmus+. Is it a European Union programme for the period of 2014-2020 and follows on from the successful Lifelong Learning and Youth in Action programmes. Erasmus+ combines a number of existing educational programmes in one, builds on the experience acquired by its predecessors while introducing a number of new features. The Erasmus+ programme encourages student and staff mobility throughout Europe and promotes multilateral cooperation between higher education institutions in Europe, and between higher education institutions and enterprises.

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Fiber-optic sensors in civil engineering

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Abstract. This article deals with the theme of using the fiber-optic sensor for monitoring parameters of rocks disintegration of small and large in scale. The sensor is based on the fiber-optic interferometer. The basic advantage of the presented sensor against the conventional seismic station can be a small size, electrical passivity, immunity to electromagnetic interference, and low attenuation of optical cables, which allows the separation of the measuring point and evaluation. The presented article also summarizes the author's activities during four years of his study, his research and development activities related to the studies and research projects.

Keywords: optical fiber, sensor, interferometer, civil engineering

1 Introduction

Allow me to introduce myself. My name is MSc. Stanislav Zabka. I am a doctoral student at the Faculty of Electrical Engineering and Computer Science at the Technical University of Ostrava. My education program is called Computer Science, Communication Technology and Applied Mathematics and field of study called Communication Technology. I am also working (part-time job) as a Java developer in big software corporation and I am using these skills to achieve the best results when it comes to creating software that handles and computes big data from sensors. In my fourth year of study, I am extended my knowledge especially in the field of civil engineering. I am also a participate of five research projects. To date 7/2020, I have a total of 21 accepted or published publications and 5 utility models.

2 About my work and dissertation work

During the first three years of my study, I was helping to design a novel type of sensor based on the fiber Bragg grating sensor for biomedical applications [1] which can be used in the harsh (MR) magnetic resonance environments (1.5 T and 3 T). Now I am preparing my dissertation thesis which will describe this sensor and its application in biomedical, especially for breath triggering.

In my fourth year of study, I am extended my knowledge especially in the field of civil engineering. My task was to provide the first steps and information about using the

fiber-optic interferometric sensor as an alternative sensor against convectional seismic stations.

Sensor technologies based on fiber optics can form new alternative method of implementing the monitoring of seismic effects, namely with high added value. Fiber-optic interferometric sensors (for example Mach-Zehnder, Sagnac, Michelson or Fabry-Perot) are well known for their ability to perform highly accurate measurement of differences of optical paths caused by a change in the reflective index in the arm or arms of the interferometer, e.g. by physical displacement (vibration) or acoustic wave. The sensitivity of the interferometer depends on the length of the fiber-optic in the measuring arm and can be changed by this. Thanks to its principle, it is one of the most sensitive sensors, which can also have a wider frequency range than in practice commonly used seismic stations. For a basic understanding of the function of an interferometric sensor, the principle of the function is presented below on the simplest case, namely a two-arm Mach-Zehnder interferometer. Phase differences between two optical waves whose paths are the same (maximums and minimums) or very similar (different interference patterns) are monitored. According to relation (1), a total of three parameters can be defined (refractive index n , wavelength λ and geometric length L representing the optical path), which can cause a phase change marked $\Delta\phi$ occurring in the measuring arm of the interferometer due to impact of the measured value. [2]

Fig. 1. Schematic diagram of the basic Mach-Zehnder interferometric sensor.

Seismic manifestations consisting of frequencies (ω) that affect the measuring part (L_1) of the interferometer. The result is a change in the optical length of the interferometer arm (can be defined as the product of the geometric length L and the refractive index n). [2-4]

According to relation (2), the resulting phase change marked $\Delta\phi$ can be defined as:

$$\begin{aligned}\Delta\phi &= 2\pi L n/\lambda \\ \Delta\phi &= kLn, \\ k &= 2\pi/\lambda.\end{aligned}\tag{1}$$

$$\Delta\phi = 2\pi \frac{n}{\lambda} \delta L + 2\pi \frac{L}{\lambda} \delta n - 2\pi nL \left(\frac{1}{\lambda^2}\right) \delta\lambda.\tag{2}$$

My research and analysis aimed to find a suitable material composition of the two-arm interferometer membrane, as well as the location, mounting and installation of the measuring arm and reference arm, including passive fiber optic elements (couplers, insulators) within the internal structure of the interferometric type sensor. Primarily, my effort was to find the optimal dimensions and materials of the resonant membrane of the interferometer. Everything was created concerning low-frequency ranges related to vibrations (up to 200 Hz) according to the standard ČSN 73 0040 - Loading of construction objects by technical seismicity and their response. The aim was to achieve maximum transmission of vibrational oscillations to the measuring part of the two-arm interferometric sensor and at the same time to design a reference part of the sensor enabling maximum isolation of the reference arm from external influences

A real photo of the first proposed type of interferometric sensor (I participated in the development) is depicted in Figure 2. This type was tested in real conditions (a measurement of ground vibrations due to the vibratory roller).

Fig. 2. Real photo of the proposed interferometric sensor.

The research of the material composition of the membrane, from which the two-arm interferometric sensor was formed, was chosen to maintain the full dielectricity of the resulting sensor and to be able to operate it in potentially hazardous environments. The length of optical fibers in the arms of the interferometer was chosen based on laboratory research 3 m, the research was focused on finding the length of the arms to achieve maximum sensitivity in the frequency range up to 200 Hz. The entire sensor has been encapsulated to be resistant to weather conditions (especially temperature, dust, rain).

The initial results from the application of the assembled type of interferometric sensor were realized as a measurement of ground vibrations due to the vibratory roller. As a reference was used conventional seismic station entitled BRS32. [5]

The results of experimental measurements are presented in the frequency domain. Below (Fig. 3) are presented examples of frequency spectra of the realised experiment where we can see spectra from the two-arm interferometric sensor and used conventional seismic station BRS32.

Fig. 3. Frequency images of the passage of the vibratory roller: (a) interferometric sensor; (b) conventional seismic BRS32 station.

It can be seen that we can identify identical peaks (on the same frequency) in the frequencies spectra which correspond to the compaction frequency of the vibration roller. Research is now underway to get as much data as possible.

Below (Table 1) I present a comparison of the basic parameters of a used two-arm interferometric sensor and conventional BRS32 seismic station. I do not present the cost of the proposed interferometric sensor, because during my follow research I need to gain more information to clarify preliminary price.

Tab.1. Comparison of the basic parameters of a used two-arm interferometric sensor and conventional BRS32 seismic station.

	Frequency Range (Hz)	Size (cm)	Weight (kg)
BRS32	4.5-100	27 x 24.5 x 13	4.6
Interferometric sensor	3-1500	24 x 22 x 12	3.4

3 Projects

As part of my studies, I was actively involved in solving 7 projects, namely:

- 1. Measuring the weight of trash bins, while being lifted by the truck.
- 2. SGS SP2017/79 - New types of photonic systems for IoT.
- 3. SGS SP2018/184 - Optical communication technologies and sensors.
- 4. SGS SP2019/80 - New Fiber Optic Technologies for Comm. and Sensors.
- 5. SGS SP2019/85 - Advanced Signal Processing Methods.
- 6. SP2020/38 – Fiber-optic technologies for industrial applications.
- 7. SP2020/156 - Advanced Signal Processing Methods II.

Now we prepared the project (TREND Programme) to the Technology Agency of the Czech Republic (TA CR). This project focuses on applied research and experimental development of new monitoring techniques based on fiber-optic sensors during the excavation of underground constructions, during mining blasting or demolition work. The project uses fiber optic-sensors, technologies associated with 5G mobile network and a cloud data storage and processing system using innovative principles in the field of IoT.

4 Publications activities

During the dates 9/2016 and 7/2020, I have a total of 21 accepted or published papers and 5 utility models, please see my Scopus Author ID 57191343671.

5 Pedagogic part and other activities at the Department of Telecommunications

In the winter and summer semester, I was part of courses UDKT (Introduction to communication technologies) and OK III (Optical communications III) as help for academic teachers.

6 Future work

Now I am focusing on the individual subjects of my Ph.D. study and my dissertation thesis. Also, I will be actively involved in the above-mentioned project entitled "Monitoring of parameters of rocks disintegration of small and large in scale by fiber-optic sensors", where my role will focus on construction fiber-optic interferometric sensor.

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Sensing of gaseous analytes via surface waves in the spectral domain

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Abstract. Theoretical study of a new sensing concept based on interference of *s*- and *p*-polarized waves reflected from a one-dimensional photonic crystal (1DPhC), represented by a multilayer structure comprising a glass substrate and five bilayers of TiO₂/SiO₂ is presented. 1DPhC has number of advantages including physical and chemical robustness, enhanced sensitivity, etc. For the system under study we express the reflectance of *p*- and *s*-polarized waves as a function of wavelength of light incident on the prism. Dips in the reflectance spectra represent the coupling of light waves to surface modes and this can be confirmed by sensitivity to refractive index changes at the multilayer-analyte interface.

Keywords: surface electromagnetic waves, one-dimensional photonic crystal, Kretschmann configuration, BK7, sensor, analyte

1 Introduction

Recently, Bloch surface waves (BSWs) have emerged as an attractive alternative to surface plasmon polaritons (SPPs) for sensing applications [1, 2].

BSWs are related to the forbidden bands (band gaps) of photonic crystal. BSW is a surface electromagnetic excitation that exists at the interface between an optically active composite and a homogeneous dielectric. BSW can be excited at any wavelength by suitably changing the refractive index and thicknesses of the dielectric materials in the multilayer structure.

BSWs are non-radiative electromagnetic modes, i.e., they do not exist in free space on their own. The BSW wave vector is longer compared to the free space wave vector at a given frequency. Thus, we need to provide an additional momentum to the wave vector of the incident wave so that it can satisfy the phase matching condition with the BSW wave vector. This is usually done by a prism coupling technique, either using Kretschmann configuration or Otto configuration. Here Kretschmann configuration is used. BSW using the prism coupling is excited when the parallel wave vector (β) on the top of the 1DPhC is equal to k_{BSW} as given by

$$\beta = k_{\text{BSW}} = k_0 n_{\text{glass}} \sin \theta \quad (1)$$

where $k_0 = \frac{2\pi}{\lambda_0}$ is the free-space wave number, n_{glass} is the refractive index of the prism, and θ is the angle of incidence of the incident wave.

2 Computation method

To express the optical response of structure, which is described in following section, a matrix method is used.

Since the whole medium is homogeneous in the z direction (i.e., $\partial n/\partial z = 0$), the electric field that satisfies Maxwell's equations has the form

$$E = E(x)e^{i(\omega t - \beta z)}, \quad (2)$$

where β is the z component of the wave vector and ω is the angular frequency. We assume that wave is propagating in the xz plane, and we further assume that the electric field is either s - or p -polarized. If we represent the amplitudes of $E(x)$ as column vectors, the column vectors of different sides of j -th interface are related by

$$\begin{pmatrix} A_j \\ B_j \end{pmatrix} = \mathbf{D}_j^{-1} \mathbf{D}_{j+1} \begin{pmatrix} A_{j+1} \\ B_{j+1} \end{pmatrix}, \quad (3)$$

where $\mathbf{D}_j$ are dynamical matrices given by

$$\mathbf{D}_j = \begin{cases} \begin{pmatrix} 1 & 1 \\ k_j & -k_j \end{pmatrix} & \text{for } s \text{ wave,} \\ \begin{pmatrix} 1 & 1 \\ \frac{k_j}{n_j^2} & -\frac{k_j}{n_j^2} \end{pmatrix} & \text{for } p \text{ wave,} \end{cases} \quad (4)$$

where

$$\beta = n_0 \frac{\omega}{c} \sin \theta \quad k_j = \left[\left(n_j \frac{\omega}{c} \right)^2 - \beta^2 \right]^{1/2}. \quad (5)$$

Propagation through the medium of the j -layer is described by the so-called propagation matrix $\mathbf{P}_j$, which is given by

$$\mathbf{P}_j = \begin{pmatrix} e^{ik_j t_j} & 0 \\ 0 & e^{-ik_j t_j} \end{pmatrix}, \quad (6)$$

where t_j is the thicknesses of j -th layer.

The relation between A_0 , B_0 and A_A , B_A can thus be written as

$$\begin{pmatrix} A_0 \\ B_0 \end{pmatrix} = \mathbf{D}_0^{-1} \left[\prod_{j=1}^N \mathbf{D}_j \mathbf{P}_j \mathbf{D}_j^{-1} \right] \mathbf{D}_A \begin{pmatrix} A_A \\ B_A \end{pmatrix} = \mathbf{M}_{\text{tot}} \begin{pmatrix} A_A \\ B_A \end{pmatrix} \quad (7)$$

Here, we recall that N is the number of layers, A_0 , B_0 and A_A , B_A are the amplitudes of plane waves in the input and output semi-infinite media, respectively.

For our structure $\mathbf{M}_{\text{tot}}$ can be written as

$$\mathbf{M}_{\text{tot}} = \mathbf{D}_{\text{BK7}}^{-1} (\mathbf{D}_{\text{TiO}_2} \mathbf{P}_{\text{TiO}_2} \mathbf{D}_{\text{TiO}_2}^{-1} \mathbf{D}_{\text{SiO}_2} \mathbf{P}_{\text{SiO}_2} \mathbf{D}_{\text{SiO}_2}^{-1})^N \mathbf{D}_A, \quad (8)$$

where N in Eq. (8) is number of bilayers, $\mathbf{D}_{\text{TiO}_2}$, $\mathbf{D}_{\text{SiO}_2}$, $\mathbf{P}_{\text{TiO}_2}$, $\mathbf{P}_{\text{SiO}_2}$ are dynamical and propagation matrices of TiO_2 and SiO_2 layers, respectively. From matrix elements of matrix $\mathbf{M}_{\text{tot}}$ one can calculate reflectance R as

$$R = \left| \frac{M_{21}}{M_{11}} \right|^2. \quad (9)$$

Fig. 1. Schematic representation of matrix method for considered structure.

3 Structure

Structure, which we model is shown in fig. 2. It consists of 5-bilayers of TiO_2 and SiO_2 and prism made of glass BK7. As analyte we consider air with small changes in refractive index - representing different concentration of ethanol in the air. Dispersion characteristics of BK7, TiO_2 and SiO_2 used in the computation are expressed using oscillator-based models. The wavelength-dependent refractive index $n_{\text{BK7}}(\lambda)$ for pure BK7 optical glass can be approximated by expression

$$n_{\text{BK7}}^2(\lambda) = 1 + \frac{1.03961212\lambda^2}{\lambda^2 - 0.00600069867} + \frac{0.231792344\lambda^2}{\lambda^2 - 0.0200179144} + \frac{1.01046945\lambda^2}{\lambda^2 - 103.560653} \quad (10)$$

where λ is wavelength in μm . We also consider wavelength-dependent refractive index of both TiO_2 [3] and SiO_2 [4] over the range of $0.43 \mu\text{m}$ to $0.8 \mu\text{m}$ given by

$$n_{\text{TiO}_2}^2(\lambda) = 5.913 + \frac{0.2441}{\lambda^2 - 0.0803}, \quad (11)$$

and

$$n_{\text{SiO}_2}^2(\lambda) = 1 + \frac{0.6961663\lambda^2}{\lambda^2 - 0.0684043^2} + \frac{0.4079462\lambda^2}{\lambda^2 - 0.1162414^2} + \frac{0.8974794\lambda^2}{\lambda^2 - 9.896161^2}, \quad (12)$$

respectively. We note that λ in Eqn. (11) and (12) is in the units of μm . We also introduce small losses in these materials through the imaginary parts of their refractive indices. The values used here are 0.000016 and 0.0000034 for TiO_2 and SiO_2 respectively. Refractive index of analyte (air) is taken as $n_A = 1$.

Fig. 2. Schematic representation of theoretically modelled structure. It consists of 5-bilayers of alternating layers of TiO_2 and SiO_2 surrounded by two semi-infinite media (glass BK7 and analyte).

4 Results

Calculation was done by a transfer matrix method (TMM). Figure 3 (a) shows dependence of reflectance R on wavelength λ for s and p polarized wave, respectively. Dip in reflectivity about wavelength of 633 nm for s polarized wave indicated a surface mode resonance that is promising for sensing applications. The remaining dips are the due to the guided modes of the multilayer system. To confirm that this is a surface mode, electric field distribution at mention resonance wavelength is shown in Fig. 3 (b). This figure clearly demonstrates optical field enhancement in the structure. Similarly, the normalized intensity distribution of guided mode field in the multilayer is demonstrated at a wavelength 592.4 nm. In both cases, an exponential tail in the analyte is obtained with amplitude much greater for the surface wave. Consequently, the structure is acceptable to be used as an optical sensor. For p - polarized wave non Bloch waves were excited as it is clearly seen from Fig. 3 (a). From the experimental point of view, a more pronounced dip than that shown in Fig. 3. is desirable. So we propose a new concept by which the resolution of the dip can be substantially improved. The concept is based on the spectral interference of s - and p -polarized waves. The corresponding reflectance R_{sp} can be expressed as [5]

$$R_{sp}(\lambda) = \frac{1}{4} \{ R_s(\lambda) + R_p(\lambda) + 2\sqrt{R_s(\lambda)R_p(\lambda)} \cos [\delta_{sp}] \}, \quad (13)$$

where δ_{sp} is the phase difference between s - and p -polarized waves and $R_s(\lambda)$, $R_p(\lambda)$ are reflectances of s - and p - polarized waves, respectively. From Fig. 4 (a) one can clearly see that resonance obtained by the method of interference of s and p wave has much deeper dip then resonance obtained for s wave and thus is far

Fig. 3. (a) Theoretical dependence of reflectance R on wavelength of incident light λ calculated for both polarizations. (b) Electric field distribution in the structure for s -polarized wave.

more appropriate for experimental purposes. Figure 4 (b) shows dependence of

Fig. 4. Spectral reflectances for s - and " sp " waves.(a) and for different refractive indices of analyte n (b).

reflectance R_{sp} on wavelength λ , when angle of incidence was set on $\theta = 54.1^\circ$, for different refractive index of analyte. The shift of resonance wavelength with changing refractive index of analyte is clearly observable (refractive indices of analyte represent different concentration of ethanol vapors in the air). Resonance wavelength shift towards longer wavelengths as the refractive index of analyte is increasing. The corresponding resonance wavelength as a function of refractive index of analyte is shown in the Fig. 5. We successfully used a linear fit to approximate the above mentioned dependence. From this linear dependence

the sensitivity defined as

$$S_n = \frac{\delta\lambda_r}{\delta n} \quad (14)$$

is expressed as $S_n = 153 \text{ nm/RIU}$.

Fig. 5. Resonance wavelength as a function of refractive index of analyte.

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Analysis of Partial Discharges Count in Relation to Charge Value

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Abstract. This article describes basic knowledge about partial discharges and diagnostics of them. Various methods are described, and their advantages and disadvantages are evaluated. Furthermore, there is off-line measurement of XLPE cable and results are analyzed. Usability of acquired data for further analysis is explained. Information that can be obtained if detailed analysis of measured that is conducted are described. There is also list of issues that can occur if diagnostics is not carried out correctly or if unsuitable method is used for specific test object. In the end the usefulness of partial discharge diagnostics is summarized with example of application and measurement conducted in paper is evaluated.

Keywords: Partial Discharge, Charge, Electrical Field, Diagnostics, Cable, Insulation.

1 Introduction

1.1 Partial discharges

Partial discharges are high frequency pulses with low energy. They can appear in in insulation voids or bubbles. Their presence in insulation systems is always unwanted because it signalizes issues with insulation system and further degrades the material. Diagnostics of partial discharge presence is therefore good way to assess the state of insulation systems of various objects. Early detection of partial discharge activity in insulation systems can prevent further degrading of the insulation system and prolong its lifetime. [1]

For correct evaluation of measured data, it is important to realize that it always depends on pattern the partial discharges create. Different patterns can symbolize different fault in insulation system. This is important for online diagnostics of overhead power lines. You can then recognize if there is earth fault or if there is tree fallen onto the power lines. The main attributes of partial discharges are amplitude, position in relation to test voltage and count. [3]

1.2 Measurement methods

There are many ways to detect or measure partial discharges. Each of existing methods have their pros and cons. To figure out the most appropriate method, there are things that has to be considered. One of them is type of object, the method most suitable for electric motor diagnostics does not also have to be most suitable for cables etc. It also depends if the goal is only the detection if partial discharges are present or if the measured data will be further analyzed.

Some of the methods are visual, so special cameras that can capture the spectrum of light emitted by partial discharges. Ultrasound microphones can also be used for partial discharge measurement, this method can be useful for transformer or other objects that can have partial discharge activity hidden by the insulation system. Both of previous methods pros are that can be used for online measurement without disconnecting the object from the circuit. However, they might not be the most precise methods. For detailed measurement high voltage oscilloscope can be used with the combination of high voltage power supply.

There are two basic groups: VLF (Very low frequency) and nominal operating frequency. The VLF power sources are very small in comparison to nominal frequency ones. The biggest disadvantage of VLF power sources is the fact it is not suitable for multi-layer insulation systems. When using very low frequencies, the electrical field is distributed based on conductivities of each layer. When using 50 Hz power source, the electrical field is distributed based on capacitances.

Fig. 1. Equivalent circuit of multiple layer insulation

From Figure 1 it is apparent that insulation acts as frequency compensated divider. That causes inaccuracies in measurements. Acquired data then cannot be measured correctly. In case the inner semi-conductive layer is very thin in comparison to diameter of the cable, the effect can be neglected.

2 Measurement

The measured sample is 22 kV XLPE insulated cable. That means the nominal voltage of this cable is 12,7 kV line to ground. Testing voltage used in this measurement is 25 kV line to ground. The measurement has three phases. The first one is setup and calibration of measurement chain. Cable properties has to be inserted into the control software and voltage steps have to be selected.

In second phase voltage is increased in steps and the goal of the second part is to find inception and extinction voltages. Extinction voltage is where partial discharges start to appear. In this part it is important to check if the pulse can really be partial discharge (considering position of the pulse in relation to phase of test voltage) and if it appears repeatedly. After that voltage is lowered until there is no partial discharge activity at all.

Third phase is 5 minute measurement at each voltage level that is above inception voltage. All partial discharge activity in this time period for each voltage level is recorded and can be further used after the measurement cycle is finished. Since the inception voltage was determined to be 19 kV, the third phase measurement was started at that voltage level. With 1 kV step all voltage levels up to 25 kV were applied to cable and partial discharge activity was measured. After measurement is finished, signals have to be checked and measurements that are not showing properties of partial discharges have to be removed so the diagnostics is as accurate as possible. [4]

Fig. 2. Measurement of partial discharges

2.1 Analysis

Data acquired via measurement were checked for signals that did not have all the properties suggesting validity of them and they were removed. After that basic statistical analysis for pulse charge and count was applied.

Arithmetic average was determined to be 176,4 pC. Important is to realize arithmetic average is hugely influenced by outliers. Therefore if the removal of inadequate signals was done improperly, this value might not be accurate.

Modus on the other hand describes the most common value from data set, that means it is not influenced by outliers. It can also signalize if the values are symmetrically divided. Modus value was determined to be 94,7 pC.

Median of the data set was determined to be 171,8 pC. Meaning that half of the pulses were above this value and half was below.

2.2 Histogram

One of the options to graphically analyze the data set based on charge value and count is to use histogram. To use this plot correctly, correct intervals have to be set. In this case Struges' rule was used to determine those intervals. After correction of the intervals were set to be $d=30$ with the number of intervals $k=10$ resulting in range 0-300.

Fig. 3. Histogram of charge value

From graph it is apparent that one group of pulses stands out at that are pules with charge value in the interval from 150 pC to 180pC. Intervals further from this one have descending trend. From this it can be assumed that there is only one defect in the insulation, or it can mean no defect but degradation of insulation system as whole. But that would probably result in higher charge value. To confirm this hypothesis graphical depiction of pulse placement can be generated from control software.

Fig. 4. Pulse placement

Graphical illustration of pulse placement confirms the hypothesis that there is only one defect and it also suggests that the defect is probably in near end terminal.

3 Conclusion

Diagnostics of partial discharges is very useful method that can prevent insulation system failures and provide us with information about its current state. There are various implementations of this method. For example, on-line partial discharge monitor was designed at VSB – TÚO that allows detection of insulation faults on medium voltage overhead power lines. With expert knowledge about partial discharge patterns even type of fault can be determined from obtained data. [2]

From measurement conducted earlier there is also apparent there are various off-line methods that can be used for diagnostics. Method used is very useful for under-

ground cable diagnostics because it can determine the location of fault and therefore only the faulty section of cable has to be dug out to repair it.

From charge value and count of pulses we can determine the severity of the defect also if there is only one or more. If there were more defects with different severity, there would be multiple outstanding intervals in histogram. In case the defect would be same, only amount of pulses would increase.

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Island operation of wastewater treatment plant during blackout

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Abstract. This article is focused on possibilities of island operation of wastewater treatment plants (WWTPs). Those plants are very important to stay in operation during blackout because otherwise there will be a high risk of river pollution. There are few ways how wastewater treatment plants can be protected from the negative consequences of blackout. The first solution which can be considered are the diesel engine-generators. This solution is usually applied to small wastewater treatment plants. However, for larger plants in large cities, this is not only an unprofitable solution, but also technically complicated due to the amount of required power. Another option is to install sufficient number of solar panels near the plant in combination with high-capacity batteries, as in Fayetteville, Arkansas. This solution requires large investments, but they can return within few years. The article is most focused on the third solution which is use of biogas as a combined heat and power source (CHP). Biogas in a wastewater treatment plant arises during anaerobic fermentation of sewage sludge. Therefore, during the blackout, the wastewater treatment plant could switch to island operation for a certain period of time, producing electricity independently to the grid for its own consumption. Transition to an island operation could be realized by frequency relay in combination with microprocessor device. Then for maintaining island operation is necessary automatic load shedding/application system.

Keywords : wastewater treatment plant, blackout, biogas, island operation

1 Introduction

Because of the planned increase in the share of renewable energy sources in electricity production, the risk of large electric power outages (blackouts) is increasing. Blackout means a major problem for the supply of drinking water and wastewater treatment. Particularly in case of long-term outage as happened for example in New Zealand which lasted for 5 weeks. [1]

During power outage the emergency discharge of wastewater from the WWTP will take place directly to the recipient (usually a river) in 6-8 hours. This discharge will occur much faster if there is heavy rainfall during this period. Therefore, long power outage would result in significant pollution of rivers and also technological difficulties at the WWTP, which may reduce the efficiency of treatment even after the end of the power outage. The cause of this will be sedimentation and decay of the activated sludge in the activation tank, which occurs after about 12-16 hours. Without the supply of new wastewater, which will not pass through the WWTP due to the blackout, the activated sludge will eventually die. When the function of the electrical distribution system is restored, the subsequent regeneration of the dead sludge would take about 3 weeks to achieve the ability to break down pollution. That means it is very important to ensure the supply of electricity to WWTPs even during a blackout. [2]

Wastewater treatment is therefore a part of critical infrastructure of the Czech Republic. It means that its protection must be ensured by means of preventive, mitigating measures, disaster preparedness, resources, equipment and aids to deal with disaster impacts, and especially targeted attacks on critical infrastructure, ability to manage critical situations and ensure rapid recovery.

To ensure operation of WWTP during blackout there are three main possibilities:

- Diesel engine-generators
- Photovoltaics with storage systems
- Combined heat and power production from biogas

Those possibilities will be explained in next chapter.

2 Means of generating electricity in wastewater treatment plants

2.1 Diesel engine-generators

For smaller wastewater treatment plants, the most common solution is petrol or diesel engine-generators. These can be stationary (generators with outputs of several tens of kVA are commonly used) or there can be also used portable power generators of smaller outputs (few kVA) in the case of the smallest WWTPs. [3]

Large wastewater treatment plants (over 100,000 population equivalent PE) would need to have a large output power (e.g. 10 MVA at the WWTP in Ostrava). This is a very costly requirement, which the market is currently unable to cover. The only possibility would be connection of multiple generator units at once. However, this is also a very expensive solution. [2]

Another option is to install a suitable spare power supply with the required power, ensuring the function of the turbochargers. Then the activated sludge would not decay for the next 20 days. Furthermore, there will be a gradual suppression of biogas production in fermentation tanks. Due to the impossibility of maintaining the required temperature in them biogas production will subsequently stop completely. [2]

2.2 Photovoltaics with storage systems

Second solution is to build a photovoltaics near the plant in combination with high-capacity batteries. This is also very expensive, but those investments can return in few years. Example of this solution is in Fayetteville, Arkansas. [4] There is the project which consists of three solar arrays of total power 10 MW and two battery facilities (capacity 24 MWh) located near Fayetteville's two wastewater treatment plants. The city spent \$700,000 for installation but will save approximately \$180,000 per year. The two Fayetteville's wastewater treatment plants consume approximately 67% of the City's overall consumption. The new solar arrays will generate approximately 18.3 million kWh/yr of clean energy, offsetting approximately 103% of the Wastewater Treatment Plants' usage, increasing the City's clean energy use from the current 16% to 72%. When electricity generated by the solar panels exceeds the demand of the wastewater treatment facilities, energy will be distributed to the grid for use by cooperative members or to the on-site battery storage systems which can be dispatched into the grid during peak usage periods. [4] [5]

2.3 Combined heat and power production from biogas

The third solution is the use of biogas as a combined heat and power source (CHP). Biogas in the wastewater treatment plant is formed during anaerobic digestion of sewage sludge. During a blackout, some WWTPs may switch to island operation for a certain period of time. During this time, it will produce electricity and heat from biogas for its own consumption and possibly other operations (e.g. WWTP in České Budějovice [11]).

Biogas in the WWTP is created by anaerobic fermentation of sewage sludge in digestion tanks, where the primary and secondary sludge is fed. The sludge in the digestion tanks must be heated to a temperature of approximately 38 ° C. It is possible to use biogas for heating, which is produced during digestion. The largest energy consumption from the entire WWTP are turbochargers, which blow air into the aerobic part of the activation tanks, through which the wastewater passes from the primary sedimentation tanks. [6] [7]

Energy autonomy of WWTP

Wastewater treatment plants that generate at least as much energy as they need for their regular operations are classed as "energy-autonomous". Complete heat autonomy is already being achieved by many plants, while complete energy autonomy today is achieved only by very advanced and sophisticated plants. For achieving full energy autonomy of WWTP there is necessary to cover the entire consumption of turbochargers. This is realistic only in large WWTPs (as shown in Table 1) and if very expensive quality filters are installed in the WWTP, thanks to which the consumption of turbochargers will be significantly reduced. Another option how to achieve energy-autonomous WWTP is to generate electricity also from biogas from biowaste and/or from nearby landfill (e.g. WWTPs in Gera and Braunschweig, Germany). [8] [9]

Table 1. Electricity autonomy of WWTPs in case of CHP use [10]

Population equivalent	Autonomy
< 10 000	25-35 %
> 100 000	68-100 %

3 Island operation of WWTP with biogas production

Example of WWTP with CHP which can operate in island operation during blackout is WWTP in České Budějovice. This WWTP serves for the residential agglomeration of two cities and fifteen municipalities with a capacity of 112 thousand inhabitants (375 000 population equivalent). Two CHP units for biogas with an output of 512 kW are installed directly in the wastewater treatment plant. This will cover about 2/3 of the electricity needed for the WWTP's own consumption. In its vicinity, there is a new water treatment plant for the emergency supply of drinking water for the city. In the case of a blackout, the CHP units at the WWTP in island operation are able to cover the consumption of both the WWTP and the water treatment plant for a limited time after disconnection of the turbochargers. During normal operation, the CHP source works into the network and the consumption of the WWTP is supplied from the network. At the same time, the current consumption of all technological units of the wastewater treatment plant is monitored. The control system calculates the difference between the production of electricity from biogas and the total consumption of technological units. [11] [12]

Table 2. Example of power balance during normal operation of WWTP [11]

Highest consumptions in WWTP in České Budějovice					
Turbochargers	Water treatment plant	Engine room for digestion tanks	Biological lines	Blower in rough pre-cleaning	Sludge dewatering
182.0 kW	63.3 kW	32.7 kW	26.9 kW	25.6 kW	23.1 kW
Power balance					
Production		Consumption		Deficit	
292.8 kW		418.2 kW		125.4 kW	

When a fault occurs in the electrical network it is necessary to detect and evaluate that fault very quickly, automatically (in the order of tenths of a second) disconnect the wastewater treatment plant from the network and change the power supply to the local biogas CHP station. Because the CHP station is not enough to cover the entire consumption of the wastewater treatment plant (there can be more than 100 kW deficit as shown in Table 2), it is necessary to disconnect some equipment. The turbochargers required for aeration of activation tanks have the highest consumption (see Table 2),

and therefore it is necessary to disconnect them. This will cause the production of secondary sludge needed for biogas production will gradually decrease. However, if the supply of primary sludge to the digestion tanks is maintained, the partial development of biogas will be also maintained and the WWTP should be able to operate in the island mode for at least two days. Biological treatment will also gradually deteriorate. If we take into account a normal rainless day, then it will affect the quality of the discharged water after about 36-48 hours. [11]

When the network voltage is restored, the island operation is automatically synchronized with the network and normal operation is restored. [11]

4 Technical requirements for island operation

The transition to island operation is not a matter of course. In island operation, the balance between power sources and consumption must be ensured in the same way as in a conventional electricity grid. At the moment of a power outage, it is necessary to switch to island operation in a fraction of a second. A typical situation for the beginning of island operation is a lack of power. Therefore, it is necessary to disconnect the remaining consumers in order to bring the newly created island network into power balance. This is ensured by the automatic load shedding/application system, which compares the consumption with the power of sources and determines how much it will be necessary to reduce consumption. If possible, the reducing will be performed according to the priorities determined, for example, from the analysis of smart meters. [13]

The frequency relay monitors the deviation of the network frequency from the nominal value and sends signal to disconnect from the distribution network when the defined interval is exceeded. It can be part of a multifunctional IED (intelligent electronic device).

If the conditions for the creation of island operation are met, island is disconnected at the splitting point (s). If the fault is behind the splitting point (within the expected island operation of the WWTP), island operation must not be activated, and local protection ensures the elimination of the fault. [14]

During normal operation the automatic load shedding/application system constantly monitors the consumption from the area of island operation and compares their consumption with the power of sources that are located in island operation (e.g. a CHP unit for biogas in the case of a WWTP). Individual consumptions are divided into categories according to their importance. If their total consumption is higher than the power of the CHP unit, then the less important consumptions are included in the group for possible shutdown. Otherwise (in case of excess power) the generator is regulated, which reduces the power and achieves the required balance between consumption and production. [14]

5 Conclusion

Most wastewater treatment plants have the potential to switch to island operation during a blackout. The smaller ones can be supplied by fossil fuel generators. Large WWTPs can use biogas, which is produced in digestion tanks. However, most of them will not be able to work in island operation for a long time (more than two days), because the consumption of turbochargers will not be covered, and the development of biogas will decrease. There are also energy-autonomous WWTPs that do not have to be connected to the grid at all, because they also use biogas from biowaste and/or landfill. Another possibility is to build photovoltaics with battery storages near the WWTP. It can therefore be stated that we already have the necessary technologies to be able to operate most of the WWTPs in island operation even during a blackout.

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Use of Empirical Mode Decomposition as a Part of Hybrid System for Non-Invasive Fetal ECG Extraction

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Abstract. This paper focuses on the non-invasive fetal electrocardiogram (NI-fECG) processing, which appears to be one of the most promising fetal monitoring techniques. Unfortunately, during this type of monitoring, in addition to the fetal signal, the maternal signal and other types of noise are also recorded. To extract a useful fECG signal, it is necessary to choose the appropriate filtration technique. Recent studies have shown that filtering fECG signals using individual methods is not as effective as hybrid systems that combine two or more of these methods and their advantages. In this paper, a combination of independent component analysis (ICA), recursive least squares (RLS), and empirical mode decomposition (EMD) was used to create a hybrid ICA-RLS-EMD system.

Keywords: Non-invasive fetal electrocardiography (NI-fECG), hybrid methods, independent component analysis (ICA), recursive least squares (RLS), empirical mode decomposition (EMD).

1 Introduction

Electronic fetal monitoring is an integral part of modern obstetrics, used mainly to prevent fetal hypoxia. Cardiotocography (CTG) is the most common technique used in clinical practice. This method allows continuous monitoring of fetal heart rate (fHR) and uterine contractions. The first commercially available model was introduced in 1968. Since then, there has been a marked decrease in the number of fetal deaths during childbirth, but, subsequently, there has also been an increase in the number of unnecessarily performed caesarean sections [4]. This phenomenon is due to the low reliability and accuracy of this method [5]. For these reasons, there are demands from physicians for conceptually new solutions of diagnostic devices usable for the development of new non-invasive diagnostic methods, such as fetal electrocardiography (fECG). The main advantage of this technique is, in addition to the determination of fHR, the possibility of performing a morphological analysis of the fECG signal (e.g. the ST analysis or QT interval analysis), which can help diagnose fetal hypoxia more accurately [6]. The disadvantage of non-invasive fECG is the rela-

tively low magnitude of the fetal component compared to maternal one and these signals overlap in time as well as frequency domain and thus the accurate extraction or morphological analysis of the fECG waveform is a challenging task [7]. The use of advanced signal processing techniques is therefore inevitable.

2 Material and Methods

In this chapter, the individual methods that were selected based on the literature review are described. Within the hybrid system, the following methods were implemented: independent component analysis (ICA), recursive least squares (RLS) and empirical mode decomposition (EMD).

2.1 Independent Component Analysis

Independent component analysis (ICA) is a computational method based on high order statistics. It is used to separate mixed independent signals and to obtain the original source signals. It is possible to achieve good results if two assumptions are met. The source signals are independent and have non-Gaussian distribution. There are many variants of the ICA method, but very often the FastICA algorithm is used, which is much more efficient than the conventional ICA algorithm [8].

2.2 Recursive Least Squares

Recursive least squares (RLS) is an adaptive method based on minimizing the error function. The error function is determined as the difference between the desired output and the real output of the adaptive algorithm. Minimization of the error function is achieved by automatic adjustment of the adaptive filter coefficients. The RLS algorithm achieves excellent results in a time-varying environment. Nevertheless, the RLS algorithm in its basic form has higher computational demands and, in some cases, it may have stability problems [9].

2.3 Empirical Mode Decomposition

Empirical mode decomposition (EMD) is a relatively new signal processing technique that can decompose any non-stationary and non-linear signal into individual oscillatory functions. These components are called intrinsic mode functions (IMFs). The first step of the algorithm is the detection of local minima and maxima in the input signal and calculation of the upper and lower envelope. Then the mean of envelopes is calculated and subtracted from the original signal. This is how the first IMF is obtained. To get more IMFs, it is necessary to repeat the whole procedure, but the residue is used instead of the original signal. The residue is obtained by subtracting the IMF from the original signal [10].

3 Hybrid System Design

This chapter describes a hybrid algorithm that was used to extract the fECG signal. Two different approaches are generally used in fECG extraction, *adaptive* and *non-adaptive*. These two approaches differ in the way of suppressing the maternal component. The non-adaptive systems do not contain any adaptation mechanism for fECG signal extraction. Contrary, the adaptive ICA-RLS-EMD hybrid system uses the RLS algorithm to adapt to the reference input corresponding to the maternal signal in order to subtract it from the aECG and consists of the following stages:

- First, the abdominal signals (aECG) are filtered by an FIR filter in the range from 3 to 150 Hz to eliminate the variations in isolines. The ICA-RLS-EMD hybrid method is multichannel and thus requires the use of at least two input signals.
- The ICA method is further applied to these signals and extracts 3 components. One component corresponds to the mECG signal, the second one to the aECG* with the enhanced fECG component, and the third one is noise. The components are assigned to the source signals based on the number of detected peaks.
- The mECG and aECG* signals are time and amplitude centred and fed to the RLS algorithm. The output of the RLS algorithm provides an fECG signal with a suppressed mECG component.
- Finally, the EMD method is then applied to this signal in order to remove the residual noise. This algorithm is based on the decomposition of the input signal into 19 oscillatory functions (IMFs). The most suitable IMFs are selected using an automated algorithm and summed to create an enhanced fECG*. This automated algorithm compared all IMFs combinations and selected the combination that achieved the highest accuracy. The comparison was carried out using the reference annotations. The principle of the ICA-RLS-EMD method is shown in Fig. 1.

Fig. 1. Block diagram of an adaptive ICA-RLS-EMD hybrid system.

4 Results and Publications

The hybrid method was tested on 12 real recordings from the *Abdominal and Direct Fetal ECG Database* (ADFECGDB) [11]. The evaluation of the extraction quality was performed by determining the accuracy of fQRS complexes detection using the statistical parameters accuracy (ACC), sensitivity (SE), positive predictive value (PPV) and F1 score. Also, by determining fHR using fHR traces and Bland-Altman plots (determining of mean value μ and standard deviation 1.96σ). Performance comparison was done according to reference annotations containing markers that accurately indicate the location of R-peaks.

The results achieved with this algorithm were compared with the results of other hybrid algorithms, which are also based on the EMD method presented in [1]. It is a hybrid ICA-EMD algorithm and approaches using wavelet transform (WT), EMD-WT and ICA-EMD-WT. More detailed results of the ICA-RLS-EMD hybrid method and optimal setting of its parameters can also be found in this publication. Another comparison was performed with the results achieved using the conventional ICA method. Extraction of fECG using the ICA method is presented in [2] and the use of another hybrid method combining the ICA and principal component analysis (PCA) in [3]. The results achieved by all hybrid methods based on EMD are summarized in Table 1. ACC, SE, PPV, F1, μ , and 1.96σ parameters determine the average value that was achieved for all 12 recordings.

Table 1. Comparison of performance of the methods when extracting the fECG signals. The columns with the ACC, SE, PPV, F1, μ , and $\pm 1.96\sigma$ parameters determine the average value that was achieved for all 12 recordings from the ADFECGDB database.

Methods	ACC (%)	SE (%)	PPV (%)	F1 (%)	μ (bpm)	$\pm 1.96\sigma$ (bpm)
ICA	47.77	57.68	57.59	57.37	-28.56	23.29
ICA-EMD	48.22	52.66	60.02	55.71	-25.38	16.14
EMD-WT	48.28	56.52	62.59	59.17	-27.08	22.59
ICA-EMD-WT	59.34	65.21	77.23	68.15	-19.67	15.36
ICA-RLS-EMD	84.73	87.99	92.72	90.10	-3.92	10.02

According to the ACC parameter, the worst results were achieved using the ICA method, which confirms the assumption that hybrid methods are more efficient in fECG extraction. Better results were achieved using the ICA-EMD and EMD-WT methods. However, the results showed that the methods work correctly only with some aECG signals. Subsequently, the ICA-EMD-WT method was designed and tested, which was able to extract fECG with higher accuracy. The last method tested was ICA-RLS-EMD, which was able to almost completely remove the residual mECG and to improve the fECG extraction quality.

The results of the research showed that a hybrid system based on the EMD method is able to accurately detect fQRS complexes and determine fHR with high accuracy. An example of the resulting output signal extracted by the ICA-RLS-EMD method

and other previously proposed hybrid algorithms is shown in Fig. 2. Each of these methods has its advantages and limitations. The ICA-EMD and ICA-EMD-WT methods were not able to reliably suppress the maternal component, leading to an increase in false positive peaks occurrence. When the EMD-WT method was used, the maternal component was more effectively eliminated. However, the fetal component was also significantly suppressed, leading to increased detection of false negative peaks. The best results were achieved using the ICA-RLS-EMD hybrid method, which was able to extract a high-quality fECG signal and determine fHR very accurately. Inaccurate extraction was achieved only in those aECG recordings that were not well recorded and the fetal component was almost invisible in them. In addition, the advantage of this method is that there is no deformation of the shape of fQRS complexes (compared to hybrid methods using the WT method), which would allow the subsequent morphological analysis of the signal.

Fig. 2. Comparison of the signal extracted by the ICA-RLS-EMD hybrid method with signals extracted by other hybrid methods and example of the input aECG signal.

5 Conclusion and Future Work

The results of the study have shown that combining two or more methods increases the efficiency of the extraction system. Compared to other hybrid methods, the ICA-RLS-EMD adaptive algorithm has achieved the most accurate detection of fQRS complexes and the determination of fHR, but there are still opportunities to increase the quality of extraction. The EMD method is burdened with limitations in the form of the occurrence of a phenomenon called mode mixing, which can significantly affect the decomposition results. To prevent this phenomenon, further research will focus on

an extended version of this method, termed ensemble empirical mode decomposition (EEMD), which will be implemented and tested within the new hybrid algorithm ICA-RLS-EEMD. In the future, the author's research will also focus on the morphological analysis of the fECG signal in terms of the ST segment analysis or the QT interval analysis. An accurate extraction system would thus make it possible to extract clinically valuable information from the fECG with the benefit of maintaining the non-invasiveness of the method. This could enable introducing a non-invasive variant of the clinically used STAN diagnostic method, which would help to increase the accuracy of the early diagnosis of fetal hypoxia, thereby reducing the number of unnecessary caesarean sections.

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Statistical Analysis of Pulse Wave Measurement on Vascular Model

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Abstract. The vascular model simulates human cardiovascular system, which is important for further work of noninvasive blood pressure estimation and definition of calibration procedure. The pressure pulse wave is detected from two point at known distance. Statistical testing is important part of the evaluation biomedical models. It provides simple summary about the data acquisition methods and processing of measured signal. For comparison of measured data from two points, the normality test is important for further analysis. The last test indicates significance of mean values from both sensors.

Keywords: pulse wave · vascular model · pressure measurement · statistical hypothesis test.

1 Introduction

Pulse wave is measured on vascular model, which simulates the human cardiovascular system. Pressure sensors located at a distance of 30 cm on the artificial vessel segment were used for the measurement. The three parameters of vascular model can be changed, that characterize contractions of the heart muscle. These parameters include heart rate, cardiac output and pulsatility, which expresses the ratio of the contraction duration of heart muscle (systole) to the time of heart muscle relaxation (diastole). Other parameters as the pulse wave shape can be changed by using different types of artificial vascular segments. The aim of this article is a statistical verification of the method of measurement and signal processing, whether the measured parameters of both sensors will ideally match. [1, 9, 10]

2 Measurement technique

For statistical verification of pulse wave was measured at two different locations on artificial vessel, where the shape of the pulse wave is observable. The measurement was performed for all combination of setting listed in Table 1. The time of one acquisition was 120 seconds, the sampling frequency was chosen according to the measuring device limit of 200 samples per second, overall, for each setting 2400 samples were acquired. Thus, 27 signals were measured, which needed to

Table 1. Changeable parameters of the pump from vascular model

Cardiac output [ml]	Heart rate [bpm]	Pulsatility [%]
10	30	25
15	60	35
20	90	45

be converted to a pressure value according to the calibration of the used pressure sensor and the noise from the signal was removed using filter based on wavelet decomposition. Subsequently, the key points of the pulse wave were detected. The first of the key points of the pulse wave is the heel of the pulse curve (min), the next key points are located at the highest peaks of pulse wave (max) and the last but no least key point is the steepest point of rise of pulse wave (steep). These points are detected by using derivative of the acquired signal. [5, 6]

To verify the accuracy of the measurement, the differences between adjacent key points were calculated, which indicate the period of the pulse curve. Ideally, these measured values will be identical, this property is demonstrated only by statistical hypothesis testing of measured values. [1–4, 8]

3 Statistical analysis

Based on descriptive statistics the outliers were removed from dataset and the null hypothesis of a Shapiro-Wilk test about the normal distribution is tested on 95% confidence interval.

Null hypothesis H_0 : data are taken from normal distributed population

Alternative hypothesis H_A : negation of H_0

Table 2. Results of Shapiro-Wilk normality test

settings			p-value					
			P1			P2		
cardiac output	heart rate	pulsatility	min	max	steep	min	max	steep
10	30	25	0.365	0.213	0.124	0.503	0.409	0.244
10	30	35	0.811	0.567	0.207	0.380	0.636	0.819
10	30	45	0.327	0.793	0.001	0.419	0.028	0.085
10	60	25	0	0	0	0	0	0
10	60	35	0	0	0	0	0	0
10	60	45	0	0	0	0	0	0
10	90	25	0	0	0	0	0	0
10	90	35	0	0	0	0	0	0
10	90	45	0	0	0	0	0	0
15	30	25	0.081	0.719	0.141	0.516	0.491	0.215
15	30	35	0.006	0.355	0	0.217	0.136	0.014
15	30	45	0.434	0.361	0	0.781	0.884	0.125
15	60	25	0	0	0	0	0	0
15	60	35	0	0	0	0	0	0
15	60	45	0	0	0	0	0	0
15	90	25	0	0	0	0	0	0
15	90	35	0	0	0	0	0	0
15	90	45	0	0	0	0	0	0
20	30	25	0	0.121	0	0.396	0.013	0.007
20	30	35	0.999	0.031	0.217	0.977	0.189	0.545
20	30	45	0.663	0.766	0.003	0.821	0.101	0.472
20	60	25	0	0	0	0	0	0
20	60	35	0	0	0	0	0	0
20	60	45	0	0	0	0	0	0
20	90	25	0	0	0	0	0	0
20	90	35	0	0	0	0	0	0
20	90	45	0	0	0	0	0	0

When the p-value of the statistical test is higher than 0.05, the null hypothesis is not rejected, and data are normally distributed. The dataset is not normally distributed based on the p-values in Table 2. For further statistical testing the nonparametric Mann-Whitney statistical test is used.

Null hypothesis H_0 : $x_{0,5}^{P1} = x_{0,5}^{P2}$

Alternative hypothesis H_A : $x_{0,5}^{P1} \neq x_{0,5}^{P2}$

Table 3. Results of Wilcoxon-Mann-Whitney test for significant difference

settings			p-value		
cardiac output	heart rate	pulsatility	min	max	steep
10	30	25	0.989	0.907	0.381
10	30	35	0.710	0.405	0.584
10	30	45	0.579	0.872	0.600
10	60	25	0.589	0.943	0.290
10	60	35	0.443	0.587	0.355
10	60	45	0.974	0.681	0.051
10	90	25	0.954	0.969	0.953
10	90	35	0.976	0.777	0.042
10	90	45	0.890	0.417	0.184
15	30	25	0.411	0.886	0.687
15	30	35	0.742	0.867	0.279
15	30	45	0.789	0.689	0.776
15	60	25	0	0.823	0
15	60	35	0.075	0.981	0
15	60	45	0.302	0.926	0.464
15	90	25	0.771	0.001	0.997
15	90	35	0.573	0.971	0.994
15	90	45	0.969	0.912	0
20	30	25	0.315	0.844	0.031
20	30	35	0.298	0.059	0.913
20	30	45	0.257	0.236	0.931
20	60	25	0	0.872	0.433
20	60	35	0.063	0.718	0.416
20	60	45	0.030	0.615	0.279
20	90	25	0.901	0.926	0.942
20	90	35	0.711	0.861	0.979
20	90	45	0.972	0.659	0.910

According to the results of Mann-Whitney statistical test in Table 3, a statistically significant difference can be determined mainly in measurements, where the cardiac output was greater than 10ml. This test revealed that the data is skewed after data processing due to imperfect filtering of signal artifacts or the vascular model pump does not generate a stable pulse wave according to its setting. The vascular model pump error can be assumed because the adjustable heart rate values do not correspond to the real heart rate values. [7]

4 Conclusion

The vascular model is used to simulate the vascular system of the human body, and measurements are performed on it, from which a calibration procedure will be defined to determine blood pressure from the measurement of the pulse transit time. This statistical testing revealed an inaccuracy in the blood pump, which generates a pulse wave and a higher frequency than the set value. At the same

time, the error of non-robust detection of key points in the pulse wave due to signal artifacts at a set cardiac output of more than 10 ml could occur. Based on this statistical testing, it will be necessary to adjust and verify the function of the blood pump to ensure that the adjustable parameters are stable throughout the measurement in order to acquire signals for input to artificial intelligence algorithms to determine the calibration procedure for continuous non-invasive blood pressure measurement.

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Automated Identification Of Leukemic Cells From Microscopic Peripheral Blood Smear Images

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Abstract. Leukemia is the second leading cause of cancer deaths among children, adolescents, and young adults. The prognosis of the disease highly depends on its early detection and diagnosis. In medical practice, the primary suspicion of the leukemia is determined by the microscopic examination of peripheral blood smears. Since this diagnostic technique is time-consuming, lacks standardization, and prone to errors due to various human factors, such as the operator's fatigue or experience, there is a high demand for such an automated system, which would minimize human intervention and overcome the drawbacks of the manual examination. In this paper, we propose a computer-aided leukemia diagnostic system, which uses a novel combination of image processing and machine learning techniques. To detect and identify the leukemic cells in blood smear images, we implemented the conventional image processing sequence, including image segmentation, features extraction, and classification. The reliability of the proposed system was assessed by constructing the confusion matrix and computing the chosen performance metrics.

Keywords: Automated leukemia detection, Microscopic blood smear analysis, Leukemic cells

1 Introduction

The term leukemia is referred to an excessive and unregulated proliferation of abnormal leukocytes in the bone marrow. From a pathophysiological perspective, the malignancy is manifested by abnormal buildups of immature white blood cells, which prevent blood from performing its normal functions. This rapid production of leukemic cells disturbs the immune system and reduces the bone marrow's ability to produce normal blood elements. Clinically, leukemia is subdivided based on the rapidity of the disease progression and the lineage of the affected cell to acute lymphoblastic leukemia, acute myeloid leukemia, chronic lymphoblastic leukemia, and chronic myeloid leukemia. Acute leukemia develops quickly, and the leukemic cells cannot perform their normal function, while the chronic forms progress slowly, and leukemic cells retain a part of their normal functionality. [2] In hematological practice, the di-

agnosis of the disease is determined based on a series of medical examinations. Despite the advancement, microscopic examination of blood smears is still the gold standard in leukemia diagnosis and monitoring. [1] This microscopic manual examination is time-consuming and greatly depends on the domain expert's experience and fatigue. These high interpersonal differences in human vision often result in non-standardized reports; therefore, there is a high demand for a cost-effective and accurate automated system for leukemia screening, which will eliminate human errors and standardize the microscopic examination. The goal of this paper is to design and implement a fully automated identification system for the detection of leukemic cells, which would circumvent the abovementioned drawbacks and increase the reliability of the examination.

2 The Proposed Framework

The methodology presented in this work is based on various image processing and machine learning techniques. Our proposed computer-based diagnostic system follows the general conventional image processing sequence, including image segmentation, features extraction, and objects classification phase. The experiment in this work is realized on the local image database comprising 31 peripheral blood smear slides from patients with acute lymphoblastic leukemia and patients with the normal diagnosis. All slides were prepared and stained using Giemsa staining to visualize cell components and were captured with an effective magnification of 500. The captured samples of microscopic peripheral blood smear images are demonstrated in Figure 1. [3]

Fig. 1: Blood smear image dataset samples: blood smear with acute lymphoblastic leukemia (Left), blood smear without a pathological diagnosis (Right)

2.1 Blood Cell Segmentation

The main aim of the segmentation phase is to obtain single leukocytes and separate them into individual meaningful morphological regions, i.e. nucleus and cytoplasm. These segmented regions carry pivotal information about the cell structure; hence the accuracy of the subsequent stages is strongly dependent on the results of the segmentation. Due to the presence of different cellular blood components and the adjacency of leukocytes to erythrocytes and each other, segmentation is considered as the most challenging phase. To overcome these challenges, we divided the segmentation phase

into two parts, the localization of white blood cells and the extraction of cell components. [3]

The main purpose of the localization phase is to remove the unnecessary blood components such as erythrocytes and platelets and to separate the adjacent leukocytes. This algorithm consists of six fundamental steps. The first step of the proposed methodology converts the image into a binary format. For this purpose, a simple global threshold operation with a properly selected threshold value is used. The thresholding helped to reduce a part of erythrocytes and removed the background of the image, while all leukocytes were retained. To filter the noise and the remaining blood film defects, which were resistant to the thresholding, several filtration phases were implemented. Thus include especially small object filtration that is realized by the morphological opening operation with a disc-shaped structuring element and some filtrations based on the histogram and particle's area that eliminated large objects and blood film artifacts. Since the adjacent cells may introduce high inaccuracies in the following phases of the inspection system, each cell should be separated individually. To solve the problem with the detection of touching cells, the combination of morphological erosion with the total particle area computation was used. The adjacent cells were afterward separated by the application of a fine edge detection technique determining the splitting boundary. For this purpose, we used a 3×3 Sobel edge detection kernel for both horizontal and vertical directions. [3]

Since the peripheral blood smear images comprise several leukocytes that will disrupt further processing, it is necessary to extract each cell into a single-cell sub-image. This was carried out by an automatic image crop, which utilizes the bounding rectangle size of the object. After the single-cell extraction, the second segmentation level that is focused on the cell region extraction can be performed. To achieve the best results of the nucleus localization, we employed histogram equalization and applied two subsequent color thresholds extracting a saturation channel from two different color spaces. The whole process of region extraction is afterward accomplished by the application of mathematical operations on the original and obtained binary image. The results of the proposed segmentation process are shown in Figure 2. [3]

Fig: 2: Segmentation results: segmented leukemic cell, segmented cytoplasm, segmented nucleus (Left to right).

2.2 **Features Extraction**

Generally, features describe the shape or texture information retrieved from the segmented pattern. The main goal of feature extraction is to obtain a set of descriptors that will be separated into various classes by classification techniques. Due to the specific character of the nucleus and the cytoplasm of normal and leukemic white blood cells, feature extraction plays a vital role in automated leukemia diagnosis and classification. In this study, we tried to extract a specific set of features, which are similar to the visual information on which the domain experts focus during the manual examination. For this purpose, sixteen features were extracted from each cell in the image. Our feature set includes nine morphological features and seven statistical or textural features. All features listed in Table 1 were selected based on the conducted research. [3]

Table 1: A Detailed overview of some of the selected features

Feature	Description
<i>NC ratio</i>	the ratio of the area of the nucleus to the cytoplasm area
<i>Nucleus perimeter</i>	perimeter of the nucleus in pixels
<i>Nucleus compactness</i>	the extent to which the shape is compact
<i>Nucleus form factor</i>	the measure of the shape irregularities
<i>Nucleus eccentricity</i>	indicates the deviation from a circular shape
<i>Nucleus elongation</i>	indicates abnormal bulging
<i>Nucleus solidity</i>	the degree to which the shape is convex or concave
<i>Nucleus energy</i>	measure of the local textural uniformity of grey levels
<i>Cell contrast</i>	measures the number of local variations
<i>Nucleus correlation</i>	represents the linear dependency of grey tone values
<i>Cell dissimilarity</i>	calculates the grey level difference distribution
<i>Cell entropy</i>	measures the randomness or complexity of texture

To suppress the effect of non-uniform features, data normalization was performed for each attribute of a feature vector before the classification. To standardize the range of various independent variables, we employed the Min-max algorithm, which scales a variable in the range of values lying within a predetermined range of $<0, 1>$.

2.3 **Classification Model Selection**

In the classification phase, the input data of the unknown category are classified into one of the predefined classes based on the features extracted in the previous stage. This is carried out in this work by supervised classification algorithms, which used part of the data as a training set to construct a classification model, while the remaining data are used to test the proposed classifier. For the leukocytes classification, we employed two different classifiers, the support vector machine, and an artificial neural network.

To select the best-performing SVM model, various kernels were experimentally tried. This included Linear, Polynomial, Gaussian, and Radial basis function kernel. Using optimization methods, we tuned all parameters of the SVM until we achieved the maximum accuracy of the model. For a better evaluation and prediction of the model's behavior, the cross-validation technique was performed. This statistical model, also known as out of sample testing, estimates the accuracy of the predictive model's performance on the independent unknown data. For our evaluation, we selected the 10-fold cross-validation technique, where the whole dataset was divided into ten folds. During the process, one of the folds is retained as the validation data for testing, and the rest of the folds are used as training data. The cycle is repeated ten times, whereas each fold is used once as a validation set. The results of the individual iterations are afterward averaged or computed by other alternative methodologies to obtain a single estimation. [3]

Unlike SVM, the computational complexity of the artificial neural network highly depends on the dimensionality of the input space. Since there are no guidelines on how to construct the appropriate architecture, including the selection of the activation function and the optimum number of both, hidden layers and neurons, these parameters are often selected through a trial and error process. During this trial process, we tried several different neural networks with various numbers of hidden layers and neurons. The input layer of the neural network architectures consisted of sixteen neurons (one neuron per each extracted feature), and the output layer had two neurons, which represented the leukemic and the normal class. Depending on the type of the given data, all neurons in all layers were based on a sigmoid activation function. To train and test all proposed neural network architectures, we utilized the whole range of the dataset samples and divided the dataset into training and testing set in a general convention ratio of 80:20. All neural network architectures were trained by randomly selected samples, which prevented the neural network to overfit and to focus on one specific domain. For the training process, two different numbers of learning iterations were chosen. The first sequence of neural network training was set to 10 000 iterations. This value at the constant distribution function and a total of 200 learning samples resulted in an average value of 50 for one sample learning. Additionally, to improve the subsequent learning cycles, the number of iterations was enlarged ten times. Each learning cycle during the experiment used identical learning rates that ensured a uniform impact of all training samples. [3]

3 Evaluation Of The Results

For the final classification, we selected the polynomial C-SVM model and artificial neural network with two hidden layers and a descending number of neurons in particular layers (specifically, 400 and 200). Both classification models reached the highest accuracy during the preceding process of the optimal model selection. To test the proposed framework of both classifiers, overall 241 extracted cells containing 128

normal leukocytes and 113 leukemic cells were used. Due to the lack of data, we assigned only 50 percent of the samples to the training set, which ensured more reliable classification results in comparison with validations using larger training sets.

To assess the performance of the classification algorithms, we constructed the confusion matrix and computed the corresponding performance measures, namely the sensitivity, specificity, and accuracy (see Table 2). Accuracy denotes the ratio of correct prediction, whereas sensitivity and specificity reflect early warnings from two different perspectives. While sensitivity, also known as recall, denotes how often the positive results are predicted correctly, specificity measures correct negative predictions. In medical practice, a very high value of sensitivity is required to minimize the second type of error, and therefore the false negative predictions. [4]

Table 2: Performance of the particular classification algorithms

Classifier	Sensitivity	Specificity	Accuracy
Artificial neural network	100.0	95.3	97.5
Support vector machine	98.3	95.3	96.7

4 Conclusion

In this paper, we proposed a framework for an automated system for the identification of leukemic cells from microscopic blood smear images. To achieve the most accurate classification results, we implemented an extensive segmentation method and extracted overall 16 features from particular regions of the segmented cell. To classify the blood cells, two supervised algorithms were implemented; the support vector machine and artificial neural network. The proposed support vector machine achieved an overall accuracy of 96.7 %, while the artificial neural network was able to classify 118 leukocytes correctly out of 121, which has given an efficiency of 97.5 %. Regarding the false classifications, all incorrect classifications of the neural network model were false positive, while the SVM commit the false negative error causing the doctor and patient to believe the patient doesn't have a condition that can lead to disease progression even beyond the point of survival.

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Nonlinear optimization with REXYGEN and SOLNP

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Abstract. This paper presents SOLNP, a module used to solve the nonlinear problem of a system. It solves the non-linearity by applying a Sequential Quadratic Programming(SQP) to an Augmented Lagrangian cost function. The paper also deals with REXYGEN and REXLANG function blocks which allows the user to experience the real-time behaviour of the system. The Python code is integrated with REXYGEN. Illustrative example showing the mathematical formulation and step-by-step guide to apply SOLNP is presented as well.

Keywords: Nonlinear · SOLNP · Python · REXYGEN · REXLANG · Sequential Quadratic Programming · optimization

1 Introduction

A nonlinear program consists of an objective function, constraints, and boundary variable. The major difference between linear and nonlinear programs lies herewith: A non-linear program consists of at least one non linear function[1],[2]. Many of the real systems that we come across are inherently non-linear, so it becomes important that optimisation methods be applied to these systems so as to manage the non-linearity[3]. Nonlinear models can be tricky at times as finding the initial guess and satisfying the given constraints can lead to certain challenges[4].

Nonlinear programming problem is the minimization or maximization of a nonlinear objective function $f(\mathbf{x})$, $\mathbf{x} \in R^n$, of n variables, subject to equation and or inequality constraints involving a vector of nonlinear functions $c(\mathbf{x})$. A basic statement of the problem is[4]:

$$\begin{aligned} & \text{minimize}_{\mathbf{x} \in R^n} && f(\mathbf{x}) \\ & \text{subject to } c_i(\mathbf{x}) \geq 0 && i = 1, 2, \dots, m \end{aligned} \tag{1}$$

In this paper, we aim to discuss solving of a nonlinear system using SOLNP, which is a sequential Quadratic Programming(SQP) solver[5]. Sequential quadratic

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programming is another important and effective optimization method. The highlight of SQP is its ability to solve nonlinear constraints. SQP models an approximate solution x^k by quadratic programming subproblem, then using this problem to produce the next approximation, $x^k + 1$. This process of iteration is continued till the solution converges to give x^* . An advantage of SQP is that it is not a feasible-point method, which implies that the initial point and the future iterations need not be feasible. This resolves the difficulty of finding a feasible starting point which can be as taxing as finding a solution.

2 Solving Nonlinear Problem-SOLNP

The solver belongs to the class of indirect solvers and implements the augmented Lagrange multiplier method with an SQP interior algorithm [6]. SOLNP is a package linked to Python that solves nonlinear programming problem in the following form:

$$\begin{aligned} & \text{minimize} && f(x) \\ & \text{subject to} && g(x) = 0 \\ & && l_h \leq h(x) \leq u_h \\ & && l_x \leq x \leq u_x \end{aligned} \quad (2)$$

where,

$f(x) : R^n \rightarrow R$ is the objective function (n is the number of free variables),
 $g(x) : R^n \rightarrow R^{m_e}$ are the equality constraint functions (me is the number of equality constraints),

$h(x) : R^n \rightarrow R^{m_i}$ are the inequality constraint functions (mi is the number of inequality constraints),

l_h, u_h are the lower and upper bounds for inequalities, and l_x, u_x are the bounds for free variables.

SOLNP is a method of iterations which solves the QP sub-problem at every major iteration. QP is a special case of non-linear programming optimization where the objective function is quadratic and the constraints are linear[7]. Each major iteration starts by solving a linearly constrained problem with an augmented Lagrangian objective function of the following form:

$$\begin{aligned} & \text{minimize} && f(x) - y^k g(x) + (\rho/2) \|g(x)\|^2 \\ & \text{subject to} && J^k (x - x^k) = -g(x^k) \\ & && l_x \leq x \leq u_x \end{aligned} \quad (3)$$

The inequality constraints are converted to equality constraints by adding slack variables. j^k is a numerical approximation to the Jacobian:

$$J^k = \left. \frac{\partial g}{\partial x} \right|_{x^k} \quad (4)$$

and y^k is the vector of Lagrangian multipliers at the k^{th} major iteration.

The augmented Lagrangian objective function plays the role of a merit function measuring the quality of each iteration for finding a better point estimate.

Both major and minor processes repeat until the optimal solution is found or the user specified maximum number of iterations is reached.

2.1 Motivation

Lets assume that we want to travel to point x and $f(x)$ represents cost of covering the distance. There are some obvious constraints on covering this said distance. For instance, there may be limited fuel cost, $h(x) \leq b$ or so many other constraints during the time period. The driver's goal is to minimise the time or fuel cost. If this cost is optimised or minimised, the driver can maximise on the profit of either saving the fuel or time. Optimization is concerned with finding policies that handle the system in an optimal way[8].

It is a powerful tool where one looks for variable values within the said domain that minimises or maximises the given function. One can use the above analogy where certain variables represent decisions or some definition of parameters and functions to measure the performance. The user can use this framework to support decision making in various applications, from planning routes to training robots to learn from given data.

3 Illustrative examples

In this section, a nonlinear problem is considered. This example has only equality constraints.

$$\begin{aligned} \min . & \exp(x_1 x_2 x_3 x_4 x_5) \\ \text{s.t. } & x_1^2 + x_2^2 + x_3^2 + x_4^2 + x_5^2 = 10 \\ & x_2 x_3 - 5 x_4 x_5 = 0 \\ & x_1^3 + x_2^3 = -1 \end{aligned}$$

The cost function for this would look like the following lines:

```
function [f] = cost(x, par)
f(1) = exp(x(1) * x(2) * x(3) * x(4) * x(5))
f(2) = x(1)^2 + x(2)^2 + x(3)^2 + x(4)^2 + x(5)^2 - 10
f(3) = x(2) * x(3) - 5 * x(4) * x(5)
f(4) = x(1)^3 + x(2)^3 + 1
f = f'
return
```

The starting point chosen for this example is:

$$x_0 = (-2, 2, 2, -1, -1)$$

This example is transcribed into Python and later REXYGEN runs the algorithm to produce real time data acquisition.

3.1 Implementation of Python Block in REXYGEN

The problem considered in section 3 is written in Python. The code is loaded into the Python block in REXYGEN. The code in Python is as follows:

Algorithm 1 Python

```

0: procedure PROCEDURE
0:   import  $\leftarrow$  pysolnp
0:   import  $\leftarrow$  numpy
0:   import  $\leftarrow$  timeit
0:   import  $\leftarrow$  datetime
0:   import  $\leftarrow$  random
0:   from PyRexExt import  $\leftarrow$  REX
0:   define objective function
0:   result  $\leftarrow$  numpy.exp(x[0] * x[1] * x[2] * x[3] * x[4])
1: return result
1:   define equality function
1:   result  $\leftarrow$  [pow(x[0], 2) + pow(x[1], 2) + pow(x[2], 2) + pow(x[3], 2) +
   pow(x[4], 2), x[1] * x[2] - 5 * x[3] * x[4], pow(x[0], 3) + pow(x[1], 3)]
2: return result
2:   starting point  $\leftarrow$  [-2, 2, 2, -1, -1]
2:   equality point  $\leftarrow$  [10, 0, -1]
2:   define solve function
2:   result  $\leftarrow$  pysolnp.solve(objfunc = boxobjectivefunction, par_start_value =
   startingpoint, eqfunc = boxequalityfunction, eq_values = equality_values)
3: return result
3:   if name == "main" then
3:     result  $\leftarrow$  solve_box()
3:     final parameters  $\leftarrow$  result.optimum
4: print final parameters[0]
4:   define init function
4:   result  $\leftarrow$  solve_box()
4:   final parameters  $\leftarrow$  result.optimum
4:   REX.y0.v  $\leftarrow$  finalparameters[0]
4:   define main function
4:   result  $\leftarrow$  solve_box()
4:   final parameters  $\leftarrow$  result.optimum
4:   REX.y1.v  $\leftarrow$  finalparameters[0] + random.random()
4:

```

The functions such as *main()* and *init()* are reserved functions that are then executed by REXYGEN. The *main()* function is executed periodically during runtime. Alongside the *main()* function the *init()* function is executed once at startup.

REXYGEN control system doesn't require the typical hand coded programming, but uses function blocks that are part of its library[9] [10]. The REXYGEN system provides us with a standard function blocks that can be used in

most control applications, but a user-defined function gives us more room to be resourceful. That's what a REXLANG block gives us. A REXLANG block is used when a real-time behaviour needs to be observed[11]. In the case presented in this paper, a PYTHON block is used. The block implements the above algorithm in Python language[10].

Fig. 1. Executable REXYGEN Diagram

The Python block is fed the Python script and gets embedded in the REXYGEN configuration when it is compiled. The script gets stored in the directory during the initialisation process of the block when the configuration is downloaded and executed on to the target.

4 Conclusion

In this paper, we presented SOLNP: a solver to manage the non linearity of a system. The solver was presented within the framework of Python. Later, a software tool called REXYGEN was used to implement the solver. The Python block is present in the REXYGEN library which the users can take advantage of. This enables the user to visualize the behaviour in real-time. The example problem demonstrated the simplicity and power of SOLNP solving the nonlinear problems.

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Statistical Analysis of the Distribution of Intensities from MR Images of Abdominal Area

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Abstract. The role of magnetic resonance imaging (MRI) for non-invasive quantification of fat from the abdominal area, especially the pancreas, is currently a large discussed topic. Although the quantification of fat degeneration in the pancreas is very important, especially in association with civilian diseases, such implementation is very complicated. In this study, a statistical analysis of the pixels intensities distributions of the pancreas, liver and kidneys was performed. 10 subjects were analyzed from 1.5 T Dixon MR images without the use of contrast agents. Regions of interest (ROI) for comparison were the head, body and tail of the pancreas, the adipose capsule of kidney and the 7th, 5th and 3rd segment of the liver. At the level of significance α 0.05, statistically significant differences between the individual subjects could be observed. The null hypothesis between the adipose capsule of the kidneys (Capsula adiposa) and the pancreas (P 0.654 and P 0.967) was statistically verified in one subject. Images from the Dixon sequence appears to be useful for quantifying pancreatic fat degeneration.

Keywords: magnetic resonance imaging · pancreas · fat · statistical hypothesis test

1 Introduction

The accumulation of fat in the pancreas, can be described as a pancreatic steatosis. This term characterizes the accumulation of fat in the pancreas as a reversible process. This condition, pancreatic steatosis, was first described by Ogilvie [6] in 1933, when 9 % of pancreatic fat was observed in lean individuals compared to 17 % of pancreatic fat in obese individuals. Pancreatic steatosis is associated with diseases of civilization, such as type 2 diabetes, acute pancreatitis, and pancreatic cancer. Therefore the early diagnosis is very important, and hence it is necessary to quantify the degree of pancreatic fat degeneration reliably and non-invasively [13, 4, 12]. Nowadays, early diagnosis is complicated, histological examinations are invasive with associated complications. However, Magnetic resonance imaging allows non-invasive in vivo quantification of fat content in tissues [5, 10].

Patel and co-workers [7] in their pilot study of a cohort of 43 patients in 2013, point to the use of a chemical shift-based gradient-echo MRI technique to

measure proton density fat fraction (PDFF), which allows the quantification of pancreatic fat. According to the authors, pancreatic fat is positively correlated with liver histology and the degree of steatosis. Among other things, pancreatic fat determined by MRI correlates with a histologically determined degree of hepatic steatosis. However, the authors also report the problem of unequal accumulation of fat in the pancreas, especially focal accumulation in the tail and front of the head of the pancreas. The work of Koc et al [3] from 2020 investigated the 3D - VIBE CAIPIRINHA - Dixon technique to evaluate pancreatic steatosis. In their analysis, they tested a total of 90 subjects (49 diagnosed with pancreatic steatosis and 41 was control group). They reaches the conclusion that the used sequence is a very accurate and fast choice for the evaluation of pancreatic steatosis according to the pancreatic signal index (PSII).

Further observations indicate that the Dixon MRI technique is also significantly correlated (0.76 %) with the volume of fat fraction measured by dual energy CT, according to the authors Kameda et al from 2020 [2]. The Dixon method was also used in the work of Sijent et al [11] from 2010. Among other things, they draw the attention to MR spectroscopy and significant positive correlation with Dixon method. Other analyzes indicating the possibility of using MR spectroscopy, Dixon method, PDFF and dependences of adipose tissue distributions in connection with type 2 diabetes mellitus [1, 9].

2 Material and Methods

In order to statistical verification of the parameters, a 1.5 T Dixon MRI was performed on 10 subjects with set parameters: TR 6.85 ms, TE_1 2.39 ms, TE_2 4.77 ms, average 2, FoV 380 mm, Slice thickness 3.0 mm with CAIPIRINHA parallel imaging technique. Firstly, manual extraction of distribution of intensities from images (320x260) of the pancreas, liver and kidney were manually extracted. Total of 3 ROIs were selected from the pancreas, the head (caput pancreatis), body (corpus pancreatis) and tail (cauda pancreatis) and areas of the 7th liver segment, the 5th liver segment and the 3rd liver segment were selected from the liver. In the kidney, the ROI was selected on the adipose capsula. During extraction, care was taken to not to include other anatomical structures in the ROI (e.g. large vessels or the main canal of the pancreas). An example of extracting brightness distributions from the tail of pancreas and the 7th liver segment is shown in Fig. 1.

Secondly, the basic description of the data were performed. For the basic description, the values of medians, quartiles, standard deviations and variances for each ROI were calculated for all tested subjects. To verify the statistically significant differences between the individual subjects the Shapiro-Wilk normality test [8] was used.

Fig. 1. Extraction of intensity values performed from the tail area of the pancreas (red arrow) and the 7th liver segment (blue arrow). ROI size approximately 1 cm² on a Dixon opposed-phase image.

3 Results

The first set of analyses investigated basic description of the data, where is possible to clearly observe a comparison of extracted values between individuals see Fig. 2. The Shapiro-Wilk normality test about normal distribution was tested on 95% confidence interval. Null hypothesis H_0 :the extracted distributions of intensities comes from the normal distributed population. Alternative hypothesis H_A : negation of H_0 .

Fig. 2. Box plot shows extracted brightness intensities from the tail of the pancreas from all subjects.

Table 1. Results of the Shapir-Wilk test on a 95% confidence interval to determine normality in individual ROIs and all tested subjects.

Subject ID	P-value						
	BoP	HoP	ToP	7th SoL	5th SoL	3rd SoL	ACK
P2217	0.218	0.456	0.223	0.005	0.018	0.229	0.045
P131	0.086	0.356	0.236	0.025	0.052	0.056	0.153
PH69	0.050	0.776	0.004	0.014	<<0.001	0.034	0.023
P001	0.113	0.127	0.001	0.108	0.013	0.216	0.150
P002	0.113	0.095	0.002	0.005	0.015	0.027	0.043
P003	0.257	0.262	0.256	0.057	0.075	0.084	0.387
P1008	0.523	0.274	0.125	0.174	0.046	0.931	0.069
P120	<<0.001	0.007	0.910	0.084	0.022	0.084	0.025
P122	<<0.001	0.001	0.438	0.006	0.099	0.016	0.051
P1596	0.001	0.013	0.142	0.004	0.019	0.052	0.149

Table 2. Results of Wilcoxon Mann’s Whitney test to determine a statistically significant difference.

Subject ID	P-value					
	BoP	HoP	ToP	7th SoL	5th SoL	3rd SoL
P2217	<<0.001	<<0.001	<<0.001	<<0.001	<<0.001	<<0.001
P131	<<0.001	<<0.001	<<0.001	<<0.001	<<0.001	<<0.001
PH69	<<0.001	<<0.001	<<0.001	<<0.001	0.989	<<0.001
P001	<<0.001	<<0.001	<<0.001	<<0.001	<<0.001	<<0.001
P002	<<0.001	<<0.001	<<0.001	<<0.001	<<0.001	<<0.001
P003	<<0.001	<<0.001	<<0.001	<<0.001	<<0.001	<<0.001
P1008	<<0.001	0.654	0.967	<<0.001	0.492	<<0.001
P120	<<0.001	<<0.001	<<0.001	<<0.001	<<0.001	<<0.001
P122	<<0.001	0.012	<<0.001	<<0.001	0.594	<<0.001
P1596	<<0.001	<<0.001	<<0.001	<<0.001	0.977	0.999

Based on Fig. 2 could be clearly pointed that the brightness intensities do not change much for most subjects. Significant changes can be observed in subjects P1008, P122, P1596. The hypointense in selected ROIs could be attributed to

a greater fat degeneration in the tissue. Tab. 1 and 2 describe the results of the statistical tests performed, BoP stands for (Body of Pancreas), HoP (Head of Pancreas), ToP (Tail of Pancreas) and SoL (Segment of Liver). The Shapir-Wilk test revealed that data are not mostly normally distributed, so based on the resulting p-value at the significance level $\alpha = 0.05$, the null hypothesis is rejected. Due to the results a nonparametric Mann-Whitney statistical test is used for all analyzed values, see Tab 2. Null hypothesis $H_0: x_{\frac{ROI_1}{0.5}} = x_{\frac{ROI_2}{0.5}}$. Alternative hypothesis $H_A: x_{\frac{ROI_1}{0.5}} > x_{\frac{ROI_2}{0.5}}$. Significantly the distribution of intensities of individual ROI's differs statistically, it can be stated that the distribution of kidney's adipose capsula is not the same as with the selected anatomical area of the renal adipose tissue.

4 Conclusion

Nowadays, magnetic resonance imaging has appeared in the literature as the most ideal method for non-invasive quantification of fat in the abdominal area. One of the possible methods of data acquisition via MRI is the Dixon technique. Based on statistical testing, it was found that an increase in tissue fat fraction correlates with a decrease in the distribution of intensity which is in line with previous findings in the literature. Furthermore, statistically significant differences were mostly found in comparison with the adipose capsule of the kidney. However, subject P1008 had statistically verified agreement between the extracted values from the pancreas. These findings would seem to show greater proportion of the fat fraction. In our view these results represent an excellent initial step toward to non-invasively quantificate fat in the pancreas.

This work clearly has some limitations. Despite this we believe that work could be the basis for a greater analyses. This could hypothetically lead to measurement of more subjects divided with diagnosed pancreatic steatosis and a control group. Also, the other indicators such as blood tests, histology findings etc. could also refine future work. Research into solving this problem is already underway.

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The Use Of The Digital Twin In The Critical Real-Time Systems

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Abstract. Usually it is very difficult to test critical real-time systems comprehensively. It is not possible to test these systems on production systems and their sub-systems. It is very expensive and it can affect the actual operation.

However, it is not even possible to create a physical model of the production sub-system because it would be very costly and every change would have to be made physically. Since the various processes of the system are linked to each other at the time t , we would have to physically test every single change on the entire interval T . Therefore, it is necessary to use a digital twin.

The digital twin can encapsulate the processes of the physical sub-system and with the help of various tools it can simulate the operation of the whole system, even the outages and errors. Then we are able to easily switch the connection string to the testing version and then we can test different parts or even the whole thing without affecting the real operation.

In my work I deal with the design of the system for testing individual production processes.

1 Introduction To Digital Twins

The concept of the digital twin originated for the purpose of faster and more efficient development of complex control systems. The digital twin can simulate various sensors, the behavior of physical models such as production lines, etc.

The main advantage of using a digital twin over creating a control system directly is the ability to go through most of the phases/states of the system without compromising the current operation of production. It is a purely virtual system where errors that can occur during development can be caught and debugged faster. The digital twin in fact represents the final physical product. [1]

Although the digital twin is a purely virtual planning and testing system, its digital footprint contains all the important information from real systems (mostly from those that will be encapsulated in a system that represents the digital twin). The digital twin also serves as a virtual distributed system that manages the life cycle of the final product and following business planning. The digital

twin can process both static and dynamic system status information. By static information it is meant:

- Material quality
- Order of individual processes
- Geometric representation of individual products.

One of the key points of the digital twin is the possibility of simulating autonomous behavior and decision elements. In practice, optimization methods and linear programming are used to simulate the optimal use of internal inputs to optimize the output. The system can keep information about its status and statistical result and according to this information it can adjust the individual attributes of management and administration. [1]

2 Critical Real-Time Systems

In the real systems (RT systems), computers are programmed in the way that the individual process steps are in accordance with the time schedule of the system and it could solve the new requirements of the controlled system as efficiently as possible. Depending on the time schedule and the importance of each process, we can divide the individual processes into:

- Soft process
- Hard process.

For soft processes, time instability can be tolerated if the process differs in time from a given schedule, however, this time instability is reflected in an increase in costs associated with the operation and control of the system. For hard systems, process delays can never be tolerated.

Real systems process the flow of events and these events are sent using the data flow either as a message that contains 0 and 1. Then the position of the number tells what part of the system it is and in what state (0 or 1). Today, however, IoT (Internet of Things) is beginning to use object sending using JSON / XML. These events are called time-controlled tasks. However, when events occur that are signaled from outside the system, such as a signal interruption or system overheating, these events are called event-controlled task events.

The last possibility of communication can take place between the operator and the system. This type of communication is called interactively-controlled tasks. [2]

2.1 Requirements of RT systems

Software that manages time-dependent systems should know in advance the response of the operating system. It should also know the duration of each task with possible defined inputs. All critical tasks must be managed to meet the timetable.

3 Design Of A Data Collection System For A Digital Twin

3.1 Problem Formulation

The plant contains various production lines and sensors that sense various attributes, such as air temperature, CO_2 in the air etc. Some production lines are data-dependent, that means that line A transmits data on the consistency and condition of the material to line B and that line B continues production accordingly. The production process is also strictly dependent on some values from the sensors, ie for example a different mixture is added depending on the temperature. Priority tasks can occur if the temperature rises above a certain degree or CO_2 rises etc.

3.2 Inputs from production lines

Each production line sends using a serial port every 2 with the string 0 and 1. Each position of the character represents a different attribute of the system or another running task. The sensors are connected to the central control unit and this unit also sends via the serial port co 1 with the string 0 and 1. This data flow is shown on picture 1

3.3 Output: Design of RT system using IoT technology

Business model for processing data from lines Production lines will use the serial port to send input data to the application. The application processes this data in parallel and then sends it to the database using network ropes.

Business model for data processing from sensors The control unit collects data from the sensors and then sends it via the serial port to an application that processes the data in parallel. It then uploads them to the database. This data flow is shown on picture 2 and 3

4 Results

4.1 Input data processing solutions

For periodic tasks The application downloads from the local database all active processes, which are sorted according to the priority of the process and are not critical tasks, and then it downloads their last written values of all attributes. Then it processes these individual processes, which have the ExecutableProcess set to true . For these executable processes, it then returns all associated processes in order of priority. It then calls each method for each associated process name. If the associated process has the "can run asynchronously" attribute set to true, the process runs in a different thread than the main process. This should ensure the thread locking and concurrent data processing.

Fig. 1. Design for data processing from lines

Fig. 2. Design for data processing from sensors

Fig. 3. Class diagram for RT system

For sensors The application downloads all last measured values of sensors that have a value higher than the Maximum safe value. If the returned data is not null, then it calls an aperiodic task.

For aperiodic problems According to the sensor, the periodic task and its subtasks are called and processed in the same way as for periodic tasks. Periodic and aperiodic problems are distinguished by the attribute Critical task.

4.2 Use of the digital twin

With the knowledge of a similar line, this process can be simulated using a digital twin and thanks to that it can be successfully virtually debugging any errors that may occur.

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Seeking Relevant Information Sources

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Abstract. In this paper, we present an algorithm for seeking relevant informational sources from many textual resources. The algorithm is based on Carnapian explications of an atomic concept formalized as constructions of Transparent Intensional Logic (TIL). The algorithm applies machine learning methods in order to propose a hypothetical explication of the sought concept. With obtained approximations of the meaning of the sought concept, a user is able to choose textual resources relevant to him.

1 Introduction

With an increasing number of textual resources available at our disposal, we encounter a problem of information overload. During a search for relevant information, we often study several resources only to realize that they are of no use for us, and we must search for others. To deal with this problem, we proposed a system which automatically recommends informational resources based on which a user can obtain those most relevant to him.

Seeking for relevant resources is based on Carnapian explication (see [2]) of atomic concepts, which is obtained from natural language sentences. Considering the nature of this problem, we exploit the system of Transparent Intensional Logic (TIL). TIL is an expressive higher-order logic with procedural semantics suitable for this task. Explication of an atomic concept is achieved by implementing methods of machine learning adjusted to natural language processing.

Our algorithm is simply described as follows. First, text data are linguistically and logically processed so that TIL constructions are extracted. Then we transform these constructions into the TIL-Script language, which is a computational variant of TIL, to obtain input for machine learning algorithms. Finally, a post-processing of results is the domain of logic. We compare compound constructions obtained from different resources as for their consistency, compatibility and similarity to inform the user on potential discrepancies or even fake data.

2 Supervised machine learning

In supervised machine learning, the supervisor trains an agent by training examples. These examples are described by attributes divided into input and output

attributes. Values of input attributes describe the examples; values of output attributes are given by an unknown function from values of input attributes. For example, meteorological situation can be described by input attributes such as *air pressure*, *air humidity*, *wind speed*, etc. Type of weather, such as *sunny*, *rainy*, *windy*, etc., would serve as values for an output attribute.

During a training phase, the supervisor would train the agent by presenting chosen examples. Generally, where $x_1, \dots, x_n$ are values of input attributes and y the output attribute value, there is a function f such that $y = f(x_1, \dots, x_n)$. By observing input/output values of examples attributes presented by the supervisor, the agent would obtain his own function h , called the *hypothesis*, which approximates the original function f .

The correctness of the hypothesis is verified by a set of test examples where only values of input attributes are known to the agent. The hypothesis is plausible if the agent predicts the value of an output attribute with maximum accuracy¹.

3 Explication of an atomic concept

Since we are dealing with natural language processing, we use TIL as our background theory. TIL allows us to formalize salient semantic features of natural language in a fine-grained way. For more details see [9], [3].

By combining TIL and machine learning, we explicate atomic concepts for the purpose of understanding them and for retrieval of additional useful information. *Carnapian explication*² is a process of refinement of an ambiguous or vague expression. The expression, to be refined, is called an *explicandum*; its refinement, obtained by the explication, is called an *explicatum*. For example, a simple expression such as a dog (explicandum) can be refined as “*Dog is a domesticated carnivore*” (explicatum). In terms of TIL, the explicandum is an atomic concept, i.e. an atomic closed construction. The explicatum is a molecular construction defining the explicandum. We also say that the molecular concept is an ontological definition of the object falling under the atomic concept.

For example:

$${}^0\textit{Dog} =_{df} \lambda w \lambda t \lambda x [[{}^0\textit{Domesticated} \ {}^0\textit{Carnivore}]_{wt} x]$$

$$\text{Types: } \textit{Domesticated}/((ol)_{wt}(ol)_{wt}); \textit{Dog}, \textit{Carnivore}/(ol)_{wt}; x \rightarrow \iota$$

Since we deal with natural language processing, we adjusted its methods to it. As training examples, natural language sentences are used. The role of the input/output attributes is replaced by concepts. The role of the output attribute is now played by the atomic concept (explicandum) to be learnt. Input attributes are constituents of the molecular concept that defines the atomic concept. For example, a concept of dog, i.e. Trivialization ${}^0\textit{Dog}$ of the property of being a

¹ For more detail see [4], [8]

² See [2]

dog of type $(ol)_{wt}$, can be explicated by examples such as “*Dog is a domesticated mammal of the family Canidae*”.

Explicating the atomic concept is realized by an algorithm of Patrick Winston³ adjusted to natural language processing. The adjusted algorithm can be described by a general framework which consists of four parts:

- *The goal.* As mentioned above, the goal of an agent is to discover the best refinement of the learned atomic concept of an object O, i.e. a molecular closed construction that produces the same object. Moreover, this molecular concept should define the object falling under the atomic concept as adequately as possible so that it also excludes other similar concepts.
- *The training data.* An agent works with positive and negative examples that are sentences extracted from a textual base. Positive examples contain concepts of requisites, typical properties or even a semantic association specifying the learned atomic concept, while negative examples specify properties that do not belong to the essence of the intension provided by the concept.
- *Data representation.* The agent must have a formal internal representation of data obtained by examples. Plausible hypotheses are then formulated in terms of this representation. Our formalism is that of Transparent Intensional Logic so that sentences are analyzed in terms of TIL constructions.
- *Knowledge modifying module.* The agent uses a set of operations to modify the hypothesis during a heuristic search in the hypothesis space⁴. The three main operations to modify a hypothetic concept are generalization, specialization and refinement. Those three methods include five heuristic functions described below.

4 Inductive heuristics

Patrick Winston’s algorithm³ is based on iterative generalization or specialization of the hypothesis in symbolic notation. Examples, presented by the supervisor, differ from the hypothesis by a significant difference. Since the input of our algorithm are TIL constructions, we do not compare examples to the hypothesis in a search for a significant difference; instead, we compare the hypothetic concept with information in constructions of sample sentences.

We introduced a method *Refinement* which is essential for introducing a new concept from examples into the molecular concept. Refinement is triggered by a positive example and contains a new heuristic function called *Concept-introduction*. If the supervisor presents an example which contains a constituent not contained in the molecular concept, Concept-introduction will enrich the molecular concept with the new constituent in conjunctive way.

Generalization method is a special case of the refinement which replaces one or more constituents contained in the molecular concept for a more general one. The general constituent is either extracted from an agent’s ontology or created from special constituents in the disjunctive way.

³ Details in [10]

⁴ More details in [5]

- If a value of a constituent in a positive example differs from a value of the same constituent in the molecular concept, then *Climb-tree* or *Union-set* heuristic function is triggered. If different values have a common most specific general value in the agent's ontology, then *Climb-tree* heuristic is triggered and the value in the molecular concept is replaced by the general one from the ontology. Otherwise, the value in the molecular concept is replaced by a union of those values by *Union-set heuristic*.
- If the value of the constituent in the positive example differs from the value of the same constituent in the molecular concept in numeric value, then heuristic *Close-interval* replaces the value in the molecular concept with a numerical interval spanning both values

Using *Specialization*, we insert new constituents into the molecular concept, which do not belong into the essence of the atomic concept, in the negated way. Specialization serves to distinguish the output concept from similar ones. *Forbid-link* is the only heuristic function of *Specialization method*.

The algorithm is specified as follows:

Refinement

1. Compare the model hypothesis (to be refined) and the positive example to find a significant difference
2. If there is a significant difference, then
 - (a) if the positive example contains as its constituent a concept that the model does not have, use the *Concept-introduction*
 - (b) else ignore example

Specialization

1. Compare the model hypothesis (to be refined) and the near-miss example to find a significant difference
2. If there is a significant difference, then
 - (a) if the near-miss example has a constituent of the concept that the model does not have, use the *Forbid-link*
 - (b) else ignore example

Generalization

1. Compare the model hypothesis (to be refined) and the positive example to determine a difference
2. For each difference do
 - (a) if a concept in the model points at a value that differs from the value in the example, then
 - i. if the properties in which the model and example differ have the most specific general property, use the *Climb-tree*
 - ii. else use *Union-set*
 - (b) if the model and example differ at an attribute numerical value or interval, use the *Close-interval*

(c) else ignore example.

As a simple demonstration will serve an explication of a hypothetical concept of dog. From textual resources, we obtained six sentences as examples mentioning the concept of dog.

Positive examples:

- The dog is a mammal. - $[{}^0Req\ {}^0Mammal\ {}^0Dog]$
- The dog has four legs. - $[{}^0Typ-p_{wt}\ \lambda w\lambda t\ \lambda x[{}^0= [{}^0Leg-number_{wt}\ x]{}^04]{}^0Dog]$
- The dog has fur. - $[{}^0Typ-p_{wt}\ {}^0Has-Fur\ {}^0Dog]$
- The size of the litter of dog is two pups.
- $[{}^0Typ-p_{wt}\ \lambda w\lambda t\ \lambda x[{}^0= [{}^0Litter-size_{wt}\ x]{}^02]{}^0Dog]$
- The size of the litter of dog is nine pups.
- $[{}^0Typ-p_{wt}\ \lambda w\lambda t\ \lambda x[{}^0= [{}^0Litter-size_{wt}\ x]{}^09]{}^0Dog]$

Negative example:

- The dog meows. - $[{}^0Typ-p_{wt}\ {}^0Meows\ {}^0Dog]$

Result of explicating by the algorithm mentioned above is this molecular construction:

$$[{}^0Req\ {}^0Mammal\ {}^0Dog] \wedge [{}^0Typ-p_{wt}\ \lambda w\lambda t\ \lambda x[{}^0= [{}^0Leg-number_{wt}\ x]{}^04]{}^0Dog] \wedge [{}^0Typ-p_{wt}\ {}^0Has-Fur\ {}^0Dog] \wedge [{}^0Typ-p_{wt}\ \lambda w\lambda t\ \lambda x[{}^0\geq [{}^0Litter-size_{wt}\ x]{}^02] \wedge [{}^0\leq [{}^0Litter-size_{wt}\ x]{}^09]]{}^0Dog] \wedge [\neg[{}^0Typ-p_{wt}\ {}^0Meows\ {}^0Dog]]$$

Types: $Req, Typ-p/(o(\iota)_{wt}(\iota)_{wt}); Dog, Mammal, Has-fur, Meows/(\iota)_{wt}; Leg-count, Litter-size/(\tau\iota)_{wt}; =, \leq, \geq /o\tau\tau$

The molecular concept was built incrementally by presenting examples from the top to the bottom. Heuristic function Concept-introduction was applied four times. Then the molecular concept was generalized by the 5th example using Close-interval heuristic function. With the last example, the molecular concept was specialized by Forbid-link heuristic function.

5 Relevant source selection

The selection of relevant sources to the user is divided into three separate parts. In *Preparation* part, the user inputs an atomic concept and available textual resources. From those resources, only sentences mentioning the atomic concept are extracted and formalized into TIL constructions and grouped by the source from which they were extracted.

In the next phase called *Inductive heuristics*, hypothetical molecular concepts that should explicate the atomic concept are produced.

In the *Relevant source selection* phase, the user can study obtained molecular concepts and compare them for similarities or inconsistencies, i.e. acquire additional information about the atomic concept. If the user finds some of molecular concepts interesting, the system will present sources from which they were explicated.

6 Conclusion

In this paper, we presented the combination of TIL and supervised machine learning intended for natural language processing. The goal was to explicate a given atomic concept by analyzing text documents that mention the concept.

We introduced the algorithm which supports finding relevant information in a huge amount of textual resources. The user selects sources based on explications of the atomic concept obtained by machine learning methods from TIL constructions of sentences extracted from textual resources.

In [1], we introduced a post-processing method of the obtained molecular concepts in the form of Association rule data mining for additional information gain. As future research, we plan to improve the post-processing of the acquired molecular concepts.

Results summarized in this paper were published in [5], [6], [7].

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Towards Faster Matching Algorithm Using Ternary Tree in the Area of Genome Mapping

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Abstract. In area of precision medicine [1] there is a need to map long sequences of DNA, which are represented as strings of characters or numbers. Most of the computer programs used for genome mapping use suffix-based data structures, but those are much more suitable for mapping of short DNA sequences represented as strings over small alphabets. The most crucial parameters of data structure used for DNA mapping are time to fill the data structure, search time and system resources needed, especially memory, as the amount of data from scanning process can be really large. This article will describe implementation of memory optimized Ternary Search Tree (TST) for indexing of positions of labels obtained by Bionano Genomics DNA imaging device [2][3]. Experiments were performed on real life data from BNX file obtained by Bionano Genomics Saphyr device.

Keywords: precision medicine · genome mapping · data structures · ternary search tree

1 Ternary Search Tree

Ternary Search Tree (TST) [4][5] is a memory optimization of R-way trie data structure. Each node doesn't contain list of all possible values from the alphabet of R characters, as in R-way trie, but only three pointers to its child nodes. This is similar to binary search tree where each node has only two child nodes. TST is data structure used to store sets of strings. TST can be also used to store suffixes of given string, but those suffixes has to be generated and inserted into the TST as original strings.

Pointers of a TST node will be denoted as *left*, *equal* and *right*, node of the TST as N and child nodes of the node N as N_{left} , N_{equal} and N_{right} .

TST is then constructed based on following rules: If node $N[S[i]]$ contains i -th character of string S , then node $N_{equal}[S[i]]$ contains $S[i+1]$ character of the string S . Node $N_{left}[S[i]]$ (and $N_{right}[S[i]]$) contains character which meet relation $S[i] < N_{left}[S[i]]$ ($S[i] > N_{right}[S[i]]$ respectively). Each node in TST must contain one last information, and that is, if the node represents end of the string. Average time complexity for searching in TST is $O(\log n)$, where n is number of nodes in the TST. Height of the tree is proportional to $\log_3 N$ and so

average search time complexity is $O(\log N)$. Construction of TST has at worst time complexity of $O(n)$, where n is the length of inserted string.

Worst case space complexity of TST is $O(p)$, where p is a sum of lengths of all strings stored in the TST. This can happen only in the situation when each string contains character from the alphabet only once and each character is used only in one string (super-linear TST).

Real-life strings don't have such characteristics, so some nodes of the TST can be reused, thus saving the space required to store the TST. This especially applies to strings which have common prefixes. Rigorously it can be described as relation of space complexity (number of nodes) on entropy of the input set $3n/H$, where n is a number of strings in the input set and H is entropy of the input set [4].

Big benefit of TST is its ability to easily implement partial-match search algorithm which allows to search TST for strings by not fully defined keys (i.e. some characters in the search key are replaced by wild cards) or for searching against keys with given tolerance function (i.e. search for key *abc* with diff factor ± 1 will match strings like *bcd*, *bbc*, *aab*, ... in the TST). s

2 Ternary Search Tree Improvements

Main thought behind presented optimization of TST is to save memory on unnecessary "technical" parts of the tree [6]. Classic, not optimized, implementation of TST needs following data fields per tree node:

- Key data (char / integer / pointer; for calculations in this section 32-bit integer will be used)
- 3 pointers to child nodes (depends on the system architecture; for calculations in this section 64-bits pointers will be used)
- Boolean flag indicating if the node is end of the word (for calculations in this section 8 bits will be used)
- 1 pointer to value data if the TST serves as an index (not needed if TST only stores keys and queries for presence of given key string in the TST)

This gives us total of 37 Bytes of memory. Please note here that this is only theoretical value. In specific implementation this number varies quite a lot depending on the platform, programming language, concrete data types used, computer architecture and compiler.

Second thought is not to create tree nodes from certain depth of the tree at all, but rather store key string from some depth just as sequence of key values linked to the last tree node, i.e. introduction of *Node Stop Creation Depth* parameter. This is based on the observation that branching in the tree happens just at the beginning of the string which is being indexed. This optimization is highly empirical and efficiency differs a lot depending on the alphabet size and entropy of the strings indexed. When this parameter is too low, then optimized TST will become array of arrays as there will be only one node, root, and all data will be stored in the arrays which leads to degenerated TST. But if this

parameter is set correctly it can significantly speed up TST build times and improve space efficiency.

Node classes which are used to represent optimized TST can be categorized as follows:

- Base nodes ($4 + 8 = 12$ Bytes)
- Inner nodes ($12 + 16 = 28$ Bytes)
- End nodes ($28 + 17 = 45$ Bytes)

All node types contain pointer to it's center child and key value. This minimal form of node is used for Base node. Inner nodes have two more pointers, one for left and second for right child node. End node is an extension of Inner node and contains data fields for storing end of the string - collection of pointers to metadata which are linked to the stored word, pointer to Residual Data object (which will be described later on) and boolean flag signaling end of the string. Base and Inner nodes are used to build the TST and are unable to hold any data apart from the key value and End Nodes are data storage nodes.

This optimization of course comes with some cost - there is a need to evaluate what type of node is needed when new node is linked to the optimized TST. Nodes are only "upgraded" during the insertion and can be "downgraded" during the deletion of node according to the relation *BaseNode* < *InnerNode* < *EndNode* - End Node is the most universal kind of node, but requires most memory to represent.

Further optimization is introduction of Residual Data object. It consists of two arrays - first stores pointers to collection of keys and second contains pointers to metadata which are linked to respective key sequence. Optimized TST has a parameter which specifies key sequence depth from which keys are no longer stored as nodes, but are put into Residual Data collection. Metadata which are connected to that key are stored on the same array index in the Residual Data object.

Figure 1 illustrates structure of optimized TST which stores words "ABAC", "ACC", "ACCD" and "ABACDDD". MP denotes Metadata Pointer for respective word (for simplicity only one metadata pointer is shown, but as was mentioned above there is a collection of pointers). Parameter for use of Residual Data object is set to 4, i.e. sub string "DDD" from "ABACDDD" won't be stored as TST nodes, but is placed into Residual Data structure.

Optimized TST is constructed as regular TST. All nodes starts as base nodes. Inner nodes are created only in case when branching is needed but there is no need to store data in the node (i.e. node with key value "B" from the example). In case there is a end of key sequence (word), the type of node is changed to end node. This also happens when newly added key sequence ends in the middle of TST where we have only base node (i.e. word "ABA" will be added to the example).

Fig. 1. Optimized TST example

3 Experiments and Achieved Results

This section describes experiments with current implementation of BNX parser and optimized TST data structure and presents achieved results.

All experiments were done on a computer with Intel Core i7 CPU, 32GB RAM, NVMe SSD hard drive and Windows 10 operating system. Algorithm was implemented in a C++ programming language and compiled with a g++ compiler. BNX source data file containing 4 546 748 molecules has size of 2 496 MB

Tables 1, 2 and 3 shows measured performance data and legend is as follows:

- M_{cnt} - count of the molecules loaded from the BNX file
- t_1 - time to load and parse source BNX file
- C_{cnt} - count of characters in the parsed molecules
- N_{tot} - total count of the tree nodes
- N_e - count of the end nodes
- N_i - count of the internal nodes
- N_b - count of the base nodes
- t_2 - time to fill the TST with the data
- S - memory size of the TST

Measured data shows how size of the TST decreases with the count of tree nodes. Comparison with not optimized TST was done on theoretical level. In our implementation of TST size of nodes is $24B$ for the base node, $40B$ for the inner node and $64B$ for the end node. Not optimized TST would have all the nodes represented as end nodes. This leads to assumption, when also accounting for some technical specific constants, that not optimized TST would be ten times

Table 1. TST with nodes created for all characters in the strings

M_{cnt}	$t_1 [s]$	C_{cnt}	N_{tot}	N_e	N_i	N_b	$t_2 [ms]$	$S [MB]$
10k	0,4	413k	198k	5k	4k	189k	27	6,7
95k	3	2,4M	1,1M	45k	30k	1M	141	39
1M	39	34M	16M	489k	328k	15M	2 195	548
4,6M	182	169M	77M	2 108k	1 437k	73M	10 473	2 655

Table 2. TST with the Node Stop Creation Depth = 20

M_{cnt}	$t_1 [s]$	C_{cnt}	N_{tot}	N_e	N_i	N_b	$t_2 [ms]$	$S [MB]$
10k	0,4	413k	87k	5k	4k	78k	20	5,7
95k	3	2,4M	561k	45k	30k	486k	162	36
1M	39	34M	6,3M	489k	328k	5,5M	1 757	451
4,6M	182	169M	28M	2 108k	1 437k	24,4M	9 095	1 520

larger than the optimized TST with the node stop creation depth parameter set to 10. Difference between real sizes of the nodes and theoretical sizes are caused for example by memory alignment of data fields in structures and objects when allocated in computer memory.

Table 4 shows average measured search time for some value in the TST. Again, it can be seen that searching in TST is faster when there is fewer nodes in the TST. This is caused by saving unnecessary comparisons when going down the tree branches. Finding optimal value for the node stop creation depth parameter will be subject of further research.

4 Conclusion

In this article novel implementation of BNX file parser with memory optimized TST indexing data structure was described. Main goal is to shorten time needed to align DNA molecules to reference genome and to find differences between them. This is much needed in precision medicine as the whole process now takes up to several days and large part of the time required is spent just in data processing. There, quality and speed of DNA mapping software plays significant role. Hopefully improvement in efficiency and speed of DNA mapping software will lead to greater expansion of precision medicine into clinical practice.

Table 3. TST with the Node Stop Creation Depth = 10

M_{cnt}	$t_1 [s]$	C_{cnt}	N_{tot}	N_e	N_i	N_b	$t_2 [ms]$	$S [MB]$
10k	0,4	413k	40k	5k	4k	32k	14	2,9
95k	3	2,4M	290k	45k	30k	216k	113	20
1M	39	34M	3M	489k	328k	2,2M	1 545	254
4,6M	182	169M	12,3M	2 107k	1 435k	8,8M	8 860	1 145

Table 4. TST search times

Node stop creation depth	t_s [ns]
OFF	~5 100
20	~3 900
10	~3 650

Thorough performance and quality testing of presented solution was done. Results show that the TST can be build in reasonable times even for quite large amounts of data on mediocre computer so much better performance can be expected on more powerful machines. Memory optimization shows significant savings in memory consumption on real-life data. Search performance was also improved by saving unnecessary comparisons when searching for data in the TST.

Whole solution can be further improved and optimized with technical improvements such as use of low level programming using AVX. BNX parser, TST building and searching can also be parallelized for better utilization of system resources on modern computers. Further testing should be done on more powerful server class computers on much larger input data-sets. Also finding impact of different alphabet sizes on performance should be analyzed.

5 Full Article Information

Full article named *Towards Faster Matching Algorithm Using Ternary Tree in the Area of Genome Mapping* was submitted and accepted to workshop MIDAP-2020 under INCoS-2020 conference.

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TIL meaning, context and anaphora

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Abstract. In this paper, I present my work I have done during this academic year. I studied the system of Transparent Intensional Logic (TIL), in particular: what is the meaning of a natural-language expression in TIL, three kinds of context recognized in TIL and how do we spot them, the substitution method and its applications, forms of supposition in which a concept can occur and anaphora resolution.

Keywords: TIL-Script, meaning, procedure, context, anaphora

1 Introduction

To properly utilize the advantages of an expressive logical system like TIL to create better tools for language processing, deduction and machine learning using the TIL-Script language, we need to understand not only basic, but also advanced concepts of TIL.¹ To this end, I studied TIL, presented the results in conferences and published them with co-authors in journals as well as in the proceedings, see [2], [3], [4], [5].

2 Meaning in TIL

Perhaps the most important feature of TIL is its *procedural* (as opposed to set-theoretic denotational) semantics. Meaning of a language term is conceived as an abstract, algorithmically structured procedure. Pavel Tichý, the founder of TIL, coined these procedures *constructions*. The goal of a semantic analysis of a language is to assign TIL constructions to its expressions as their meaning. These constructions are then vehicles of information and a central tool of our mutual communication. For semantic analysis to be adequate, the meaning construction must construct the object denoted by the analysed expression, its denotation. The semantic schema of TIL that illustrates the relations between an expression, construction and denotation is depicted by Fig.1.

¹ TIL-Script is a computational variant of Transparent Intensional Logic

Fig. 1 Semantic schema of TIL

There are six kinds of constructions. *Atomic constructions* that supply objects on which molecular constructions operate are *variables* and *Trivialization*. To each type, countably many variables are assigned.² Variables $x, y, p, q, \dots$ produce objects of their respective ranges depending on valuation, they *v-construct*. Trivialization of an object X , 0X in symbols, is a simple grabbing mechanism that produces X , a pointer to X . *Composition* $[C\ C_1\ \dots\ C_m]$ is the procedure of applying the function f (if any) produced by C to its tuple argument $\langle a_1, \dots, a_m \rangle$ (if any) produced by $C_1, \dots, C_m$, respectively. If the function f is defined at the tuple argument $\langle a_1, \dots, a_m \rangle$ then the Composition *v-constructs* the value of f at $\langle a_1, \dots, a_m \rangle$. Otherwise the Composition fails to produce anything, it is *v-improper*. Dual operation to Composition is λ -Closure. Where $x_1, \dots, x_m$ are pairwise distinct variables and C a construction, then the Closure $[\lambda x_1 \dots x_m\ C]$ *v-constructs* a function in the ordinary manner of λ -calculi. Constructions, being procedures, can be executed twice over. To this end, there is the construction Double Execution, 2C . If C is a construction that *v-constructs* a construction D that in turn *v-constructs* an object a , then 2C *v-constructs* a . Otherwise 2C is *v-improper*. For more information see [1].

3 Three types of context

Since constructions are entities of its own right, they can serve as objects on which other constructions operate. In such a case a construction C is *displayed*, it occurs in a *hyperintensional* context. In principle, constructions are displayed by Trivialization. A dual operation to Trivialization is Double Execution. Hence, in the context like $[\dots {}^0C \dots]$ the construction C is displayed, while in the context ${}^2[\dots {}^0C \dots]$ the construction C occurs *executed*. An implicit mode in which constructions occur is *executed*. If a construction C is not an object of predication, it occurs in the executed mode; then C can occur either extensionally or intensionally. If the whole constructed function is an object of predication, then the construction C occurs in an *intensional* context. Otherwise, if the object of predication is a functional value, then C occurs in the *extensional* context. Contexts have a hierarchy, where the hyperintensional context is the highest one, followed by a lower intensional context and at the lowest level of the hierarchy there is an extension context. The higher-level context is always dominant over a

² TIL is a system based on *ramified* theory of types. Basic non-procedural types are o (the set of truth values $\mathbf{T}, \mathbf{F}$), ι (the set of individuals), τ (times or real numbers) and ω (possible worlds). The type of constructions is $*_n$. Over these types infinitely many *partial* functions are defined by the inductive rule; where $\alpha, \beta_1, \dots, \beta_n$ are types, then $(\alpha\ \beta_1\ \dots\ \beta_n)$, i.e. the set of all partial functions mapping $(\beta_1 \times \dots \times \beta_n)$ to α , is a functional type as well.

lower-level one. For instance, the construction ${}^0_+$ producing the function of adding two numbers of type $(\tau\tau\tau)$ occurs extensionally in the Composition $[{}^0_+ {}^0_2 {}^0_5]$. However, in the composition $[{}^0\textit{Compute}_{wt} {}^0\textit{John} {}^0[{}^0_+ {}^0_2 {}^0_5]]$ the same construction ${}^0_+$ occurs in the hyperintensional context; this is due to the Trivialisation of the Composition $[{}^0_+ {}^0_2 {}^0_5]$.³

3.1 Extensional context

A construction C occurs in an *extensional context* if the construction C occurs executed and is thus used to construct the *value* of a function, which is then an object on which other constructions can operate. Moreover, C does not occur in another intensional or hyperintensional context.

3.2 Intensional context

A construction C occurs in an *intensional context* if the construction C occurs executed and is used to construct the whole *function* rather than its value, which is then an object on which other constructions can operate. Moreover, C does not occur in another hyperintensional context. As an extreme case the constructed function can be nullary, i.e. without any arguments, like a number or an individual. Hence, the constructions 0_2 and 0_5 occur intensionally in the Composition $[{}^0_+ {}^0_2 {}^0_5]$.

3.3 Hyperintensional context

A construction C occurs in a *hyperintensional context*, if C occurs in the displayed mode; in such a case there is another higher-order construction D that produces C . In the above example of the displayed Composition $[{}^0_+ {}^0_2 {}^0_5]$ there is the Trivialization that displays this Composition.

4 Substitution method

Whenever there might be a conflict of contexts in the occurrence of constructions, we must use the *substitution method*. In particular, variables occurring in a hyperintensional context are o-bound, hence not amenable to λ -binding, and we need some mechanism to overcome this problem. That mechanism is the substitution method. For instance, an “invalid” construction, trying to analyse the proposition “There exists a number, such that the cotangent function has no value at this number” is this:

$$[{}^0\exists\lambda x [{}^0\textit{Improper} {}^0[{}^0\textit{Cotg} x]]] \quad (1)$$

³ The above characteristics are just brief descriptions of the three kinds of context in which a construction can occur. For rigorous definitions see [1, §2.6].

Types. *Improper*/($o*_n$): the class of constructions that are improper for every valuation v ; $\exists/(o(o\tau))$: the existential quantifier that assigns **T** to a non-empty class of numbers, otherwise **F**; $x \rightarrow \tau$, *Cotg*/($\tau\tau$).

The variable x inside the hyperintensional context of ${}^0[Cotg\ x]$ is o -bound. This Trivialization produces the Composition ${}^0[Cotg\ x]$ independently of any valuation. Hence, λ -binding applied on this variable x is of no effect.

The substitution method uses functions *Sub* and *Tr*. The function *Sub* operates on constructions in the following way. When applied to constructions X , Y and Z , it produces a new construction Z' that arises from Z by a collision-less substitution of the product of X for the product of Y into Z . The functions *Tr* returns as its value the Trivialization of its argument. Hence, a plausible analysis of the above sentence is this:

$$[{}^0\exists\lambda x [{}^0Improper [{}^0Sub [{}^0Tr\ x] {}^0x {}^0[Cotg\ x]]]] \quad (2)$$

5 De dicto vs de re

When we analyse empirical expressions, it is not always clear how is that expression meant because there are many ambiguities in natural language. TIL, as any other logic, cannot dissolve these ambiguities, it is a matter of pragmatics. However, it can contribute to disambiguation by making these ambiguities explicit even in those case where the ambiguity is not obvious. In case there are two or more different meanings of a given sentence, we furnish the sentence with two or more different meaning constructions. Moreover, type-theoretical analysis can also help us to dissolve ambiguities in a correct way.

In case of empirical expressions, we use the medieval terminology. Hence, the *de dicto* vs *de re* occurrence of constructions of *PWS-intensions* corresponds to intensional vs extensional occurrence of these constructions.

We say that a construction $C \rightarrow \alpha_{\tau_0}$ occurs with *de dicto* supposition in a superconstruction D , if C occurs in D intensionally, i.e. the whole intension of type α_{τ_0} is an object of predication within D . For instance, the analysis of the sentence

“Pope is the head of Catholic church”

on its *de dicto* reading comes down to this construction:

$$[{}^0 = {}^0Pope\ \lambda w\lambda t [{}^0Head_of_{wt}\ {}^0Church]] \quad (3)$$

On the other hand, we say that a construction C occurs in a super-construction D with supposition *de re*, i.e. extensionally, if the value of the intension produced by C in a given world w and time t of evaluation is an object of predication in D . Moreover, C does not occur in any higher-order context. For instance, the analysis of the sentence

“Pope is the head of Catholic church”

on its *de re* reading comes down to this construction:

$$[{}^0 = {}^0Pope_{wt}\ \lambda w\lambda t [{}^0Head_of_{wt}\ {}^0Church]_{wt}] \quad (4)$$

6 Anaphora resolution

When analysing a sentence containing anaphoric references, we encounter two common problems. The first problem is how to combine the meaning of an antecedent of the anaphoric reference with the meaning of the expression containing this anaphoric reference. The second problem consists in choosing a plausible antecedent of the anaphoric reference in sentences, where it is not obvious.

To solve the first problem, we apply the substitutional method. The second problem concerns again ambiguities of natural language. Hence, if the sentence is ambiguous, there is no other logical solution but to show all the possible analyses of such a sentence. More information in [1].

7 Conclusion

I used gained knowledge to update software tool, that is used for logical deduction in TIL-Script, that I created during my master's thesis. Gained knowledge was especially helpful, when I was designing better algorithms for analysis of context and type checking.

I also added additional modules for machine learning to the program, which are based on papers [3], [4] and [5]. Program updates proved useful when checking formulas mentioned in those papers.

I have included screenshot from program with updated user interface in Fig. 2.

Fig. 2. Software tool for deduction in TIL-Script

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Short-term natural gas consumption forecasting using machine learning

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Abstract. The development of natural gas consumption forecasting tools is an interesting application of forecasting models. Complicated and expensive logistics of this commodity makes increasing precision of the developed tools absolutely crucial task. Plenty of research efforts were already performed in this area. However, datasets used in these works often could not be published and made accessible to other researchers. This complicates further research and comparison of forecasting methods. We have addressed this issue in our work, and we have prepared a new dataset. We have taken into account state of the art research works and included many data features that were previously proven to have a significant impact on the model precision. We have also conducted a baseline evaluation of machine learning algorithms used in the time series forecasting domain to validate the provided data's high usability.

Keywords: Natural gas consumption · Forecasting · Machine learning

1 Introduction

Natural gas is an essential commodity for our society. Distribution network operators are penalized for the differences in the ordered amount, and the real consumption on a daily basis, so precise consumption forecasting tools and methods are naturally highly demanded as a consequence of this state of affairs. This submission covers the current state of our research in the area of short-term natural gas consumption forecasting. Until the recent decade, there was a significant lack of available datasets in this specific field; research in the area was focused mostly on the annual, monthly, or daily data. Only a minority of researchers had access to the hourly consumption data and included them in their experiments [5]. Unfortunately, none of those datasets were publicly available for other researchers. Our main goal is a proposition of the precise forecasting method, but our work is not limited to it. The availability of the data with a higher sampling frequency of natural gas consumption is limited. We want to create a baseline for all researchers who will conduct similar research in this field, and we plan to publish our dataset with the release of our complete paper as well. We provide

a brief overview of currently employed methods and commonly used features in the area of short-term natural gas consumption forecasting [6]. Among the wide variety of the existing techniques for time-series forecasting, our work is focused mainly on the machine learning. These techniques are not limited only to the usage of forecasted endogenous variables, but we are able to make use of the exogenous variables with this approach as well. This ability of the mentioned methods is convenient for our task because the dataset contains beside the natural gas consumption also weather and economic input variables [7]. Successful application of the machine learning algorithms in the time-series forecasting domain may be challenging due to the occurrence of a trend and, possibly, multiple seasonal components in the time-series data. These challenges are addressed in our research, and we present methods for overcoming them using detrending and time-series decomposition approach.

2 Natural gas forecasting methods and algorithms overview

The main part of our experiments was focused on machine learning algorithms. There are two mainstream ways of forecasting time series using machine learning algorithms - cumulative and direct. The cumulative approach takes forecasts of the previous values into account and uses it as additional input variables for the model. The advantage of this approach is the need for only one model because the final forecast of the whole forecast horizon can be ensembled from the partial next hour forecasts. The main disadvantage of this approach is forecast error accumulation through the forecast horizon, which can lead to the increasing error over the forecasted period. On the other hand, the direct approach treats forecasts as independent variables, so there is no error accumulation. The disadvantage of this approach is its complexity because multiple models or heavy preprocessing of the data is usually needed. We have decided to include both of the methods in our work to offer their comparison.

There is a wide variety of machine learning algorithms, but in the last years, the prevalent ones were the ensemble methods using bagging or boosting approach. Taking these circumstances into account, we have decided to use two algorithms in our experiments. The first one is the Random forest, which uses the bagging, and the second one is Light gradient boosting. Both of the algorithms use decision trees as their partial regressors [3].

Our experiment can be divided into two parts based on the selected approach and feature engineering steps. The forecasted consumption variable shows complex seasonality patterns and our dataset includes various exogenous variables as well. Therefore we have decided to build our time series forecasting baseline on the machine learning approach. Unfortunately, machine learning algorithms do not provide time series forecasting support out of the box, unlike other models like ARIMA [1] or TBATS [4]. However, their indisputable advantage lies in their versatility in the area of feature engineering for the input data. Machine learning is heavily used in other domains with the need for short-term

forecasting. A good example is electricity consumption forecasting, where the machine learning algorithms provided very competitive results compared with the classical statistical methods [2].

3 Experiment

One of the most crucial parts of every forecasting task is setting the forecasted horizon. Based on the operation of the gas trading market, we have decided to use the next 24 hours as a forecast horizon because the gas trade is usually realized for the next day, so the last known value is for the midnight of the previous day as we mentioned beforehand. Our dataset covers the time period from January 1, 2013 to December 31, 2018. Due to the amount of available data, we have decided to use the data from 2013 to 2017 as our training set. The whole year 2018 became the test set for our model performance evaluation. With the given setup, we were able to analyze our model's performance throughout the year and not only in the selected part of it.

3.1 Cumulative approach with single model

Cumulative forecasting is a single model approach to time-series forecasting. The main idea of this model is based on the property of very strong autocorrelation of the endogenous variable. In our setup, we took into account not only the autocorrelation values but in particular significantly high partial autocorrelation value of the consumption variable at lag of 1 hour. Both the autocorrelation and the partial autocorrelation value at lag of 1 hour show higher values than the seasonal lag of 24 hours thus it makes sense to reduce the time dependency of the gas consumption even more than with the seasonal difference by taking first-order difference with a lag of 1 hour. A complication of this approach is based on the condition that the shortest possible forecast horizon is 24 hours long due to the operation of the gas trading market. This condition is obviously not met except for the 1 A.M. forecast. The differencing of the gas consumption with a lag of 1 hour creates a dependency between two consecutive values. It is not possible to forecast the next value without the knowledge of the previous one. A possible solution to overcome this issue is temporarily taking the forecast of the previous value as the ground-truth for forecasting the next value. This allowed us to fulfill the 24-hour forecast horizon condition for the whole time horizon. Time series preprocessed in this manner allowed us to perform the STL decomposition and proceeding with taking the difference of the added residual component, trend component and consumption at last midnight for every value. This approach enabled us to use only a single forecasting model for the whole task.

3.2 Direct approach with multiple models

This simplicity of a single model solution is its main advantage, but it does not come without a cost. The main drawback is an information loss in the area of

extracted features as a lagged value of both endogenous and exogenous variables caused by the nature of machine learning algorithms, which is moreover affected by the forecast horizon. The common requirement of the machine learning algorithms is that the input vectors are of the same dimensions which is a possible source of information loss in case of time series forecasting. To fulfill this requirement, it is impossible to add a lagged variable as a feature with a lag shorter than the forecast horizon. Otherwise, it causes an information leak in the model. It is clear that we are ignoring valuable pieces of information by forbidding lagged features with lags shorter than the defined forecast horizon.

Fig. 1. Forecasting pipeline of the direct approach with multiple models.

We have addressed this emerging complication in our work with the proposed solution of multiple model approach in which is the forecast horizon divided into smaller ones to fulfill the mentioned requirement of a vector dimensions equality

among used instances. There are different models responsible for forecasting each hour’s consumption of the forecast horizon resulting in 24 models in total. Every model follows the same steps for creating the forecasted value. Complete forecasting process is depicted in Fig. 1. A possible challenge in the training phase of the models is the data selection for the training set. Each model is responsible only for forecasting the value for a specific hour in the forecast horizon. The majority of the data will be discarded if the training set contains only the data for that hour. Each model is trained on the full training dataset with only the partial forecast horizon in mind based on the order of the model in the pipeline to avoid such loss of the data. Predictions for longer forecast horizon than the defined partial one are treated as invalid and are not used in the final forecast.

Table 1. Machine learning approach results from the hourly perspective. RF indicates the Random forest algorithm, LGB the Light gradient boosting algorithm. SM stands for single model and MM for multiple models.

Approach\Metric	Algorithm	MAE	MSE	MAPE	SMAPE	R2
Cumulative SM	RF	20400	141.25e+07	28.33	25.90	0.748
	LGB	20220	140.83e+07	28.98	26.94	0.749
Direct MM	RF	5700	8.57e+07	6.12	6.01	0.985
	LGB	5800	8.60e+07	6.61	6.50	0.985

4 Conclusions

A series of conducted experiments demonstrated the usability of the proposed dataset for the natural gas consumption forecasting task. The results in Table 1 clearly show that the direct forecasting approach provides more precise results compared with the cumulative approach. Even though the cumulative approach preprocessing step was able to reduce time dependency better than the seasonal differencing in the direct approach model and required fewer preprocessing steps, its MAPE was almost four times higher than the direct approach. The cause of such high error values is the dependency on previously forecasted values, which implies the same dependency in forecast errors. Thus, the errors are propagated further into the forecast horizon.

Residual error distribution overview for the mentioned time interval is depicted in Fig. 2. We can see on the figure that gas consumption from May to September is rather low and less variational than the gas consumption in the heating season during winter and early spring. Thus the forecast error values in summer are at a much lower level and are more stable than errors in the rest of the year. Moreover, we can see that the error spread does not change sharply after the heating season ends, but it is gradually declining towards the summer months. Subsequently, it again starts to rise continually in September.

In our future work, we will continue with the evaluation of more advanced forecasting methods. We will also be on the lookout for new possible input vari-

Fig. 2. Residual errors in both hourly (a) and daily (c) forecasts distributed through the year 2018 for direct Random forest model. Daily residuals are aggregated by summing the hourly residual errors. Distributions of both types of residual errors are depicted in histograms (sub-figures (b) and (d) respectively.)

ables which can be used to expand created dataset and improve forecasting precision even more.

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Big Data Image Processing in MPI Parallelized Fiji

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Abstract. Fiji is a popular n-dimensional image analysis framework among bioscientists but seems to be impractical for larger datasets. Current parallelization approaches use threads of a single node or cores on the graphical processing unit. This paper introduces MPI massive parallelization without user interence for even larger datasets. The benefit of this approach is measured on Salomon supercomputer on the most common image processing operation of convolution and the multi-stage algorithm of edge detection.

Keywords: image processing, big data, Fiji, ImageJ, OpenMPI, HPC

1 Introduction

Many image analysis algorithms are hard-coded just for two dimensions and a single data type. 3D datasets and even 5D datasets are not uncommon in biology, so it makes further analysis harder to develop for bioscientists. A 3D dataset can be captured by microscope from 2D captured images in time, in different angles, or combination of both. Some algorithms like maximum intensity projection access the whole dataset so it is not possible to process dataset planes individually.

Fiji [5] framework in Java chooses a more generic strategy - all algorithms are n -dimensional and templated for any underlying data type. The framework is split into multiple projects. The most fundamental is ImgLib2 [4] providing data structures for n -dimensional datasets, SCIFIO [3] supports loading and storing datasets in various formats. ImageJ2 implements reusable n -dimensional algorithms that are called as *Ops*. Concrete Op implementation with the highest priority is selected at runtime according to passed arguments and constraints.

The growing volume of datasets requires more computation power and memory that may not be satisfied by the ordinary workstation. HPC cluster of several powerful nodes can drastically improve the computation time of larger dataset. Unfortunately, memory is not shared across all nodes and the computation needs to synchronise results with message passing, that is standardized with MPI. This article adds MPI parallelization support to the Fiji framework and shows the results of the benchmarks.

2 Existing Parallelization Approaches in Fiji

Some ImageJ2 Ops utilizes all threads to speed up computation, but it is not yet unified. Some Ops make their thread pool, some use *Chunker* Op, and there is also some support directly in ImgLib2.

CLIJ [2] project adds support for GPU accelerated computation with implemented OpenCL kernels. It mainly adds new ops for 2D or 3D datasets. These datasets must be copied to the GPU or from the GPU by the end user. Datasets are also limited by GPU memory - larger datasets may not fit there. All Ops needs to be rewritten from the Java to OpenCL kernels in C. The big advantage may be faster computation because all data are in plain memory and there are is no Java abstraction.

3 MPI Parallelization Approach

All previous parallelization approaches were using a single node. Multiple nodes could have more computation power - especially on supercomputers. Unfortunately, memory is not shared across nodes and their memory has to be shared explicitly. MPI stands for Message Passing Interface and adds some functions for sending or receiving data, reducing, gathering, scattering, or making a barrier where ranks are waiting until other ranks reach the same barrier.

OpenMPI [1] is an open-source implementation of the MPI interface that is available as a C library. Java support is provided by Java Native Interface (JNI) but is not compiled by default. Different strategy Java Native Access (JNA) allows mapping a shared library to the Java process and call functions without any additional code. This strategy has been chosen to make easier use of parallelized Ops, especially on supercomputers. Unfortunately, it is not possible to pass Java array directly to a C library. Data has to be copied which adds additional overhead. OpenMPI rank is a process that executes the same executable on any node in a cluster. MPI allows to fully utilize all node cores by running multiple ranks on a single node. This approach requires no code support but adds overhead in case of Fiji because memory for whole input/output datasets has to be allocated multiple times.

The main goal is to override original Ops with MPI parallelized implementations that require no modification to be run on the MPI enabled cluster.

Datasets can be passed to Ops as an interface of *Iterable*, *IterableInterval*, *RandomAccess* or *RandomAccessibleInterval*. *Iterable* can only sequentially iterate over a whole dataset. There is no information about dataset dimensions or a number of elements so it is not possible to split it to the chunks. *Iterable* can also generate the next value on the fly, so data may not be backed by a memory. *IterableInterval* combines interface of *Iterable* and *Interval*. If the concrete implementation is backed by memory, then it is possible to split the dataset to equal chunks. *RandomAccess* allows making expensive random accesses to the whole dataset. There is no information about the dimensions of a dataset. *RandomAccessibleInterval* combines *RandomAccess* with a dataset dimensions.

Output datasets backed by memory and implementing *Interval* can be split to equally sized chunks. Splitting is based on a number of elements rather on dimensions to make equally sized chunks. The visualisation of this split can be seen in the Fig. 1. Each colored chunk is processed by a single rank. The result of each rank is then distributed to all others ranks because the output can be used as an input to another op. OpenMPI simplifies this operation with a *MPI_Allgatherv* function. This function does not make naive broadcasting to all each other ranks, but other ranks help to distribute results. Unfortunately, the whole dataset is not in continuous memory due to Java limitations, so this simple approach is not possible. This single gather function has to be replaced with a series of *MPI_Bcast* calls that distributes dataset planes individually.

Fig. 1. Visualisation of 3D dataset split to 6 chunks

For simpler use we have introduced new *Parallel Op* taking output dataset as the *IterableInterval* interface and a function. Op is implemented for MPI parallelization, threaded parallelization and no-parallelization where the provided function is just called. Threaded parallelization splits the output dataset to chunks that are processed on threads with provided function. The function iterates over each element in a chunk and computes the result. Input datasets are not passed to the function, because they are accessible as captured variables. MPI parallelization implementation splits the output dataset to chunks that are processed on individual nodes in a cluster. A chunk of each node is then processed by threaded parallelization to fully utilize node computation power. Computed output chunks are then synchronized to all other ranks with MPI broadcast, so the output of the Op is the same on all nodes and can be used as an input to the next Op. All strategies can be seen on the Fig. 2. Unfortunately, synchronisation adds significant overhead that depends on the size of the dataset.

4 MPI-enabled Convolution Op

The convolution is a fundamental operation in image processing. Its naive implementation is ideal for benchmarking because it is computationally expensive

Fig. 2. Different parallelization strategies: Multiple threads in a single process (a), Multiple nodes running a single processing thread (b), Multiple nodes running multiple threads (c).

with complexity $\mathcal{O}(D_1 \cdot D_2 \dots D_n \cdot K_1 \cdot K_2 \cdot K_m)$, where D_i is the i th dimension of dataset and K_i is the i th dimension of the kernel.

The benchmark was performed on up to 8 IT4Innovations Salomon cluster nodes on ordinary 3×3 kernel and various 5D datasets with an uncompressed size of 4 MiB up to 6.75 GiB. Each node of the cluster is equipped with 2×12 -core Intel Xeon E5-2680v3 and 128 GiB RAM.

All combinations of dataset size and number of nodes were measured in 10 runs. The final execution time is computed as the median of the worst node execution time from each run. Fig. 3 shows the speedup of the single-threaded approach. For the larger datasets, it scales with the number of nodes efficiently. Fig. 3 shows the speedup of the multi-threaded approach. Additional nodes don't shorten computation time because synchronisation time increases with the number of nodes and the size of the dataset as can be seen on the Fig 5.

Fig. 3. Single-threaded convolution speedup of dataset size ($2048 \times 2048 \times N \times N \times N$) with respect to the number of nodes

Fig. 4. Multi-threaded (24 threads/node) convolution speedup of dataset size ($2048 \times 2048 \times N \times N \times N$) with respect to the number of nodes

Fig. 5. Synchronisation time as a function of dataset size and number of nodes

5 MPI-enabled Pipeline of Multi-stage Edge Detector

The Canny edge detector is a suitable algorithm for showing the impact of multiple synchronisations on the computation speedup. The detector is composed of multiple operations in the pipeline. Computed chunks results from individual nodes are synchronised with each other and then used as an input to the next operation in the pipeline.

The first operation of the pipeline transforms the dataset to grayscale values by reducing the dimension. The noise from the grayscale dataset is then reduced by 5×5 Gaussian convolution. Edges are emphasised by Sobel operator in vertical and horizontal directions. Each direction is computed with generic n -dimensional convolution. These three convolutions are the most expensive operations in the pipeline and gain the biggest speedup. The results for the following operations can be seen on the Fig. 6. The single-node edge detection median computation time took 622 709 s. Adding additional 7 nodes speeded-up the median computation time $6.14 \times$ to 101 322 s.

Fig. 6. Speedup for single-threaded edge detector and its individual stages

6 Conclusion

The growing volume of datasets increases computation time, that can be reduced by more efficient algorithms or with more computation power. Single node parallelization has limits in a number of available threads and GPU parallelization is limited by its memory. This article presents MPI parallelization approach¹ that scales horizontally over multiple nodes and requires no modification from bioscientists. Unfortunately, memory is not shared across all nodes hence node computed chunks must be synchronised with each other node. This step adds additional overhead for the price of general use. The MPI parallelization approach is demonstrated on the commonly used operation of convolution and the multi-stage edge detector requiring multiple synchronisations.

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¹ <https://github.com/fiji-hpc/scijava-parallel-mpi>

Bolt pretension

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Abstract. Screw connections are one of the most useful construction elements and therefore we develop bolt pretension element for numerical library ESPRESO. There exist many methods to model bolts, but the solid model is able to predict the physical behavior of the structure most accurately. Disadvantages of solid model of bolts are higher computational time and memory requirements but these drawbacks can be overcome by efficient implementation based on the use of high performance computing (HPC).

Keywords: bolt pretension, linear elasticity, displacement pretension, force pretension, FEM, Lagrange multipliers.

1 Introduction

Bolt connection is one of the most useful construction elements. It is used to hold two or more parts together to create an assembly in mechanical structure. The bolt connection is more frequently used than other connection methods because the bolt connection is easy to installation and also easy to disassembly. Disadvantage of bolts is that it is necessary to drill holes what can weaken some parts of construction. Many fabricated construction use bolts to connect components together. In some constructions hundreds or thousands of bolts are used, such as ships or airplanes. This is the main reason why bolt pretension is important part of calculations.

We can model the bolt pretension using many different methods such as solid model, coupled bolt model, spider model, no-bolt model etc. A comparison of these methods is introduced in [1], [2]. The comparison shows that the most accurate method is solid model. The results of this model offers the most accurate prediction of the physical behavior of the structure. This model is the most complicated because it needs very fine mesh with a lot of elements and often contact elements too. Therefore we need to use a library based on High Performance Computing (HPC) for such complex and large problems, e.g. numerical library ESPRESO [3] developed at IT4Innovations which uses HPC to solve large engineering problems. Our goal is to develop bolt pretension for this library.

The implementation is compared with the results of commercial software Ansys.

2 Bolt pretension

A mesh of the bolt must be divided into two parts to apply pretension, see **Fig. 1**. The pretension can be applied by force or displacement.

Dividing of mesh is not easy because in the case of irregular meshes we must find nodes which create a continuous surface from the existing element faces, see **Fig.1-left**. In the case of the regular meshes, finding of cutting nodes is easier than in irregular meshes, see **Fig.1-right**.

The mesh is divided by a plane which is perpendicular to the bolt axis. Then we choose the nodes near to the cutting plane. The selected nodes must create a continuous surface from the original mesh. It is achieved by selection of element faces which are a part of only one element after cutting. From these element faces we choose corresponding nodes and the pretension is applied to them.

Fig. 1. Bolt cut

2.1 Mathematical model

For solving this problem the classical FEM is used. After discretization we obtain the following algebraic formulation:

$$\mathbf{K}\mathbf{u} = \mathbf{f}, \quad (1)$$

where $\mathbf{K}$ is the stiffness matrix, $\mathbf{f}$ is the vector of surface loads and $\mathbf{u}$ is the displacement vector. We must add other equations for implementation of the bolt pretension without violation of the structure. For this implementation we use Lagrange multipliers and equation (1) is replaced by equation (2):

$$\begin{bmatrix} \mathbf{K} & \mathbf{B}^T \\ \mathbf{B} & \mathbf{0} \end{bmatrix} \begin{bmatrix} \mathbf{u} \\ \boldsymbol{\lambda} \end{bmatrix} = \begin{bmatrix} \mathbf{f} \\ \mathbf{h} \end{bmatrix}, \quad (2)$$

where $\mathbf{B}$ is the constraint matrix of boundary conditions, $\boldsymbol{\lambda}$ is the vector of Lagrange multipliers, and $\mathbf{h}$ is the right hand side constraint vector of boundary conditions.

The equations in the system $\mathbf{B}\mathbf{u} = \mathbf{h}$ look as follows:

$$u_{x1} - u_{x2} = 0, \quad (3)$$

$$u_{y1} - u_{y2} = 0, \quad (4)$$

$$u_{z1s} - u_{z1e} - u_{z2e} + u_{z2s} = 0. \quad (5)$$

Fig. 2. Rotation of areas

Equation (3) ensures that the displacements in x direction on the interface created by cutting plane are equal. Equation (4) ensures the same for the displacements in y direction and equation (5) for rotations, see Fig. 2.

3 Comparison of calculations with commercial program

The benchmark problem is illustrated in **Fig. 3**. The tested structure is general problem of the bolt pretension where compression and bending of the bolt occur. The geometry of the structure is depicted in **Fig. 3**. Young's modulus is 200 000 MPa and Poisson's ratio is 0,3.

Fig. 3. Geometry of benchmark problem

3.1 Force pretension

Described procedure of the bolt pretension was implemented in MATLAB and compared with Ansys APDL and Ansys Workbench. The procedure was implemented into the MATLAB library MATSOL, which is developed by IT4Innovations.

The results are demonstrated in **Fig. 4** and in **Tables 1** and **2** for hexahedral and tetrahedral elements, respectively. Applied pretension of the bolt was 16000 N. The structure was fixed in all directions on the left side.

Table 1. Results for brick elements of the shank screw [mm]

	x_{max}	x_{min}	y_{max}	y_{min}	z_{max}	z_{min}
Matlab	0,61001	-0,20149	0,02994	-0,02841	4,17575	-1,54792
APDL	3,26726	-0,20149	0,02994	-0,02841	4,17571	-1,54791
Workb.	0,61	-0,20149	0,02994	-0,02841	4,17571	-1,54791

Table 2 Results for tetrahedral elements of the shank screw [mm]

	x_{max}	x_{min}	y_{max}	y_{min}	z_{max}	z_{min}
Matlab	0,58804	-0,19719	0,02984	-0,02885	4,05439	-1,51708
APDL	3,20258	-0,19707	0,03015	-0,02855	4,04926	-1,51794
Workb.	0,58738	-0,19707	0,03015	-0,02855	4,0493	-1,5179

Fig. 4. Force pretension results for brick elements (total displacement [mm], left-Workbench, right-APDL, bottom-MATLAB), magnification parameter is 0,3

3.2 Displacement pretension

The results of displacement pretension you can see in **Fig. 5** and in **Tables 3** and **4** for hexahedral and tetrahedral elements, respectively. As in the previous problem, the

structure is fixed in all directions on the left side. Applied displacement pretension of bolt was 0,5 mm.

Table 3. Results for brick elements of shank screw [mm]

	x_{max}	x_{min}	y_{max}	y_{min}	z_{max}	z_{min}
Matlab	0,09335	-0,03083	0,00458	-0,00435	0,63902	-0,23688
APDL	0,5	-0,03083	0,00458	-0,00435	0,63902	-0,23688
Workb.	0,09335	-0,03083	0,00458	-0,00435	0,63902	-0,23688

Table 4. Results for tetrahedral elements of the shank screw [mm]

	x_{max}	x_{min}	y_{max}	y_{min}	z_{max}	z_{min}
Matlab	0,09172	-0,03078	0,00474	-0,00442	0,63243	-0,23682
APDL	0,5	-0,03078	0,00474	-0,00442	0,63243	-0,23682
Workb.	0,09172	-0,03078	0,00474	-0,00442	0,63243	-0,23682

Fig. 5. Displacement pretension results for tetrahedral elements (total displacement [mm] , left-Workbench, right-APDL, bottom-MATLAB), magnification parameter is 2,7

4 Conclusion

By comparison of the results of the created MATLAB program and the commercial codes we see that the results achieved by displacement pretension are the same. The results achieved by force pretension are a little different. This difference is caused by the type of method used for the force distribution to the nodes. The resulting program must be supplemented by suitable weighting function which will distribute more accurately force to nodes. In both cases, the results of the maximum displacement in x direction in APDL are much higher than in other directions and in other programs. Therefore, in my opinion, there is a small mistake in APDL program during evaluation of

displacement in x direction. A new element type (PRETS179) is created when implementing bolt pretension in APDL. The abnormal x displacement is computed in these new elements. In the **Table 5** and **6** you can see x displacement without the influence of the PRETS179 element. These results are consistent with results from Workbench and MATLAB.

Table 5. x_{max} results for brick elements of the shank screw [mm]

	x_{max}
Force pretension	0,61
Displacement pretension	0,09335

Table 6. x_{max} results for tetrahedral elements of the shank screw [mm]

	x_{max}
Force pretension	0,587376
Displacement pretension	0,091704

The next step will be to implement this code in the numerical library ESPRESO.

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Benchmarking DGX-2 Platform

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Abstract. In this paper, I evaluate the performance, power consumption, and its variation and also thermal behavior of the DGX-2 server from Nvidia. I used specialized synthetic benchmarks to measure the raw performance of GPUs for single, double, half-precision, and also Tensor Core units. I was able to reach peak performance and verify the specification provided by Nvidia. On a single GPU, I achieved 130.79 TFLOPS peak performance in half-precision on Tensor Cores. The DGX-2 system can hold its peak performance when all 16 GPUs are fully loaded except for the Tensor Core workload when thermal throttling occurred with up to a 1 % performance penalty. During single-precision workload I observed a 23 % variation of the power consumption of individual GPUs installed in the system. Finally, I have evaluated the behavior of the Tesla V100-SXM3 chip under the DVFS tuning. Running at the optimal frequency, the compute bound workload can save up to 39% energy while the run-time increases by 51 %. More importantly, memory bound workload can save up to 31 % energy with a 2 % throughput penalty and during the communication over NVLink one can save up to 26 % energy with no penalty.

Keywords: DGX-2 · tensor core · performance analysis · energy efficiency · dynamic voltage and frequency scaling (DVFS)

1 Introduction

In this paper, I evaluate the performance of the Nvidia DGX-2 system using a synthetic benchmark, designed to measure and achieve the peak performance of both CPUs as well as Nvidia GPUs. This benchmark was modified to support Tensor Core units. With this benchmark, I was able to match and verify V100-SXM3's peak performance stated by Nvidia. In addition, I measured GPU memory and NVLink throughput. The next goal of this paper is to evaluate the thermal stability and GPU power consumption. I performed dynamic frequency and voltage scaling (DVFS) for compute bound, memory bound and communication workloads and stated the most efficient configuration for these workload types. In the end, I also evaluate the power consumption of the whole node.

1.1 DGX-2 platform description

DGX-2 contains 16 Tesla V100-SXM3 GPUs equipped with NVLink interconnect [4]. It features a pair of Intel Xeon Platinum 8168 CPUs, 1.5 TB of memory, and 30 TB of fast SSDs. Fast networking is provided by eight EDR Infiniband or 100 Gb Ethernet cards. [5] The NVLink network consists of 12 NVSwitches connected with NVLink-V2 links providing 300 GBps bidirectional peer-to-peer (P2P) throughput. [2] The physical GPU layout is shown in Figure 1.

The V100-SXM3 GPU is equipped with 80 streaming multiprocessors (SMs) and 32 GB of HBM2 memory. Each SM consists of these processing units: 64 FP32 (float), 64 INT32 (32 bit integer), 32 FP64 (double precision), and 8 Tensor Cores (16 bit floating point – half precision). [4] Tensor Cores are processing units introduced in Volta GPU architecture designed to perform fused multiply-add operation with 16×16 half precision matrices.

Fig. 1. Physical GPU layout of the DGX-2 server.

2 Measurement methodology description

2.1 Benchmarks

The Mandelbrot benchmark is designed to measure the pure floating point performance of the processor at a very high arithmetic intensity. It executes the Mandelbrot iterations $z_{k+1,i} = z_{k,i}^2 + c_i$ where $z_{0,i} = 0$, and the constants c_i are from the Mandelbrot set of complex numbers. For simplicity and efficiency are these constants selected from the numbers on the real axis. The Mandelbrot iterations may be repeated indefinitely and remain bounded. To measure Tensor Core performance the Mandelbrot benchmark may be naturally extended to the matrix domain. In matrix form, the square matrix Z is updated as $Z_{k+1} = Z_k * Z_k + C$, where the $*$ refers to matrix-matrix multiplication, the matrix $Z_0 = \mathbf{0}$, and the square matrix C has eigenvalues from the Mandelbrot set. Such matrix iterations may be repeated indefinitely and matrix Z will remain bounded. [1] The memory subsystem throughput was measured by STREAM [3] benchmark modified for GPUs with all it's functions: copy, scale, add, triadd. The throughput of the NVLink interconnect was measured by performing uni-directional as well as bidirectional P2P data transfer between two GPUs.

2.2 Frequency Scaling and Energy Measurement

I measured energy consumption with frequency scaling of three types of workload: compute bound represented by Mandelbrot benchmark, STREAM benchmark as a memory bound workload, and P2P data transfer between 2 GPUs over NVLink. GPU energy consumption was measured with Nvidia Management Library – NVML which provides an interface for monitoring Nvidia GPUs as well as access to a counter with GPU’s total energy consumption.

To analyze power and thermal properties the Nvidia System Management Interface – `nvidia-smi` was used. With this interface, I took samples with power, frequency, and temperature at approximately 100 Hz rate. I also used this interface to scale the frequency of GPUs from a maximum of 1597 MHz to 675 MHz with 7 MHz predefined steps. The frequency of HBM2 memory can not be tuned, it remained fixed at 958 MHz even at idle state.

3 Results

3.1 Performance

I found the peak performance specification of the V100-SXM3 GPU in Nvidia Profiler. However, it did not include Tensor Core performance. V100-SXM2 at 1530 MHz reaches 125 TFLOPS. [4] To match SXM3’s 1597 MHz the Tensor Core performance should be 130.484 TFLOPS. Global memory throughput is specified to 980.992 GBps, NVLink’s P2P unidirectional throughput is 150 GBps and bidirectional 300 GBps. Table 1. shows the results of my measurements.

3.2 Power and Thermal Properties

Figure 1. shows that GPUs in DGX-2 are placed in two trays and each tray contains two rows of 4 GPUs. First row GPUs receive cold air from high-RPM fans directly whereas the second row receives air heated by the GPUs in the first row. This causes that second row GPUs run at a higher temperature than the ones in the first row. Furthermore, under full load they reach their 350 W

Table 1. Left table compares performance measured by Mandelbrot benchmark to Nvidia specification. Middle table shows memory throughput measured by STREAM benchmark. Right table shows the result of P2P data transfer over NVLink.

Mandelbrot benchmark			STREAM benchmark		NVLink P2P transfer	
	Specification	Measurement		Throughput		
	[TFLOPS]	[TFLOPS]		[GBps]		
double	8.177	8.1765	copy	825.473	latency	2.45 us
float	16.353	16.3530	scale	826.518	unidirectional	145.16 GBps
half2	32.707	32.7038	add	873.631	bidirectional	266.46 GBps
tensor	130.484	130.7928	triadd	872.368		

TDP. Because of this there is a performance imbalance between the first row and second row GPUs.

During the Tensor Core workload running on all GPUs simultaneously, front row reaches maximum temperature 57°C while second row peaks at 72°C . For this reason certain GPUs in second row throttle down frequencies to 1575 MHz from the original 1597 MHz with approx. 1 % performance loss. Figure 2. shows significant power consumption variation of individual GPUs, reaching up to 23 % for single precision workload caused by physical location and manufacturing variations. Some GPUs under-clock their frequencies when they reach the TDP.

Fig. 2. Power consumption variation of all the GPUs in the DGX-2 when under full load using compute bound workload with four different data-types.

3.3 Frequency Scaling

I performed the DVFS tuning test for compute bound, memory bound, and NVLink workloads. The first frequency scaling test was done for all data types of Mandelbrot benchmark, each performing the same amount of floating-point operations: 81920×10^9 . The left plot in Figure 3. shows the result of this experiment. Table 2. compares the most efficient frequency configuration to the base frequency 1597 MHz. Generally, the most efficient frequency for the Mandelbrot benchmark is 1057 MHz – it can save up to 39 % of the energy with the run-time increased by 51 %. Interestingly the energy efficiency of double data type at base frequency achieves 24.8 GFLOPS/W whereas at 1050 MHz it reaches 40.67 GFLOPS/W. The performance at this frequency drops to 5.37 TFLOPS – 66 % of the original 8.17 TFLOPS.

The second test was done for the STREAM benchmark. Each workload transferred the same amount of data – 7.924 TB. The throughput measured in this experiment is lower than in Section 3.1 because the average value is reported while Section 3.1 contains the peak value. The middle plot in Figure 3. shows the experiment result. Up to 31 % of the energy can be saved on average by scaling down the frequency to 1005 MHz with the time increased only by 2 %.

The third frequency scaling test was done for unidirectional P2P NVLink transfer – each transferring 859 GB of data. Running at 1140 MHz can save up to 26 % energy without any throughput penalty. From this frequency downwards the throughput starts to drop. This is shown in the right plot in Figure 3.

Fig. 3. The result of frequency scaling experiment. The left plot shows Mandelbrot benchmark. Plot in the middle shows STREAM benchmark and right plot shows P2P transfer over NVLink.

3.4 Overall Power Consumption of DGX-2

In addition, I measured the power consumption of the whole DGX-2 server using `ipmitool`. This utility requires administrative privileges and therefore I was able to take only a single power sample for each workload. Despite not having accurate data, they can give us some idea about whole node efficiency including cooling and peripherals. In idle state GPUs alone consume 768 W and the whole node 2.3 kW. During the Tensor Core workload at maximum frequency 1597 MHz, the consumption of GPUs rises to 5.3 kW and the whole node consumes 7.3 kW. Running this workload at its most efficient frequency 1057 MHz consumption of GPUs drops to 2.3 kW and the whole node consumes 4.1 kW.

Table 2. Mandelbrot benchmark running at base frequency compared to the most efficient frequency for each workload.

	Frequency [MHz]	Time [s]	Time difference	Energy [J]	Energy savings	Performance [TFLOPS]	Energy efficiency [GFLOPS/W]
double	1597	10.02		3303		8.17	24.80
	1050	15.25	152.16%	2015	39.01%	5.37	40.67
float	1597	5.01		1596		16.34	51.33
	1057	7.57	150.99%	982	38.50%	10.82	83.46
half2	1597	2.51		870		32.69	94.18
	1057	3.78	151.05%	531	38.97%	21.64	154.30
tensor	1597	0.63		219		130.65	374.90
	1057	0.95	151.04%	132	39.58%	86.50	620.51

While running double precision workload at maximum frequency GPUs consume 4.9 kW and the whole node consumes 6.7 kW. In this case, the performance of all GPUs reaches 130.8 TFLOPS with performance per watt 19.52 GFLOPS/W. Using the most efficient frequency 1057 MHz for this workload GPUs consume 2.1 kW and the whole node consumes 3.7 kW. In this case, the performance drops to 86.4 TFLOPS despite computational efficiency which increases to 23.6 GFLOPS/W.

4 Conclusion

Using a synthetic benchmark I verified that the performance of V100-SXM3 GPUs of the DGX-2 server matches its specification. I measured 130.79 TFLOPS in half-precision using Tensor Cores on a single GPU. When all 16 GPUs are fully loaded altogether, some of them may throttle down their performance by 1 % due to an uneven cooling solution and manufacturing variations. The efficiency of DGX-2 can be improved by scaling down the GPU frequency. For compute bound workload, the best frequency is 1057 MHz saving up to 39 % energy and increasing run-time by 51 %. The sweet spot for memory bound workload is at 1005 MHz with a throughput penalty 2 % the energy savings can reach 31 %. Peer-to-peer transfer over NVLink achieves the best energy efficiency at 1140 MHz frequency, being able to save 26 % energy with no throughput penalty.

5 Acknowledgments

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Mobile sensor with optical FBG for traffic density monitoring

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Abstract. This paper deals with the development of a mobile portable measuring sensor used to measure traffic density. The measuring sensor is based on an optical fiber with a Bragg grating in a carbon tube, which is encapsulated in silicone addition rubber (bicomponent addition silicone rubber). The design of the mobile sensor makes it possible to monitor and detect traffic density and car transitions in single lane. The functionality of the sensor was verified in real traffic. The presented article summarizes the author's activities during the first year of study, his research and development activities related to the study.

Keywords: FBG sensor · Fiber Bragg Grating · optical fiber · car detection · traffic monitoring.

1 Introduction

Allow me to introduce myself. My name is Michael Fridrich. I am a Ph.D. student at the Faculty of Electrical Engineering and Computer Science at the Technical University of Ostrava. My education program is called Communication Technology. In my first year of study, I am extending my knowledge especially in the field of optical fiber Bragg Grating sensors. To date 07/2020, I have a total of 4 accepted or published publications and 2 utility models.

2 About my dissertation work

During the first year of my study, I was to design a measurement fiber Bragg grating sensor [1], which can be used in the real traffic for monitoring traffic density.

2.1 Fiber Bragg Grating

Fiber optic Bragg gratings (FBG) are rapidly evolving a group of single-point optical fiber sensors. FBG fibers are formed in the core of an optical fiber by periodically changing the refractive index. The structure of Bragg Grating, in which there are periodically changing layers of the refractive index of the nucleus

n_1 with a higher refractive index n_3 , is shown in Figure 1. The uniform Bragg grating is characterized by a constant magnitude of induced refractive index $\delta n = n_3 - n_1$ and a constant period of refractive index changes.

Fig. 1. Schematic diagram of the Bragg grating sensor.

The structure of the Bragg grating reflects a narrow frequency band of the broadband light and transmits the others. The central part of the reflected spectrum is called the Bragg wavelength λ_B and is given by:

$$\lambda_B = 2n_{eff}\Lambda, \quad (1)$$

where n_{eff} is the effective refractive index of the grating in the fiber core Λ is the grating period. Other wavelengths are transmitted without attenuation. The Bragg wavelength is the geometric and optical properties that change under the influence of mechanical and thermal stresses. The relation of the Bragg wavelength change, the relative deformation and temperature is expressed by the following relation:

$$\frac{\Delta\lambda_B}{\lambda_B} = k\epsilon + (\alpha_\Delta + \alpha_n) \Delta T \quad (2)$$

where $\Delta\lambda_B$ is Bragg wavelength shift, k is deformation coefficient, ϵ is deformation, α_Δ is the coefficient of thermal expansion, α_n is the thermo-optic coefficient and ΔT is change of temperature [2].

The relation in Equation 2 suggests that thermal and deformation sensitivity changes with the absolute value of the Bragg wavelength. With regard to the values of coefficients stated in the above relations, the standardized deformation coefficient at a constant temperature is expressed by Equation 3

$$\frac{1}{\lambda_B} \frac{\Delta\lambda_B}{\Delta\epsilon} = 0.78 \cdot 10^{-6} \text{ } \mu strain^{-1}. \quad (3)$$

2.2 Design and Realization of FBG sensor

From the results of the research during a master's program, polymer materials were selected for the mobile sensor's design. In selecting a suitable mold, any desired shape of the resulting sensor can be obtained. The polymer then cures either at either room temperature or raised temperature. Based on experimental measurements with several types of polymers, ZA 50 LT two-component additive rubber (ELCHEMCo, Zruc nad Sazavou, Czech Republic) [3] was selected. This material cures at room temperature. The selection criteria for a suitable polymer included polymer hardness, resistance to passing cars, sensor lifespan and curing temperature.

For creating the mobile sensor, I used an apodized Bragg grating that was made using the phase mask method. For the production process, I used a standard single-mode optical fiber (ITU-T recommendation G.652) with primary acrylic protection of 250 μm . This type of material and size of protection was used for the recounting at the place of the Bragg grating. The length of Bragg grating itself was 1.6 mm.

The mobile sensor strip consisted of an optical fiber Bragg grating with a Bragg wavelength of 1573.158 nm, reflectivity of 94.04%, and spectrum width (full width at half maximum, FWHM) of 211 pm. The first prototype of the mobile sensor was completed by casting a bare optical fiber with FBG. Manual handling of the mobile strip and passing cars created a large deformation of more than 10,000 μstrain . This large deformation exceeded the maximum deformation (5000 μstrain) defined by the manufacturer of the used Bragg gratings. Different types of optical fiber protection tubes (polymer, metal, fiberglass and carbon) were therefore tested to compensate. Testing showed that the most suitable form of protection was a carbon tube with an internal diameter of 0.3 mm and external diameter of 0.7 mm.

Figure 2 shows a scheme of a mobile fiber optic sensor with a Bragg grating in a carbon tube, which was subsequently encased in a ZA 50 LT polymer. The length of the sensor was selected according to the width of the car lanes. The criterion for monitoring traffic density was a vehicle passing over the mobile strip with at least one wheel in the lane. The minimum width of the local road in the Czech Republic is 2.75 m, and a length of 2.5 m was therefore selected. The width of the active area of the measuring tape is given by the length of the carbon tube, which was 2.35 m long. Outside the active area, sensitivity to a passing car is significantly reduced. The height of the strip was 2 cm, and its width was 6 cm. These values represent a compromise in order to sufficiently protect the FBG sensor while also minimizing the axle load of a passing vehicle. The optical fiber was pre-stressed by 500 pm in the carbon tube and glued at both ends with a two-component adhesive. A supplying optical fiber with a width of 900 μm and length of 5 m was inserted into a protective ELASTOLLAN C98 polyurethane tube (Gumex, Brno, Czech Republic) along with internal and external protective tubes with outer diameters of 2 mm and 4 mm, respectively, and a wall thickness of 1 mm.

The polymer was then cured at 25 °C for 72 h. The curing process itself caused a shift of the Bragg wavelength from 1573.158 nm to 1573.766 nm (shift to a higher wavelength by 608 pm). This change was very small and had no effect on the functionality of the Bragg gratings. A semi-cylindrical shape was selected for the sensor in order to eliminate the impact of a passing car as much as possible and to maximize the comfort and safety of vehicle passengers in traffic. A photo of the FBG measuring sensor is shown in Figure 2(c).

Fig. 2. Structure of the mobile portable sensor for monitoring density of automobile traffic density: (a) longitudinal section; (b) cross-section [4] and (c) photo of the measuring sensor.

2.3 Traffic Density at the Main Entrance to the VSB-TUO Campus

Traffic density was measured at the main entrance to the VŠB-Technical University of Ostrava (GPS: 49°49'50.1"N 18°09'38.1"E). Measurements were conducted over 12 hours (from 6.00 to 18.00). Sensor measurements recorded the crossing time, type of car (passenger, truck, trailer) and the number of axles. All instances of passes were also manually recorded.

The mobile sensor was placed in the centre of the road, which had a width of 5.55 m, so that passing cars in both directions always approached the sensor strip with at least one side of the vehicle. The placement of the sensor is shown in Figure 3.

Fig. 3. Schematic diagram of the Bragg grating sensor.

Figure 4 shows a passing passenger car. Distinguishing individual axles makes it possible to differentiate each pass with respect to the time intervals between individual axles and thus allow traffic density to be calculated. A total of 1518 cars passed during the measurement period (1515 passenger cars, 2 passenger cars with a two-axle trailer and 1 truck with three axles). Only 1502 cars were correctly detected using the sensor strip. The remaining 16 passes were not detected because the vehicles passed the sensor strip outside the active area. The overall efficiency of detecting cars was 98.946%.

Fig. 4. Schematic diagram of the Bragg grating sensor.

3 Projects

During my studies, I actively participate in X projects. For example:

- Development of new implants for growth regulation of lower limb in sterile finish - faculty FMT
- SP2019/41 - Networks and Communication Technologies for Smart Cities II - faculty FEI
- SP2020/38 - Fiber optical technology for industrial applications - faculty FEI

4 Publications and pedagogic activities

I have a total of 4 accepted or published papers and 2 utility models.

- Fridrich, M.; Fajkus, M.; Mec, P.; Nedoma, J.; Kostelansky, M.; Bednar, E. Portable Optical Fiber Bragg Grating Sensor for Monitoring Traffic Density. *Appl. Sci.* 2019, 9, 4796.
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- Jan Nedoma, Michal Kostelansky, Michael Fridrich, Jaroslav Frnda, Miroslav Pinka, Radek Martinek, Martin Novak, Stanislav Zabka. Fiber Optic Phase-Based Sensor for Detection of Axles and Wheels of Tram Vehicles. *Communications [Internet]*. 2020Jul.8 [cited 2020Jul.16];22(3):119-27. Available from: <http://komunikacie.uniza.sk/index.php/communications/article/view/1576>
- M. Fajkus et al., "PDMS-FBG Based Fiber Optic System for Traffic Monitoring in Urban Areas," in *IEEE Access*, doi: 10.1109/ACCESS.2020.3006985.
- Portable grid sensor for detecting vehicles. Registration number 33827
- Chain sensor for monitoring road traffic. Registration number 34137

In the winter semester, I was part of courses LO (Logical Circuits) as help for academic teachers.

5 Future work

I now focus on the Ph.D. study and individual subjects. I also work with colleagues on the preparation of new and current projects and work on other impacted publications.

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3D printed FBG sensor for heart rate monitoring of the human body

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Abstract. This article describes the design and functional verification of the biomedical fiber-optic sensor as a sensor for monitoring heart rate of the human body. The sensor is based on Fiber Bragg Grating (FBG), and it is encapsulated by using 3D print. The main advantage is immunity to electromagnetic interference so it is possible to use in the electromagnetically environments. This article also presented summary of the author's activities during the first year of his study.

Keywords: fiber bragg grating, heart rate, fiber optic sensor.

1 Introduction

Allow me to introduce myself. My name is Michal Kostelanský. I am studying for Ph.D. at the Faculty of Electrical Engineering and Computer Science at the Technical University of Ostrava. During my doctoral studies I focus on Fiber Bragg Grating sensors in biomedical applications. To the date 7/2020, I have a total of 3 accepted or published publications.

2 About my project and dissertation work

During my first year of study, I designed the measuring sensor for monitoring heart rate of the human body which is based on Fiber Bragg Grating, and it is encapsulated by using 3D print. The sensor designed in this way can be used in magnetic resonance imaging.

Fiber-optical Bragg gratings are most commonly used fiber-optical sensors for their spectral characteristics [1]. Repeated changes in refractive index of the core of an optical fiber creates the grating. Spectral reflection of a selected wavelength, known as Bragg wavelength, occurs on periodic interfaces. All the other wavelengths pass through the Bragg grating without damping. Figure 1 shows the structure of the FBG.

Fig.1. Example of structure of Fiber Bragg Grating.

The Bragg wavelength λ_B is given by following equation:

$$\lambda_B = 2n_{\text{eff}}\Lambda, \quad (1)$$

where n_{eff} is the effective refractive index of the optical fiber with Bragg grating and Λ is the period of changes in the refractive index pitch for the fiber's core.

The primary use of FBG is based on the deformational and temperature sensitivities. Based on the temperature evolution of mechanical stress, the Bragg wavelength shift can be defined as:

$$\frac{\Delta\lambda}{\lambda_0} = k\varepsilon + (\alpha_n + \alpha_\Lambda)\Delta T, \quad (2)$$

where k is the deformational coefficient, α_n is the optical temperature coefficient, α_Λ is the coefficient of thermal expansion, ΔT is the temperature change and ε is the applied deformation. Deformational dependence and temperature dependence are determined both by the parameter values and the central Bragg wavelength. Normalized deformational and temperature coefficients [2] are introduced for determination of the individual sensitivities. Normalized deformational coefficient is given by:

$$\frac{1}{\lambda_B} \frac{\Delta\lambda_B}{\Delta\varepsilon} = 0,78 * 10^{-6} \mu\text{strain}^{-1}, \quad (3)$$

and normalized temperature coefficient by:

$$\frac{1}{\lambda_B} \frac{\Delta\lambda_B}{\Delta T} = 6,678 * 10^{-6} ^\circ\text{C}^{-1}, \quad (3)$$

I have created a prototype of a measuring sensor which was tested in magnetic resonance imaging (MRI) scanner (3T MRI scanner, CEITEC MU, Brno). Real photo from the measurement in MRI is shown on Figure 2. The sensor was created by the

encapsulation of the Bragg grating structure into Poly-lactic acid (PLA), which is a typical material for 3D printing and there is a possibility to use it in MRI.

Fig.2. Real photo from the measurement in MRI.

Sensor dimensions are 30mm length, 15 mm height and 0,6 mm width. Real photo of the sensor is shown on Figure 3.

Fig.3. Real photo of the sensor.

The key experimental results of heart rate measurements in the laboratory environment (five volunteers) are summarized in Table 1. The data from designed sensor and the data from conventional electrocardiography (ECG) sensor were

compared by the objective medicine used the Bland-Altman method [3]. The reproducibility is considered to be good if 95% of the results lie within a ± 1.96 SD (Standard Deviation) range.

Tab.1.Table of results from measurement in the laboratory environment.

Subject	Rec. time (s)	HR	
		Number of samples	Samples in ± 1.96 SD (%)
Male1	1137	1267	95.55
Male2	1334	1613	95.68
Male3	1329	1568	95.20
Male4	1445	1712	95.66
Female1	1262	1768	94.64

According to the obtained data, it can be said that this method can be used instead of the current conventional heart rate sensors of the human body.

In the next step of this research, we will continue to improving the design and construction of the sensor. We will try to find out what shape and size of the sensor will provide the best results.

3 Projects

SGS SP2020/38 - Fiber optic technologies for industrial applications

4 Publications activities

From the date 9/2019 since to the date 7/2020, I have a total of 3 accepted or published papers and 3 utility models.

5 Pedagogic part and other activities at the Department of Telecommunications

In the winter semester, I was part of UDKT course as help for academic teachers.

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Machine learning methods for isolated word automatic speech recognition

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Abstract. This paper summarizes my first year of doctoral study. In the first part, there is a description of my publication which deals with machine learning methods for automatic speech recognition. The created system for isolated word automatic speech recognition was designed and implemented in Python using Keras and TensorFlow. In the following section are research projects I am involved in. The last part is about my educational activity.

Keywords: automatic speech recognition, machine learning, hidden Markov models, deep neural networks.

1 Introduction

Let me introduce myself. My name is Martina Slívová. I am a doctoral student at the Faculty of Electrical Engineering and Computer Science at the Technical University of Ostrava. I am on full-time study and my educational program is Communication Technology. I am in my first year of study and I am involved in some research projects. To this date, I have one accepted publication.

2 About my publication

This school year I wrote the paper 'Isolated word automatic speech recognition system' which was accepted to the MCSS2020 conference. The conference was supposed to be in June but was postponed to October due to the current situation.

This publication is based on my diploma thesis. I created a system for isolated word automatic speech recognition (ASR). This system was developed in Python using Keras and TensorFlow[1] frameworks. After some search, I decided to use Mel-frequency cepstral coefficients (MFCC) for feature extraction and Convolutional neural network (CNN) for classification. The Speech commands dataset version 2 [2] was used for training and testing the neural network.

The first part of the paper belongs to the search of other papers devoted to this topic, for example [3,4,5]. After that, there is a theoretical description of the methods used for preprocessing, feature extraction, and classification. For training and testing, 15 words from the dataset was used. The final neural

network model has 6 convolution layers, 11 ReLu layers, 10 dropout layers, 3 pooling layers, 3 noise layers, 1 flatten layer and 2 fully connected layers. I tried many different models, but this one had the best results. In figure 1 is the diagram of the architecture of the CNN. This CNN model has accuracy 94.08% for testing data. It was trained for 50 epochs which is a compromise between accuracy and the length of the training.

The trained system can recognize keywords from speech using a microphone in real-time. Recognition is possible using a console application or a graphics application, which also plots the sound wave in time captured from the microphone.

Fig. 1. Architecture of CNN

3 Projects

As part of my studies, I was actively involved in solving 2 projects, namely:

- EG17_1070012408 The new generation of the fuel distribution of the control system
- CZ.01.1.020.00.019_2620020122 Development of external modules TAMAS II

4 Educational activity

In the winter semester, I taught the course VoIP, where I had one class. In the summer semester, I was part of a ZAP (Basics of Algorithms and Programming), for this subject I created some materials for distance learning and some moodle tests.

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Surface plasmon resonance and a phase detection in the spatial domain

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Abstract. In this paper, a phase shift detection method based on spatial domain interferometry is presented. An experimental set-up comprising a laser source, launching optics, a gold coated SF10 glass plate, a coupling prism, a Wollaston prism and a CCD camera are involved. Two fringe patterns are recorded using the set-up, the reference one for air, when plasmons are not excited at the source wavelength and the other one for analyte, when plasmons are excited. Phase functions are extracted from a single row of each pattern using a windowed Fourier transform and the phase shift is determined for different types of analytes, that is, solutions of distilled water and ethanol in various weight ratios.

Keywords: Surface plasmon resonance · Phase detection · Spatial domain · Refractive index · Water · Ethanol.

1 Introduction

The surface plasmon resonance (SPR) phenomenon has already been used in many areas of sensing [1–6] since it was described by Kretschmann and Raether [7] in 1968. It is a free electron plasma oscillating on a boundary that separates a dielectric material and a metal. Efficient way to excite the surface plasmons is by attenuated total reflection (ATR) of a p -polarized light from a thin metallic layer by using a coupling prism. When the resonance condition is fulfilled [7, 8], that means when the tangential part of the wave vector of the incident light wave matches the real part of the wave vector of the surface plasmon wave, the SPR occurs and it manifests as a decrease in intensity of the reflected light wave and as a shift in its phase. The effect strongly depends on local changes of refractive index of an analyte near the metallic layer. Various ways of using the SPR in sensing exist, as wavelength [9] and angle [10] interrogations, respectively, or a phase detection in both spatial [11] and spectral domains [12, 13].

In this paper, a phase detection method, which uses spatial domain interferometry, is presented and demonstrated. First part deals with the fundamentals of interaction of light with an SPR structure and of two beam interferometry in the spatial domain. Second part is focused on an experimental set-up and measurement process. In the final part, results and discussion are presented.

2 Theory

The SPR structure under consideration is in Fig. 1. It consists of a substrate made of glass SF10, an adhesive layer of chromium with thickness $t_{Cr} = 2$ nm, an SPR layer of gold with thickness $t_{Au} = 42.8$ nm, a thin layer of effective medium with thickness $t_{eff} = 2$ nm and an analyte as an superstrate. The effective medium layer represents surface roughness of the golden layer. Its thickness is in agreement with thickness of surface roughness of the real layer used in experiments measured by atomic force microscopy. Suppose that p -polarized wave and s -polarized wave reach the thin layers in the SPR structure with analyte at angle of incidence θ that is close to the resonance angle θ_R . The waves reflect from the structure according to complex reflection coefficients $r_p = \sqrt{R_p}e^{i\delta_p}$ and $r_s = \sqrt{R_s}e^{i\delta_s}$, respectively, where R_p , R_s and δ_p , δ_s are reflectances and phases of p - and s -polarized waves, respectively. The reflection coefficients can be expressed using Fresnel formulae and refractive indices [14] of all materials involved in the structure. Only the p -polarized wave excites the surface plasmon wave, which manifests as decrease in intensity of the reflected wave and also as the shift in its phase. Spatial interference of the reflected waves can be then achieved by splitting them, projecting to one direction of polarization and combining them again. The pattern is formed by fringes of equal thickness according to the interference law that can be expressed limited to only one spatial dimension as

$$I(y) = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos [\Delta\phi(y) + \delta_{SPR}], \quad (1)$$

where I_1 and I_2 are the intensities of the interfering waves, $\Delta\phi(y) = 2ky \sin \alpha$ is the interference phase, where α is half of the angle between wave vectors of the interfering waves and k is the wave number of the incident light at the source wavelength λ_0 and $\Delta\delta_{SPR} = \delta_p - \delta_s$ is the phase shift introduced by the SPR. From the overall phase, the period of the fringes can be determined as

$$\Lambda = \frac{\lambda}{2 \sin \alpha}. \quad (2)$$

In Fig. 2, two model patterns are shown. The left one for air and the right one for analyte (distilled water). Shift of the fringes is obvious in the right pattern contrary to the reference one, as well as decrease in the visibility.

Fig.1: The SPR structure under consideration.

Fig. 2: Interference patterns for air (left) and for analyte (right), $\alpha = 7^\circ$, $\lambda = 637$ nm. As the analyte, distilled water is used.

3 Experiment

The experimental set-up is seen in Fig. 3. It consists of light source LS (laser diode DL-4039-011, Sanyo), polarizer P and analyzer A (LPVIS050, Thorlabs), Wollaston prism WP (WP10, Thorlabs), a coupling prism made of SF10 glass, a slide made of the same glass with thin layer structure, a sensing chamber for the analyte, CCD camera (PL-B952U, Pixelink), a computer and lens L . An index matching oil is used to attach the glass slide to the prism of same refractive indices.

Fig. 3: Experimental se-tup for measuring the phase shift introduced by the SPR.

A collimated light wave passes through the polarizer with polarization axis oriented 45° with respect to the plane of incidence, so both polarizations s - and p - are generated. The light wave reflects from the SPR structure on angle θ that

is approximately 60° and then the Wollaston prism splits the polarization components. The polarization axis of the analyzer is also oriented 45° with respect to the plane of incidence, so the components of polarization are projected to that direction and after combining them on the CCD camera objective by the lens they interfere. Two patterns are recorded for the source wavelength $\lambda_0 = 637$ nm, one for analyte in the sensing chamber, when the SPR does occur, and the reference one for air, when the SPR does not occur. As the analytes, solutions of distilled water and ethanol are used. The weight concentrations of ethanol are 2.5, 5, 10, 20, 30, 40 and 50 wt%. In Fig. 4, two interference patterns are shown. The left one for air and the right one for analyte with 50 wt% of ethanol. Decrease in visibility of the fringes is evident in the pattern for analyte as well as shift of their position contrary to the reference pattern. It can be also seen that diffraction patterns are involved, which are attributed to impurities on optical elements.

Fig. 4: Interference patterns for air (left) and for analyte (right). As the analyte, a solution of distilled water with 50 wt% of ethanol is used.

Images captured by the CCD camera can be treated as RGB matrices and since the used wavelength is $\lambda_0 = 637$ nm, only the R components are relevant. Each row of these components represents 1D interferogram as a function of the pixel number and in this work, only the row 354 from each pattern is processed. Using the windowed Fourier transform [15], the overall phases $\Phi = \Delta\phi + \Delta\delta_{\text{SPR}}$ and $\Phi_R = \Delta\phi$ are obtained and finally, the phase shift $\Delta\delta_{\text{SPR}} = \Phi - \Phi_R$ can be determined.

4 Results and discussion

In Fig. 5 on left are resulting phase shifts for seven analytes with different weight concentrations of ethanol. The range of pixels is only from 400 to 600. Since the signals are finite, errors are significant on both edges of the evaluated phase shifts. In Fig. 5 on right, the average value of the phase shift as a function of ethanol concentration is depicted. In range of ethanol concentrations from 0 wt% to 30 wt%, the phase shift changes linearly.

Fig. 5: Phase shift as a function of the pixel number for different analytes (left). Phase shift as a function of the concentration of ethanol (right).

5 Conclusions

In this paper, a phase shift detection method based on spatial domain interferometry has been presented. The method has been demonstrated in measuring the phase shift induced by the SPR for analytes composed of distilled water and ethanol with weight concentrations of ethanol 2.5, 5, 10, 20, 30, 40 and 50 wt%. Since the phase shift dependence on the concentration is not linear in the whole interval, the method is suitable for sensor applications only for range of concentrations from 0 wt% to 30 wt%. Results are important from point of view of new sensors development and design.

Acknowledgement

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1. Kanok, R., Ciprian, D., Hlubina, P.: Surface plasmon resonance detection based on a phase method in the spatial domain. *Proc. SPIE*, 11354, 113542H (2020).
2. Kanok, R., Hlubina, P., Ciprian, D.: Surface plasmon resonance-based sensing utilizing spatial phase modulation in an imaging interferometer. *Sensors*, 20, 1616 (2020).

Analysis and Classification of Vibroarthrographic Signals

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Abstract. This paper presents current state-of-the-art vibroarthrography (VAG) signal classification problems, features extraction methods, as well as limitations and differences in comparison to classical knee joint diagnosis tools. A brief summary of current research was also included; focusing on frequency and time-frequency VAG signal analysis methods and feature evaluation problem.

1 Introduction

1.1 Vibroarthrography

Vibroarthrography (VAG for short) is an examination procedure used to record vibrations generated by a moving articular surface. An accelerometer attached close to the examined joint (1cm above the apex of the patella in this paper) generates signal of vibrations caused by the irregular frictions between two cartilages. Those irregularities are felt by the patient as cracks and squeaks, and can be sign of some knee joint condition.

The signal base used in this paper consist of 184 VAG signals diagnosed by radiologists, based on the RTG scan. Each signal was assigned to one of five groups: three stages of chondromalacia patellae, osteoarthritis and the control group (so the knee without any condition). In the span of roughly 6 seconds, four flexion-extension motions were performed. The signals were obtained and used for the first time in [1]. Exemplary signals were plotted in Fig. 1.

As can be seen in Fig. 1, the more advanced condition, the more high frequency distortions appear in the signal. Additionally, with the osteoarthritis, some quick, high amplitude peaks appear. However, these are just brief, general remarks, which not all of the signals seem to follow.

The dynamic character of vibroarthrography is probably the biggest difference with the standard knee joint diagnostic methods (like RTG, MRI or arthroscopic surgery). The diagnosis of signals analyzed in this research was based on RTG, so the method with more static character.

1.2 Goals of the Research

The main goal of the research is construction of the classifier based on the signal features characteristic for each condition. The task is not as straightforward

Fig. 1. Exemplary VAG signals.

as it may seem, since distinction between particular conditions is ambiguous to some extent. This causes neighboring classes to have relatively big overlap in values of signal features. However, in most cases, it is possible to classify VAG signal precisely.

Main goal can be divided into two essential steps: signal analysis leading to the definition of characteristic features and classification of signals based on features selected in previous step. These steps can be further divided into:

1. signal analysis step:
 - (a) the signal analysis itself; consisting of statistical, frequency, time-frequency, complexity etc. methods,
 - (b) feature evaluation step required to differentiate *good* features from *bad* ones,
2. classification step:
 - (a) the feature selection, required to select the best feature subset from the full set of features obtained in previous step,
 - (b) the dimensionality reduction, needed for removal of correlations between features,
 - (c) classifier construction, tuning and training.

1.3 Literature Review

The VAG signal literature include, besides others:

- statistical analysis methods [1–10],
- frequency analysis methods [1, 9–11],
- time-frequency analysis methods [12–17],
- signal decomposition methods; wavelet [18–20], EMD and VMD [2, 21–24] and incremental [14],

- fractal methods [2, 4, 25, 26].

Despite the vastness of VAG literature, most references focus on two-class distinction, without precise specification of particular condition [3–8, 11–13, 17–19, 21, 22, 25].

2 Results Summary

In this section, the completed original research studies were presented, as well as current ones.

2.1 Peak and Slope Analysis of the Decomposed Signal

Peak and slope analysis of signal decomposed with the use of the spectrogram [15]. In this paper, some new VAG signal descriptors (characteristic features) were proposed. Additionally, robustness of proposed features was tested, adding white noise to VAG signals. The features were based on time-margin condition, selecting part of time-frequency plane and filtering it with low-pass filter. The features themselves were defined as:

- average amplitude of peaks in the obtained signal,
- number of peaks in the obtained signal,
- average slope values in the obtained signal.

2.2 Feature Quality Evaluation

Preliminary research concerning feature quality evaluation was done. Paper summarizing this research is currently edited. Feature evaluation methods are commonly divided into three main categories [27]. Wrapper and embedded methods use some selected classification algorithm to evaluate the quality of the feature (or feature set). Filter methods, on the other hand, evaluate the quality without classification. In the scope of the study, six filter methods were compared. Bhattacharyya coefficient, based on the overlap between probabilities distribution proved to be the best one. As a result, it was used to generate Frequency Range Maps in research mentioned below.

2.3 Frequency Analysis

In this research, new method of frequency signal features visualization was proposed. It allowed definition of new spectral features, utilizing VAG signal itself, as well, as its derivative. Proposed visualization method was presented in Fig. 2.

Three dimensional plots, called Frequency Range Maps (FRMs for short), represent the relevance of VAG signal energy in specific frequency range as an classification input. Using those maps, new spectral features were proposed and compared to state-of-the-art [1], proving to be superior. To obtain best possible objectivity of the research, ten different classifiers were additionally constructed. Their accuracies further confirmed that new features are better than features from [1]. Exemplary FRM was showed in Fig. 2.

Fig. 2. Example of the Frequency Range Map. The x -axis is the lower frequency range, the y -axis is the upper frequency range and the z -axis is the relevance of the feature, measured as a Bhattacharyya coefficient.

2.4 Spectral Moments Analysis

Preliminary research concerning spectral moments of the VAG signal was conducted. This study is currently further developed, with the statistical analysis applied to the signal of instantaneous frequency of the VAG signal.

General idea of this study is that analyzing the spectral properties of the VAG signal as a function of time will provide more information about the condition of the diagnosed knee joint than the simple frequency analysis.

3 Conclusions and Discussion

After visually analyzing exemplary VAG signals presented in Figure 1, frequency and time-frequency analysis seems fruitful in the classification task. Research focusing on frequency analysis proved it to be effective tool in VAG classification problem. However, simple spectral analysis lacks the information about precise moment of high frequency appearance. Therefore, the classification accuracy could potentially be further improved, using features based on *time*-frequency analyzes. Some preliminary spectral moments statistical analyzes were conducted, however, no results were published yet.

Preliminary research concerning classification was done, as a tool of results objectivity verification in the spectral analysis and the feature evaluation method research. The research devoted to feature evaluation methods was conducted rather fruitfully and most probably will not be further continued. To evaluate feature quality, Bhattacharyya coefficient will be used in future studies.

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The Pepper humanoid robot as a testbed for interaction design and sentiment analysis research

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Abstract. In this paper authors summarize available information about humanoid robot Pepper and evaluate the possibility to use it as a testbed for interaction design and sentiment analysis research. The paper includes not only a review of the preinstalled hardware, sensors, and software-based functionalities, but also a brief proposal of ways to extend the possibilities of Man-Machine interaction by adding hardware- or software-based addons and sensor subsystems.

Keywords: Pepper, HMI, Interaction, Humanoid Robots

1 Introduction

Communication with robots has fascinated humanity for centuries. In the past, machines that performed simple activities were built, and with time their design and applicability have evolved. Today, the computer with appropriately selected components, in some applications, is able to achieve much more than a human. Nowadays, one of the challenges is designing an efficient and natural form of interaction between a person and a computer or a robot. Simply typing a text into a document is also, in a way, an interaction with the machine - the text is being entered and displayed on a computer screen. Other forms of interaction are for example: text commands, voice commands, or gestures. In the field of Artificial Intelligence (AI), the quality of interaction possibilities is increased, because the robot, or a personal computer, is able to generate a response to human communication basing on the AI. However, in some cases, especially in humanoid robots, the Artificial Intelligence may be perceived as controversial. People have various kinds of attitudes towards the robot-AI connection, because of the physical proximity - appearance of a robot close to a human being. This seems to hamper the progress in the area of man-machine interaction - the current human attitude seems to be a reasonable limit to HMI research. Such belief may result from movies and books in the science fiction genre, in which the machines are often said to have hostile intentions, to “take over the world”. The other possible issue is that robots (including humanoids) are a relatively new piece of our culture, their appearance and functionality are not always user-friendly, and finally they do not meet the expectations of their users/owners.

There are many different and intriguing hardware platforms for interaction-oriented robots available on the market. Some of them are clearly targeted at the entertainment sector, for example the Karotz [1] - small, rabbit-looking robot from SoftBank Robotics, with basic functionality and optional social media synchronisation. However, there are some interesting robots that extensively use AI, for instance Musio [2] - a social robot powered by MUSE [3], deep learning AI engine made specifically for communication and for people that want to learn to speak English. Overall mobility of this particular robot is strongly limited and was not updated from its first version at all.

There are robots that resemble humans in appearance and overall “behaviour”, especially from SoftBank Robotics. One of them is Nao [4] - autonomous, programmable, humanoid robot. It was created for research and educational purposes. Another robot, designed by Aldebaran Robotics (acquired by Softbank Robotics), of increasing popularity, is a humanoid robot called Pepper. It is specifically designed to interact with people. It is also capable of simple emotion recognition by analyzing expressions and voice tone.

2 Hardware platform - Pepper

Pepper has a wide range of motion, as well as well-developed components, sensors and software that enables it to be one of the best humanoid - looking robots on the market. Produced by SoftBank Robotics, Pepper is specifically designed to interact and communicate with humans, to enhance people’s lives and connect them with outside world [5]. Founder of SoftBank, Masayoshi Son, introduced Pepper on June 5, 2014 in Tokyo. It was available in Japan in June 2015 and launched in UK in 2016. Today, Pepper is used in over a thousand homes in Japan [6] and in many universities. Pepper is usually referred to as a humanoid robot although it has a wheeled platform instead of legs. It has a head resembling a human face. The “eyes” include RGB LEDs, configurable within the code, and a depth sensor. The “mouth”, as well as the “forehead” have the regular vision cameras. There is also a matrix of four microphones on Pepper’s head, which uses simplified beamforming to determine the location of the interlocutor. Pepper’s body consists of the upper half (the chest), with motorized arms that can be programmed for various movements [see Fig. 1].

Fig. 1. Joint placement of Pepper [7]

Pepper can also close and open his hand and pick up light items. There is a touch-screen tablet on the chest which allows for additional interaction with the user. In addition to the user's voice commands, it is possible to communicate with Pepper via the tablet (by touching, selecting the appropriate options displayed on the robot's screen), and by human gestures.

3 Advantages and Disadvantages

The undoubted advantage of a robot Pepper is its overall design, implementing highlevel API access for programmers, which allows not only to detect emotions of the interlocutor, but also to simulate emotions by the robot itself in many different ways: by means of gestures, voice modulation and showing informations on a tablet.

Pepper's gestures are performed using the entire body. Gestures include not only waving its arms, but also moving and tilting its head and body. As Pepper does not have legs, the only part that can move in the lower part of the body is a waist, but it is perfectly sufficient - leaning to the sides of the body or back and forth, moving the head and all joints of the arms allows a very wide a range of gestures that the robot can perform to show its emotions.

Pepper's voice modulation is done using the built-in speaker and using the text-to-speech module, allowing fluent speech with the use of a generated text or text written by the programmer. A ten-inch tablet placed on Pepper's chest allows the to display additional information for the user - animations, pictures or buttons.

Another very important advantage of the Pepper robot is its already implemented ability to read emotions. Using sensors and cameras placed on the head - the upper part of the robot - the robot is able to read emotions on the face with high accuracy.

This may allow for future research in this field and the possible refinement of the robot so that the recognition of emotions works not only with the use of images, but also sound or words in a sentence.

The disadvantage of the robot is undoubtedly its internal structure. The Atom E3845 quad-core processor, 4GB RAM and 16GB microSDHC memory [8] do not allow for many calculations in the robot itself. The data to be processed in a larger amount or multi-threaded must be sent to an external computer, processed there, and sent back to the robot, which slows down the process of the robot's response to the user or listener. If these are the answers already programmed, there is no major problem, but the problem begins when the robot has to generate the answer by itself.

The most important advantage of the Pepper robot is the ability to implement custom software while using high level APIs provided by the SoftBank Robotics. It is noteworthy that it is possible (and highly beneficial) to supplement or to replace some of the functionalities, e.g. use the Google Speech Cloud Service instead of the preinstalled one, Nuance.

The final advantage of the Pepper humanoid is the possibility to include it within a bigger system, that has a wider knowledge of the robot's realm, possible interaction/discussion topics, and the overall purpose of interaction. The robot's data inputs can be supplemented by additional subsystems, including for example access control devices/gates or the "covid module" [9] (a thermovision camera integrated by software with the vision system).

4 Conclusion

The above mentioned features, along with the high level API for all of the hardware functions and for managing and processing all input data streams, as well as the possibility to use Google Speech and other cloud services make the Pepper humanoid robot a perfect hardware platform for experimenting with sentiment analysis, emotion recognition, and for implementing custom AI engines. With available components and sensors, Pepper is a perfect candidate for human-machine interaction.

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Designing a Human-Machine Interface of a humanoid robot for people with disabilities

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Abstract. This paper presents some of the experiences of the authors regarding the design of the Man-Machine interaction with humanoid robot (SoftBank Robotics Pepper). The authors had the possibility to design the interaction engine with some of the testers (interlocutors) being impaired. This paper discusses two basic aspects: (1) the great advantage (in both: ease and time) of advancing and raising the quality of interaction because of those testers, and (2) the need for a very well-designed interaction engine (and how to achieve that) if the purpose of the machine is to interact with people with impairments.

Keywords: Pepper, HMI, Interaction, Humanoid Robots

1 Introduction

One of the obvious functionalities of humanoid robots is their ability to interact with people. The level of interaction varies significantly between hardware platforms, giving the user multiple ways and means of interaction. The basic mechanical functionality gives the possibility to use a specific robot as ‘automata’ [1], i.e. a device that performs a predefined behaviour (e.g. set of movements). In this case the interaction is limited to starting the behaviour. Although the term ‘automata’ is centuries old, it is surprising how many robot architectures and movements still uses sets of predefined movements, even within the most sophisticated frameworks. The second level of the interaction complexity is such a situation in which there are many basic behaviours that can be triggered. This interaction model can be simply named ‘remote controlled robot’ (e.g. [2]), and it is very common in the entertainment industry. The third group of devices are robots designed specifically in order to interact with people. Some of them are research-oriented prototypes, but there are some products that can be bought and used out-of-the-box (inter alia: Sanbot [3], NAO [4], Pepper [5], and more). The Application Programming Interfaces (APIs) of the platforms usually give the possibility to implement some basic interaction logic, including conditional statements, and

behaviours that can be chosen depending on the logical state of the interaction. Basic example of decision-dependant behaviour can be a Python script for the NAO robot to shake hands with its interlocutor (triggered by a tactile sensor on its wrist). More advanced example can be a speech-controlled behaviour using a predefined set of words and an offline Speech-To-Text engine (for example using the Nuance [6] engine to distinguish “yes” and “no” words within a predefined dialogue scenario using the Dialog Topic [7] on the NAO humanoid robot). The most advanced group of applications is the implementation of un-scripted interaction, where the user does not have a limited set of possible dialogue options, but instead he/she can ask any question. This is definitely the most challenging application, requiring an implementation of some kind of Artificial Intelligence (AI) decision-making algorithms. The less sophisticated the algorithms are, the less impressive the prototype is.

Due to the cooperation between the Weegree company and the Opole University of Technology, the authors have the possibility to advance the field of Man-Machine Interaction by conducting research using the SoftBank Robotics ‘Pepper’ robot.

Some of the issues and challenges of HMI (Human-Machine Interfaces) regarding the use of the Pepper robot were already analyzed in the previous research: the possibility to use Pepper at a reception [8], influence of the eye-contact on the interaction with the Pepper [9], extending the humanoid’s acquisition possibilities by additional IoT sensor subsystems [10,11], etc.

The pursuit of User Experience (UX) parameters and the quality of interaction brought the authors’ attention towards some of the nonverbal perception -oriented aspects of interaction, inter alia: designing emotion recognition subsystems [12], and multimodal sentiment analysis applied to interaction between patients and Pepper [13].

As a consequence of the above-mentioned research it turned out that some of the Pepper’s interlocutors have special needs or preferences regarding the interaction form, resulting from their preferences, abilities or disabilities. During preliminary research it turned out that modifying various aspects of the interaction to meet their expectations (even though this might be one or two persons) results in better UX for the majority of users.

2 Interaction possibilities of the Pepper humanoid robot.

Pepper is a humanoid robot produced by SoftBank Robotics. This robot is 120 cm high and weighs 28 kg. It is equipped with a 10-inch touch screen as an additional interaction feature. The robot’s head includes four microphones, two speakers, two RGB cameras, a depth sensor and three tactile sensors. Additional touch sensors are located on the robot’s hands. Pepper has many moving joints: the neck, in the arms, elbows, wrists, fingers, and hips. The base of the robot has three motors and wheels. There are twenty motors in total. The robot is also equipped with LEDs located in the “eyes”, shoulders, and near its “ears” (speakers). The eyes’ and shoulders’ LEDs offer RGB colours, while the speakers’ LEDs offer only 16 shades of blue. Such a huge variety of sensors, actuators, motors, communication and interaction options allows the robot

to use a wide variety of verbal and nonverbal messages during interaction with humans.

Man-Machine interaction can be done in many ways. One of them is to use the included Natural Language Processing (NLP) libraries [6]. When a human talks to a robot, the speech is being converted into text and analyzed/processed. Then it generates an appropriate response presented using a voice synthesizer through the speakers.

Another possibility of interaction is with the use of the included touch screen. Any kind of visualisation, graphical interface, or menu can be presented and used for interaction.

The motors of the robot can be accessed using a high-level API, resulting in many different gestures, movements and micromovements (including the ALAutonomous-Life API [14], that uses micromovements to make Pepper more lifelike - e.g. by simulating breathing chest movements, eye blinking, random movements), thus freely simulating the "robot's emotions", so that a human can easily read what the sentiment engine wants to convey.

3 Motivation

Each disease entity not only has symptoms that need to be prevented or at least to be slowed down, but also has some limitations within the method of physiotherapy. For example, in the treatment of visually impaired patients, it may be necessary to replace the exercise regimen with a verbal description. The opposite is also true for a hearing impaired person: a demonstration of exercises may be more effective than a description. A disturbed or lost sense should be "replaced" with others. This will work properly in many cases.

However, if in addition to sensory disorders there are also neurological disorders present, then the contact with the patient may be significantly more difficult. Especially in such a situation, the Pepper robot can be extremely helpful.

Difficulties in contact may occur with both elderly people with neurodegenerative diseases (e.g. Alzheimer's disease or other dementia syndromes) as well as children with cerebral palsy or patients with autism [16-18]. Therefore, the use of humanoid robots in the rehabilitation of patients carries a very wide range of applications. Properly programmed, it can be used in many disease entities in a large group of patients. The robot can be used as a "tool" supporting the therapist's work and their contact with the patient, and perhaps in the future it could even replace them in some situations [19][20].

A significant advantage of the Pepper robot is the touch screen attached to its chest. In the case of a patient with hearing impairment, it can be used for displaying graphics showing particular exercise on the screen. Pepper can also present exercises with the use of upper limbs. This seems to be a particularly good solution for working with children who, on the one hand, have a keen interest in new technology, and on the other hand, when they have disorders such as autism, will be able much easier to make contact or even bond with a robot like Pepper.

Due to the conjunction of all Pepper functions and features, providing verbal contact, the possibility to present information on a tablet, as well as the ability to move its arms, it can be successfully used during group exercises, e.g. for geriatric patients or for children, as an additional stimulus encouraging them to such necessary physical activity.

Apart from strictly therapeutic use (similar to the use of NAO robot here: [19]), Pepper is sometimes used for entertainment purposes, e.g. in nursing homes [21][22]. This is due in part to the very well-functioning Natural Language Processing engine (especially when using Google Speech instead of the built-in Nuance), which greatly enhances its ability to communicate verbally. Robot is able to have conversations with seniors, making their time more pleasant, and thus preventing them from growing a feeling of rejection.

4 Methodology (Searching for Imperfections)

The authors had the possibility to implement numerous interaction applications of NAO and Pepper robots. Some of them were simple scenario-based verbal interactions, some of them were multimedia-based speech-triggered interactions, and some of them were AI-based multi-topic conversation engines. The authors had the possibility to assess the quality of interaction measured as interlocutor's impression (User Experience) by a questionnaire. Conducting numerous interactions and analyzing numerous questionnaires resulted in the possibility to refine the system's "user interface", (i.e. the form of presenting the information), towards a better UX of the system as a whole.

The interlocutors of the Pepper robot, during the development of the system, were the employees of the Weegree company (over 60 people). Within this group there was a small group of employees with impairments. While the research team was strongly interested in making the Man-Machine interaction better, it turned out that fine-tuning the system's interaction engine is easier with the help of employees with impairments, while they were more patient, they were able to name the interaction imperfections more precisely, their requirements regarding graphical information and non-verbal communication were more essential than average.

This resulted in two important conclusions: (1) the process of refining the interaction engine (forms, content and methods) is easier and faster if some of the interlocutors are people with impairments, and (2) creating an interaction engine designed for people with disabilities requires much more robust and user-friendly interface (not only graphical interface, but also spoken messages and clear non-verbal communications, e.g. gestures).

5 Conclusions

From the perspective of physiotherapy, the Pepper robot seems to be not only the future of this discipline, but also its indispensable element. Due to the multitude of functions, functionalities and programming possibilities, it finds application areas in

the treatment of many disease entities. It will be able to both supplement the work of a physiotherapist and, in some situations, replace it. Its use as “a friend to talk with” as a socially assistive robot is also interesting and promising.

Designing the interaction of the robot with a person with special needs might seem not much different from designing the interaction with any other person. However, there are differences. Some of them are easy to find, like bigger font size on the screen for elderly people, more images and less text for pediatric rehabilitation applications. Nevertheless, some of the features of a well-designed interaction engine are difficult to define, or even find, e.g. people with hearing impairment might need clear text-based displayed information and some kind of non-verbal communication, e.g. gesture. While it is easy to say “the font needs to be bigger”, it is much more complex to say “the gesture needs to be a little more meaningful”. For this reason it is crucial to investigate the quality of communication and this can be done easier and faster if some of the testers are people with impairments. Due to their special situation, the resulting fine-tuned interaction engine offers better UX as a benefit for all the interlocutors of the system/robot.

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Author Index

Albert, Adam, 422
Andrešič, David, 237
Augustynek, Martin, 141

Bača, Jakub, 44, 50
Bailová, Michaela, 285
Barnová, Kateřina, 388
Baros, Jan, 87
Barvik, Daniel, 394
Běčák, Petr, 1
Behan, Ladislav, 343
Béreš, Michal, 291
Bílík, Petr, 174, 219
Blazek, Vojtech, 6
Bodzás, Alexandra, 399
Borova, Monika, 93
Brablík, Jindřich, 99
Bryjová, Iveta, 105
Byrtus, Radek, 111

Cerny, Martin, 394
Ciprian, Dalibor, 370, 478

Damec, Vladislav, 81
Danys, Lukas, 117
Dedek, Jan, 123
Docekal, Tomas, 129
Dohnal, Jakub, 135
Domesová, Simona, 297
Duží, Marie, 422

Fait, Michal, 243
Fiedorova, Klara, 141
Fridrich, Michael, 464

Gaiová, Karolína, 147
Gajdoš, Petr, 428
Golembiovský, Matej, 152
Goňo, Radomír, 382
Gryga, Michal, 370

Hájovský, Radovan, 225
Harach, Tomas, 62
Hlubina, Petr, 370, 478
Horák, David, 303, 320
Hřivňák, Rostislav, 428

Jahan, Ibrahim S., 13

Jalowiczor, Jakub, 349

Kabot, Ondřej, 376
Kaňok, Roman, 478
Klein, Tomas, 68
Kocman, Stanislav, 56
Kodytek, Pavel, 399
Kolar, Jakub, 355
Kolarik, Jakub, 163
Konečný, Marek, 452
Kong, Lingping, 249
Koreny, Martin, 74
Kostelanský, Michal, 470
Kotík, Vojtěch, 255
Kouřil, Daniel, 44, 50
Kozubek, Tomáš, 452
Krestanova, Alice, 179
Krupa, Filip, 169
Kružík, Jakub, 303
Kryl, Martin, 174

Ladrova, Martina, 185
Lazecky, David, 18
Lukáš, Dalibor, 326
Łysiak, Adam, 484

Majidzadeh, Gorjani Ojan, 158
Martinek, Radek, 87, 99, 117, 152, 163,
185, 215, 388
Misak, Stanislav, 6, 13
Mrovec, Martin, 309

Němčík, Jakub, 191
Novák, Tomáš, 1
Nowak, Stanislav, 56

Oczka, David, 197
Ožana, Štěpán, 225, 405

Paláček, Stanislav, 315
Patschka, Vojtěch, 434
Pečíková, Bronislava, 237
Pecha, Marek, 320
Penhaker, Marek, 203, 231, 411
Petružela, Michal, 24
Pieš, Martin, 225
Platoš, Jan, 255, 261, 279, 440
Podpora, Michal, 490, 495
Prokop, Petr, 261
Putna, Tomas, 360

Raj, Akshaya, 405
Révay, Lukáš, 267
Rozanska, Agnieszka, 490, 495

Seroiszka, Petr, 31
Schmidt, Martin, 203
Schneider, Miroslav, 209
Sidikova, Michaela, 215
Simkanič, Radek, 273
Slívová, Martina, 475
Snášel, Václav, 249
Soustek, Lukas, 219
Spetko, Matej, 458
Straková, Erika, 326
Strossa, Jan, 81
Sun, Yujia, 279
Surma, Emilia, 495

Svoboda, Radek, 440

Šaloun, Petr, 237

Trnka, Daniel, 446

Velička, Jan, 225
Vilimek, Dominik, 411
Vondrak, Jaroslav, 231
Voznak, Miroslav, 349
Vrtková, Adéla, 332
Vrzala, Matouš, 382
Vůjtek, Adam, 417
Vysocký, Jan, 37

Zabka, Stanislav, 364
Závada, Jakub, 338
Zidek, Jan, 123

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