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690091, г. Владивосток, ул. Суханова, 8

E-mail: editor_dvfu@mail.ru

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Раздел I
АННОТАЦИИ ЛЕКЦИЙ ДЛЯ СТУДЕНТОВ, АСПИРАНТОВ
И МОЛОДЫХ ИССЛЕДОВАТЕЛЕЙ

THE PRIMARY LANGUAGE I: FROM PRIMARY
TO CONVENTIONAL SCIENCE

Stilman Boris
University of Colorado Denver, Denver, USA

This is the first lecture in a series of lectures on the Primary Language, a Language of Visual Streams (LVS) or the so-called mental movies. Our hypothesis about the structure of the Primary Language of the human brain goes back to J. von Neumann who hypothesized its existence in 1957. According to von Neumann, the Primary Language should have empowered all the Secondary languages, i.e., human symbolic languages and sciences. I will explain how this is accomplished with introduction of the LVS. This lecture includes the details of communication between the primary and conventional languages and demonstrates examples of such communication. Visual streams, the components of the Primary Language, operate via multiple thought experiments. There are various types of streams including communication and internal streams as well as mundane and science streams. The communication streams include expression and impression streams. The expression streams pass information from the internal streams to the outer world via converting it into the strings of symbols and pictures while the impression streams pass information in the opposite direction. The science streams may generate new knowledge because they include the discovery streams controlled by the Algorithm of Discovery (AD). We assume that there exists a universal AD, the ultimate tool utilized by the human brain for discovering new algorithms and perfecting the existing ones. One of the goals of our research is to understand the AD to the level which will permit producing discoveries on demand. Several examples of discoveries rediscovered employing the simulated AD are given in other lectures titled “The Primary Language II and III...”

THE PRIMARY LANGUAGE II: DISCOVERING STRUCTURE
OF DNA AND DIFFERENTIAL CALCULUS

Stilman Boris
University of Colorado Denver, Denver, USA

This lecture continues a series of lectures on the Primary Language, a Language of Visual Streams (mental movies). The Algorithm of Discovery (AD) is the major algorithm based directly on the Primary Language. The AD makes discoveries via visual streams within the primary science and then reflects them in the secondary science, the

conventional one. The AD operates via initiating thought experiments, programing them, and executing them in due course. The streams are focused employing various themes including proximity and mosaic reasoning. In this lecture, I will demonstrate execution of the AD on two examples of discoveries. These examples include different reasoning themes and different communication between the primary and conventional science. Each example consists of a series of thought experiments that turn a piece of the primary science to the conventional one. Those examples include discovery of the Double Helix, the structure of DNA (by Watson and Crick) and discovery of the formulas of differentiation (by Newton and Leibnitz).

UNIVERSITY SPIN-OFF IN THE USA: HOW WE TURNED IDEA INTO REALITY

Stilman Boris
University of Colorado Denver, Denver, USA

In the USA, many research-oriented start-ups are the university spin-offs, i.e., they were originally created within the university's environment. I will describe chronologically the process of creation, survival, and subsequent take-off of such companies on example of STILMAN Advanced Strategies, the company created in 1999 based on my research in Linguistic Geometry, a type of Game Theory (within AI). Intelligent software tools developed at STILMAN for the US Army are currently considered vital for the US national defense. This lecture includes a comparison of roles of investors, competitive government contracts, large businesses, and foreign sources in obtaining working capital for small companies. The emphasis is on the US government system of competitive awards, especially, in defense, including SBIR (Small Business Innovation Research) as well as those from the federal agencies such as DARPA (Defense Advanced Research Agency), AFRL (Air Force Research Laboratory), etc. I will provide details of the relationship of a university and spin-off businesses. Special attention will be payed to the role of customers in developing new problem domains, theoretical ideas, and turning those ideas into working systems.

MULTIDIMENSIONAL VISUALIZATION

Inselberg Alfred
Tel Aviv University

The first part is introductory with an *overview* of the subject. *Visualization – Insight from Images*: incorporating our tremendous pattern recognition into the problem solving process. Overview of visualization methodologies. *Parallel Coordinates*: Motivation, point $\leftrightarrow$ line duality in 2-D. The goal is to map multivariate relations into distinct visual

2-dimensional patterns. The patterns for Lines, Hyperplanes and various kinds of Hypersurfaces (Developable, Ruled, Convex, Non-orientable) are presented followed by interactive demonstrations of applications to Air Traffic, Data Mining (Visual and Automatic) and Decision Support.

The second part is foundational and mathematical. The results/theorems are explored in depth discussing the special properties of Parallel Coordinates and how they are used. The representation of linear flats is constructed recursively (in increasing dimension). Then the representation of smooth hypersurfaces is obtained by considering them as envelopes of their tangent hyperplanes. The resulting patterns provide some new geometrical insights. Our intuition, obtained from our 3-dimensional habitation, together with the new representations becomes a laboratory to make conjectures from the picture, in the true spirit of Geometry, and then try to prove a new result. Geometrically based/motivated algorithms like convex hypersurface interior point construction with applications to Intelligent Process Control and elsewhere are presented. Research topics will be pointed out.

THE PRIMARY LANGUAGE III: DISCOVERING NO-SEARCH APPROACH TO OPPOSING GAMES

Stilman Boris
University of Colorado Denver, Denver, USA

This lecture continues a series of lectures on the Primary Language, a Language of Visual Streams (mental movies). The Algorithm of Discovery (AD) is the major algorithm based directly on the Primary Language. In this lecture, the AD is applied to rediscover Linguistic Geometry (LG), a type of game theory that permits solving a class of opposing games by constructing (not searching) the solution and this way avoid combinatorial explosion. This lecture consists of two parts:

The first part includes theoretical account into the LG Game Solving. It includes step-by-step manual execution of the AD to obtain the major result in LG, the so-called No-Search Approach. This Approach shows that LG generates optimal solutions for a class of opposing games without search and demonstrates construction of those solutions. At first, the AD initiates the Terminal Set Expansion, i.e., expansion of the subsets of terminal states into “bubbles,” the larger sets of states. For each of the states from those bubbles the AD determines a strategy leading to the respective terminal states. Then, it realizes that the bubbles of states permit to decompose the whole game state space into subspaces. This decomposition is implemented via constructing a visual model called a State Space Chart. This Chart is intended to serve as a strategic “geographical map” of the state space by providing guidelines for “travel” from state to state. Then the AD

utilizes this Chart for constructing classes of potential strategies for all the opposing sides and for pruning those classes that cannot be implemented for a given problem. Subsequent application of the non-pruned potential strategies leads to construction of the optimal solution – the only real strategy existing in this problem.

The second part includes brief introduction to the LG Game Construction for solving real world defense problems (with a short movie). The LG Game Construction includes construction of the Abstract Board Games (ABG) and the LG Hypergames including abstract boards, abstract pieces, and relations of reachability.

Раздел II
УСТНЫЕ ДОКЛАДЫ СТУДЕНТОВ, АСПИРАНТОВ
И МОЛОДЫХ ИССЛЕДОВАТЕЛЕЙ

MODELING OF RADIATION-CONDUCTIVE HEAT TRANSFER
IN A TWO-LAYERED MEDIUM

Astrakhantseva A.A.¹, Kovtanyuk A.E.^{1,2,3}, Grenkin G.V.^{1,2}, Chebotarev A.Yu.^{1,2}

¹ Far Eastern Federal University

² Institute of Applied Mathematics
Vladivostok, Russia

³ Technical University of Munich
Munich, Germany

astra92293@gmail.com, kovtanyuk.ae@dvfu.ru
glebgrenkin@gmail.com, cheb@iam.dvo.ru

Abstract — A nonlinear model of radiative-conductive heat transfer in a two-layered medium with Fresnel matching condition at the interfaces is considered. For the computation of solutions of this problem, two approaches are considered. First, a recursive algorithm based on some modification of the Monte Carlo method is proposed. Second, the P_1 (diffusion) approximation of the radiative-conductive heat transfer model is utilized. Numerical comparison of the approaches proposed is given.

Keywords— radiative heat transfer; conductive heat transfer; Monte Carlo method; diffusion approximation; layered medium.

INTRODUCTION

The study of the coupled heat transfer [1–3] where the radiative and conductive contributions are simultaneously taken into account is important for many engineering applications. So, Andre and Degiovanni [4,5], Banoczy and Kelley [6], and Klar and Siedow [7] have studied the thermal properties of some semi-transparent and insulating materials in the context of a coupled radiative–conductive model. The mathematical treatment of this nonlinear model is studied in [8–10]. In [8], Siewert and Thomas use the simple iteration method and a computationally stable version of the PN approximation. In work [9], Siewert has applied the Newton iteration method instead of the simple iteration procedure. This allows the author to calculate some numerical examples which are not feasible using the simple iteration method (compare [8]). Kelley has provided existence and uniqueness theorems for the considered problem in the case of isotropic scattering and non-reflecting boundaries [10].

In the above mentioned works, the reflection and refraction at the interfaces are not taken into account. When account is taken of these phenomena, the intensity of radiation is discontinuous because of jumps at the interfaces. Various mathematical problems for radiative transfer equation with reflection and refraction phenomena are considered in [11–16]. Nevertheless, the theory of radiative-conductive heat transfer accounting for reflection and refraction is poorly developed. Here, we can only mention [17], where an initial-boundary value problem describing radiative-

conductive heat transfer in a system of semitransparent bodies is studied. To describe radiation propagation, the authors use the transport equation with radiation diffuse reflection and refraction boundary-value conditions. The unique solvability of a weak solution is established.

In our paper, some iterative algorithm for solving this problem is considered. For the calculation of solutions of the radiative transfer equation, two ways are used. The first approach proposed by the authors utilizes a recursive algorithm based on some modification of the Monte Carlo method. This algorithm suits for the application of parallel calculations, and hence it can provide a good accuracy within a reasonable computing time. The second approach uses the diffusion approximation of the radiative transfer equation. It is shown that using this approximation gives a good description of the solution behavior. A numerical comparison of the approaches proposed is done in the case of isotropic scattering and reflecting boundaries.

FORMULATION OF THE PROBLEM

Let us consider the coupled radiative–conductive heat transfer problem which is formulated as in [18]. The equation of the radiation transfer in a two-layered medium $G_0 = G_1 \cup G_2$, $G_i = (\tau_{i-1}, \tau_i)$, $i = 1, 2$, where τ is the nondimensional optical coordinate. We assume that the medium G_0 is composed of a two number of materials each separated by surfaces $\tau = \tau_i$, $i = 0, 1, 2$.

For $\tau \in G_0$ we will use the following normalized intensity of radiation $I(\tau, \mu)$ and normalized temperature $\theta(\tau)$:

$$I(\tau, \mu) = (\pi/\sigma T_{max}^4) \tilde{I}(\tau, \mu)/n^2, \quad \theta(\tau) = T(\tau)/T_{max},$$

where $T(\tau)$ is the absolute temperature, $\theta(\tau) = \theta_i(\tau)$ if $\tau \in G_i$, where $\theta_i(\tau)$ is the normalized temperature of i -th layer, $\tilde{I}(\tau, \mu)$ describe the radiation intensity at the point $\tau \in G_0$ and in the direction $\mu \in [-1, 1]$, where μ is cosine of the angle between the positive direction of the axis τ and the radiation propagation direction, σ is the Stefan–Boltzmann constant, n is piecewise constant function $n(\tau) = n_i$, if $\tau \in G_i$, where n_i is the refractive index of i -th layer, T_{max} is the maximum temperature.

The equation of the radiation transfer in medium G_0 is described as follows:

$$\mu I_\tau(\tau, \mu) + I(\tau, \mu) = \frac{\omega(\tau)}{2} \int_{-1}^1 P(\tau, \mu, \mu') I(\tau, \mu') d\mu' + (1 - \omega) \theta^4(\tau), \quad (1)$$

where ω is the albedo of the single scattering, P is the phase function, where $\omega(\tau) = \omega_i$ and $P(\tau, \mu, \mu') = P_i(\mu, \mu')$, if $\tau \in G_i$.

At the interfaces $\tau = \tau_i$, $i = 0, 1, 2$ the Fresnel matching conditions hold [19]:

$$I^-(\tau, \mu) = (BI^+)(\tau, \mu). \quad (2)$$

The boundary conditions at the external boundaries have the form:

$$I^-(\tau_0, \mu) = (1 - R_0) \theta_b^4(\tau_0) + R_0 I^+(\tau_0, -\mu), \quad \mu > 0, \quad (3)$$

$$I^-(\tau_2, \mu) = (1 - R_2) \theta_b^4(\tau_2) + R_2 I^+(\tau_2, -\mu), \quad \mu < 0. \quad (4)$$

$$I^\pm(\tau, \mu) = \begin{cases} I(\tau \pm 0, \mu), & \mu < 0, \\ I(\tau \mp 0, \mu), & \mu > 0, \end{cases}$$

$$I(\tau \pm 0, \mu) = \lim_{\varepsilon \rightarrow 0, \varepsilon > 0} I(\tau \pm \varepsilon, \mu),$$

where θ_b is a given normalized temperature at the external boundaries, R_0, R_2 are the constant coefficients of specular reflection corresponding to the external boundaries, $\tau = \tau_0$ and $\tau = \tau_2$, accordingly.

The boundary conditions at the internal boundary have the form:

$$\begin{aligned} I_1^-(\tau_1, \mu) &= R_1(\mu)I_1^+(\tau_1, -\mu) + (1 - R_1(\mu))I_2^+(\tau_1, \psi(\mu)), \\ \mu &< 0, \\ I_2^-(\tau_1, \mu) &= R_1(\mu)I_2^+(\tau_1, -\mu) + (1 - R_1(\mu))I_1^+(\tau_1, \psi(\mu)), \\ \mu &> 0. \end{aligned}$$

The reflection coefficient $R_1(\mu)$ and cosine of refraction angle $\psi(\mu)$ are determined as follows:

$$\begin{aligned} R_1(\mu) &= \frac{1}{2} \left(\left(\frac{\tilde{n}(\mu)\psi(\mu) - \mu}{\tilde{n}(\mu)\psi(\mu) + \mu} \right)^2 + \left(\frac{\psi(\mu) - \mu\tilde{n}(\mu)}{\psi(\mu) + \mu\tilde{n}(\mu)} \right)^2 \right), \\ \psi(\mu) &= \begin{cases} \operatorname{sgn}(\mu)\sqrt{1 - \tilde{n}^2(\mu)(1 - \mu^2)}, & 1 - \tilde{n}^2(\mu)(1 - \mu^2) \geq 0 \\ 0, & 1 - \tilde{n}^2(\mu)(1 - \mu^2) < 0, \end{cases} \end{aligned}$$

where

$$\tilde{n}(\mu) = \begin{cases} n_2/n_1, & 0 < \mu \leq 1, \\ n_1/n_2, & -1 \leq \mu < 0. \end{cases}$$

The equation of the conductive heat transfer is written as:

$$\theta''(\tau) = \frac{1}{2N_c} \left(\int_{-1}^1 I(\tau, \mu) \mu d\mu \right)', \quad (5)$$

here $N_c(\tau) = N_{ci}$ is piecewise constant function, if $\tau \in G_i$, where $N_{ci} = k_i \kappa_i / 4\sigma T_{max}^3 n_i^2$, is the conduction-to-radiation parameter of i -th layer, k_i is the thermal conductivity of i -th layer, κ_i is the extinction coefficient of i -th layer, $i = 1, 2$.

For equation (5), we set the following boundary conditions:

$$\theta(\tau_0) = \theta_b(\tau_0), \quad \theta(\tau_2) = \theta_b(\tau_2), \quad (6)$$

and the conditions of continuity of the heat flow take place:

$$N_{c1} n_1^2 \theta'_1(\tau_1) = N_{c2} n_2^2 \theta'_2(\tau_1). \quad (7)$$

For finding the solution of system (1)–(7), we will use a simple iteration method with parameter. The main complexity in the numerical realization of this iterative method is finding the solution of the boundary-value problem (1)–(4). For its treatment, we will mainly use a recursive algorithm based on the Monte Carlo method. As alternative, we will construct a diffusion approximation of the problem (1)–(4) (P_I approximation).

SOLVABILITY OF THE RADIATIVE TRANSFER EQUATION

Let us consider the problem (1)–(7). We assume that the function $\theta(\tau)$ is nonnegative, and $\theta(\tau) \in C_b(G_0)$, where $C_b(X)$ is the Banach space of functions bounded and continuous on X with the norm $\|\varphi\|_{C_b(X)} = \sup_{x \in X} |\varphi(x)|$. Also, let $P(\tau, \mu, \mu') \in C_b(\Omega \times \Omega)$, where $\Omega = [-1, 0) \cup (0, 1]$, and

$$\int_{-1}^1 P(\tau, \mu, \mu') d\mu' = 1.$$

Denote $X = G_0 \times \Omega$. We define a class $D(X)$ where solution of the problem (1) – (4) are sought.

Introduce the following sets for the definition of boundary conditions:

$$\begin{aligned} \Gamma^- &= \Gamma_{int}^- \cup \Gamma_{ext}^-; \\ \Gamma_{int}^- &= \{\{\tau_1\} \times \{[-1, 0) \cup (0, 1]\}\}; \\ \Gamma_{ext}^- &= \{\{\tau_0\} \times \{[-1, 0)\}\} \cup \{\{\tau_2\} \times \{(0, 1]\}\}. \end{aligned}$$

Note that the operator $B: C_b(\Gamma^+) \rightarrow C_b(\Gamma^-)$ is linear, bounded, nonnegative, and $\|B\| < 1$.

Definition 1. A function $I(\tau, \mu)$ belongs to $D(X)$, if the following properties hold:

- 1) $I(\tau, \mu)$ is absolutely continuous in $\tau \in (\tau_{i-1}, \tau_i]$, where $i = 1, 2$, for all $\mu > 0$, and absolutely continuous in $\tau \in (\tau_{i-1}, \tau_i]$, where $i = 1, 2$, for all $\mu < 0$;
- 2) $I'_\tau(\tau, \mu) + I(\tau, \mu) \in C_b(X)$;
- 3) $I(\tau, \mu) \in C_b(\Gamma^-)$.

For further purposes, we introduce the following function:

$$\xi(\tau, \mu) = \begin{cases} \tau_{i-1}, & \mu \in (0, 1], \quad \tau \in [\tau_{i-1}, \tau_i], \\ \tau_i, & \mu \in [-1, 0), \quad \tau \in (\tau_{i-1}, \tau_i]. \end{cases}$$

The differential expression $LI(\tau, \mu) = \mu I'_\tau(\tau, \mu) + I(\tau, \mu)$ defines a linear operator $L: D(X) \rightarrow C_b(X)$. In the space $D(X)$, we introduce the norm:

$$\|\varphi\|_D = \max\{\|\varphi\|_{C_b(\Gamma^-)}, \|L\varphi\|_{C_b(X)}\},$$

and note that the inclusion $D(X) \subset C_b(X)$ holds.

The expressions

$$\begin{aligned} (A\varphi)(\tau, \mu) &= \frac{1}{\mu} \int_{\xi(\tau, \mu)}^{\tau} e^{\left(-\frac{\tau-\tau'}{\mu}\right)} \varphi(\tau', \mu) d\tau', \\ (S\varphi)(\tau, \mu) &= \omega \int_{-1}^1 P(\tau, \mu, \mu') \varphi(\tau, \mu') d\mu', \end{aligned}$$

$$(TI)(\tau, \mu) = (BI)(\xi(\tau, \mu), \mu) e^{\left(-\frac{\tau-\xi(\tau, \mu)}{\mu}\right)} + (ASI)(\tau, \mu), \quad (9)$$

define linear operators $A: C_b(X) \rightarrow D(X)$, $S: C_b(X) \rightarrow C_b(X)$ и $T: D(X) \rightarrow D(X)$.

According to [20], the following statements hold:

Theorem 1. A function I is a solution of the problem (1)–(4), if it is a solution of the operator equation

$$I(\tau, \mu) = I_0(\tau, \mu) + (TI)(\tau, \mu), \quad (10)$$

$$I_0(\tau, \mu) = e^{\left(-\frac{\tau - \xi(\tau, \mu)}{\mu}\right)} h(\xi(\tau, \mu)) + (1 - \omega)(A\theta^4)(\tau, \mu),$$

in the class $D(X)$.

Theorem 2. Assuming that the inequalities $\|B\| < 1$ and $\omega < 1$ hold, there exists a unique solution of the problem (1)–(4) (or of the integral equation (10)), that can be found in the form of the Neumann series

$$I(\tau, \mu) = \sum_{k=0}^{\infty} (T^k I_0)(\tau, \mu) \quad (11)$$

converging in the norm of $C_b(X)$.

Remember that $\|B\| < 1$, in our case, and therefore the conditions of Theorem 2 are satisfied.

RECURSIVE ALGORITHM BASED ON THE MONTE CARLO METHOD

For computing a solution to the problem (1)–(4) corresponding to a given function $\theta(\tau)$, we propose a recursive algorithm based on the Monte Carlo method. According to Theorem 2, there exists a unique solution of the problems (1)–(4) that can be found in the form of the Neumann series (11). The Monte Carlo method is appropriate for computing the finite sums:

$$I_N(\tau, \mu) = \sum_{k=0}^N (T^k I_0)(\tau, \mu). \quad (12)$$

To implement the computation, rewrite (12) as the following recurrence relation:

$$I_n(\tau, \mu) = (TI_{n-1})(\tau, \mu) + I_0(\tau, \mu), \quad n = 1, 2, \dots, N.$$

Let us consider a structure of the operator T (see equation (9)). It contains two summands: the first one describes reflection effects, the second one describes the contribution of scattering effects. Consider the second summand in more detail. Applying simple transformations, we rewrite it in the form

$$I(\tau, \mu) = \omega \left(1 - e^{\left(-\frac{\tau - \xi(\tau, \mu)}{\mu}\right)} \right) \times$$

$$\times \int_{\xi(\tau, \mu)}^{\tau} \int_{-1}^1 \frac{e^{\left(-\frac{\tau - \tau'}{\mu}\right)}}{\mu \left(1 - e^{\left(-\frac{\tau - \xi(\tau, \mu)}{\mu}\right)} \right)} P(\tau, \mu, \mu') I(\tau', \mu') d\mu' d\tau'. \quad (13)$$

According to the Monte Carlo method, we can approximate the integral in this expression as the mean value of a random sequence defined by the random variables τ' and μ' distributed over the intervals $(\xi(\tau, \mu), \tau)$ and $(-1, 1)$ with the densities

$$\frac{e^{\left(-\frac{\tau-\tau'}{\mu}\right)}}{\mu \left(1 - e^{\left(-\frac{\tau-\xi(\tau,\mu)}{\mu}\right)}\right)} \text{ and } P(\tau, \mu, \mu'), \quad (14)$$

respectively. Therefore, the integral (13) is being approximated with the following finite sum:

$$\bar{I}(\tau, \mu) = \frac{\omega}{M} \left(1 - e^{\left(-\frac{\tau-\xi(\tau,\mu)}{\mu}\right)}\right) \sum_{k=1}^M I(\tau_k, \mu_k).$$

Here, $\tau_k, \mu_k, k = 1, 2, \dots, M$, are independent realizations of the random variables τ' and μ' distributed over the intervals $(\xi(\tau, \mu), \tau)$ and $(-1, 1)$ with the densities (14), respectively. Hence, we can approximate the functions $I_n(\tau, \mu), n = 1, 2, \dots, N$:

$$I_n(\tau, \mu) \approx \bar{I}_n(\tau, \mu) = \frac{1}{M} \sum_{k=1}^M s_{n,k}(\tau, \mu), \quad (15)$$

$$\bar{I}_0(\tau, \mu) = I_0(\tau, \mu),$$

$$s_{n,k}(\tau, \mu) = (B\bar{I}_{n-1})(\xi(\tau, \mu), \mu) e^{\left(-\frac{\tau-\xi(\tau,\mu)}{\mu}\right)} + \\ + \omega \left(1 - e^{\left(-\frac{\tau-\xi(\tau,\mu)}{\mu}\right)}\right) \bar{I}_{n-1}(\tau_k, \mu_k) + I_0(\tau, \mu). \quad (16)$$

Thus, the finite sum (12) can be calculated using the recurrence relations (15), (16). The proposed Monte Carlo algorithm allows us to obtain more precise results, because it deals with the exact model, but this method is a statistical one and therefore it requires significant computation time to achieve a precision result. However, the Monte Carlo algorithm is well appropriate for parallelization.

IMPLEMENTATIONS OF THE ITERATIVE METHOD

At the j -th step of the iterative procedure, the normalized radiation intensity $I^{(j+1)}(\tau, \mu)$ is found using the Monte Carlo method for a given $\theta^{(j)}(\tau)$. Calculation of the normalized temperature $\theta^{(j+1)}(\tau)$ is carried out according to a given $I^{(j+1)}(\tau, \mu)$ on the basis of formulas (5), (6), (7).

We rewrite the equation of the conductive heat transfer (5) and boundary conditions (6), (7) for a two-layer medium in the following form:

$$D_i \theta_i''(\tau) = Q_i'(\tau), \quad \tau \in (\tau_{i-1}, \tau_i), i = 1, 2, \quad (17)$$

$$D_1 \theta_1'(\tau_1) = D_2 \theta_2'(\tau_1), \quad \theta_1(\tau_1) = \theta_2(\tau_1), \quad (18)$$

$$\theta_1(\tau_0) = \theta_{b1}, \quad \theta_2(\tau_2) = \theta_{b2}, \quad (19)$$

where

$$D_i = N_{ci}n_i^2, \quad Q_i(\tau) = \frac{n_i^2}{2} \int_{-1}^1 I_i(\tau, \mu) \mu d\mu.$$

Wherein:

$$Q_1(\tau_1) + C_1 = Q_2(\tau_1) + C_2, \quad (20)$$

From the equation (17) and the boundary conditions (18), (19), we obtain the following formulas for calculating the normalized temperature in a two-layer medium:

$$\theta_1(\tau) = \theta_{b1} + \frac{1}{D_1} \left(\int_{\tau_0}^{\tau} Q_1(\tau) d\tau + C_1(\tau - \tau_0) \right), \quad (21)$$

$$\theta_2(\tau) = \theta_{b2} - \frac{1}{D_2} \left(\int_{\tau}^{\tau_2} Q_2(\tau) d\tau + C_2(\tau_2 - \tau) \right). \quad (22)$$

We find the constants C_1 and C_2 :

$$C_1 = \frac{D_1}{L_1} (\theta_c - \theta_{b1}) - \frac{1}{L_1} \int_{\tau_0}^{\tau_1} Q_1(\tau) d\tau,$$

$$C_2 = \frac{D_2}{L_2} (\theta_{b2} - \theta_c) - \frac{1}{L_2} \int_{\tau_1}^{\tau_2} Q_2(\tau) d\tau.$$

where $\theta_1(\tau_1) = \theta_2(\tau_1) = \theta_c$, $L_i = \tau_i - \tau_{i-1}$, $i = 1, 2$.

The expression for θ_c is found from (20):

$$\theta_c \left(\frac{D_1}{L_1} + \frac{D_2}{L_2} \right) = \frac{D_1}{L_1} \theta_{b1} + \frac{D_2}{L_2} \theta_{b2} + \frac{1}{L_1} \int_{\tau_0}^{\tau_1} Q_1(\tau) d\tau - \frac{1}{L_2} \int_{\tau_1}^{\tau_2} Q_2(\tau) d\tau + Q_2(\tau_1) - Q_1(\tau_1).$$

Assume that the approximation of the temperature is already obtained in the $(j-1)$ -th step of the iterative procedure. On the basis of (21) and (22), using the Monte Carlo method, we obtain the following approximation of the temperature in the j -th step:

$$\bar{\theta}_1^{(j)}(\tau) = (1 - \alpha) \bar{\theta}_1^{(j-1)}(\tau) +$$

$$+ \alpha \left(\frac{\tau}{MN_{c1}} \sum_{k=1}^M n_1^2 \mu_k \bar{I}_N^{(j)}(\tau_k, \mu_k) + C_1(\tau - \tau_0) + \theta_{b1} \right), \quad (23)$$

for $\tau \in [\tau_0, \tau_1]$,

$$\bar{\theta}_2^{(j)}(\tau) = (1 - \alpha) \bar{\theta}_2^{(j-1)}(\tau) +$$

$$+ \alpha \left(\frac{(\tau - \tau_1)}{MN_{c2}} \sum_{k=1}^M n_2^2 \mu_k \bar{I}_N^{(j)}(\tau_k, \mu_k) + C_2(\tau - \tau_1) + \theta_c \right), \quad (24)$$

for $\tau \in [\tau_1, \tau_2]$.

where the random variables τ_k and μ_k are uniformly distributed over the intervals $(0, \tau)$ and $(-1, 1)$, respectively. The computation of the $\bar{I}_N^{(j)}(\tau_k, \mu_k)$ is implemented on the base of formulas (15) and (16) assuming that the temperature is equal to $\bar{\theta}_1^{(j-1)}$. The constants C_1 and C_2 are also computed on the base of the Monte Carlo method. Thus, the approximations $\bar{\theta}_1^{(j)}(\tau)$ and $\bar{\theta}_2^{(j)}(\tau)$ of the functions $\theta_1^{(j)}(\tau)$ and $\theta_2^{(j)}(\tau)$ are computed by formulas (15), (16), and (23), (24).

DIFFUSION APPROXIMATION

Suppose that scattering is isotropic, i.e. $P_i(\mu, \mu') = 1$ for all $i=1, 2$. The equations of P_1 approximation for the radiative transfer equation have the following form [18]:

$$-\frac{1}{3}\varphi_i''(\tau) + (1 - \omega_i)\varphi_i(\tau) = (1 - \omega_i)\theta_i^4(\tau),$$

$$-N_{ci}\theta_i''(\tau) + (1 - \omega_i)\theta_i^4(\tau) = (1 - \omega_i)\varphi_i(\tau).$$

Here $\varphi_i(\tau) \approx \frac{1}{2} \int_{-1}^1 I(\tau, \mu) d\mu$ is the approximation of the mean normalized intensity of radiation.

The boundary conditions are as follows:

$$-\frac{1}{3}\varphi_1'(\tau_0) = \gamma_0(\theta_b^4(\tau_0) - \varphi_1(\tau_0)),$$

$$\frac{1}{3}\varphi_2'(\tau_2) = \gamma_2(\theta_b^4(\tau_2) - \varphi_2(\tau_2)),$$

$$\theta(\tau_0) = \theta_b(\tau_0), \quad \theta(\tau_2) = \theta_b(\tau_2),$$

where $\gamma_i = \varepsilon_i/2(2 - \varepsilon_i)$, $\varepsilon_i = 1 - R_i$, and the matching conditions at $\tau = \tau_1$ have the form

$$n_i^2\varphi_i'(\tau_1) = n_{i+1}^2\varphi_{i+1}'(\tau_1) = G_i(\varphi_{i+1}(\tau_1) - \varphi_i(\tau_1)),$$

$$N_{ci}n_i^2\theta_i'(\tau_1) = N_{ci+1}n_{i+1}^2\theta_{i+1}'(\tau_1),$$

where $G_i = n_{i+1}^2 \int_0^1 \mu(1 - R_i(\mu))d\mu \left(\int_{-1}^1 \mu^2 R_i(\mu)d\mu \right)^{-1}$.

NUMERICAL EXPERIMENTS

For numerical experiment, we considered a two-layered medium corresponding to the following parameters:

Number of layer i	Index of refractio n	Albedo of single scatterin ω	Length of layer l	Temperatu re on the external boundary θ_b	Conduction-to- radiation parameter N_C
1	1.5	0.5	1	1	1
2	1	0.5	1	0.5	0.1

The calculation of the normalized temperature was carried out at 46 points of the two-layered medium. In order to find the temperature at one point, 12000 trajectories were generated and 6 members of the Neumann series were used. The iteration parameter α is 0.01, the number of iterations was taken as 400.

Fig.1. Results of numerical simulation: the iterative algorithm based on the Monte Carlo method after 400 iteration steps (dashed curve); the diffusion approximation (solid curve).

The solution of the equations of P_1 approximation was computed with the finite difference method, and the solver Joker FDM (github.com/grenkin/joker-fdm) was used.

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ALGORITHMS FOR DETECTION OF SHADED SEABED AREAS

Sushchenko A.A.^{1,2}, Vornovskikh² P. A., Kan² V.A.

¹ Institute of Applied Mathematics FEB RAS

² Far Eastern Federal University
Vladivostok, Russia

Abstract – The problem of determining the seabottom relief in a fluctuating ocean using the side scan sonar is considered. Effective algorithms have been developed for the determining of the shaded seabottom areas and taking into account deferent movement properties of the sonar.

The numerical experiment showing efficiency of algorithms is done.

Keywords—seabottom reconstruction, shaded areas, radiative heat transfer equation, volume scattering

I. INTRODUCTION

Nowadays the problem of mapping the ocean floor using the side-scan sonars is topical and quite promising (see e.g. [1-4]). The functioning of the sonar is based on periodic emission of the

pulsed sound signals and detection of the echo signals reflected from the distant segments of the seabottom. When the sonar's antenna is moving, an acoustic image is formed on both sides of the vehicle. Most popular transport for sonar is underwater unmanned which equipped with monitoring systems [5].

A number of works [6-11] have been devoted to the study of the problems of mapping the seabed, the main purpose of which is to determine the deviation of the height of the bottom surface from a certain predetermined level. It should be noted that the problem was considered only under the condition of visibility of each point of the seabed from the antenna carrier.

However, when simulating the acoustic sounding of the seabed by the side-scan sonar, zones of invisible areas of the bottom surface arise. The nature of such zones is so different. There are volume scattering in the ocean [12] or large deviation of the seabed relief. In this paper, algorithms for determining invisible seabed areas in the case of a stationary source and a receiver are described. Also, one of the algorithms is generalized for a point isotropic source moving along the r_2 axis and emitting impulse messages at regular intervals.

II. CASE OF A STATIC OBSERVER

A. The Problem Formulation

Authors study a new problem formulation for a static source and receiver. Therefore the problem for determining of shaded areas on the seabottom could be considered in $\mathbb{R}^2$ space. Echo signals are propagated in the medium

$$G' = \{\mathbf{r} = (r_1, r_2) \in \mathbb{R}^2: r_2 > -l + u(r_1)\},$$

which represents the top semi-space, bounded by the surface $\gamma' = \partial G' = \{\mathbf{y} \in \mathbb{R}^2: y_2 = -l + u(y_1)\}$, interpreted as an ocean seabed. The function $u \in C^1(-\infty, +\infty)$ describes some deviations of a bottom surface from the average level $-l$. The source and the receiver (observer) are located in the origin. Geometry of the problem is presented in Fig. 1.

Fig.1. Geometry of the problem in $\mathbb{R}^2$

Denote $\hat{\gamma}' = \{\mathbf{y}_i \in \mathbb{R}^2: y_i = (y_i, -l + u(y_i))\}$, where $i \in \overline{0, N}$, $y_i = ih$, h denotes the sampling step. Therefore, vector $\mathbf{k} = (-y_i, l - u(y_i))$ exists for any point $\mathbf{y} \in \hat{\gamma}'$ and connects the point at the seabottom with the position of the antenna carrier. Let $\mathbf{n} = (u'(y_i), -1)$ define a vector of an external normal to the surface γ' . Hence, an inner product is $(\mathbf{n} \cdot \mathbf{k}) = -y_i u'(y_i) - l + u(y_i)$. The solution of the problem authors search in the following form

$$\hat{u}(y_i) = \begin{cases} u(y_i), & \text{if } \mathbf{y}_i \text{ is visible by the observer} \\ 0, & \text{otherwise.} \end{cases}$$

It is worth to note that in section 1, $\mathbf{n}$ and $\mathbf{k}$ were taken as unit vectors, but here and further authors consider only the sign of inner product $(\mathbf{n} \cdot \mathbf{k})$ which is independent on vector length.

B. Algorithm #1

Definition 1 (Invisibility criteria). *The point $\mathbf{y}_i$ is invisible by observer if $(\mathbf{n} \cdot \mathbf{k}) > 0$.*

Each point y_i is verified by the invisibility criteria. If it does not satisfy it, we let than $\hat{u}(y_i) = u(y_i)$. Otherwise, we construct a beam in the direction $\mathbf{k}$ from the point $\mathbf{y}_q$, in which invisibility criteria is valid. All points $\mathbf{y}_i$ are invisible while the beam does not intersect γ' . The construction of the algorithm is presented below.

- (1) $y_i = 0$
- (2) FOR $i = 0, 1, \dots, N$ DO
 - (a) $\hat{u}(y_i) = u(y_i)$
 - (b) $(\mathbf{n} \cdot \mathbf{k}) = -y_i u'(y_i) - l + u(y_i)$
 - (c) IF $(\mathbf{n} \cdot \mathbf{k}) > 0$ THEN
 - (i) $y_q = y_i$
 - (ii) REPEAT
 - (A) $u(y_i) = 0$
 - (B) INC(i)
 - (C) $y_i = ih$
 - (iii) UNTIL $u(y_i) < u(y_q) + \frac{(l - u(y_q))(y_q - y_i)}{y_q}$
 - (d) $y_i = ih$

For numerical experiment, authors set $l = 5$. The function describing a seabottom has the following form

$$u(y) = e^{\left(-\frac{(y-100)^2}{10^2}\right)} - e^{\left(-\frac{(y-200)^2}{10^2}\right)}. \quad (1)$$

For the calculation of a derivative $u'(y_i) = (u(y_i + h) - u(y_i))/h$ authors use the finite differential approximation.

(a)

(b)

Fig. 2. An example of the algorithm #1. Functions: (a) $\hat{u}$; (b) $|\hat{u} - u|$;

The results of the algorithm #1 are shown in Fig. 2. The right side of the first pick and most inner points of the second cavity are invisible by the observer. Thus, a series of numerical experiments showed efficiency of the algorithm #1.

C. Algorithm #2

The main idea of the next algorithm is based on the visibility angle of the observer. Increasing of a slant range is requires decreasing of this angle. Denote the unit basis vector by $e_2 = (0,1)$, the function, which corresponds to the visibility angle, may be expressed as

$$\phi(y_i) = \cos(\alpha_i) = \frac{(k \cdot e_2)}{|k|} \quad (2)$$

For each y_i the minimum of $\phi(y_i)$ is recalculated, e.g. if $\phi(y_i) > \phi(y_{i+1})$ then local minimum changes to $\phi(y_{i+1})$. If it is not each y_{i+j} , in which $\phi(y_{i+j})$ less then previous minimum, is invisible by the observer. The construction of the algorithm is presented below.

- (1) $min = 1$
- (2) FOR $i = 0, 1, \dots, N$ DO
 - (a) $y_i = ih$
 - (b) $\phi(y_i) = (l - u(y_i)) \left(y_i^2 + (l - u(y_i))^2 \right)^{-\frac{1}{2}}$
 - (c) IF $\phi(y_i) < min$
 - (d) THEN $\hat{u}(y_i) = u(y_i)$; $min = \phi(y_i)$
 - (e) ELSE $\hat{u}(y_i) = 0$

For the numerical experiment authors use the same input data as in algorithm #1, i.e. u from Eq. (1) and $l = 5$.

(a)

(b)

(c)

(d)

Fig. 3. An example for the algorithm #2. Functions: (a) $\hat{u}$; (b) $|\hat{u} - u|$; (c), (d) ϕ

The results of the algorithm #2 are shown in Fig. 3. The algorithm #2 recognized more visible points than #1. In the Fig. 3 (d) the function ϕ , which corresponds to the visibility angle of observer, reaches a local minimum $\phi(y_i) \approx 0.4$ at the point $y_i = 100$. All next points y_i , in which $\phi(y_i) > 0.4$, is invisible by observer ($\sim (100, 120)$). There are for the interval $\sim (190, 198)$, analogically. Thus, the effective algorithm has been developed for the determining of the shaded seabed areas in the case of the static source and the receiver.

III. CASE OF A SEMI-STATIC OBSERVER

A. Problem Formulation

After two algorithms for simplified model, we return to the $\mathbb{R}^3$ problem. Further, we consider the case of a narrow directivity pattern of the receiving antenna [13]. Actually, in this case a sonar receives a signal on the plane which is orthogonal to the motion of vehicle only, i.e. for each sounding interval j the problem is transformed to $\mathbb{R}^2$ with constant $r_2 = Vt_j$.

Denote the discrete set of the seabottom by $\gamma' = \{\mathbf{y}_{i,j} \in \mathbb{R}^3: \mathbf{y}_{i,j} = (y_i, Vt_j, -l + u(y_i, Vt_j))\}$, where $i = \overline{0, N}$, $j = \overline{0, M}$. Hence, for each point $\mathbf{y}_{i,j} \in \gamma'$ we can construct a vector

$\mathbf{k} = (-y_i, 0, l - u(y_i, Vt_j))$, which connects point $\mathbf{y}_{i,j}$ on the seabottom to the observer located in $z = (0, Vt_j, 0)$.

Let $\mathbf{n} = (u'_{y_1}(y_i, Vt_j), u'_{y_2}(y_i, Vt_j), -1)$ denote the exterior normal for γ in $\mathbf{y}_{i,j}$. Therefore, the inner product has the following form

$$(\mathbf{n} \cdot \mathbf{k}) = y_i u'_{y_1}(y_i, Vt_j) - l + u(y_i, Vt_j) \quad (3)$$

Geometry of the problem is presented in Fig. 4.

Fig. 4. Geometry of the problem in $\mathbb{R}^3$

Thus, we present the solution of the problem in the following form

$$\hat{u}(y_i) = \begin{cases} u(y_i, Vt_j), & \text{if } \mathbf{y}_{i,j} \text{ is visible} \\ -2l, & \text{otherwise.} \end{cases}$$

The "otherwise" condition changed to $-2l$ for better visualization results.

B. Algorithm

The idea of the algorithm #3 is based on the algorithm #1. Actually, authors add a new cycle for j which corresponds to sounding intervals. The construction of the algorithm #3 is presented bellow.

FOR $j = 0, 1, \dots, M$ DO

- (1) $t_j = j\Delta t$
- (2) $y_i = 0$
- (3) FOR $i = 0, 1, \dots, N$ DO
 - (a) $\hat{u}(y_i, Vt_j) = u(y_i, Vt_j)$
 - (b) COMPUTE $(\mathbf{n} \cdot \mathbf{k})$ AS (14)
 - (c) IF $(\mathbf{n} \cdot \mathbf{k}) > 0$ THEN
 - (i) $y_q = y_i$
 - (ii) REPEAT
 - (A) $\hat{u}(y_i, Vt_j) = -2l$
 - (B) INC(i)
 - (C) $y_i = ih$
 - (iii) UNTIL $(l - u(y_i, Vt_j)) / y_i < (l - u(y_q, Vt_j)) / y_q$
 - (d) $y_i = ih$

In numerical experiments for the function, describing the seabottom relief authors use

$$u(y_1, y_2) = 3e^{\frac{-(y_1-100)^2+(y_2-20)^2}{10^2}} - 3e^{\frac{-(y_1-200)^2+(y_2-20)^2}{10^2}}. \quad (4)$$

The first term in Eq. (4) corresponds to peak of the seabottom relief, the second one corresponds to the cavity. Visualization of Eq. (4) is shown in Fig. 5. White color corresponds to the level +3, black is for the level -3. All values, which are not in $[-3; 3]$, have a projection to the boundary levels.

Fig. 5. The seabottom relief satisfying Eq. (15)

Fig. 6. An example for the algorithm #3. Input data: u satisfies Eq. (15) and $l=5$.

Fig. 7. An example for the algorithm #3. Input data: u satisfies Eq. (15) and $l=10$.

respectively. The monoblack zones correspond to shaded area on the seabottom, i.e. the part of γ which is invisible by the observer due to peak and cavity on the seabottom relief.

Therefore, the algorithm #1 is successfully modified to algorithm #3.

IV. CONCLUSIONS

Moreover, for invisible zones by the sonar authors designed three algorithms of determining shaded areas on the sea bottom. Each of them could be used depending on properties of the observer. The algorithms #1,2 is satisfied to the static observer. The algorithms #3 is satisfied to the semi-static sonar, i.e. assuming that during one sounding interval the observer is stopped. The numerical experiment showing efficiency of the algorithms is done. The results of the this work could be used as continuous research of the [14].

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LYAPUNOV STABILITY ANALYSIS OF A RADIATIVE HEAT TRANSFER MODEL

Grenkin G.V., Chebotarev A.Yu.
Far Eastern Federal University
Institute for Applied Mathematics FEB RAS
Vladivostok, Russia
glebgrenkin@gmail.com, cheb@iam.dvo.ru

Abstract—A nonstationary model of radiative-convective-conductive heat transfer in a three-dimensional domain within the diffusion P1 approximation of radiative transfer is considered.

Lyapunov nonasymptotic stability of a steady state is proved and sufficient conditions of asymptotic stability are derived. Numerical examples demonstrating exponential stability are presented.

Keywords—radiative heat transfer; diffusion approximation; Lyapunov stability

INTRODUCTION

Thermal radiation transfer needs to be taken into account in high temperature engineering applications, e.g., glass production [1] or simulation of gas turbine combustion chambers [2].

The present paper deals with a complex heat transfer model which is based on the diffusion P_1 approximation for the radiative transfer equation [3]. The radiative heat transfer is described by the following equation which is considered in a bounded domain Ω :

$$\mu \frac{\partial \varphi}{\partial t} - \alpha \Delta \varphi + \kappa_a (\varphi - |\theta| \theta^3) = 0, \quad (1)$$

and the conductive-convective heat transfer is described by the following one:

$$\frac{\partial \theta}{\partial t} - \alpha \Delta \theta + \mathbf{v} \cdot \nabla \theta + b \kappa_a (|\theta| \theta^3 - \varphi) = 0, \quad (2)$$

where θ denotes normalized temperature, φ – normalized intensity of radiation, $\mathbf{v}$ is a prescribed velocity field, $\mu = 1/c$, c is the speed of light in the medium, κ_a is the absorption coefficient, α , a , b are positive numbers. We also specify boundary and initial conditions:

$$a \frac{\partial \theta}{\partial \mathbf{n}} + \beta (\theta - \theta_b) \Big|_{\Gamma} = 0, \quad \alpha \frac{\partial \varphi}{\partial \mathbf{n}} + \gamma (\varphi - \theta_b^4) \Big|_{\Gamma} = 0, \quad (3)$$

$$\theta|_{t=0} = \theta_0, \quad \varphi|_{t=0} = \varphi_0. \quad (4)$$

Hereinafter $\mathbf{n}$ is the outward normal vector. The functions β , γ describe reflecting properties of the boundary $\Gamma = \partial\Omega$ and θ_b is the ambient boundary temperature. The boundary condition for θ expresses Newton's law of cooling, and the boundary condition for φ represents Marshak condition.

Analysis of Lyapunov stability of steady states is necessary to justify the application of steady state models. In this paper, sufficient conditions of asymptotic stability of a steady state of model (1)–(4) are established. Some numerical experiments demonstrating the stabilization of complex heat transfer process are presented. Nonasymptotic stability in a general case is proved.

The unique solvability of model (1)–(4) and the stability of a constant steady state are proved in [4]. The asymptotic stability of a steady state with small range of values of the stationary temperature field is proved in [5]. The existence and the uniqueness of a steady state is shown in [6].

PROBLEM FORMALIZATION

Assume that Ω is a Lipschitz bounded domain, $Q = \Omega \times (0, T)$, and the problem data satisfy the following conditions:

- (i) $\mathbf{v} \in H^1(\Omega) \cap L^\infty(\Omega)$, $\operatorname{div} \mathbf{v} = 0$;
- (ii) $\beta, \gamma \in L^\infty(\Gamma)$, $\beta \geq \beta_0 > 0$, $\gamma \geq \gamma_0 > 0$, $\beta_0, \gamma_0 = \operatorname{Const}$, $0 \leq \theta_b \in L^\infty(\Gamma)$;
- (iii) $\beta + \mathbf{v} \cdot \mathbf{n} \geq c_0 > 0$, $c_0 = \operatorname{Const}$;
- (iv) $0 \leq \theta_0$, $\varphi_0 \in L^\infty(\Omega)$.

Let $H = L^2(\Omega)$, $V = H^1(\Omega)$. Denote by $\|\cdot\|$, $\|\cdot\|_V$ the norms in H and V respectively. Also define the space $W = \{y \in L^2(0, T; V): y' \in L^2(0, T; V')\}$ where $y' = dy/dt$.

Definition 1. A pair $\{\theta, \varphi\} \in W \times W$ is called a (weak) solution of problem (1)–(4) if

$$\theta' + A_1\theta + \mathbf{v} \cdot \nabla \theta + b\kappa_a(|\theta|\theta^3 - \varphi) = f_1 \text{ a.e. on } (0, T),$$

$$\mu\varphi' + A_2\varphi + \kappa_a(\varphi - |\theta|\theta^3) = f_2 \text{ a.e. on } (0, T),$$

$$\theta|_{t=0} = \theta_0, \quad \varphi|_{t=0} = \varphi_0.$$

Here the operators $A_{1,2}: V \rightarrow V'$ and functionals $f_{1,2} \in L^2(0, T; V')$ are defined by using the following formulas which are valid for any $\theta, \varphi, v \in V$:

$$(A_1\theta, v) = a(\nabla\theta, \nabla v) + \int_{\Gamma} \beta\theta v d\Gamma,$$

$$(A_2\varphi, v) = \alpha(\nabla\varphi, \nabla v) + \int_{\Gamma} \gamma\varphi v d\Gamma,$$

$$(f_1, v) = \int_{\Gamma} \beta\theta_b v d\Gamma, \quad (f_2, v) = \int_{\Gamma} \gamma\theta_b^4 v d\Gamma \text{ a.e. on } (0, T).$$

Theorem 1. [4] Suppose that conditions (i)–(iv) are fulfilled. Then, in any finite time interval $(0, T)$, $0 < T < \infty$, problem (1)–(4) is uniquely solvable. The solution satisfies the inequalities $0 \leq \theta \leq M$, $0 \leq \varphi \leq M^4$ where $M = \max\{\|\theta_b\|_{L^\infty(\Gamma)}, \|\theta_0\|_{L^\infty(\Omega)}, \|\varphi_0\|_{L^\infty(\Omega)}^{1/4}\}$.

Let $\{\theta_s, \varphi_s\}$ be a steady state solution of system (1)–(4) that is a solution of the following system:

$$A_1\theta + \mathbf{v} \cdot \nabla \theta + b\kappa_a(|\theta|\theta^3 - \varphi) = f_1, \quad A_2\varphi + \kappa_a(\varphi - |\theta|\theta^3) = f_2. \quad (5)$$

Theorem 2. [6] Suppose that conditions (i)–(iii) are fulfilled. Then problem (5) is uniquely solvable. The solution satisfies the inequalities $0 \leq \theta \leq M$, $0 \leq \varphi \leq M^4$ where $M = \|\theta_b\|_{L^\infty(\Gamma)}$.

Let $\zeta = \theta - \theta_s$, $\xi = \varphi - \varphi_s$. Then

$$\zeta' + A_1\zeta + \mathbf{v} \cdot \nabla \zeta + b\kappa_a(g(\zeta, x) - \xi) = 0, \quad (6)$$

$$\mu\xi' + A_2\xi + \kappa_a(\xi - g(\zeta, x)) = 0, \quad (7)$$

$$\zeta|_{t=0} = \zeta_0 = \theta_0 - \theta_s, \quad \xi|_{t=0} = \xi_0 = \varphi_0 - \varphi_s. \quad (8)$$

Here $g(\zeta, x) = (\zeta + \theta_s(x))^4 - \theta_s^4(x)$.

NONASYMPTOTIC STABILITY

Suppose that the initial data satisfy the condition

(iv') $0 \leq \theta_0, \varphi_0 \in L^\infty(\Omega) \cap V$.

Define a function $r_\varepsilon(s)$ for any $\varepsilon > 0$:

$$r_\varepsilon(s) = \begin{cases} -1, & \text{if } s \leq -\varepsilon, \\ s/\varepsilon, & \text{if } -\varepsilon \leq s \leq \varepsilon, \\ 1, & \text{if } s \geq \varepsilon. \end{cases}$$

Multiply equation (6) by $r_\varepsilon(\zeta)$ and equation (7) by $r_\varepsilon(\xi)$ and integrate in t . We obtain

$$\begin{aligned} & \int_0^t \left((\zeta', r_\varepsilon(\zeta)) + a(\nabla \zeta, r'_\varepsilon(\zeta) \nabla \zeta) + \int_\Gamma \beta \zeta r'_\varepsilon(\zeta) d\Gamma + \right. \\ & \left. + (\mathbf{v} \cdot \nabla \zeta, r_\varepsilon(\zeta)) + b \kappa_a(g(\zeta, x) - \xi, r_\varepsilon(\zeta)) \right) d\tau = 0, \\ & \int_0^t \left((\xi', r_\varepsilon(\xi)) + \alpha(\nabla \xi, r'_\varepsilon(\xi) \nabla \xi) + \int_\Gamma \gamma \xi r'_\varepsilon(\xi) d\Gamma + \right. \\ & \left. + \kappa_a(\xi - g(\zeta, x), r_\varepsilon(\xi)) \right) d\tau = 0. \end{aligned}$$

Then pass to the limit as $\varepsilon \rightarrow 0$. It can be proved that $r_\varepsilon(\zeta) \rightarrow \text{sign } \zeta$, $r_\varepsilon(\xi) \rightarrow \text{sign } \xi$ in $L^2(Q)$. Due to (iv') we have $\zeta', \xi' \in L^2(Q)$ [7, theorem 3.3, p. 72]. Therefore

$$\begin{aligned} & \int_0^t (\zeta', r_\varepsilon(\zeta)) d\tau \rightarrow \int_0^t (\zeta', \text{sign } \zeta) d\tau, \\ & \int_0^t (\xi', r_\varepsilon(\xi)) d\tau \rightarrow \int_0^t (\xi', \text{sign } \xi) d\tau, \\ & \int_0^t (\mathbf{v} \cdot \nabla \zeta, r_\varepsilon(\zeta)) d\tau \rightarrow \int_0^t (\mathbf{v} \cdot \nabla \zeta, \text{sign } \zeta) d\tau, \\ & \int_0^t (g(\zeta, x) - \xi, r_\varepsilon(\zeta)) d\tau \rightarrow \int_0^t (g(\zeta, x) - \xi, \text{sign } \zeta) d\tau, \\ & \int_0^t (\xi - g(\zeta, x), r_\varepsilon(\xi)) d\tau \rightarrow \int_0^t (\xi - g(\zeta, x), \text{sign } \xi) d\tau. \end{aligned}$$

It can be also proved that

$$\begin{aligned} & \int_0^t \int_\Gamma \beta \zeta r'_\varepsilon(\zeta) d\Gamma d\tau \rightarrow \int_0^t \int_\Gamma \beta |\zeta| d\Gamma d\tau, \\ & \int_0^t \int_\Gamma \gamma \xi r'_\varepsilon(\xi) d\Gamma d\tau \rightarrow \int_0^t \int_\Gamma \gamma |\xi| d\Gamma d\tau. \end{aligned}$$

Apply the relations

$$\begin{aligned} & \int_0^t (\zeta'(\tau), \text{sign } \zeta(\tau)) d\tau = \int_\Omega |\zeta(t)| dx - \int_\Omega |\zeta_0| dx, \\ & \int_0^t (\xi'(\tau), \text{sign } \xi(\tau)) d\tau = \int_\Omega |\xi(t)| dx - \int_\Omega |\xi_0| dx, \\ & (\mathbf{v} \cdot \nabla \zeta, \text{sign } \zeta) = \int_\Gamma \mathbf{v} \cdot \mathbf{n} |\zeta| d\Gamma \end{aligned}$$

and notice that $r'_\varepsilon(s) \geq 0$, so $(\nabla \zeta, r'_\varepsilon(\zeta) \nabla \zeta) \geq 0$ and $(\nabla \xi, r'_\varepsilon(\xi) \nabla \xi) \geq 0$. After limit passage we obtain

$$\begin{aligned} & \int_\Omega |\zeta(t)| dx + \int_0^t \int_\Gamma (\beta + \mathbf{v} \cdot \mathbf{n}) |\zeta| d\Gamma d\tau + \\ & + b \kappa_a \int_0^t (g(\zeta, x) - \xi, \text{sign } \zeta) d\tau \leq \int_\Omega |\zeta_0| dx, \end{aligned}$$

$$\begin{aligned} & \mu \int_{\Omega} |\xi(t)| dx + \int_0^t \int_{\Gamma} \gamma |\xi| d\Gamma d\tau + \\ & + \kappa_a \int_0^t (\xi - g(\zeta, x), \text{sign } \xi) d\tau \leq \mu \int_{\Omega} |\xi_0| dx. \end{aligned}$$

Adding these inequalities after multiplication the second one by b and taking into account the inequality

$$(g(\zeta, x) - \xi, \text{sign } \zeta - \text{sign } \xi) \geq 0$$

yields

$$\begin{aligned} & \int_{\Omega} |\zeta(t)| dx + b\mu \int_{\Omega} |\xi(t)| dx + \int_0^t \int_{\Gamma} (\beta + \mathbf{v} \cdot \mathbf{n}) |\zeta| d\Gamma d\tau + b \int_0^t \int_{\Gamma} \gamma |\xi| d\Gamma d\tau \leq \\ & \leq \int_{\Omega} |\zeta_0| dx + b\mu \int_{\Omega} |\xi_0| dx. \end{aligned}$$

We have proved the following theorem that establishes nonasymptotic Lyapunov stability of the steady state.

Theorem 3. *Let conditions (i)–(iii), (iv') be satisfied. Then*

$$\int_{\Omega} |\zeta(t)| dx + b\mu \int_{\Omega} |\xi(t)| dx \leq \int_{\Omega} |\zeta_0| dx + b\mu \int_{\Omega} |\xi_0| dx, \quad t > 0.$$

ASYMPTOTIC STABILITY

Sufficient conditions of asymptotic stability require that the stationary temperature field should have small range of values.

Denote $f = 4\theta_s^3$, $M_1 = \text{ess inf } f$, $M_2 = \text{ess sup } f$,

$$k_1 = \inf \left\{ a \|\nabla v\|^2 + \int_{\Gamma} \left(\beta + \frac{1}{2} \mathbf{v} \cdot \mathbf{n} \right) v^2 d\Gamma : v \in V, \|v\| = 1 \right\},$$

$$k_2 = \inf \left\{ \alpha \|\nabla v\|^2 + \int_{\Gamma} \gamma v^2 d\Gamma : v \in V, \|v\| = 1 \right\}.$$

Theorem 4. [5] *Let conditions (i)–(iv) be fulfilled and the following inequality hold:*

$$M_2 - M_1 < \frac{4}{\kappa_a} \left(k_2 M_1 + \frac{k_1 k_2}{b \kappa_a} + \frac{k_1}{b} \right). \quad (9)$$

Then there exist constants $k_4, k_5, f_0 > 0$ such that if the inequality

$$f_0 \|\theta_0 - \theta_s\|^2 + \mu b \|\varphi_0 - \varphi_s\|^2 < (k_4/k_5)^{1/2}$$

is satisfied, then the asymptotic stability estimate holds:

$$\begin{aligned} & f_0 \|\theta(t) - \theta_s\|^2 + \mu b \|\varphi(t) - \varphi_s\|^2 \leq \\ & \leq \left(f_0 \|\theta_0 - \theta_s\|^2 + \mu b \|\varphi_0 - \varphi_s\|^2 \right) e^{-k_4 t}, \quad t > 0. \end{aligned}$$

NUMERICAL EXPERIMENTS

Let us consider a one-dimensional problem of radiative heat transfer for a plane-parallel layer with thickness L . Numerical experiments demonstrate asymptotic stabilization of complex heat transfer process even when sufficient condition (9) is not fulfilled.

Choose the values of parameters from [6] corresponding to air at the normal atmospheric pressure and the temperature of 400°C, so that $a = 0.92$ [cm²/s] and $b = 18.7$ [cm/s]. Let $T = 30$ [s], $\mathbf{v} = 0$, $\kappa_a = 0.01$ [cm⁻¹], $\beta = 10$ [cm/s], $c = 3 \cdot 10^{10}$ [cm/s].

Consider three cases of parameters values:

- 1) $\gamma = 0.3, \theta_{b1} = 0.4, \theta_{b2} = 0.6$;
- 2) $\gamma = 0.01, \theta_{b1} = 0.4, \theta_{b2} = 0.6$;
- 3) $\gamma = 0.1, \theta_{b1} = 0.2, \theta_{b2} = 0.6$.

We prescribe the initial conditions

$$\zeta_0(x) = \xi_0(x) = 0.1 \left(1 - \cos \frac{2\pi x}{L} \right).$$

In the case 1) the sufficient condition is fulfilled and in the other cases it is not fulfilled.

Figures 1 and 2 represent plots of squared norms $\|\zeta\|^2$ and $\|\xi\|^2$ in the logarithmic scale.

Squared norm $\|\zeta\|^2$ for three cases.

Squared norm $\|\xi\|^2$ for three cases.

Next we calculate the stabilization speeds

$$\text{speed } \zeta = - \frac{\ln \|\zeta(t_2)\|^2 - \ln \|\zeta(t_1)\|^2}{t_2 - t_1},$$

$$\text{speed } \xi = - \frac{\ln \|\xi(t_2)\|^2 - \ln \|\xi(t_1)\|^2}{t_2 - t_1}.$$

Let us consider the case 3) and vary some parameters. Figures 3 and 4 show plots of the stabilization speed depending on parameters b and κ_a . In our computations $\text{speed } \zeta \approx \text{speed } \xi$.

Stabilization speed depending on b .

Stabilization speed depending on κ_a .

It is seen that the stabilization speed grows when b or κ_a increases despite the fact that sufficient condition (9) is not satisfied for large values of b and κ_a .

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**MEDICAL INSTRUMENT-COMPUTER SYSTEM FOR CALCULATING
THE FATAL OUTCOME OF CARDIOVASCULAR DISEASES**

Grunberg K.V., Dolzhikov S.V.
Far Eastern Federal University
Vladivostok, Russia
grunberg94@gmail.com

Plekhova N.G., Nevzorova V.A., Rodionova L.V.
Pacific State Medical University
Vladivostok, Russia
pl_nat@hotmail.ru

Abstract - The use of a computer in combination with measuring technology in clinical diagnostics allows creating effective means for providing collection of information about the patient's. In this study the specialized information system for analysis of data with assess the overall and relative risk of fatal outcome cardiovascular diseases is presented. This program was developed on the basis of collection and processing of data obtained with the help of biochemical analyzers on detection of biomarkers patient's blood serum in considering age, sex and weight.

Keywords: information systems; meta-analyses; randomized trials; cardiovascular diseases; hypertension; biochemical analysis

INTRODUCTION

The basis of a specialized medical information system consists of the instrument-computer complexes. Such use of a computer in combination with measuring technology in clinical and laboratory diagnostics allows creating new effective means for providing automated information, collection on a patient's condition and processing of this data in real time. Data used for medical diagnosis have a number of features, such as the qualitative nature of information [1, 2], the presence of data gaps, a large number of variables with a relatively small number of observations. Moreover, the significant complexity of the object of observation (disease) often does not allow to build even a verbal description of the doctor's diagnosis procedure. The creation of medical device-computer complexes allows us to approach from the new positions to the understanding of instrumental diagnostic methods in the cumulative consideration of all parameters with the aim of establishing an accurate diagnosis [3].

Cardiovascular diseases (CVD) associated with atherosclerosis are the main cause of adult mortality in both economically developed and developing countries. In the development and progression of CVD, the accompanying criteria, called risk factors (RF), play a leading role. Today, more than 200 RF of the CVD are known, and their number annually increases [4, 5]. RF are divided into two subgroups: non-modifiable, impossible to influence, and modifiable, amenable to both non-medicamentous and medicamental correction. Moreover, it is necessary to determine the total cardiovascular risk, that means - the probability of developing a cardiovascular event connected with atherosclerosis over a specific period of time. This is the key to selecting preventive strategies and specific interventions for patients.

The purpose of the study: the formation of a specialized medical information system for the collection and analysis of data in order to assess the total and relative risk of fatal outcome of CVD.

SOLUTION TECHNIQUE AND PROCEDURE

Study design

Cross sectional study of cholesterol (CHOL) is continuing prospective population study, conducted on a representative sample of the population of Vladivostok, made according of the multicenter observational Russian program "Epidemiology of Cardiovascular Diseases (ESSE-RF)" in Primorsky Region, carried out to identify the prevalence and incidence of noncommunicable diseases and the attendant risk factors. Data on CS were published earlier [6]. One basic survey (2012-2014) was briefly carried out until 2014, and three observation phases were conducted at intervals of about 3 years.

Elimination of samples for the evaluation of mortality from all causes and analysis of cardiovascular events was carried out by including two separate samples in the study. Out of 1090 participants (510 women and 490 men), 840 healthy people (346 men and 498 women) were included in the first representative sample and 250 patients (64 men and 68 women) in the second, with a diagnosed arterial hypertension (AH). The age of the examined people was from 25 to 64 years.

In our research we used special methods: the method of questioning, methods of clinical research, including anthropometric, instrumental (investigation of arterial pressure, pulse, ECG recording, echocardiography). Determination of serum cholesterol and components of low and high density lipoproteins was carried out in a colometric method using an automatic biochemical analyzer Mindray BS-200.

Flow Solution Technique

In the list of variables that were considered as risk factors for the development of cardiovascular pathology, were introduced the following parameters (in brackets are their possible values): the sex of the subject (male or female); age (interval variable); presence of smoking factor (yes, no), values of systolic pressure (1 - 90-120, 2 - 120-130, 3 - 130 and above); the serum content (interval variables 4-20 in mmol / l) of cholesterol. The listed variables are the total cardiovascular risk, according to the European scale SCORE, intended for countries with very high risk, including Russia. Calculation of the coefficient makes it possible to determine the probability, evaluated as a percentage of the fatal outcome of the main cardiovascular complications (events).

The transformation of these variables was done using modular and agent approaches, which were implemented in C # (C Sharp), Ecma International, C-like syntax as a software module for Microsoft. NET Framework using IBM PC based on Pentium III, Pentium IV processors and compatible with them. The consultant program is developed on the basis of a mathematical model, one formula for each risk category (low, medium, high), with the calculation of the CVD fatal outcome coefficient to the honeycomb value after the decimal point.

NUMERICAL RESULTS AND DISCUSSION

In laboratory and clinical diagnostics, when collecting data obtained with the help of analytical systems, we often work with a large array of data. At the entrance of the automated system comes a file with records about patients, that need to be validated and divided into classes. In this case, we need to select the optimality of processing algorithms according to the speed of processing data and memory expended. Especially, it applies to the search problems

and algorithmic classification, when it is necessary to review repeatedly the available input arrays.

When solving the problem for identifying the risk of developing cardiovascular diseases and multicriteria search for calculating their fatal outcome, we applied the algorithm for distributing data from biochemical analyzers and other medical equipment to clusters, an example for healthy individuals is shown in Fig. 1. During the loading process, when validating records according to class separation using the set of heuristic criteria, it is easier to download and process data, the result of which is the calculated indicator-coefficient. Further, the records that have already been processed are divided into groups that, if necessary, are imported into the database (batch update), if an addition is not required, they are simply taken into consideration when generating the whole report.

Fig. 1. An example of constructing an algorithm for observing the population of healthy individuals under study.

The developed system improves the shortcomings of existing systems, specifically; in the testing files, data is recorded without columns; the name is given in 3 columns, there is no connection of the specific "Name" parameter with the patient data; the lack of uniqueness of search columns, support only for a group of attributes; the file is imported not all, but in parts, therefore directly at the moment of validation we do not see it all. We used the following principles and heuristics: enumeration of combinations of values, correlated with one parameter, with further permutation; discard some higher priority fields, when there is a filled combination of several less priority ones; repeated check of records with the purpose of reorganization of the final decision in case of occurrence of new duplicates. This way, the created system began to divide enough input data into classes (the number of errors is close to zero), according to the algorithm that was set before.

More than that, the difficulty is in the combination of data received and processed in specific programs of specific equipment used to analyze biomarkers. Typically, this type of program is designed to determine values not comparable with control, the range of which is very wide, for

example, the conditional cholesterol content is 2.97-8.79 mmol / l. From this moment starts the interpretation of data in order to predict the course of a disease. This way, the software of the biochemical analyzer opens an access to the "test-by-test" system, when performing manipulations sequentially parameter by parameter, or to "patient-by-patient" system - with full analysis for all parameters for a specific sample (patient) followed by using a "test" system, and in addition, an express examination of any parameter by the choice of a laboratory assistant-clinician (the so-called Stat-study). This type of program requires a high qualification of the medical specialist, performing the analysis, and capable to interpret the results correctly.

Created software for correlation a unique barcode with the obtained analysis data allows us to perform logical processing with a conclusion and recommendations to the operator's activity (Fig. 2). The program uses the system's memory (both real and virtual) to execute both user processes and the medical equipment software processes, and to cache data objects. All components of the program: database files, memory structures, background and user processes are located on the same machine using the internal network of the laboratory. To implement client / server or server-server interaction, Oracle SQL * Net software product must be used, which allows to interact with the network protocol. Using the SQL * Net intermediate program allows us to support most network protocols for local area networks (such as TCP / IP, IPX / SPX) and for mainframes (for example, SNA).

Fig. 2. Software support for correlating unique barcoding with data analysis

SQL * Net options allow one machine to work with one network protocol, communicating with another machine that works with another protocol. The components are two important parts of the architecture of the RDBMS program itself (the core, software) and the data dictionary, which consists of the system-level data structures used by the kernel and the database manager. The operating system is designed specifically to control access to data with basic storage, sampling and data security functions. The system is integrated with the provided service access

functions at the machine level to resources such as memory, the central processing unit, devices and file structures of the medical equipment used for analysis. RDBMS maintains its own list of authorized users and their privileges; manages the memory cache and paging; controls the blocking of shared resources; accepts and plans execution of user requests.

As an example, consider the SCORE (Systematic Coronary Risk Evaluation) scale, designed to increase the accuracy of risk assessment in patients in Europe [7], which allows one to assess the 10-year risk of the first fatal event connected with atherosclerosis, including myocardial infarction, stroke or aortic aneurysm. The developed program-consultant allows to calculate the coefficient of fatal outcome of CVD to the honeycomb value after the decimal point. The program interface is shown in Fig. 3. The user enters age, gender, hemodynamic parameters corresponding to the individual level of measured systolic blood pressure (BP mmHg) and total cholesterol (mmol / L), as well as the presence of smoking status. The number that appears as a result of the calculation shows the 10-year total cardiovascular risk of this patient. This program, in addition to the digital expression interface, provides recommendations for correcting risk factors. This program was tested and preliminary results were obtained after counseling patients.

Fig. 3. Program window, mode and sequence of access to tests

The script is based on formulas:

$$cs0 = e^{-e^{\alpha} \cdot (age-20)^p}$$

$$cs10 = e^{-e^{\alpha} \cdot (age-10)^p}$$

where $\alpha = -21.0$ or -28.7 and $p=4.62$ or 6.23 in dependent from gender

$$ncs0 = e^{-e^{\alpha} \cdot (age-20)^p}$$

$$ncs10 = e^{-e^{\alpha} \cdot (age-10)^p}$$

where $\alpha = -25.7$ or -30.0 and $p=5.47$ or 6.42 in dependent from gender
age

$$bchol = 0.24;$$

$$bsbp = 0.018;$$

$$bsm = \text{smoke} * 0.71;$$

$$wc = bchol * (h - 6.0) + bsbp * (ad - 120.0) + bsm;$$

```

bchol = 0.02;
bsbp = 0.022;
bsm = smoke * 0.63;
wnc = bchol * (h - 6.0) + bsbp * (ad - 120.0) + bsm;
where bchol, bsbp, bsm, wc, wnc – weighting factors affect the final calculation
cs = cs0ewc
cs1 = cs10ewc
ncs = ncs0ewnc
ncs1 = ncs10ewnc
cs1 = cs1 / cs;
ncs1 = ncs1 / ncs;
r = 1.0 - cs1;
r1 = 1.0 - ncs1;
result = (100.0 * (r + r1));

```

where result is of fatal outcome of CVD in the period of 10 years

The script itself was originally written in the programming language Java Script we copied it into the C# for the purpose of simplifying.

An example, if the patient is 55 years old, currently smokes, has a systolic blood pressure of 145 mm Hg. and a total cholesterol level of 6.8 mmol / l, its risk is high and equal to 9%. This program, in addition to the digital expression interface, provides recommendations for correcting risk factors. This scale is optimized for assessing the overall risk of fatal outcomes of CVD, made for the Russian population and applicable in the population as a whole, and not only at the time of the study, free from clinical symptoms of CVD.

The program module allows us to assess the total and relative risk in order to motivate patients to follow doctor's recommendations for lifestyle changes and drug therapy.

The program was based on the formula for calculating the absolute risk (AR) of cardiovascular diseases:

$$R_i(T,x) - 1 - S_i(T,x) = 1 - S_i(T,x_r) \cdot \exp(b \cdot (x - x_r)),$$

$R_i(T,x)$ - absolute (total) risk of cardiovascular disease for an individual with a "profile" x at time T for stratum i ;

$S_i(T,x)$ - corresponding survival function for an individual with a "profile" x for educational stratum i , estimated from given data;

x_r - "profile" of a typical (average, reference) individual;

b - the regression coefficient vector, estimated from the data and independent of the level of education a .

The value of $b \cdot x$ is called the "patient risk profile" with factors x , and the value of $b \cdot (x - x_r)$ is the "relative profile" (in relation to the "typical" individual x_r).

The risk value calculated by the proposed method for assessing the overall risk of developing cardiovascular diseases is specific for the Russian population. Low values of monotonous scale indicate low values of relative risk, values close to the values of "typical" individual, show the "typical" nature of the individual at relative risk, and high values of the scale indicate a high relative risk of the individual. Moreover, at a different level of cholesterol: high < 2.59 mmol / L, averaged < 3.37 mmol / L and low < 4.14 mmol / L, a correlation is necessary with the presence of pathologies that automatically transfer a person to a high-risk group [8]. While, for young patients (under 40 years) with a positive smoking status, the

program proposes to significantly reduce relative risks and then reduce the inevitable increase in absolute risk. In this group of patients it is advisable to make therapeutic decisions by calculating the relative risk, as well as determining the "vascular age".

On the other hand, taking into consideration the fact, that the norms of the content of certain substances in the body are the average values characteristic for the majority of healthy people, their correction in each individual case is necessary. So, patients suffering from diabetes, obesity and other diseases that usually accompany hyperlipoproteinemia, are recommended to maintain the level of cholesterol at the lowest level for the prevention of cardiovascular diseases, while for healthy people, these values may be slightly increased. In addition, when evaluating research data, not only the figures obtained for different indicators are important, but also their ratio among themselves. Then, the conditional norm of the cholesterol content is 2.97-8.79 mmol / l (for middle-aged people - up to 5.2 mmol / l or 200 mg / dl) and stays in a rather wide range. Therefore, for individuals younger than 40 years, this indicator should be considered in conjunction with other factors, namely age, sex, smoking status and the values of systolic pressure. Such an approach from the position of multifactorial analysis allows to diagnose the state of lipid metabolism in healthy individuals more accurately, considering an objective assessment of the developing cardiovascular diseases risk for an earlier treatment of lipid-regulating therapy.

CONCLUSION

During our further work, by constructing a regression model of proportional risk, in which additional parameters, such as the heart rate, the high-density lipoprotein cholesterol level, the body mass index, the adiponectin content, etc., we can make individual characteristics of the specific patients to improve the accuracy of predictions and expand the indications for the use of the risk scale.

The value of the coefficient, calculated according to the proposed method, for assessing the overall risk of developing cardiovascular diseases specific for the Russian population, allows us to estimate also the relative risk (RR), since it establishes a monotonous numerical scale, low values of which indicate low relative risk values - close to the values of a "typical" individual, show the "typical" nature of relative risk, and high scales indicate a high relative risk.

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**DEVELOPMENT AND TESTING OF A COMPLEX OF PROGRAMS
FOR THE STUDY OF BRAIN ACTIVITY IN THE PROCESS OF SPORTS TRAINING
AND THE IMPACT OF PHYSIOLOGICALLY ACTIVE COMPONENTS**

Emelianov.I.I.
*Far Eastern Federal University,
Vladivostok, Russia
e.ilya.i@mail.ru*

Abstract - The work is devoted to the task of processing signals, the source of which was the human brain. To obtain these signals was used portable EEG.

Keywords: brain activity modelling

The problem of analyzing electrograms is complicated. Numerous special studies and reviews are devoted to this question. This is primarily due to the fact that, in essence, a useful signal is a non-stationary polyharmonic process with oscillations that are often far from sinusoidal form. Like most other biophysical phenomena, the EEG is more or less irregular fluctuations that cannot be described in a rigorous mathematical form, however, can be described in statistical terms, including probabilistic categories of the mean, variation, spectrum, high moments Order, etc.

The purpose of creating the suitable program complex is to reveal changes in brain wave activity in a group of rowing students against the background of taking a complex of physiologically active compound. For the analysis of signals, spectral, spectrogram, magnitudes, and dispersions analysis are used.

For the analysis of signals and the subsequent construction of spectra and spectrograms, a fast Fourier transform is used.

The Fourier series is a representation of the periodic function $x(t)$, in the form of an infinite sum, of which the sines and cosines of the arguments are multiples of $2\pi t$.

Mathematical representation of the Fourier series:

$$x(t) = \frac{a_0}{2} + \sum_{k=1}^{\infty} (a_n \cos(\omega_k t) + b_n \sin(\omega_k t))$$

Where :

- $x(t)$ is the signal which integrable on the interval $[0, T]$
 - T is the period of the signal.
- t is time.
- ω - is the frequency.
 - The frequency can be obtained as: $\omega_k = \frac{2\pi k}{T}$.
- a_0, a_n, b_n - The coefficient of the Fourier series.

Or basing on Euler's formula:

$$e^{it} = \cos(t) + i * \sin(t)$$

Fourier series can also be represented as

$$x(t) = \sum_{k=-\infty}^{k=\infty} c_n e^{i\omega_k t},$$

For successfully approximation of the signal, we need to find a_n and b_n

To do this, the Fourier transform are used, which decomposes the original signal into elementary components, in our case the frequency of the rhythm of the brain, defined as follows:

$$\hat{F}(x) = \int_{-\infty}^{\infty} x(t) e^{-2\pi i F t} dt$$

On a discrete series of points Discrete Fourier Transformation is used and defined as follows:

$$\tilde{x}(k) = \sum_{n=0}^{N-1} x(n) e^{-\frac{2\pi i k n}{N}},$$

Where:

$\frac{k}{N} = F$ – is the frequency of the signal

$n = t$ – the number of reference points will coincide with the duration of the signal

To efficiently compute the discrete Fourier transform, a fast Fourier transform will be used. That is, calculations for the number of actions are less than $O(N^2)^{[1]}$ required for direct DFT calculation.

The experiment:

The rowers group was divided into 2 subgroups. At certain time intervals, during the year the first subgroup (control group) took an experimental preparation, the second subgroup took a neutral drug (not causing any changes in the body). Two series of measurements were made. Measurements were made in various qualitative conditions of the training process, such as: pre-training, post-training. From the collected pool of data, samples will be compiled that can show the difference in the EEG of the first and second subgroups.

As already stated for the analysis of signals, spectral, spectrogram, magnitudes, and dispersions analysis were used.

Spectra - a graph of the frequency decomposition of a signal by means of a fast Fourier transform,

where the frequencies are located along the abscissa axis, and the amplitude of the signals are located along the ordinate axis.

Spectral densities in frequency bands - a graph where the intervals of frequency summation are located along the abscissa axis and the values of the sums of the terms of the Fourier series of the corresponding frequency are located along the ordinate axis

Figure 1. Screenshot of the form of the calculation of averaged spectra and spectral densities. Here group 1 took experimental preparation, group 2 took a neutral drug

The spectrogram - a pseudo-three-dimensional graph where the time is located along the abscissa axis, the frequency of the signal is located along the ordinate axis and the amplitude are on “applicata” which made by changing a color

Figure 2. The averaged spectrogram of the group taking the experimental preparation

Figure 3. The averaged spectrogram of the group taking the neutral

From the dispersion analysis, was measure of deviation from the norm (in comparison with the group that did not take a physiologically active compound)

Figure 4. Graph of deviation from the norm of spectral density peaks

Based on the dispersion and spectral analyzes, a sedative effect from the experimental preparation directed to the δ , θ , α , β rhythms of the brain and the tonic effect of the γ -rhythm of the brain in persons who were in the process of training under the conditions of the was revealed in a way.

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PROCESSING OF SONAR IMAGE BY GPU PROCESSORS

Ermolaev E. V.¹, Kovalenko E. O.¹, Sushchenko A. A.^{1,2}

¹ Far Eastern Federal University

² Institute of Applied Mathematics FEB RAS
Vladivostok, Russia

e-mail: barsikdacadat@gmail.com, kovalenko.eo@dvfu.ru, sushchenko.aa@dvfu.ru

Abstract—Authors research the double filtration algorithm for improving quality of sonar images. For the algorithm implementation authors compare 2 parallel technology GPU-processors (CUDA) and Multi-CPU (mpi). For GPU, optimal parameters of algorithm are found for decreasing program runtime. There are value of threads, value of column per treads, power of processors, etc. Results are usable by online sonar image processing and by cloud computing service for sonar image processing.

Keywords—*image processing; signal processing; mpi; CUDA; acoustics; cloud computing;*

INTRODUCTION

Nowadays, the problem of image processing has current interest of many scientists. Actually, the application area is miscellaneous. On the one hand, there is simple example such as image-to-text processing. On the other hand, there is complicated one such as person identification. Each of them required different approaches for the solution. But also both have a common problem such as image noise. In this paper authors consider a noise processing of hydroacoustic images which is constructed by the signal from side-scan sonar.

The sonar channel is non-stable due to refraction, non-stationary and other physical effects. It appears as multipath and interference. At best this effects affect to image distortion. At worst

$$f(z) = \lim_{a \rightarrow \infty} \lim_{m \rightarrow \infty} \sum_{k=-N}^N f(x_k) e^{2\pi i a(x_k - z)} \frac{2i\sigma}{z - x_k + 2i\sigma} \prod_{\substack{j=-m \\ j \neq k}}^m \frac{(z - x_j)(x_k - x_j + 2i\sigma)}{(x_k - x_j)(z - x_j + 2i\sigma)}, \quad (1)$$

they totally destroyed all signal. In the hydroacoustics area a lot of different solutions have already been considered.

For instance, in papers [1,2,3] authors considered influence of volume scattering in the ocean on the sonar signal. For solving they use several assumptions which correspond a real physical notation. Firstly, indicatrix of scattering from the bottom is isotropic. Secondly, the sending interval of signal is much less than the receiving interval. Thirdly, the radiation pattern of receiving antenna is at angle range from 50 to 60 degrees. Input data for this algorithm is a signal from side-scan sonar. Moreover, in paper [4] authors use the logarithm method for filtering high amplitude noise in sonar images.

In paper [5] some mathematical problems of acoustic probing are considered. The most attention is focused on problems of determination of shape of radiating objects. Methods of determination of diffusers characteristics are proposed and discussed.

In paper [6,7,8] author considers theoretical aspects of signal construction. Authors proved existence and solvability direct and inverse problems for kinetic model which describes signal propagation in the ocean.

Nevertheless, in this paper authors focus on the double filtration algorithm [9]. An input data for it is a sonar image which is based on the signal from side-scan sonar. Processing of image is better than processing of signal in terms of unlimited computational resources for the algorithm realization. Thereby, engineer executes the program in laboratory using parallel processors technology.

Actually, the double filtration algorithm consists of two stages. In the first, impulse noise is filtered by the interpolation method of Aizenberg (1). In the second, low amplitude noise is filtered by least-squares method. In both stages the input data is values of vertical samples of sonar image. It worth to note the main object is sonar image which represents a two-dimensional array. Each column of it is processed by first and second stages.

here $f(x_k)$ denotes signal amplitude, a, m, σ denote several parameters of Aizenberg formula which depend on area.

In previous papers authors consider mpi implementation for the double filtration algorithm. For Multi CPU technology each column or column group of array are sent to various processors. Thus, optimal number of processors is 16, i.e. 2 cluster nodes. In this paper authors focus on GPU implementation for double filtration algorithm. Note, the use of GPUs for image reconstruction problem is considered in recent work [11].

GPU IMPLEMENTATION

An algorithm designing for GPU processors requires to research setup for several GPU parameters. There are numbers of threads, file size, and characteristics of GPU directly. In the serial algorithm all columns are processed independently but nodes of column depend on next and previous elements. Thereby, designing of algorithms authors use technology parallelization by columns. In the researchers two GPU processors have been used. There are NVIDIA GEFORCE 610M(#1) and 750M(#2).

Let $n = \{32, 64, 128, 256, 512\}$ denotes the number of threads per one block, and $s = \{211, 1054, 3160\}$ denotes the file size in kilobytes (Kb). Authors researching consist of several stages. At first, it includes comparing of two different GPU processors and different file size.

Note

$$\partial t_i^s(n) = \frac{t_i^s(n)}{t_{\max_i}^s(n)}, \#(2)$$

here t_i denotes program runtime of GPU #1 if $i = 1$ and GPU #2 if $i = 2$. Moreover, each column uses one thread only.

Fig. 1. Functions $\partial t_1^{211}(n)$ – bolt line and $\partial t_2^{211}(n)$ – dot line.

Fig. 2. Functions $\partial t_1^{1054}(n)$ – bolt line and $\partial t_2^{1054}(n)$ – dot line.

Fig. 3. Functions $\partial t_1^{3160}(n)$ – bolt line and $\partial t_2^{3160}(n)$ – dot line.

As seen from the fig, 1,2,3 the GPU #1 decreases program runtime up to 27% independently of file size. It's worth to note, despite the specifications of GPU #2, GPU #1 is more usable for double filtration algorithm.

At second stage, authors compare the relativity runtime of GPU #1 and different file size. For computing the relativity time (2) is used with $i \in s$.

Fig. 4. Functions $\partial t_1^{211}(n)$ – bolt line, $\partial t_2^{1054}(n)$ – dot line, ∂t_3^{3160} dot-dash line.

As seen from the fig.4, the relativity runtime is similar. Hence, the double filtration algorithms is applicable for different input data because it has constant increasing runtime coefficient which is independent of file size. Moreover, the optimal number of threads is 128 because algorithm shows the best result for different files.

At third stage, authors consider program runtime depending on number of columns per one thread

and with the same file size $s = 211$ kilobytes by GPU #1. Thus, several columns are processed by one thread. On the fig. 5 plots of program runtime are shown.

Fig. 5. Functions t_3^s – bolt line, t_4^s – dot line, t_5^s – dot-dash line.

Here t_3^s, t_4^s, t_5^s denote program runtime processing by 1, 2, 4 columns per tread respectively. Thereby, least runtime is shown by one column per one thread. Furthermore, runtime increase with increasing number of column per thread.

CONCLUSION

Thus, in this paper authors research algorithm of double filtration for sonar image processing. Moreover, optimal parameters for GPU algorithm implementation are found. The optimal number of columns per one thread is one column. The optimal number of threads is 128. Furthermore, testing of algorithm proves GPU implementation for double filtration is scalable for different file size. Results of this research help of decreasing processing runtime for algorithm and further implementation as cloud computing service.

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THE CLOUD SERVICE FOR PROCESSING OF SONAR IMAGES

Zabluda E.V.¹, Kovalenko E.O.¹

Sushchenko A.A.^{1,2}

¹ Far Eastern Federal University

² Institute of Applied Mathematics FEB RAS

Vladivostok, Russia

e-mail: zabluda_ev@students.dvfu.ru, kovalenko.eo@dvfu.ru, sushchenko.aa@dvfu.ru

ABSTRACT

Abstract — Nowadays, a lot of autonomous unmanned underwater vehicles (AUV) are created in the Institute of Marine Technology Problem FEB RAS. Most of all include side-scan sonar (SSS) EdgeTechSonar with 32-bit resolution. Robots solve different problems. There are bottom map construction, monitoring of underwater channels, tubes, mineral searching. Signal processing requires complex numerical resources. Unfortunately, AUV doesn't solve these problems on the board independently. Real signal requires additional processing. Hence, signal is processed in the laboratory. Currently researchers have large databases of signal. Data processing in the laboratory is inconvenient. If engineer adds additional processing algorithm he change all local software. In this paper authors use cloud approach for solving this problem. The data le from SSS EdgeTechSonar upload directly to the cloud service. Afterwards, user chooses any filter for sonar image processing. The cloud service includes a database of sonar images with its geographically position. User is allowed adding a new data. Moreover, the client uses different filters for image processing. Filters in cloud service are executed with parallel technology for fastest processing. There are 512 parallel processors with mpi-technology and several GPU-processors. Choice of technology depends on filter properties. Authors research some filters for sonar image processing and design special parallel algorithms for each of them.

Keywords — cloud computing, Multi CPU, mpi, GPU-processors, image processing, acoustic.

INTRODUCTION

Currently researchers at the Institute of Marine Technology Problem FEB RAS designed a large series of autonomous underwater vehicles (AUV) which are achieved state certifications ISO 9001 and ISO 14001. Autonomous underwater robotic vehicles are equipped with monitoring systems [1]. They solve several problems - sea bottom map construction, surveillance and search operations, monitoring of underwater structures such as pipelines, cable channels[2]. These works have been carried out during more than 40 years. Nevertheless, the problem of signal processing for sea bottom image construction is relevant still today. As known, a hydroacoustic channel is specific due to non-stationarity of refractions and other physical effects which are appeared as multipath propagation or signal interferences[3-5]. These effects distort or completely destroy an image [6-8].

The second problem is saving of side-scan sonar (SSS) data[9]. Different laboratories use the different approach for organization of SSS databases. It implies a new image processing method doesn't apply for data at another laboratory. There are data duplication cases. A local software is unable to manage large data flows and fast data processing. Hence, the conservative

approach is not applied to solving contemporary problems of sonar images construction. Achievements of current technologies allow to find the best way such as designing a cloud service for processing and saving SSS-data from AUV. On the one hand, this approach kills multiply birds with one stone. There are cross-platform; the uniform of data saving; using of high performance computing which increase velocity of signal filtration; possibilities of adding new algorithms for image processing; unlimited resources in terms of expansion possibility; etc.[10]. On the other hand, user requires a permanent internet connection with the cloud. But in the age when internet is accessible in each mobile device almost everywhere it is possible to not consider this aspect.

Nowadays, several variants of cloud software for SSS-data processing have existed already, e.g. "Blackwater Acoustic Solutions". It include different services - underwater inspections, underwater site, bottom pro ling, pre-maintenance inspections, liability and claims inspections, sonar scanning, underwater photo and video imaging. It has some disadvantages. There are a big price for using, an inability of adding new algorithms, an inability of processing a confidential data. All of these reasons compel to think about creating an independent cloud service for saving and processing SSS-data.

THE CLOUD SERVICE

Authors the formulation the system requirements for the cloud service of SSS-data processing, based on the application area analysis. The system consist of three hardware nodes. There are the Client, the Server and the Cluster (Figure 1).

Fig.1 Deployment diagram

The Client is user computer which sent different requests to system. In terms of user the whole system is web-application which is managed by a standard browser. The Server is php-application on the web-server that receives requests from the Client and sends data and special commands to the Cluster. The Client and the Cluster connect by http-protocol. The Cluster is high performance computing system which includes multiprocessors and GPU-processors subsystems. The Cluster storage consist of a database with user data, SSS-data and filters. Each filter is implemented in mpi-technology using different number of nodes and GPU-technology. The choice of the way or of the nodes number depends on each filter and it properties. Below, authors explain a strategy for choosing a filter on the example the double filtration filter. The Server and The Cluster connect by ssh-protocol. The minimum hardware and software requirements for the system are indicated in Tables 1, 2 respectively.

Table 1 *Hardware requirements*

	Cluster	Server	Client
CPU numbers	512	4	1
CPU frequency	2 GHz	2 GHz	1 GHz
GPU numbers	2	-	1
GPU FMA	155 GFlops	-	-
RAM	8 Gb	8 Gb	512 Mb
HDD	5 Tb	2 Gb	512 Mb

Table 2 Software requirements

	Cluster	Server	Client
OS	Linux	Linux	Windows/Linux/Android/ iOS/etc.
Additional		Apache 5.4, Php 5.3, Libssh2 – 1.4.2	Web-browser

The most computational node is the Cluster which executes complex procedures. The Server acts as an intermediary. It receives data-files and requests from the Client. Afterwards, the Server connects to the Cluster and sends special commands to start filtering process or upload data or adding filter or another operation. The Cluster and the Server exchange by ssh-messages. Hence, the subsystem “Cluster” executes algorithms for filtration and processing of sonar images; uploading and downloading SSS-data; sending messages about processing or about errors. It is worth noting user know nothing about subsystems in the Cluster. It work with web-application only in the Server. The subsystem “Server” executes connection with the Cluster; sending of filtering images to the Client; receiving of SSS-data from the Cluster; generating a database which include user's personal cab, filenames of SSS-data in the Cluster, GPS-coordinates of this file and other parameters of sonar survey; processing commands of the Cluster, for instance, selecting the way of executing algorithm (GPU or Multi CPU). The system architecture and connection between subsystem's modules are shown in the Figure 2.

Fig. 2 System architecture and connection between subsystem's modules

For designing the cloud service authors use different program languages for different subsystem, e.g. most filters on the Cluster code on C++ incl. mpi or CUDA packages. Algorithms for transformation SSS-data to image code on Python. The Server code on PHP. The Client code on JavaScript incl. JQuery and Ajax lib.

Thus, currently the cloud service for SSS-data processing has finished already and has used as alpha-test application. This system allows to adding new algorithms of signal processing. Authors have plans for expanding functional features of the cloud service.

DATA PROCESSING BY THE CLOUD SERVICE ON EXAMPLE OF THE DOUBLE FILTRATION FILTER

In this section authors explain the filtering process on the Cluster. The Cluster receives request from the Server for processing SSS- file which is choosed by user. Next step, the Cluster analysis a state of the system, i.e. it searches free resources - number of free nodes or GPU-processors. Afterwards, it sent message with properties to the Server which decides “where filter executes” and “how much nodes are involved in the filtering process”. The way of the strategy (GPU or Multi CPU) depends on the velocity of filter implementation on each. Consider deferent implementation on the double filtration filter example.

The algorithm of double filtration is based on interpolation theory of function with finite spectrum. As the name implies the double filtration consists of 2 stages. On the first stage an impulse noise is removed by the Aisenberg formula. On the second stage a low-amplitude noise is removed by least-squares method with window 3. The main object is sonar image which represents in a two-dimensional array. Thereby, each column of array processed by double filtration algorithm. Afterwards, this column is printed to an output file.

For Multi CPU technology each column or column group are sent to various processors. The Figure 3. is showing the program runtime (t) plotted against the process number (n). As seen runtime is decreased before 16 processors. This is described that algorithm requires additional time for data transmitting from the main processor to subsidiaries processors. Thus, the Cluster executes this filter with 16 CPU processors, i.e. 2 cluster nodes.

Fig. 3 Program runtime (t) for Multi CPU technology

For GPU technology of the CUDA Grid consist of n blocks where n depends on image width (Eq. 1). Each block includes 32 threads. Thus, each column is processed by one thread. Moreover, the GPU algorithm has two implementations. There are using oat or double data type. Program runtime with both is shown in Table 3. Program runtime depends of frequency of

GPU-processors, e.g. Table 4 is showing program runtime for NVIDIA GeForce 610M and NVIDIA GeForce 750M for oat implementation.

$$n = \frac{\text{column_number}}{32} \quad (1)$$

Table 3 The double filtration with NVIDIA GeForce 610M

File size, kb	Runtime with double type, s	Runtime with float type, s
211	11.6	7.8
1054	57.82	38.46

Table 4 The double filtration with float implementation

File size, kb	211	1055	3165
NVIDIA GeForce 610M, s	7.8	38.46	118.65
NVIDIA GeForce 750M, s	6.4	31.4	93.52

As described above the double filtration filter executes on Multi CPU and GPU-processors. In this case the strategy way depends on free resources in the request time. There are algorithms which are implemented successfully on GPU or Multi CPU only. In this case the Server enqueues request on image processing.

CONCLUSION

Thus, authors have designed the cloud service for SSS-data processing. This system includes well-known and new algorithms which designed by authors or engineers at the Institute of Marine Technology Problem FEB RAS. The service solves the following problems - reducing filter runtime; fast access to data processing; controlling for duplicating data; processing of confidential data; the possibility of service extending in terms of computational resources or adding new filters (e.g. [11-14]) or new procedures for SSS-data processing. Further, authors are going to append in the cloud service additional clusters.

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DATA RATE IN DISTRIBUTED INFORMATION SYSTEMS AND ITS EFFECT ON DIGITAL RADAR SYSTEM RESOLUTION

Ivanenko Yu, Grinyak V.M.
Far Eastern Federal University
Vladivostok, Russian Federation
yurown92@yahoo.com

Abstract - Current paper is about evaluation of measurement errors at distributed digital radar system with limited network bandwidth. Radar system considered under this paper consists of 2 main blocks: ADC convertor that digitalize raw radar signal and block of secondary data processing. Since high sampling frequency generates big digital datasets that should be

transmitted from ADC to secondary processing block(s) bandwidth has crucial impact on system accuracy. Authors emphasize their efforts on analysis the systems where secondary processing block is based on common widely available hardware. Typical personal computer as common hardware is considered as suitable for research purposes. This paper is emphasis on research of system limitation based on two-coordinate radar. Problem is states as following. ADC generates amplitude matrix by signals from radar. Rows of the amplitude matrix represent angular sampling and columns represent distance sampling. The matrix is transmitted to secondary processing block that is responsible for tasks like: recognizing objects, objects tracking and rendering. The paper refer to comparison of data transmission protocols between 2 physical hardware (PC based) connected into network. Following protocols are considered as potentially suitable for inter-process communications: DDE, Mail-slots, Named-pipes, Sockets, memory-mapped files. In this paper preference is given to named-pipes. Name-pipes have been used for all computational experiments of data transmitting speed evaluation. Computational experiments for the article have been performed for system of 2 personal computers connected to local network. In order to simulate different external conditions following types of tests have been performed on the system: both hosts running data receiving-transmission without extra load, both hosts running data receiving-transmission with extra CPU utilization, both hosts running data receiving-transmission with extra memory utilization, both hosts running data receiving-transmission with extra network utilization.

The paper presents the results of data transmission experiments on charts. For 1Gbit/s Ethernet, average transmission speed is about 50Mbyte/s with 5-10% fluctuations rate. One of the results of the experiments that data transmission speed does not directly depend on CPU, memory, network utilization. Based on the experimental values of data transmission speed as main result of the paper given charts of dependency of maximum size of amplitude matrix and measurement error for typical radar system.

Keywords— radar; digital signal processing; data transfer; distributed information system; measurement error.

INTRODUCTION

Radar systems are the most important instrument of maintenance of control for object motion of different types. [1, 2, 3] In spite of evolution of modern navigation satellite-referenced aids (for example, Automatic Information System in ship navigation [4]), radar systems continue to compile the information basis of radar systems for sea and air traffic [5, 6], because it can to ensure continuity and autonomy of functioning. For example, a coastal and onboard vessel traffic system (VTS) necessarily has one or more radar system of all-round view [4].

At the present time there is a computerization of radar system in the world. It consists of electronic computer with special ADC convertor [7]. ADC convertor that digitalize raw radar signal and block of secondary data processing. Since high sampling frequency generates big digital datasets that should be transmitted from ADC to secondary processing block(s) bandwidth has crucial impact on system accuracy.

ADC of original echo signal is characterized by its sampling range and rate. High sampling rate and large sampling range are highly desirable because it allows to achieve high accuracy of measuring the coordinates of the observed objects and to solve additional tasks (for example, it allows to isolate objects against background noise, to recognize the type of an object from its radar image, to estimate weather conditions etc.) [8]. High characteristics of the sampling range

and rate lead to significant amounts of data received. The truth of the matter is that data transmission from ADC to secondary processing block(s) of distributed information system has speed limit that are determined by the characteristics of the computers, software platform and network equipment used. Under these limitations, the choice of certain parameters of ADC conversion of the original echo signal is an actual problem.

Industrial surveillance systems are built using specialized computers and software platforms, which determines their high cost and limited accessibility of specialist developers and operators of the required skills. Therefore, if the tasks solved by surveillance system do not impose high requirements on reliability and security (for example, research tasks), it is advisable to refer to typical computers and general purpose software.

The present work is devoted to the research of the limitations of the characteristics of surveillance systems created on the basis of computerized radar systems of all-round view using computer equipment and general software platforms and associated with the finiteness of the data transmission speed in distributed information systems.

THE MAIN PROBLEM ASPECTS AND FORMULATION OF THE TASK

Suppose that there is a typical radar system of all-round view with a period of rotation of the antenna T_φ and the sampling frequency ν_φ (azimuth sampling rate). With such values, the number of rulers per antenna revolution (i.e., the number of discrete azimuth values) will be $n_\varphi = \nu_\varphi T_\varphi$.

Let the range scale of the radar system correspond to the time of reception of the ruler T_r . Suppose each line be converted by an ADC convector with a sampling rate ν_r into an array of values. Then the number of elements in this array of values (that is, the number of discrete range values) for each ruler will be $n_r = \nu_r T_r$.

One revolution of the radar system antenna forms a radar image of the observable space, which by ADC conversion is represented as a matrix of amplitudes of the reflected echo signal A with a number of lines equal to n_φ and a number of columns equal to n_r . The amplitude matrix is updated with each antenna revolution, that is, once per time unit T_φ .

The surveillance system, which is built on the basis of such a radar system, has the following architecture (Figure 1). Electric video- and synchronizing signals of the radar system are fed to the input of an analog-to-digital converter (ADC) connected to the computer. The matrix of amplitudes obtained as a result of such primary processing is transmitted via the network protocol of another computer for secondary processing, which includes tracking the trajectories of observable objects, determining their motion parameters and visualizing the navigation situation in the user interface.

Fig. 1. The architecture of a computerized radar surveillance system

In general, the performance of modern computers is sufficient for solving basic problems of primary and secondary signal processing. Having in mind of the large volume of the matrix A

and its frequent updating, data transmission from the primary processing unit to the secondary processing unit via the network protocol is the "bottleneck" of the radar surveillance system under consideration.

The architecture of modern software platforms (operating systems) allows to build distributed information systems by using multitasking and data transfer between processes. These processes, which constitute the software basis of a distributed information system, can be run in parallel to each other and exchange data on one and the other computers connected by the network. There are a number of mechanisms for exchanging data between processes. [9]

Dynamic Data Exchange (DDE). DDE provides a set of tools and messages sent between applications that use shared memory to notify the application about the data change. Applications can use the DDE protocol for both one-time data transmission and continuous exchange, in which applications send messages to each other as soon as new data becomes available. Usually this method is used to transfer small amounts of data.

Mail slots. Mail slots are special areas of memory. For access to them use the standard API functions of the operating system for working with files. Any process can act as a mail slot server, creating a slot. The process that performs the role of the mail slot client connects to an already existing slot. Both the client and the server can read and write data.

Named pipes. Named pipes are used to guarantee the transfer of data between two processes. It is a kind of "dedicated line" between the processes. One of the programs (pipe server) creates a channel and writes data there. The second program (pipe client) connects to the channel (which can be located on both the current and remote computers) and reads the data. The advantage of this mechanism is the ability to synchronize the client and the server.

Sockets. Sockets are abstract objects that provide an interface for exchanging data between processes. Each process can create a server socket and bind it to some port on the operating system. Another process creates a client socket and connects to it, after which it is possible to transfer data through a file descriptor. Another process creates a client socket and connects to it. After that it becomes possible to transfer data through the file descriptor. Each socket is characterized by its network address, which makes it possible to transfer data between processes, running on different computers.

Memory mapped files. This is a way of working with files, in which the whole file or part of it is assigned a certain portion of random access memory (RAM). Non-persisted memory-mapped files are used for high-performance data exchange between processes. They are not associated with the source file on the disk. In this case, in fact, the operating system generates a shared memory, access to which processes are received through the file descriptor. The advantage of this method is platform independent.

The most suitable for the software implementation of data exchange between primary and secondary processing units is the mechanism of named pipes, in view of the peculiarity of the functionality of the radar surveillance system. It is characterized by the ability to synchronize the work of the secondary processing unit (pipe client) with the update of the data of the primary processing unit (pipe server). At the same time, it should be noted the methodological commonality of the operation of the operating system kernel when implementing various mechanisms for data exchange between processes. This leads to the proximity of their performance and resource-intensive, including - in the context of different operating systems.

The task of this paper is to estimate the characteristic data transfer rate from the primary to the secondary processing unit when using the mechanism of named pipes. This will allow us to

estimate the possible limiting values of the frequencies of discretization of the radar image in azimuth ν_φ and range ν_r , which determine the dimension of the amplitude matrix $\mathbf{A}$.

TYPE OF TESTS FOR ESTIMATING OF THE DATA TRANSMISSION SPEED.

Estimation of the typical data transmission speed from the pipe server to the pipe client will be performed based on the results of full-scale tests. Computational experiments have been performed for system of 2 personal computers connected to local network. One of the computers runs a server program that creates a named pipe, generates and writes data to it. The second computer runs a client program that reads data from the named pipe.

The data transmission speed is determined not only by the configuration of computers and network devices, but also by operating system, and by the degree of loading of computer resources by other system and application tasks. To analyze the data transmission speed under various conditions, we implement the following types of tests.

- Test 1. Both hosts running data receiving-transmission without extra load.
- Test 2. Both hosts running data receiving-transmission with extra CPU utilization.
- Test 3. Both hosts running data receiving-transmission with extra memory utilization.
- Test 4. Both hosts running data receiving-transmission with extra network utilization.

The first test conditionally simulates the ideal version of the surveillance system as a software product. The second, third and fourth are various aspects of loading computer resources (processor, memory, network).

RESULTS OF FULL-SCALE DATA TRANSMISSION SPEED MEASUREMENTS

During the experiment, computers were used with the following characteristics: Intel Core i5 processor with 2.5 GHz frequency, 4 Gb memory, 1 Gbit/s network adapter, Win7 OS (64). Such characteristics fully comply with the definition of a "general-purpose type computer".

Fig. 2. "Client – server" data transmission speed

Fig. 2 shows the graphs characterizing the values of the data transmission speed C from the pipe server to the pipe client. Fig. 2a corresponds to the first test, 2b, 2c and 2d - to the second,

third and fourth. At the moment of time $t=0$, the server and client processes were sequentially started, at the time $t=20$ sec., after the computer resource allocation stabilized, data logging began. The graphs show that the data transmission speed is about 50 megabytes per second (which is more than 2 times less than theoretically possible, due to the characteristics of the 1Gb/s network adapter used). At the same time there are fluctuations in the speed of 5-10%. The values of data transmission speed are close in all four tests, that is, the data transmission speed does not depend explicitly on the loading of computer resources, if the load is not extremely high.

The values of the dimensionality of the reflected echo signal amplitude matrix $\mathbf{A}$ - the number of rows n_φ and the number of columns n_r - for the known size of one matrix element (determined by the sampling range), the data rate from the primary processing unit to the secondary processing unit C and the period of revolution of the radar system antenna T_φ are related by the relation (1):

$$n_r = \frac{CT_\varphi}{sn_\varphi} \quad (1)$$

The resolutions for the angle and range, due to the discretization and expressed in meters, with the amplitude matrix amplitude $n_\varphi \times n_r$ are, respectively, $\delta_\varphi = 2\pi r / n_\varphi$ and $\delta_r = R / n_r$, where r is the distance to the observed object, R is the maximum range of the radar system (determined by the selected range scale).

Fig. 3 illustrates the possible values of the measurement errors of the coordinates of the observed objects, if the data transmission speed from the primary processing unit to the secondary processing unit C is estimated at 50 MB/s, the period of rotation of the radar system antenna T_φ is 3s, and the size of one element of the amplitude matrix s is 2 bytes. Figure 3a shows the dependence of the maximum number of columns n_r on the number of rows n_φ at specified values. For example, if the frequency of the radar transmissions corresponds to 4000 lines per antenna revolution, the maximum possible number of discrete range values is approximately 20,000.

Figure 3b shows the dependence of the resolution on the range δ_r from the resolution of the angle δ_φ at $R=30$ km and $r=5$ km (solid line), $r=10$ km (dotted line), $r=15$ km (points). The graph shows that for an object located at a distance of $r=5$ km, with a resolution of 4 meters in the angle δ_φ , the range resolution δ_r is 3 meters.

In Fig. 3c shows the dependence of the error in measuring the coordinates of the object $\Delta = \sqrt{\delta_\varphi^2 + \delta_r^2}$ on the number of rows n_φ of the amplitude matrix at $R=30$ km and $r=5$ km (solid line), $r=10$ km (dotted line), $r=15$ km (points). The figure shows that for an object located at a distance of $r=15$ km with the number of rulers $n_\varphi = 5000$, the measurement error of the location is 20 meters.

Fig. 3. Dimensions of the amplitude matrix, resolution of the angle and range

CONCLUSION

The paper presents the results of data transmission experiments on charts. For 1Gbit/s Ethernet, average transmission speed is about 50Mbyte/s. In this case, the error in measuring the coordinates of the observed objects at characteristic ranges of 10-15 km is about 15-20 m. Such errors are sufficient for the solution of many observation problems (for example, the assessment of the navigational situation and ensuring the safety of the collective motion of observable objects). [10, 11].

For tasks that require a smaller coordinate error of ~ 1 m [12], for a constant transmission to the secondary processing unit of the full amplitude matrix, a large data transfer speed of ~ 5 Gbytes/s is required for the typical general-purpose network equipment. The solution of such problems requires the development of special receiving and transmitting devices and algorithms for data processing.

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MULTI-LEVEL COLLISION RISK ASSESSMENT SYSTEM IN MARINE TRAFFIC CONTROL

Ivanenko Yu., Grinyak V.M.
Far Eastern Federal University
Vladivostok, Russian Federation
yurown92@yahoo.com

Abstract - The paper is devoted to the problem of traffic safety in water areas of seaports. Problem of ship-ship collision risk assessment is watched. Methods for estimating the possibility of stranding and ship collisions based on probabilistic model representations and three-valued logic of decision-making are considered. Authors offer to separate ships by alarm level in case high intensity of traffic. Ships alarm level estimation based on ship maneuver

detector. Some results of numerical analysis confirming the constructivism of the proposed models and algorithms are presented.

Keywords— vessel traffic control, maritime safety, collision avoidance, risk assessment, decision-making system.

INTRODUCTION

In planning of overseas transportation and designing waterways, both safety and economical considerations are important. The safety reasons are most urgent in so-called cramped navigation conditions (in restricted waters: on fairways, in straits, etc.), where the main emergency situations are stranding and ship collisions [1, 2].

The main reason for these accidents is erroneous maneuvering. In this sense, the international rules dictate the necessity of external regulation of the motion of ships in areas with a high traffic intensity, namely, in zones of seaport liability and in their vicinity. At present, the main technical tool of this regulation are the special marine traffic systems (VTSs) [3, 4].

The contemporary VTSs are technically and organizationally very complex enterprises, treated as a combination of detection and measurement tools, devices for data transmission, processing, interpretation, visualization, and controlling decision making. The legal status of these systems can be different. However, in any case, this does not mean that a ship controlled by such a system can be completely controlled from shore. The system produces only general instructions (for instance, to decrease speed or change lanes), and the captain chooses how to execute them.

The central link in the ship-system interaction is the VTS operator, who is controlling the traffic in his region of liability on the basis of incoming data. He takes into account the rule of law and engineering standards regulating the relations between the VTS and objects. The working Russian and international rules regulate the application of the automated tools for collecting, processing, and visualization of the information analyzed by the operator. This is the main motivation for creating various models for prediction and analysis of emergency situations with a differentiated approach to the ways for developing the danger criteria in different concrete navigational situations.

The class of prediction models considered in the paper realizes a particular approach intended for processing a flow of measurement data arriving from one or more two-coordinate shore-based radar installations with full-peripheral fields of vision that are used as basic sources of navigational information for the VTS. Due to the presence of a random component of the echo signal and noisy conditions caused, in particular, by the finite size of the digital radar serial image of the water area, probabilistic models should be chosen for prediction of dangerous situations.

MAIN MODEL REPRESENTATIONS AND STATEMENT OF THE PROBLEM

The main problem arising when attempting to construct a model of danger predictions is the complexity of the passage from the verbal representation of the concept “dangerous situation” (which is far from unambiguous) to its formalized representations. Usually, in this case, one takes into account some known data of full-scale measurements demonstrating that, for safe navigation, it is very important to keep a safety zone around the ship [5]. This zone is often called a ship domain.

The notion of ship domain can be understood in several ways [6, 7]. For instance, by a static ship domain, one usually refers to a zone which other ships are prohibited to enter. An area to be used by the ship for an avoidance maneuver is called the dynamic ship domain. The

boundary of the effective ship domain is a psychological barrier that cannot be overcome by helmsmen during closing. In all these definitions, a dangerous situation (collision or stranding) is the intrusion of a ship or prohibited zone into a ship's domain.

Most existing models of prevention of dangerous situations are dedicated for onboard realization and are based on the a priori hypothesis of object controllability [8, 9]. The main feature of the contemporary shore-based VTSs is the realization of external observation. In this case, their role in the control is restricted to the generation of warnings. In this case, the warning algorithms implemented by the system should be based on the timely generation of alarm signals and the minimization of the number of false alarms rather than on the generation of an optimal divergence trajectory.

Introduce the right-hand orthogonal coordinate system oxy with the center o related to the rotation axis of the shore-based radar installation, the y -axis directed north, and the x -axis directed west. In this case, the model of measurements made by the two-coordinate station can be represented in the form.

$$z(k) = \begin{bmatrix} z_r(k) \\ z_\varphi(k) \end{bmatrix} = \begin{bmatrix} \sqrt{x^2(t_k) + y^2(t_k)} \\ \arctan(y(t_k)/x(t_k)) \end{bmatrix} + \begin{bmatrix} \varepsilon_r(k) \\ \varepsilon_\varphi(k) \end{bmatrix} \quad (2.1)$$

where $z_r(k)$ and $z_\varphi(k)$ are the values of the distance and azimuth measured at the k th time instant ($t = t_k$), $x(t_k)$ and $y(t_k)$ are the coordinates of the object under observation, and $\varepsilon_r(k)$ and $\varepsilon_\varphi(k)$ are instrumental errors of measurements. We assume that these errors are random variables such that $M[\varepsilon_r(k)] = 0$, $M[\varepsilon_\varphi(k)] = 0$, $M[\varepsilon_r(i)\varepsilon_r(j)] = D_{\varepsilon_r}\delta_{ij}$, $M[\varepsilon_\varphi(i)\varepsilon_\varphi(j)] = D_{\varepsilon_\varphi}\delta_{ij}$, where δ_{ij} is the Kronecker delta and $M[*]$ is the symbol of expectation.

In the natural conditions, the database contains no information about the forces and momentums that act on the marine object and specify its trajectory on the observation interval. Therefore, the evolution of the object coordinates is traditionally described by the simplest polynomial models.

$$\begin{aligned} x(t) &= x(t_0) + \sum_{i=1}^{N_x} a_i^{(x)}(t - t_0)^i, \\ y(t) &= y(t_0) + \sum_{i=1}^{N_y} a_i^{(y)}(t - t_0)^i, \end{aligned} \quad (2.2)$$

where N_x and N_y are the degrees of the polynomials used for describing the x - and y -coordinate evolution and $a_i^{(x)}$ and $a_i^{(y)}$ are the polynomial coefficients identified with the object velocities and the reduced values of the highest derivatives.

Thus, one can treat the system of equations (2.1), (2.2) as a model of the observation problem. The aim of this problem is to determine a vector of estimates $(\hat{x}(t), \hat{y}(t))^T$, where the time instant t can lie either in the observation interval, or outside this interval. Since the values are probabilistic, the estimate vector $(\hat{x}(t), \hat{y}(t))^T$ is meaningful only with some information about the characteristics of the random errors of estimation (quantities $(\Delta x(t) = x(t) - \hat{x}(t))$, and $(\Delta y(t) = y(t) - \hat{y}(t))$).

Consider how the notion of a dangerous situation can be formalized in the framework of model (2.1), (2.2). We distinguish ship-ship type of dangers.

Suppose we have two objects. Define the ship domain as the square S_i ($i = 1, 2$) whose side is equal to $2R_i$ and whose center coincides with the ship's conditional center, or, similarly to the ship-shore case, as the circle S_i° of radius R_i° . If these two objects at a given instant are located in such a way that the intersection of the sets S_1 and S_2 or S_1° and S_2° is nonempty, then we treat the situation as dangerous.

We describe the position of the observed objects at a given instant by estimates of their coordinates $(\hat{x}_1(t), \hat{y}_1(t))^T$, $(\hat{x}_2(t), \hat{y}_2(t))^T$ and by the density functions of the estimate probabilities $f_1(x_1, y_1)$ and $f_2(x_2, y_2)$. The probability of a dangerous situation can be defined in the following ways.

(1) Let the ship domains of the two considered objects be given as sets S_1 and S_2 with corresponding R_1 and R_2 (Fig. 1a).

Figure 1.

For known functions $f_1(x_1, y_1)$ and $f_2(x_2, y_2)$, the probability of the fact that the ship domains are disjoint (at a given time instant) can be found by the formula

$$P_\Gamma(t) = \int_\Gamma f_1(x_1, y_1) f_2(x_2, y_2) dx_1 dy_1 dx_2 dy_2, \quad (2.3)$$

where Γ is the set of solution to the system of inequalities

$$|x_1 - x_2| > R_1 + R_2,$$

$$|y_1 - y_2| > R_1 + R_2,$$

i.e., Γ is equivalent to the set of values of $x_1(t), y_1(t), x_2(t), y_2(t)$ such that S_1 and S_2 are disjoint.

(2) Suppose that the ship domains of the two objects considered are specified as S_1° and S_2° with appropriate R_1° and R_2° . Introduce the notion of safety circle S_i^Y ($i = 1, 2$) for each object as the circle centered at $(\hat{x}_i(t), \hat{y}_i(t))$ with radius ρ_i (Fig. 1b). Here, ρ_i is defined as the solution at the specified instant to the system of equations

$$\rho_1 = \rho_2,$$

$$\sqrt{(\hat{x}_1(t) - \hat{x}_2(t))^2 + (\hat{y}_1(t) - \hat{y}_2(t))^2} - (\rho_1 + \rho_2) = R_1^\circ + R_2^\circ.$$

Then, the probability of the event $(x_i(t), y_i(t))^T \in S_i^Y$, for each i (i.e., the centers of both objects lie in their safety circles) can be found by the formula

$$P_{S^Y}(t) = \int_{S_1^Y} f_1(x_1, y_1) dx_1 dy_1 \int_{S_2^Y} f_2(x_2, y_2) dx_2 dy_2, (2.4)$$

(3) Specify the ship domains of the objects as circles S_1° and S_2° with appropriate radii R_1° and R_2° . Introduce the quantity ρ_{12} describing the distance between the object centers (Fig. 1c)

$$\rho_{12} = \sqrt{(\hat{x}_1(t) - \hat{x}_2(t))^2 + (\hat{y}_1(t) - \hat{y}_2(t))^2}$$

If $f(\rho_{12})$ is the density function of the random variable ρ_{12} , then the probability of the event $\rho_{12} > R_1^\circ + R_2^\circ$ at an instant t (i.e., the ship domains intersect each other) can be determined by the formula

$$P_{\rho > R_1^\circ + R_2^\circ}(t) = \int_{R_1^\circ + R_2^\circ}^{\infty} f(\rho_{12}) d\rho_{12}, (2.5)$$

The quantities $P_T(t)$, $P_{S^Y}(t)$, and $P_{\rho > R_1^\circ + R_2^\circ}(t)$ can be interpreted as the probabilities of a safe position of objects with respect to each other at instant t . Accordingly, the quantities $1 - P_T(t)$, $1 - P_{S^Y}(t)$, and $1 - P_{\rho > R_1^\circ + R_2^\circ}(t)$ are taken as the probabilities of a dangerous situation.

In the framework of the model representations considered, the general inverse problem (2.1), (2.2) can be stated. *This* problem includes the determination of the coordinates $x_i(t)$, $y_i(t)$ of the objects observed in a given time interval $t \in [t_1, t_m]$; the determination of the characteristics of the coordinate estimation errors (determination of function $f(x_i, y_i)$) for any instant); the determination, for each object, of quantities (2.3)-(2.5) characterizing the probability of a safe state of the objects; and, at last, the decision making about the current situation type (dangerous/safe) and the generation of the alarm signal.

I CONCEPT OF SOLUTION

The method of estimation of the state vector of problem (2.1), (2.2) used in the paper is connected with the linearization of this problem in a neighborhood of a reference solution and its representation in the form

$$\begin{aligned} \delta s(t) &= A(t) \delta s(t_0) + w(t), \\ \delta z(k) &= H(t_k) \delta s(t_k) + \varepsilon_k, \end{aligned} (3.1)$$

where $\delta z(k) = (\delta z_r(k), \delta z_\varphi(k))^T$ is the residual vector of measurements, $\varepsilon_k = (\varepsilon_r(k) + \varepsilon_\varphi(k))$ is the vector of instrumental errors of measurements (normalized, with zero mean value), $\delta s(t) = (\delta x, \delta a_1^{(x)}, \delta a_2^{(x)}, \dots, \delta y, \delta a_1^{(y)}, \delta a_2^{(y)}, \dots)^T$, is the vector of the deviations of coordinates and properties of the object motion from the reference values, $w(t)$ is the vector of unmodeled parameters of the motion, and A and H are matrix coefficients specified in accordance with the equalities

$$\delta x(t) = \delta x(t_0) + \sum_{i=1}^{N_x} \delta a_i^{(x)} (t - t_0)^i,$$

$$\delta y(t) = \delta y(t_0) + \sum_{i=1}^{N_y} \delta a_i^{(y)} (t - t_0)^i,$$

$$\delta z_r(k) = \frac{x(t_k)}{\sqrt{x^2(t_k) + y^2(t_k)}} \delta x(t_k) + \frac{y(t_k)}{\sqrt{x^2(t_k) + y^2(t_k)}} \delta y(t_k),$$

$$\delta z_{\varphi}(k) = \frac{x(t_k)}{x^2(t_k) + y^2(t_k)} \delta y(t_k) + \frac{y(t_k)}{x^2(t_k) + y^2(t_k)} \delta x(t_k).$$

In turn, problem (3.1) can be solved by reducing it to a finite-dimensional form typical for problems of the least square method

$$Z = \tilde{H} \delta s(t_*) + q, \quad (3.2)$$

where Z is the total vector of measurements on the observation interval, $\tilde{H}$ is the matrix coefficient, $\delta s(t_*)$ is the value of the required state vector at instant (t_*) , q is the vector of reduced measurement errors (normally distributed with zero mean value).

Representing the initial problem (2.1), (2.2) in the form (3.2) and applying the least square method, we can sufficiently simply determine the density function of the estimates for the object coordinates $f(x, y)$. One can show that, in this case, $f(x, y)$ (at a given instant) is close to the density function of the two-dimensional normal distribution with the mean value $(x(t_*), y(t_*))^T$ and dispersions $\sigma_x^2(t_*)$, and $\sigma_y^2(t_*)$ corresponding to the dispersion matrix of problem (3.2), namely, $D(t_*) = (\tilde{H} Q^{-1} \tilde{H}^T)^{-1}$, $Q = M[qq^T]$.

We partition the observed objects into two classes, namely, the objects moving rectilinearly and uniformly, whose motion can be described by model (2.2) of the first order (i.e., for $N_x = 1$, $N_y = 1$), and maneuvering objects whose trajectory will be described by model (2.2) of the second order (for $N_x = 2$, $N_y = 2$). In this paper, we use the following algorithm for distinguishing the maneuvering objects. Let $\hat{a}_x$, $\hat{a}_y$ and $\sigma_{a_x}^2$, $\sigma_{a_y}^2$ be the values of the object accelerations and their dispersions determined for the given informational base in the framework of the second-order model (2.2) and (3.2). Then, the probabilities that the zero values of accelerations a_x and a_y do not belong to the area of their probable values can be determined sufficiently accurately by the formulas

$$\begin{aligned} P(a_x \neq 0) &= \int_0^{2|\hat{a}_x|} f_{a_x}(\tau) d\tau, \\ P(a_y \neq 0) &= \int_0^{2|\hat{a}_y|} f_{a_y}(\tau) d\tau, \end{aligned} \quad (3.3)$$

where $f_{a_x}(\tau)$ and $f_{a_y}(\tau)$ are the density functions of normal distributions with mean values $|\hat{a}_x|$ and $|\hat{a}_y|$ and dispersions $\sigma_{a_x}^2$ and $\sigma_{a_y}^2$. The decision that the object is maneuvering is made if the value of $\max[P(a_x \neq 0), P(a_y \neq 0)]$ exceeds a certain threshold. Otherwise, the situation is treated as uncertain.

From the standpoint of the considered problem of prediction of dangerous situations, there are some principal differences between maneuvering and nonmaneuvering objects. First, in the considered case of external observation, the time of reliable prediction of the trajectory of the maneuvering object cannot be long. Second, the probability of occurrence of a dangerous situation, which is the same from the formal point of view, is characterized by a different verbal level of danger for maneuvering and nonmaneuvering (at the current instant) objects.

We define the following verbal levels of danger for an object. A red-level situation can become dangerous without any changes in the current course and velocity of the motion. A yellow-level situation can become dangerous only as a result of a ship maneuvering. Finally, a

green-level situation can only become dangerous under the very small probability of both maneuvering and rectilinear-uniform motion.

TABLE I.

$P_1^s < p^*$	$P_2^s < p^*$	$d_1 \vee d_2$	Green	Yellow	Red
+	+	1		+	
+	+	0			+
+	-	1	+		
+	-	0			+
-	+	1		+	
-	+	0		+	
-	-	1	+		
-	-	0	+		

Consider the ship-ship problem. We introduce the quantities

$$P_1^s = \min_{t \in [t_0, t_0 + T_1]} P(t), \quad (3.4)$$

for objects moving rectilinearly and uniformly, and

$$P_2^s = \min_{t \in [t_0, t_0 + T_2]} P(t), \quad (3.5)$$

for maneuvering objects. Here, t_0 is the instant of the last measurement, T_1 and T_2 are the prediction times for trajectories of the models of the corresponding order, and $P(t)$ is the probability of a safe situation (defined by (2.3), (2.4), or (2.5)).

We specify a system of rules establishing a correspondence between the danger levels and the determined values of probabilities P_1^s, P_2^s (see the table). Here, d_1 and d_2 are the values of the detector of maneuvering for the first and second object, and $d_1 \vee d_2$ is the Boolean sum of these values.

Summarizing the description of the model representations of the considered problem of prediction of dangerous situations, we briefly formulate the main stages of the algorithm for solving it.

(1) In the tracking procedure, a vector of the measurements of the distance and azimuth Z (see (3.2)) is formed for each of the observed objects.

(2) The state vectors s of the objects are estimated in the framework of the model representations (2.1), (2.2), and (3.2) for $N_x = N_y = 1$ and $N_x = N_y = 2$. The characteristics of random errors of estimation of the components of vector s are determined.

(3) The decision whether the object is maneuvering is made.

(4) The problem of prediction of a dangerous ship-ship situation is solved (the values P_1^s, P_2^s , respectively, are determined for specified values of intervals T_1 and T_2 and compared with the system of rules presented in the table for specified threshold values p^*).

(5) The corresponding alarm signal is generated.

RESULTS OF NUMERICAL SIMULATIONS

In Fig. 2, we demonstrate the properties of different model representations of the probability of a safe situation in the ship-ship problem. We show the probabilities $P_T(t)$ (dashed line), $P_{SY}(t)$ (solid line), and $P_{\rho > R_1^\circ + R_2^\circ}(t)$ (dots) for first- (Fig. 2b) and second-order (Fig. 2a) models of object motion. The probabilities are calculated by formulas (2.3)-(2.5). Here, t is the time interval of the trajectory prediction and P are the values of the corresponding probabilities. It is assumed that the observation interval is equal to 30s for the first- order model of the motion and 1 min for the second- order model.

Figure 2.

The following navigational situation is simulated: for the first object, $x_1(t = 0) = 10000 \text{ m}$, $y_1(t = 0) = 3000 \text{ m}$, $V_{1x} = 5 \text{ m/s}$, $V_{1y} = 0$; for the second object, $x_2(t = 0) = 10000 \text{ m}$, $y_2(t = 0) = 3300 \text{ m}$, $V_{2x} = 5 \text{ m/s}$, $V_{2y} = 0$ (Fig. 2c).

The motion trajectories of these two objects are shown in Fig. 3. Figure 4 illustrates the results for this case of the simulations performed by the system of prediction of the dangerous ship-ship situations. Here, $d_1 \vee d_2$ are the values of the Boolean sum of the detectors of maneuver of the observed objects (Fig. 4a) and the values of probabilities P_1^S , P_2^S for $T_1 = 300 \text{ s}$, $T_2 = 60 \text{ s}$, and $P(t) = P_{\rho > R_1^\circ + R_2^\circ}(t)$ calculated by formulas (3.4) and (3.5).

One can see from Fig. 4 that the introduction of the three-level alarm system and the procedure for maneuver detection allows one to significantly improve the accuracy of prediction dangerous situations.

Figure 3.

Figure 4.

A model interpretation of the problem of state estimation of the local navigational space for a two-coordinate informational base is formulated. It is emphasized that the errors of its solution should be taken into account. Some variants of formalization of the notion of a dangerous situation are proposed based on probabilistic representations. A system of rules for solving the problem of prediction of ship-ship dangers is proposed. This system is based on comparing the calculated values of the probability of a dangerous situation and the trajectory properties of the observed objects. The operation of such a system is modeled. The investigation results are directed to the extension of the functional possibilities of contemporary systems of motion control.

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AN ONTOLOGICAL APPROACH FOR CONSTRUCTING THE SEMANTIC HYPERGRAPH OF A DOCUMENT

Kapochkin S.V., Yakovenko E., Maksimov N.V.

National Research Nuclear University MEPhI (Moscow Engineering Physics Institute,
Moscow, Russia

several23@mail.ru, janeyakov@yandex.ru, nv-maks@yandex.ru

Abstract— The models and methods of constructing a semantic hypergraph according to a text of the document is considered. The hypergraph is formed by consistent scaling of conceptual graphs of part of the document. For construction of a hypergraph taking facts (pairs of concepts related to a functional relation) that satisfy predefined aspect. For a scientific document, a scientific novelty of the research, a significance, etc. could be an example of aspect.)

Keywords— semantic hypergraph, aspects of documents, significant concepts, types of links, topology of word-usage

INTRODUCTION

In the modern world, the task of processing constantly-growing information is attracting widespread interest in the field of information technology. Questions of document quality, doubts about the number of unique data forces us to look for ways to identify redundant blocks of information [1]. One of the popular directions of information processing is the semantic indexing of the document for later retrieval. Contrast test using for solving this issue is highlights concepts that are unique relative to the entire body of the document and reduces the weight of those already encountered. [2]. Conceptual indexing, in its turn, includes the stage of constructing an ontology that allows to outline in the search results, not individual words, but concepts [3]. The peculiarity of the documents constructed by standards is the transfer of norms from regulatory documents [4]. In this type of documents, the topology of the word usage of the concept affects its weight, and the selection of candidate terms for the main concepts takes place considering the structure specified in the norms of the regulatory document.

Since the information in the document is presented in the form of natural language constructs, the model based on a number of initial interrelated assumptions. The construction of the model is based on the syntactic analysis of the constructions, starting with the minimal element - the sentence and ending with the whole document. The construction of ontologies becomes an essential step in retrieving information that would satisfy a given unformalized aspect. The aspect of consideration (representation, description) in its turn is represented in the form of a functional system, while the projection operation is performed by crossing the original ontology of the document and the aspect ontology. [5]

The chains of words in the sentence can function as a single whole and are conform to the same grammatical rules. Grammar rules help to build a tree of dependencies between terms, in which the types of links are indicated. In this paper, we use the method of constructing the syntactic trees of dependencies, namely, the hypergraph.

The subject of the study is methods and algorithms for determining role propositional structures, as well as methods and algorithms for semantic-syntactic analysis, and then scaling

the processed structures to the text of the whole document. The results obtained later serve to "summarize" or automatically summarize the document, taking into account the constraint in the form of a given aspect. Automatic referencing can be carried out by quasi-referencing. In the context of this study, quasi-referencing is an auxiliary step, which includes:

- 1) Identify and evaluate the informative workload of the elements of the document.
- 2) Accounting for the frequency of appearance of elements and their topology, with different places of appearance in the document assigned different weight.
- 3) Compilation of markers for searching fragments of a given content structure. [6]

This study aims to examine scientific texts from the point of view of constructing a semantic network - a hypergraph in the context of applying the ontological approach and methods of syntactic and semantic analysis.

The theoretical significance of the work is the creation and experimental study of new methods of integration and interaction of syntactic and semantic types of text analysis in natural language. Practical significance lies in the algorithm, which includes methods of semantic and semantic-syntactic analysis, which are the basis for extracting information and knowledge from texts, automatic abstracting and for solving other applied problems of text processing in natural language and information retrieval.

PREREQUISITES FOR CONSTRUCTING A SEMANTIC HYPERGRAPH

There are various "syntactic" methods of researching texts that allow you to extract knowledge from texts. Extraction of knowledge from scientific (monologic) texts makes it possible to create a nomenclature of a subject domain as a projection of a terminology system into a subordinate area of knowledge defined in the scientific text or a problem relevant to the subject domain [7].

In this case, the ontology of the domain is represented in the form of a hierarchy, at the root of which is the terminology, and at the nodes - the nomenclature. It is proposed to use semantic networks of frame-signs as a model for representing knowledge of both terminology and nomenclatures [7].

The elementary fragment of the semantic network of the domain coincides with the graphic interpretation of the sign of the conceptual object "concept". The semantic network is the union of elementary fragments. The construction of a semantic network begins with the construction of an elementary starting fragment [7].

To quantify this work, we will consider the interrelationship of semantic information units in hierarchy chains. Semantic information units are units considered in the aspect of semantic content. The following semantic information units can be distinguished: concept, sentence, phrase.

In the text, the word is the limiting semantic component of the message (sentence), capable of directly correlating with the object of reflection and pointing to it; As a result, the word acquires certain semantic properties [8]. However, the word is characterized by a significative meaning and the possibility of change, which entails a change in meaning within certain limits. Therefore, the meaning of the word as an independent information object and the meaning of the word in the sentence may differ in the context of the concept (term).

The uniqueness of the method being developed lies in the fact that in the construction of the graph, aspects of the scientific text such as novelty, significance, etc. are taken into account. As a novelty, the appearance of a new object is considered: the repetition of a term in a new indivisible concept or its repetition in a new independent textual construction, for example, a

sentence in a new paragraph, is taken into account. Objects that are locally related to this term are also considered.

From novelty, this aspect of the text directly follows significance. "Significance" refers to the most discussed concepts of the document, given the number of links within the document and their nature, and the heterogeneity of the distribution of the concept under the document is also taken into account. Depending on the type of document, the method for interpreting the distribution of word usage over the text changes, which can be defined by the standard or specified by the user in an unformalized form. Thus, if the concept does not satisfy the formed set of restrictions, the branch becomes unpromising, the document is circumvented with the following candidate term.

For sentences and sentences, the semantic content is supplemented by context. A sentence in a phrase can have the property of antecedence (associativity), i.e. Correlates in meaning with the previous (other) proposal. The latter leads to the appearance in the sentence of associative links with other sentences or conceivable objects. This further fills the given information unit with an associative semantic content. [8]

ALGORITHM FOR CONSTRUCTING A HYPERGRAPH

To examine the nesting of structures and evaluate its complexity, a syntactic analysis of these structures is carried out. The result of the syntactic analysis of each sentence of the text is in the general form a network of syntactic-semantic relations - a semantic network. The presentation of the content of the text in the form of a semantic network allows one to abstract from many features of its communicative organization. Such a network is invariant to the syntactic structure of the sentence and the order of words to within the structure of the proposition chosen by the author to describe the situation [9]. In general, the result of parsing is represented in the form of templates of constructions.

The concepts that fall into the list of "dominant" key should satisfy several conditions:

1. The concept is "generative", that is, there are concepts that satisfy the first criterion and are related to the concept under consideration.
2. The information contained in the text block where the concept is found meets the criteria of uniqueness for the document [1]

The relationship between the concepts of the document is determined by morphological analysis of the structure. Let's consider existing types of connection between concepts:

- 1) object-control - is used when the concept appears in the fragment (sentence) as the main member of the sentence, that is, this concept "controls" the process, from which the subsequent chain of events is built.
- 2) object-result - is used when the concept appears in the fragment (sentence) after the action (ascertaining the fact, completion or course of the process, etc.), as its result.
- 3) addition - used when a new concept joins an already existing concept and specifies it - for example, the conditions for the appearance of the concept (object-control). With this type of connection, the concept is always attached by means of a preposition.

The type of the description and the type of relationship are defined as a value template based on morphological and syntactic analysis. Concepts are considered as vertices, and with the help of a different mapping of arcs these concepts are connected. Since the type of description and the type of connection are different, the arcs of the graph will also differ.

«Technological diagrams of the 10LAB system are presented in Figures 6.12.1.2.1.1 (10LAB-PFB0001), 6.12.1.2.1.2 (10LAA-PFB0001 and Figures 6.8.2.1.1 and 6.8.2.1.2 of Section 6.8 of Chapter 6 of the SOAP.

The system includes:

- * Basic feeding pumps 10LAC10 (20,30,40) AP001;
- * Deaerator 10LAA10AC001;
- * Feed water reserve tank 10LAA10BB001;
- * Fittings (shut-off, regulating, safety);
- * Pipelines.

On the main water supply pipelines to each steam generator, within the boundaries of the turbine building, the following are successively installed:

* Shut-off valves 10LAB 56 (57,58,59) AA001, 10LAB 56 (57,58,59) AA002, which cuts off feed water in case of uncontrolled steam withdrawal from steam generators or increase in the level in the steam generator;

* Control valves 10LAB 56 (57,58,59) AA201, which support the nominal level in the steam generators in normal operation modes ..

The 10LAA feedwater deaeration and deaeration system consists of a feedwater deaerator and a feed water reserve tank designed to compensate for changes in water volume that occurs when the water supply to the steam generator changes and when thermal expansion occurs at a load of 0 to 100%. The deaerator and the feed water storage tank jointly provide deaeration of the feed water»

Fig. 1 Investigated part of the operational documentation

Fig.2. Fragment's hypergraph of the document

The sentence graph is in its turn the minimal fragmented unit of the document, and the document hypergraph is obtained by sequential scaling of such conceptual graphs, which are part of more complex textual constructions.

The subgraph from the hypergraph is obtained as a projection on the aspect of the scientific text. The semantic model of the scientific text - the hypergraph is obtained by scaling the fragmented units (subgraphs). The interaction of subgraphs is considered in the context of aspects of the uniqueness of scientific documents. Concepts can enter with concepts localized to them in various types of communication. The type of connection is determined based on the

morphological characteristics of the concepts in the fragment in which their usage occurs. Consider the projection of the previously described "significance" aspect on the example of the operational documentation (Figure 1, Figure 2).

The result of applying the "significance" aspect for the above passage is shown in Fig. 2. The constructed initial hypergraph is a reflection of the existing links between the concept and types of communication. Due to the multiple occurrence of the concept in the passage, each of its usage is marked with an appropriate arc on the top of the concept, it is appropriately defined and to which occurrence of the word refers the relationship displayed for it. There are cases when two or more concepts are related to one: the concept of "deaerator", "reserve tank" and the associated "depletion of feedwater". The thickness of the vertex differs in the character of participation of the concept within the context of the displayed connection, conditionally defined as the dominant or subordinate notion. The subordinate concept in one connection can appear as the main one in the other ("Pipelines"). Cproject the resulting fragment of the hypergraph on the "significance" aspect. When constructing a projection, the branches that come from the candidate terms that occupy the so-called "peripheral" positions relative to the total set of the document are "cut off", the next candidate term is considered. Thus, in the constructed fragment of the hypergraph, as a result of projection, we cut out the candidate terms: "On Figures", "Feedwater Disruption", "Stop Valves", "Regulating Valve", "Deaerator", "Stock Tank". The list for subsequent selection includes candidate terms "Piping system of feedwater", "Pipelines", "System of accumulation and deaeration". With a further scaling of the graph, candidate terms that are recognized as central in the local fragment can be cut off, and so consistently to the scale of the entire document.

Concepts that are "generators" in the text or "significant" are distributed in it non-uniformly. This is explained by the fact that concepts can act as auxiliary in a completely new fragment and, accordingly, a subgraph. For example, the concept can be repeated to refer to the context of a previously considered fragment in a new context (for example, the third chapter may refer to the first chapter).

Concepts can communicate with each other not only in simple sentences (as in the example above), but also in complex ones. The peculiarity of complex sentences is that in its composition simple sentences are also connected by certain types of communication. When constructing such sentences, each sentence added specifies a certain "semantic construction" of the previous sentence: an object (ie, an object-control or an object-result), the process itself (ie, a predicate) or a process condition (i.e., addition) . Depending on the nature of the refinement, the following types of links are distinguished: determining, explanatory, causative, compiling, temporary, conditional, descriptive, objective, investigative. Among the most complex sentences, the most common are sentences with subordinate clauses and explanations, in which the main information is contained in the subordinate part, the main information function does not usually perform, but serves only to move from one thought to another [10]. It was also revealed that the causal relationship (ie with the help of the "as") is no less common than the determining and explanatory. The frequency of the use of certain types of complex sentences is determined by such a specific feature of scientific speech as logic [10].

CONCLUSION

The information on semantic roles, obtained from the semantic and semantic-semantic analyzers, is used in the algorithm for constructing the hypergraph for the situational model of the text.

Demonstrated application of the algorithm, which is the combination of formalized methods of semantic and semantic-syntactic analysis with the operation of projecting ontology according to an unformalized restriction in the form of an aspect. This combination allows you to process scientific texts without a strict binding to statistical methods, and also illustrate the complex dynamics of links between concepts within the document. Requests to a document or to the body of documents, based on the described algorithm, can help if you need to get an idea of the contents of the document or the corpus of the document. The time spent on accessing standards, according to which the document was written, is also reduced, which allows to work effectively with the document not only to its originator (in the case of operational documentation), but also to a person who does not have sufficient knowledge to take into account existing standards of documentation development. Taking into account the topology of the word usage of concepts is extremely important in the texts, where the results of scientific research are presented, it allows you to trace the lifeline of the concept, related argumentation, the way of argumentation and its completeness.

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STRESS RELAXATION IN THE CYLINDRICAL LAYER OF A MATERIAL AT THE PROCESS OF CREEP, SUBSEQUENT PLASTIC FLOW AND UNLOADING

Lemza A.O.¹

Kovtanyuk L.V.^{1,2}

¹ Far Eastern Federal University

² Institute of Automation and Control Processes, FEB RAS
Vladivostok, Russian Federation

Abstract—This paper is devoted to mathematical modelling of deforming process of an incompressible material with nonlinear elastic, plastic and viscous properties placed in the cylindrical layer located between two coaxial surfaces. The material is deformed at the rotation of a boundary surface with variable velocity. Viscous properties of the material are taken into account both on the stage of plastic flow and before it. The defining relations are constructed in cylindrical coordinates.

Keywords—elasticity; creep; plastic flow; viscosity; stress relaxation

INTRODUCTION

The construction of a mathematical model of such a process as cold forming because of slow regime of creep requires a researcher to pay attention to the creep of a material and the development of plastic flow in it. This process is the most perspective technology of material processing and producing of a finished work. Intensive forming of the deformed material causes necessity of applying a model of large deformations which considers elastic, plastic and viscous properties of the material.

THE MAIN STATEMENTS OF THE USED THEORY

The base of the mathematical model of the process considered in the present paper is the theory of large elastoplastic deformations [1, 2]. The distinguishing feature of this theory is the determination of reversible (elastic) e_{ij} and irreversible p_{ij} strains which are the components of the Almansi total strain tensor d_{ij} by differential transfer equations presented in a rectangular Cartesian system of spatial Eulerian coordinates x_i in the form:

$$\frac{De_{ij}}{Dt} = \varepsilon_{ij} - \gamma_{ij} - \frac{1}{2} \left((\varepsilon_{ik} - \gamma_{ik} + z_{ik}) e_{kj} + e_{ik} (\varepsilon_{kj} - \gamma_{kj} - z_{kj}) \right), \quad (1)$$

$$\frac{Dp_{ij}}{Dt} = \gamma_{ij} - p_{ik} \gamma_{kj} - \gamma_{ik} p_{kj},$$

where

$$\varepsilon_{ij} = \frac{v_{i,j} + v_{j,i}}{2}, \quad v_i = \frac{du_i}{dt} = \frac{\partial u_i}{\partial t} + u_{i,j} v_j, \quad u_{i,j} = \frac{\partial u_i}{\partial x_j} \quad (2)$$

In (1), (2), u_i and v_i are the components of the vectors of medium point displacement and velocity, respectively, γ_{ij} and ε_{ij} are the components of the irreversible strain rate tensor and the total strain rate tensor. An operator D/Dt of objective time derivative of tensors should be written to obtain geometrically and kinematically consistent model in the form:

$$\frac{Dn_{ij}}{Dt} = \frac{dn_{ij}}{dt} - r_{ik}n_{kj} + n_{ik}r_{kj}, \quad (3)$$

$$r_{ij} = \omega_{ij} + z_{ij}(\varepsilon_{st}, e_{st}), \quad \omega_{ij} = \frac{v_{i,j} - v_{j,i}}{2}$$

In (3), r_{ij} is the skew-symmetric rotation tensor with nonlinear part z_{ij} defined as

$$z_{ij} = A^{-1} \left[B^2 (\varepsilon_{ik}e_{kj} - e_{ik}\varepsilon_{kj}) + B (\varepsilon_{ik}e_{ks}e_{sj} - e_{ik}e_{ks}\varepsilon_{sj}) + \right. \\ \left. + e_{ik}\varepsilon_{ks}e_{st}e_{tj} - e_{ik}e_{ks}\varepsilon_{st}e_{tj}, \right. \quad (4)$$

$$A = 8 - 8L_1 + 3L_1^2 - L_2 - \frac{1}{3}L_1^3 + \frac{1}{3}L_3, \quad B = 2 - L_1,$$

$$L_1 = e_{kk}, \quad L_2 = e_{ij}e_{ji}, \quad L_3 = e_{ij}e_{jk}e_{ki}$$

Total strains are divided into reversible and irreversible parts in accordance with

$$d_{ij} = e_{ij} + p_{ij} - \frac{1}{2}e_{ik}e_{kj} - e_{ik}p_{kj} - p_{ik}e_{kj} + e_{ik}p_{ks}e_{sj} \quad (5)$$

In considered incompressible medium, stresses are completely expressed by reversible strains with the help of the relation

$$\sigma_{ij} = -p\delta_{ij} + \frac{\partial W}{\partial e_{ik}}(\delta_{kj} - e_{kj}), \quad (6)$$

which is parallel to the Murnaghan formula from the nonlinear theory of elasticity. In (6), σ_{ij} are the components of the stress tensor, p is an additional hydrostatic pressure, δ_{ij} is the Kronecker delta, and w is the elastic potential function determined as

$$W = -2\mu I_1 - \mu I_2 + bI_1^2 + (b - \mu)I_1I_2 - \chi I_1^3 + \dots, \quad (7)$$

$$I_1 = e_{kk} - \frac{1}{2}e_{ks}e_{sk}, \quad I_2 = e_{ks}e_{sk} - e_{ks}e_{st}e_{tk} + \frac{1}{4}e_{ks}e_{st}e_{tm}e_{nk},$$

where μ is the shear modulus of the material, b, χ are elastic constants of higher order.

We assume that the dissipation mechanism of deforming that defines the accumulation of irreversible strains is connected with rheological and plastic material properties. Irreversible strains which can be both creep strains and plastic ones accumulate from the very beginning of a deformation process. In areas where the stress state has not yet reached a loading surface, or plastic flow has stopped,

$$\gamma_{ij} = \varepsilon_{ij}^v = \frac{\partial V(\Sigma)}{\partial \sigma_{ij}}, \quad \Sigma = \max |\sigma_i - \sigma_j|, \quad V(\sigma_{ij}) = B\Sigma^n \quad (8)$$

In (8), which is the Norton creep power law [3], ε_{ij}^v is the creep strain rate tensor, σ_k are the principal values of the stress tensor, B, n are material creep parameters.

When the stress state reaches the loading surface, an area of plastic flow appears, the dissipation mechanism is changed, and the relation between the irreversible strain rate tensor and the stress tensor is established by the associated plastic flow rule:

$$\gamma_{ij} = \varepsilon_{ij}^p = \lambda \frac{\partial f}{\partial \sigma_{ij}} + \alpha_{ij}, \quad f(\sigma_{ij}, \varepsilon_{ij}^p) = 0, \quad \lambda > 0, \quad (9)$$

where ε_{ij}^p is the plastic strain rate tensor. To take into account material viscous properties during the stage of plastic flow, we apply the generalized Tresca yield condition as the plastic potential:

$$\max|\sigma_i - \sigma_j| = 2k + 2\eta \max|\varepsilon_k^p - \alpha_k| \quad (10)$$

In (10), ε_k^p are the principal values of the plastic strain rate tensor, k is the yield limit and η is the viscosity of medium. We consider that creep deformations accumulated to an instant of plastic flow beginning are initial values of plastic deformations which will then accumulate in the area of plastic flow. Thus, in (9) and (10), we have

$$\alpha_{ij} = \varepsilon_{ij}^{v_0}, \quad \alpha_k = \varepsilon_k^{v_0}, \quad (11)$$

where $\varepsilon_{ij}^{v_0}$ and $\varepsilon_k^{v_0}$ are the components of the creep strain rate tensor and its principal values at an instant of plastic flow beginning.

BEFORE THE STAGE OF PLASTIC FLOW

We study deforming process of an incompressible elastoviscoplastic material placed in the cylindrical layer formed by two coaxial surfaces. The material is deformed at the rotation of the internal cylindrical surface of radius r_0 with given angular velocity ω_0 . At the same time, the external cylinder of radius R is motionless. The solution of the present problem is constructed in cylindrical coordinates and in the framework of the theory of large strains, which the main relations of are described above.

We suppose that all the points of medium move in circular paths. In this case, nonzero components of the vectors and tensors of the model are

$$\begin{aligned} u_r &= r(1 - \cos \theta), \quad u_\varphi = r \sin \theta, \quad v_\varphi = r\omega = r \frac{\partial \theta}{\partial t}, \\ d_{rr} &= -\frac{1}{2} \left(r \frac{\partial \theta}{\partial r} \right)^2, \quad d_{r\varphi} = e_{r\varphi} + p_{r\varphi} = \frac{1}{2} r \frac{\partial \theta}{\partial r}, \\ \varepsilon_{r\varphi} &= \varepsilon_{r\varphi}^v + \varepsilon_{r\varphi}^p = \frac{1}{2} r \frac{\partial^2 \theta}{\partial r \partial t}, \quad \omega_{r\varphi} = -\frac{\partial \theta}{\partial t} - \frac{1}{2} r \frac{\partial^2 \theta}{\partial r \partial t}, \\ r_{r\varphi} &= -\frac{\partial \theta}{\partial t} + \frac{2\varepsilon_{r\varphi}(1 - e_{\varphi\varphi})}{e_{rr} + e_{\varphi\varphi} - 2}, \end{aligned} \quad (12)$$

where $\theta(r, t)$ is the central angle of twisting.

Due to the adhesion conditions set on rigid surfaces, the boundary conditions are

$$\begin{aligned} \bar{u}|_{r=R} = \bar{v}|_{r=R} &= 0, \quad \sigma_{rr}|_{r=R} = a_0, \\ \omega|_{r=r_0} &= \omega_0, \quad \theta|_{r=r_0} = \theta_0 = \int_0^t \omega_0 dt \end{aligned} \quad (13)$$

The internal cylindrical surface rotation velocity is considered to be sequentially increasing, constant, decreasing and zero according to the next definition:

$$\omega_0 = \begin{cases} \alpha^2 t, & 0 \leq t \leq t_1, \\ \alpha^2 t_1, & t_1 \leq t \leq t_2, \\ \alpha^2 t_1 - \beta^2 (t - t_2), & t_2 \leq t \leq t_3, \\ 0, & t \geq t_3, \end{cases} \quad (14)$$

where α, β are positive constants.

The equilibrium equations in the case of quasistatic approach can be written in the form:

$$\frac{\partial \sigma_{rr}}{\partial r} + \frac{\sigma_{rr} - \sigma_{\varphi\varphi}}{r} = 0, \quad \frac{\partial \sigma_{r\varphi}}{\partial r} + 2 \frac{\sigma_{r\varphi}}{r} = 0 \quad (15)$$

We consider further the items of an order which is more than one in diagonal components of e_{ij}, p_{ij} and more than two in nondiagonal ones to be negligible because of their minor effect on computations. This allows to significantly simplify model equations. Then the nonzero components of the stress tensor are determined from (6), (7) as

$$\begin{aligned} \sigma_{rr} &= -p - 2\mu + 2(b + \mu)e_{rr} + 2be_{\varphi\varphi} + \mu e_{r\varphi}^2, \\ \sigma_{\varphi\varphi} &= -p - 2\mu + 2(b + \mu)e_{\varphi\varphi} + 2be_{rr} + \mu e_{r\varphi}^2, \\ \sigma_{zz} &= -p - 2\mu + 2b(e_{rr} + e_{\varphi\varphi}) - 2\mu e_{r\varphi}^2, \\ \sigma_{r\varphi} &= 2\mu e_{r\varphi} \end{aligned} \quad (16)$$

Considering the last equation of (16), the integration of the second equation of (15) allows to find that

$$\sigma_{r\varphi} = \frac{c(t)}{r^2}, \quad e_{r\varphi} = \frac{c(t)}{2\mu r^2} \quad (17)$$

Applying (16) to (8), we define the components of the creep strain rate tensor:

$$\varepsilon_{r\varphi}^v = (-1)^n Bn \cdot 2^{n-1} \sigma_{r\varphi}^{n-1}, \quad \varepsilon_{rr}^v = -\varepsilon_{\varphi\varphi}^v = \frac{e_{rr} - e_{\varphi\varphi}}{2e_{r\varphi}} \varepsilon_{r\varphi}^v \quad (18)$$

Setting $\theta|_{r=R} = 0$ gives the differential equation used for the evaluation of the function $c(t)$:

$$\begin{aligned} \theta_0 &= \frac{\dot{c}_1^{n-1}(t)}{2\mu} \left(\frac{1}{R^2} - \frac{1}{r_0^2} \right) + \\ &+ (-1)^n \frac{Bn \cdot 2^{n-1}}{1-n} c_1(t) \left(\frac{1}{r_0^{2n-2}} - \frac{1}{R^{2n-2}} \right), \quad c_1(0) = 0, \end{aligned} \quad (19)$$

where

$$c_1(t) = \int_0^t c^{n-1}(\xi) d\xi \quad (20)$$

The component $p_{r\varphi}$ of the creep strain tensor can be found directly from (18):

$$\frac{\partial p_{r\varphi}}{\partial t} = \varepsilon_{r\varphi}^v \quad (21)$$

The creep strain tensor component $p_{\varphi\varphi}$ is defined by the differential equation which is obtained as a result of (1) and (18),

$$\frac{\partial p_{\varphi\varphi}}{\partial t} = -\varepsilon_{r\varphi}^v \frac{p_{\varphi\varphi} - e_{r\varphi}^2}{e_{r\varphi}} + \frac{4p_{r\varphi}\varepsilon_{r\varphi}}{e_{r\varphi}^2 + 2} \times$$

$$\times \left(1 + p_{\varphi\varphi} - \frac{1}{2}e_{r\varphi}^2 - 2e_{r\varphi}p_{r\varphi} \right), \quad (22)$$

while the rest of the components of strain tensors depend on known values and can be found with the help of the relations derived from (1) and (5):

$$p_{rr} = -p_{\varphi\varphi} - 2p_{r\varphi}^2,$$

$$e_{rr} = p_{\varphi\varphi} - \frac{3}{2}e_{r\varphi}^2 - 2e_{r\varphi}p_{r\varphi}, \quad e_{rr} = -e_{\varphi\varphi} - e_{r\varphi}^2 \quad (23)$$

PLASTIC FLOW

At some time point t_0 , the plasticity condition

$$(\sigma_{rr} - \sigma_{\varphi\varphi})^2 + 4\sigma_{r\varphi}^2 \Big|_{r=r_0} = 4k^2 \quad (24)$$

is satisfied in the neighborhood of the internal cylindrical surface r_0 , and plastic flow begins to develop. In this case, as it follows from (10), (11),

$$\sigma_{r\varphi} = \frac{c_2(t)}{r^2} = -k + \eta(\varepsilon_{r\varphi}^p - \varepsilon_{r\varphi}^{v_0}) \quad (25)$$

Taking into account the note before (11), we derive that

$$c_2(t) = -km^2(t), \quad (26)$$

where the value $c_2(t)$ is the same as $c(t)$ but has other symbol due to the different way of determination. According to (25),

$$\varepsilon_{r\varphi}^p = \frac{1}{\eta} \left(\frac{c_2(t)}{r^2} + k \right) + \varepsilon_k^{v_0} \quad (27)$$

From the instant t_0 , there are two areas in the cylindrical layer of the material, namely the area of elastic and creep strains $m(t) \leq r \leq R$ and the area of plastic flow $r_0 \leq r \leq m(t)$. These areas are separated from each other by a moving elastoplastic boundary $m(t)$ which position can be determined by solving the next differential equation:

$$\dot{m}(t) = \left\{ \frac{B\eta\mu k^{n-2}}{2^{1-n}(n-1)} \left(1 - \frac{m^{2n-2}(t)}{R^{2n-2}} + 2(n-1) \ln \frac{m(t)}{r_0} \right) - \right.$$

$$\left. - \frac{\mu}{\eta} \left(2 \ln \frac{m(t)}{r_0} - \frac{m^2(t)}{r_0^2} + 1 + \frac{\eta\omega_0}{k} \right) \right\} / \left\{ m(t) \left(\frac{1}{R^2} - \frac{1}{r_0^2} \right) \right\}, \quad (28)$$

$$m(t_0) = r_0$$

The relations for the components of strain tensors described in the previous section are valid not only before plastic flow beginning but also after this in the area $m(t) \leq r \leq R$. In the area $r_0 \leq r \leq m(t)$, most of these relations are also active except (21) and (22), which must be replaced

by new equations. The component $p_{r\varphi}$ of the plastic strain tensor can be determined by the relation which is the consequence of (27):

$$\frac{\partial p_{\varphi\varphi}}{\partial t} = \varepsilon_{r\varphi}^p \quad (29)$$

The plastic strain tensor component $p_{\varphi\varphi}$ can be found now from the differential equation

$$\begin{aligned} \frac{\partial p_{\varphi\varphi}}{\partial t} = & \varepsilon_{\varphi\varphi}^p - 2p_{r\varphi}\varepsilon_{r\varphi}^p + \frac{4p_{r\varphi}\varepsilon_{r\varphi}}{e_{r\varphi}^2 + 2} \times \\ & \times \left(1 + p_{\varphi\varphi} - \frac{1}{2}e_{r\varphi}^2 - 2e_{r\varphi}p_{r\varphi} \right), \end{aligned} \quad (30)$$

where

$$\begin{aligned} \varepsilon_{\varphi\varphi}^p = & \frac{\varepsilon_{r\varphi}^p - \varepsilon_{r\varphi}^{v_0}}{2} \cdot \frac{e_{\varphi\varphi} - e_{rr}}{e_{r\varphi}} + \\ & + \frac{e_{\varphi\varphi}(t_{\xi}(r)) - e_{rr}(t_{\xi}(r))}{e_{r\varphi}(t_{\xi}(r))} \cdot (-1)^n Bn \cdot 2^{n-2} \sigma_{r\varphi}^{n-1} \end{aligned} \quad (31)$$

In (31), $e_{ij}(t_{\xi}(r))$ is the value of e_{ij} calculated at the time point t_{ξ} of plastic flow beginning on the current radius r .

CONCLUSION

To evaluate stress relaxation, all the components of the stress tensor must be found numerically. The diagonal components of σ_{ij} are determined by (16), (17) and the equations following from (15):

$$\frac{\partial \sigma_{rr}}{\partial r} = \frac{\sigma_{\varphi\varphi} - \sigma_{rr}}{r}, \quad (32)$$

$$p = -\sigma_{rr} - 2\mu + 2(b + \mu)e_{rr} + 2be_{\varphi\varphi} + \mu e_{r\varphi}^2$$

The method of finite differences is applied to the resulting differential equations to get the numerical data of the stress-strain state parameters.

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THE PROBLEM OF THE SEABOTTOM TOPOGRAPHY USING BY THE THEORY OF RADIATION TRANSFER

Lyu E. R.¹, Kan V. A.¹, Sushchenko A. A.^{1,2}

¹ Far Eastern Federal University

² Institute of Applied Mathematics FEB RAS

Vladivostok, Russia

e-mail: elizavetarobertovna@gmail.com, kan.va@inbox.ru, sushchenko.aa@dvfu.ru

Abstract – Based on the mathematical model of the propagation of an acoustic signal in a fluctuating medium, the inverse problem is formulated, which includes determination a function that describes the deviation of the bottom level from the average specified horizontal plane. In the single-scattering approximation and the narrow directivity pattern of the receiving antenna, the solution of the direct problem is obtained. As a solution to the inverse problem, a nonlinear differential equation is obtained for a function describing the deviation of the bottom relief. A numerical analysis of the solution of the equation is carried out. The dependence of the reconstruction of the lower surface on the curvature of the function describing the relief is shown.

Keywords – radiation transfer equation; volume scattering; side-scan sonar; directivity pattern of reciver.

INTRODUCTION

Nowadays, studying of the world ocean remains a priority for the world community. Many research complexes are being developed to solve problems in the field of hydrography. Autonomous underwater robotic vehicles are equipped with monitoring systems [1]. Today, the problem of mapping the ocean floor using the side scan-sonars set on the board of an autonomous unmanned submersible is very topical and perspective[2,3]. The functioning of the sonar is based on periodic emission of the pulsed sound signals and detection of the echo signals reflected from the distant segments of seabottom [4-7]. When the sonar's antenna is moving, an acoustic image is formed on both sides of the submersible. There are some papers about improving quality of the hydroacoustic images, e.g. [8, 9]. But influence of the volume scattering in the ocean is not studying. In this paper we close this topic.

THE KINETIC MODEL. FORMULATION OF THE PROBLEM

The process of propagation of acoustic radiation is described by the transfer equation [10-13]:

$$\begin{aligned} \frac{1}{c} \frac{\partial I}{\partial t} + \mathbf{k} \cdot \nabla_{\mathbf{r}} I(\mathbf{r}, \mathbf{k}, t) + \mu I(\mathbf{r}, \mathbf{k}, t) &= \\ &= \frac{\sigma}{2\pi} \int_{\Omega} I(\mathbf{r}, \mathbf{k}', t) d\mathbf{k}' \\ &+ J(\mathbf{r}, \mathbf{k}, t), \end{aligned} \quad (1)$$

here $\mathbf{r} \in \mathbb{R}^2$, $t \in [0, T]$ and wave vector $\mathbf{k}$ belongs to the unique sphere $\Omega = \{\mathbf{k} \in \mathbb{R}^2: |\mathbf{k}| = 1\}$. The function $I(\mathbf{r}, \mathbf{k}, t)$ is interpreted as radiation intensity of wave in moment t in point $\mathbf{r}$, propagated in the direction $\mathbf{k}$ with constant velocity c . The coefficients μ and σ denote the attenuation and the scattering, correspondingly. $J(\mathbf{r}, \mathbf{k}, t)$ describes the density of inner sources.

The process of echo signal propagation occurs in the domain $G := \{\mathbf{r} \in \mathbb{R}^2: r_2 > -l + u(r_1)\}$, which is the upper half-space bounded from below by the curve, $\partial G = \gamma = \{\mathbf{y} \in \mathbb{R}^2: y_2 = -l + u(y_1)\}$, where the function $u(y_1)$ describes the change of the ocean bottom relief.

We assume that the function $J(\mathbf{r}, \mathbf{k}, t)$ describes a point isotropic sound source [14,15]:

$$J(\mathbf{r}, \mathbf{k}, t) = J_0 \delta(\mathbf{r}) \delta(t), \quad (2)$$

here δ – Dirac delta function and J_0 – source power.

Initial and boundary conditions for (1) [6,7]:

$$I|_{t=0} = 0 \quad (3)$$

$$I(\mathbf{y}, \mathbf{k}, t) = \frac{\sigma_d}{\pi} \int_{\substack{\Omega_+(\mathbf{y}) \\ \mathbf{y} \in \gamma, \mathbf{k} \in \Omega_-(\mathbf{y})}} |\mathbf{n}(\mathbf{y}) \cdot \mathbf{k}'| I(\mathbf{y}, \mathbf{k}', t) d\mathbf{k}', \quad (4)$$

here $\Omega_{\pm}(\mathbf{y}) = \{\mathbf{k} \in \Omega, \text{sgn}(\mathbf{k} \cdot \mathbf{n}(\mathbf{y})) = \pm 1\}$, σ_d denote the constant seabottom reflection coefficient, $\mathbf{n}(\mathbf{y})$ denote external normal to ∂G .

The solution of the initial-boundary problem (1), (3), (4) is deduced to the integral equation:

$$\begin{aligned} I(\mathbf{r}, \mathbf{k}, t) = & \int_0^{d(\mathbf{r}, -\mathbf{k})} \exp(-\mu t') J_0 \left(\mathbf{r} - t' \mathbf{k}, \mathbf{k}, t - \frac{t'}{c} \right) dt + \\ & + \frac{\sigma_d}{\pi} \exp(-\mu d(\mathbf{r}, -\mathbf{k})) \int_{\substack{\Omega_+(\mathbf{r}-d(\mathbf{r}, -\mathbf{k})\mathbf{k}) \\ \cdot \mathbf{k}'|}} |\mathbf{n}(\mathbf{y}) \cdot \mathbf{k}'| \times \\ & \times I_{\Gamma+} \left(\mathbf{r} - d(\mathbf{r}, -\mathbf{k})\mathbf{k}, \mathbf{k}', t - \frac{d(\mathbf{r}, -\mathbf{k})}{c} \right) d\mathbf{k}' + \end{aligned} \quad (5)$$

$$+ \int_0^{d(\mathbf{r}, -\mathbf{k})} \exp(-\mu t') \frac{\sigma}{4\pi} \int_{\Omega} I\left(\mathbf{r} - t'\mathbf{k}, \mathbf{k}, t - \frac{t'}{c}\right) d\mathbf{k}' dt',$$

here $d(\mathbf{r}, -\mathbf{k})$ – distance from the point $\mathbf{r} \in G$ in the $-\mathbf{k}$ direction to the boundary of the region G .

Using approximation of non-scattering media ($\sigma = 0$) last term is vanished.

For solving (5) authors construct a simple iteration method. Denote the initial approximation as

$$I_0 = \int_0^{d(\mathbf{r}, -\mathbf{k})} \exp(-\mu t') J_0\left(\mathbf{r} - t'\mathbf{k}, \mathbf{k}, t - \frac{t'}{c}\right) dt'$$

Thus, signal, received by sonar in the moment t , is modified to

$$I(t) = \frac{\sigma_d}{\pi} \exp(-\mu ct) \frac{(y_1 u' + l - u)^2}{(|\mathbf{y}|^3 \sqrt{1 + u'^2})}, \quad (6)$$

where $|\mathbf{y}| = \frac{ct}{2}$.

THE INVERSE PROBLEM

Further, we consider the inverse problem, which consists in determining the function u from (6). We obtain a nonlinear equation with respect to u' . To increase the stability of the solution, we use the expansion of the function $\sqrt{1 + u'^2}$ in the Taylor series:

$$\sqrt{1 + u'^2} = \sqrt{1 + v_0^2} + O((u' - v_0)^2),$$

then

$$= \frac{u' \left(u - l + \sqrt[4]{1 + v_0^2} \sqrt{\frac{I(t)\pi(ct)^3 \exp(\mu ct)}{8\sigma_d}} \right)}{y_1}. \quad (7)$$

Further, when constructing a numerical algorithm, as v_0 , we take the value of u' , calculated at the previous point: $v_{0i} = u'_{i-1}$.

COMPUTATIONAL EXPERIMENT

In the case of a narrow reception antenna pattern, the problem of remote sensing of the side-scan sonar, moving with a constant velocity V along the axis r_3 , is reduced to solving the problem (1) - (4) and is solved independently at each probing interval.

To carry out the computational experiment, the parameters from the echolocation sounding were taken from the values in Table I. [16] To solve the differential (7), the Euler method used.

TABLE I. PROBING PARAMETERS

$\mu, \text{м}^{-1}$	σ_d	$c, \text{м}/\text{с}$	J_0	$l, \text{м}$	$y_1, \text{м}$	$y_3, \text{м}$
0.018	1	1500	1	20	[0, 300]	[0, 120]

Original bottom relief described by the following function:

$$u(y_1, y_3) = \exp\left(-\frac{(y_1 - 100)^2 + (y_3 - 60)^2}{10^2}\right) - \exp\left(-\frac{(y_1 - 170)^2 + (y_3 - 60)^2}{10^2}\right) \quad (8)$$

Fig. 1 – Restoration of the seabed relief for function (8)

Fig. 2 – Observational error

Fig. 1 shows the solution of (7). As can be seen from the plot, the solution was obtained with an error of 1.8% (Fig. 2).

In the following experiment, the bottom surface is given by a more variable function and has the form:

$$\begin{aligned}
 u(y_1, y_3) = & \\
 = & 1.5 \exp \left(-\frac{(y_1 - 120)^2 + (y_3 - 75)^2}{17^2} \right) - \\
 & -0.7 \exp \left(-\frac{(y_1 - 165)^2 + (y_3 - 70)^2}{25^2} \right) + \quad (9) \\
 & + 0.5 \exp \left(-\frac{(y_1 - 155)^2 + (y_3 - 30)^2}{12^2} \right) - \\
 & -0.3 \exp \left(-\frac{(y_1 - 110)^2 + (y_3 - 40)^2}{15^2} \right)
 \end{aligned}$$

Fig. 3 – Restoration of the seabed relief for function (9)

Fig. 4 – Observational error

Fig. 3 shows the seabed profile based on the processing, the received signal, according to the (7). Maximum error $\delta u = 1,6\%$ (Fig. 4).

In the the next experiment the input signal is computed in the case of finite directivity pattern of the receing antenna with aperture 8° .

The seabottom relief is described as (10):

$$\begin{aligned}
 u(y_1, y_3) &= \\
 &= \exp\left(-\frac{(y_1 - 100)^2 + (y_3 - 25)^2}{10^2}\right) - \\
 &\quad - \exp\left(-\frac{(y_1 - 170)^2 + (y_3 - 25)^2}{10^2}\right)
 \end{aligned} \quad (10)$$

Fig.5 – Restoration of the seabottom relief for function (10)

Fig. 6 – View from above of Fig. 5

The Fig. 5,6 are shown numerical error increase with increasing slant range, and objects is defocusen along axes y_3 .

Fig. 7 – Observational error

The fig.7 are shown the maximum error is equal 40%.

Analysis of computational experiments showed that the smoothness of the bottom surface slightly affects the result of the restoration of the bottom relief, in the case of a narrow radiation pattern of the receiving antenna. The efficiency of the numerical algorithm for determining the characteristics describing the relief of the seabed on the basis of the signal received by the side-scan sonar using the formula (7) is proved. Thus, the authors carried out work on mapping the seabed based on the kinetic model of acoustic radiation transfer. The solution of the inverse problem in the form of a first-order differential equation is obtained, which consists in determining the function describing the deviation of the seabed relief from a certain predetermined depth. Computational experiments have been performed to show the effectiveness of the proposed solution for the recovery of the unknown functions.

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LANGUAGE EVOLUTION ONTOLOGY

Makusheva N.V.¹, Artemieva I.L.^{1,2}, Zavyalova V.L.¹

¹ Far Eastern Federal University

¹² Institute of Applied Mathematics FEBRAS

Vladivostok, Russia

mataiyang@gmail.com, artemeva.il@dvfu.ru, zavyalova.vl@dvfu.ru

Abstract - In this paper the authors introduce the basic level of the language evolution multi-level domain ontology that determines the base for the architecture of language evolution modeling software modules and the design of their interaction. This model provides several basic domains such as ‘language using community’, ‘individual speaker’, ‘individual language set’, and ‘language production’, as well as shows the connections between them. The model is designed with the use of the applied logic language.

Keywords — language evolution; comparative linguistics; evolutionary modeling; ontology

INTRODUCTION

The purpose of this research is to design a mathematical model that will form the basis for a software system modeling language evolution. This software system is intended for experts in the field of comparative linguistics for the experimental research of the evolution of a natural language, namely, to measure quantitative and qualitative changes in the grammatical and lexical composition of a language in time, depending on the social organization of a group of speakers. The software system can give a significant refinement for assessing the rate of language change by developing individual historical scenarios for several languages, language groups and families. The use of variable parameters will help the expert to set the most suitable conditions for the scenario of language development.

To develop a model of language evolution, we chose an ontological approach that would allow us to design the modular structure. This, in turn, will allow the model to be used for verification of various hypotheses of natural language evolution and to be quickly adapted to new knowledge and data that appear in this area on a daily basis.

The ontology model is developed in the class of unenriched systems of logical relationships with parameters [20] and is described with the use of the language of applied logic [19]. In the analysis of the subject area and the development of ontology, papers [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14, 15, 16, 17, 18, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33] were used, and ontology was discussed with domain experts.

THE ONTOLOGY OF THE DOMAIN OF NATURAL LANGUAGE EVOLUTION

We define the natural language of the species as a way of structuring and transmitting information within a group of individuals of the given species. The idea is that the language can be represented as a resource, consisting of a set of structural elements and distributed in the population of speakers.

Basic terms of the model

1.1 moment $\equiv I [0, \text{max number of moments}]$ Auxiliary term denoting the interval, one step of the system operation, for which the message can be transmitted, received and processed.

1.2 *Term max number of moments: $I [1, \infty)$* The maximum duration of the system work in steps.

1.3 *Term individual: $\{\} N \setminus \emptyset$* Unordered set of names of individuals.

Module “The Language of the Individual”

The structural elements of the language are associated with the structural nodes of the central nervous system of the speaker and are embodied in the computer model by data structures composed in a special way.

To implement the basic model, we chose the following structural elements of the language:

- words - formal-semantic units that have their own meaning and own form, so that when the form is violated, the value is lost, and the constituent part of the concept embodied in the word cannot be expressed by a part of the word;
- types of words - labels of words, characterizing the possibilities and restrictions of the use of words in the composition of syntactic sequences;
- sequences of types of words - syntactic structures, any kind of sequences.

Terms

1.1 *Term word: $\{\} N \setminus \emptyset$* An unordered set.

1.2 *Term type of word: $\{\} N \setminus \emptyset$* An unordered set.

1.3 *Term types of word: $word \rightarrow \{\} type\ of\ word$* Each word corresponds to a finite set of types.

1.4 *Term words of the type: $type\ of\ word \rightarrow \{\} word$* Each type of words corresponds to a finite set of words.

1.5 *sentence $\equiv seq\ word$* The set of all possible (and impossible) sequences of words.

1.6 *word type sequence $\equiv seq\ type\ of\ word$* The set of all possible (and impossible) sequences of types of words.

1.7 *Term valid type sequences: $\{\} word\ type\ sequence$* A subset of all admissible sequences of types of words.

1.8 *language element $\equiv \{word, type\ of\ word, word\ type\ sequence\}$* Structural elements of the language.

1.9 *Term individual's words: $moment\ X\ individual \rightarrow \{\} word$* All the words of the individual at each moment of time.

1.10 *Term individual's types of words: $moment\ X\ individual \rightarrow \{\} type\ of\ word$* All types of words of the individual at each moment of time.

1.11 *Term individual's word type sequence: $moment\ X\ individual \rightarrow \{\} word\ type\ sequence$* All sequences of types of words of the individual at each moment of time.

1.12 *Term counter of occurrence of language element: $individual\ X\ moment\ X\ language\ element \rightarrow I [1, \infty)$* A counter that marks the number of occurrences of words, types of words, and sequences of types of words in messages that the individual receives.

1.13 *Term counter of occurrence of a pair of words: $individual\ X\ moment\ X\ \{word, word\} \rightarrow I [1, \infty)$* A counter that marks the number of occurrences of an ordered pair of words that an individual receives.

1.14 Term counter of occurrence of a pair of types of word: individual X moment X {type of word, type of word} $\rightarrow I [1, \infty)$ A counter that marks the number of occurrences of an ordered pair of types of words that an individual receives.

1.15 Term counter of occurrence of a pair of word type sequences: individual X moment X {word type sequence, word type sequence} $\rightarrow I [1, \infty)$ A counter that marks the number of occurrences of an ordered pair of word type sequences that an individual receives.

1.16 Term individual's language: individual X moment $\rightarrow \{ \{ \{ (word \ X \ I [1, \infty) \ X \ I [1, \infty) \ X \ I [1, \infty) \}, \{ \{ (word, word \ } \ X \ I [1, \infty) \}, \{ \{ (type \ of \ word \ X \ I [1, \infty) \ X \ I [1, \infty) \ X \ I [1, \infty) \}, \{ \{ (type \ of \ word, type \ of \ word \} \ X \ I [1, \infty) \}, \{ \{ (word \ type \ sequence \ X \ I [1, \infty) \ X \ I [1, \infty) \ X \ I [1, \infty) \}, \{ \{ (word \ type \ sequence, word \ type \ sequence \} \ X \ I [1, \infty) \} \}$ The totality of all words, types of words, sequences of word types, counters of repetitions of language elements and their pairs, and inclusion thresholds for each individual at each moment of time.

Speakers (individuals) can acquire a language - accumulate a language resource, and communicate with each other - transfer the language resource to each other by copying.

1.17 Term individual's language next moment: individual X moment $\rightarrow \{ \{ \{ (word \ X \ I [1, \infty) \ X \ I [1, \infty) \ X \ I [1, \infty) \}, \{ \{ (word, word \ } \ X \ I [1, \infty) \}, \{ \{ (type \ of \ word \ X \ I [1, \infty) \ X \ I [1, \infty) \ X \ I [1, \infty) \}, \{ \{ (type \ of \ word, type \ of \ word \} \ X \ I [1, \infty) \}, \{ \{ (word \ type \ sequence \ X \ I [1, \infty) \ X \ I [1, \infty) \ X \ I [1, \infty) \}, \{ \{ (word \ type \ sequence, word \ type \ sequence \} \ X \ I [1, \infty) \} \}$

In order to model this process, in the individual language of the speaker (the recognizable set of elements) we define the passive (understood) and active (used in speech) subsets, so that the active subset is included into the passive subset, and the passive subset is in turn included into the set of individual language. The inclusion of a structural element of a language into a particular subset is characterized by the value of the counter of its representation. This allows us to model a gradual language acquisition.

1.18 Term threshold for inclusion into the passive language: individual X moment X language element $\rightarrow I [1, \infty)$ The number characterizing the inclusion of a language element in a subset of the language of the individual that is used to generate messages.

1.19 Term individual's passive language: individual X moment $\rightarrow \{ \{ \{ (word \ X \ I [1, \infty) \ X \ I [1, \infty) \ X \ I [1, \infty) \}, \{ \{ (word, word \} \ X \ I [1, \infty) \}, \{ \{ (type \ of \ word \ X \ I [1, \infty) \ X \ I [1, \infty) \ X \ I [1, \infty) \}, \{ \{ (type \ of \ word, type \ of \ word \} \ X \ I [1, \infty) \}, \{ \{ (word \ type \ sequence \ X \ I [1, \infty) \ X \ I [1, \infty) \ X \ I [1, \infty) \}, \{ \{ (word \ type \ sequence, word \ type \ sequence \} \ X \ I [1, \infty) \} \} \mid (v: \text{language element}) \text{ counter of occurrence of language element } (v) \geq \text{threshold for inclusion into the passive language } (v)$ A subset of an individual's language at each moment in time, in which all relevant elements of the language can participate in understanding messages; a totality of all words, types of words, sequences of types of words, repeat counters of which exceed the thresholds of inclusion in the passive language for each individual at each moment of time.

1.20 Term threshold for inclusion into the active language: individual X moment X language element $\rightarrow I [1, \infty)$ The number characterizing the inclusion of a language element in a subset of the language of the individual used to generate messages.

1.21 Term individual's active language: individual X moment $\rightarrow \{ \{ \{ (word \ X \ I [1, \infty) \ X \ I [1, \infty) \ X \ I [1, \infty) \}, \{ \{ (word, word \} \ X \ I [1, \infty) \}, \{ \{ (type \ of \ word \ X \ I [1, \infty) \ X \ I [1, \infty) \ X \ I [1, \infty) \}, \{ \{ (type \ of \ word, type \ of \ word \} \ X \ I [1, \infty) \}, \{ \{ (word \ type \ sequence \ X \ I [1, \infty) \ X \ I [1, \infty) \ X \ I [1, \infty) \}, \{ \{ (word \ type \ sequence, word \ type \ sequence \} \ X \ I [1, \infty) \} \} \mid (v: \text{language element}) \text{ counter of occurrence of language element } (v) \geq \text{threshold for inclusion into the active language } (v)$ A

subset of an individual's language at each moment in time in which all relevant elements of the language can participate in messages generation; a totality of all words, types of words, sequences of types of words, repeat counters of which exceed the thresholds of inclusion in the active language for each individual at each moment of time.

In the basic model, we accept the hypothesis that all individuals have sufficient recognition ability. Violation of the recognition ability will be considered in further studies. Thus, at the first step of message processing the elements of the incoming sentence are checked for correspondence to the passive subset of the receiver's language, the counters of existing elements are increased and new elements are created. The second step is semantic processing. Semantics in the model is represented by the links between the structural nodes coding the elements of the language. At this step correspondence of the connections between the elements of the incoming utterance and the connections between the elements of the passive subset of the receiver's language is verified, the counters of existing connections are increased and new connections are created.

Communication, i.e. the transfer of a resource from an individual to an individual is provided selectively. This process can be caused by various factors, such as modeling specialization of labor activity, modeling social status, communicative success, and others.

Module "Message"

Messages of individuals are constructed using a subset of the active language of the individual and are processed on the basis of a subset of the passive language of the individual.

In the process of communication, errors and failures may occur. All this leads to a change in the qualitative and quantitative distribution of the language resource in the population.

Terms

1.1 message = {generated message, message distorted in the process of sending, message undistorted in the process of sending, message distorted in the process of receiving, message undistorted in the process of receiving}

1.2. Term generated message: individual X moment $\rightarrow$ sentence A message that is generated by an individual is a certain sequence of words.

1.3 Term message distorted in the process of sending: individual X moment X sentence $\rightarrow$ sentence Errors that may occur during the sending of the message.

1.4 Term message undistorted in the process of sending: individual X moment X sentence $\rightarrow$ sentence Messages that were transmitted without errors.

1.5 Term message sender: moment $\rightarrow$ {} individual At each moment of time in the population of individuals there is a subset of individuals who are the senders of messages.

1.6 Term message receiver: individual X moment $\rightarrow$ {} individual

1.7 Term received message: individual X moment $\rightarrow$ {} message distorted in the process of sending $\cup$ {} message undistorted in the process of sending

1.8 Term message distorted in the process of receiving: individual X moment X sentence $\rightarrow$ sentence

1.9 Term message undistorted in the process of receiving: individual X moment X sentence $\rightarrow$ sentence

1.10 Term processed message: individual X moment $\rightarrow \{\}$ message distorted in the process of receiving $\cup \{\}$ message undistorted in the process of receiving

1.11 Term occurrence of language element in the message: individual X moment X message $\rightarrow (\{\}(\text{word } X I [1, \infty)), \{\}(\{\text{word, word}\} X I [1, \infty)), \{\}(\text{type of word } X I [1, \infty)), \{\}(\{\text{type of word, type of word}\} X I [1, \infty)), \{\}(\text{word type sequence } X I [1, \infty)), \{\}(\{\text{word type sequence, word type sequence}\} X I [1, \infty)))$ For each message, words, types of words and sequences of types of words and the number of their repetitions in this message.

Ontological agreements

2.1 ($\forall v1 \in \text{individual}$) ($\forall v2 \in \text{moment}$) ($\forall v3 \in I [1, \text{length}(\text{generated message}(v1, v2))])$ ($\forall v \in \text{generated message}$) $\exists v4 \in \text{individual's active language}(v1, v2) \mid \pi(v3, v) \in \pi(1, \pi(1, v4)) \& \text{types of word}(\pi(v3, v)) \in \pi(1, \pi(3, v4))$ The message is generated from the active language of the individual.

2.2 ($\forall v1 \in \text{individual}$) ($\forall v2 \in \text{moment}$) ($\forall v3 \in I [1, \text{length}(\text{generated message}(v1, v2))])$ ($\forall v4 \in I [1, \text{length}(\text{message distorted in the process of sending}(v1, v2))])$ ($\forall v5 \in \text{generated message}(v1, v2)$) ($\forall v6 \in \text{message distorted in the process of sending}(v1, v2, v5)$) $\exists v3 = v4 \mid \pi(v3, v5) \neq \pi(v4, v6) \& \text{types of word}(\pi(v3, v5)) \neq \text{types of word}(\pi(v4, v6))$ In a distorted message, there will be at least one position in which the language element does not match the language element in the generated message.

2.3 ($(\forall v1 \in \text{individual}) (\forall v2 \in \text{moment}) \text{message sender}(v2) = v1$) message receiver}(v1, v2) \neq \emptyset Each message sender is associated with a set of individuals who are receivers of the message.

2.4 ($\forall v1 \in \text{individual}$) ($\forall v2 \in \text{moment}$) ($\forall v3 \in \text{message receiver}(v1, v2)$) received message}(v3, v2) \neq \emptyset

2.5 ($\forall v1 \in \text{individual}$) ($\forall v2 \in \text{moment}$) ($\forall v3 \in I [1, \text{length}(\text{received message}(v1, v2))])$ ($\forall v4 \in I [1, \text{length}(\text{message distorted in the process of receiving}(v1, v2))])$ ($\forall v5 \in \text{received message}(v1, v2)$) ($\forall v6 \in \text{message distorted in the process of receiving}(v1, v2, v5)$) $\exists v3 = v4 \mid \pi(v3, v5) \neq \pi(v4, v6) \& \text{types of word}(\pi(v3, v5)) \neq \text{types of word}(\pi(v4, v6))$ Incorrectly heard words and phrases.

2.6 ($\forall v1 \in \text{individual}$) ($\forall v2 \in \text{moment}$) ($\forall v3 \in \text{message receiver}(v1, v2)$) processed message}(v3, v2) \neq \emptyset

2.7 ($(\forall v1 \in \text{individual}) (\forall v2 \in \text{moment}) \text{processed message}(v1, v2) \neq \emptyset$) $\Rightarrow$ occurrence of language element in the message $\neq \emptyset$

Module "Algorithm of Communication"

Communication is implemented by transmitting a message from one individual to another. As a result, the language of the receiver of the message changes according to the data that was received in the message.

Terms

1.1 Term message generation: individual X moment $\rightarrow \{\text{message generation true, message generation false}\}$

1.2 Term message sending: individual X moment $\rightarrow \{\text{message sending true, message sending false}\}$

1.3 Term message receiving: individual X moment $\rightarrow \{\text{message receiving true, message receiving false}\}$

1.4 Term message understanding: individual X moment $\rightarrow \{\text{message understanding true, message understanding false, message understanding partial}\}$

1.5 Term number of words in the message: message $\rightarrow I[1, \infty)$

1.6 Term types of words in the message: message $\rightarrow \{\}$ type of word

1.7 Term number of types of words in the message: message $\rightarrow I[1, \infty)$

1.8 Term number of sequences of types in the message: message $\rightarrow I[1, \infty)$

1.9 Term sequences of types in the message: message $\rightarrow \{\}$ word type sequence

1.10 Term number of understood words in the message: individual X moment X processed message $\rightarrow I[1, \infty)$

1.11 Term number of understood types of words in the message: individual X moment X processed message $\rightarrow I[1, \infty)$

1.12 Term number of understood sequences of types in the message: individual X moment X processed message $\rightarrow I[1, \infty)$

1.13 Term part of understood words in the message: individual X moment X processed message $\rightarrow R[0, 1]$

1.14 Term part of understood types of words in the message: individual X moment X processed message $\rightarrow R[0, 1]$

1.15 Term part of understood sequence of types in the message: individual X moment X processed message $\rightarrow R[0, 1]$

1.16 Term understanding threshold for words: individual X moment $\rightarrow R[0, 1]$ Percentage characteristic, reflecting the proportion of words in the received message, which should coincide with the passive language of the individual, so that the message is understood.

1.17 Term understanding threshold for types of words: individual X moment $\rightarrow R[0, 1]$ Percentage characteristic, reflecting the proportion of types of words in the received message, which should coincide with the passive language of the individual, so that the message is understood.

1.18 Term understanding threshold for sequences of types of words: individual X moment $\rightarrow R[0, 1]$ Percentage characteristic, reflecting the proportion of sequences of types of words in the received message, which should coincide with the passive language of the individual, so that the message is understood.

1.19 Term communication success: individual X individual X moment $\rightarrow \{\text{true, false}\}$

1.20 Term message sending counter: individual X moment $\rightarrow I[1, \infty)$

CONCLUSIONS

The paper describes the ontology proposed by the authors for the problem of modeling the evolution of a natural language, including the basic concepts and relations defined for the domain. The model is described by the language of applied logic, which makes the description universal.

The model described in the work is intended for designing a software system that allows creating individual scenarios for the occurrence of changes in individual languages, language groups and families. This will give experts in the field of comparative linguistics an additional tool for researching language processes. In addition, such a system can be used by experts in the field of history, sociology, and in the educational process.

Further research will focus on the refinement of the model, the introduction of new additional concepts, the formulation of relations and connections of concepts with each other. It is also necessary to adapt the model to the requirements of present-day experts in the field of comparative linguistics, which implies the development of additional modules that describe various systems of knowledge and representations. In the future, this will allow for a comparative analysis of hypotheses by a model experiment.

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SOFTWARE PACKAGE CREATION TO CONDUCT COMPUTATIONAL EXPERIMENTS FOR SOLVING OF FLAT SELF-SIMILAR PROBLEMS IN NONLINEAR ELASTICITY THEORY

Olga I. Tarasenko¹

Olga V. Dudko^{1,2}

¹ Far Eastern Federal University

² Institute of Automation and Control Processes,

Far Eastern Branch of RAS

Vladivostok, Russia

jujulianjujulia@gmail.com, dudko@iacp.dvo.ru

Abstract—The nonlinear elasticity theory solves the dynamic problems with including the stage aimed to test obtained solutions by conducting laborious computational experiments. In the paper we analyze the concept of flat self-similar problems and their classes and substantiate the necessity of software creating for the automatic computational experiments. In addition, a question of software environment choice for the package constructing is discussed.

Keywords—nonlinear elasticity; flat self-similar problems; shock wave; Riemann wave; computational experiments

INTRODUCTION

Over the past decades the development of modern technologies is associated with the application of new materials and the extensive use of various elastic elements in designs. The use of any structural or natural material must be preceded by thorough research of its deformation properties under the action of different loads. Such research can be undertaken either experimentally or theoretically, that is, (i.e.) by using the methods of mathematical modeling. The latter is associated with developing of mathematical models, posing of boundary value problems of deformation and their solving with the involvement of both known and specially developed computational algorithms.

At the same time, the important problem is not only obtaining mathematical models but also automating stated studies.

The present study deals with nonlinear elastic materials and flat self-similar problems of their dynamic deformation. The aim of the study is to analyze the developed computational schemes for solving flat self-model problems, the properties of their implementation by means of computing machinery, as well as the availability of ready-made software tools for their solution.

BASIC CONCEPTS OF NON-LINEAR DYNAMIC THEORY OF ELASTICITY

Before we move on to considering and posing such problems, the basic concepts must be introduced.

The mathematical theory of elasticity studies changes in the stress-strain state of an elastic solid under the action of external and internal forces. Deformation is geometric characteristic and measure of volume or shape change of a solid; stress characterizes internal forces, opposing such changes.

By elasticity we understand the idealized characteristic of a solid to completely return to its original volume and shape after removing external influence. Simultaneously, it is supposed that there is only one state, characterized by the absence of stresses and deformations, to which a solid returns after removing of external influences. This state is called the natural or free state of the deformable solid [13].

The analysis of the stress-strain states is carried out by the methods of mathematical physics. For this purpose, the concepts of continuous media and its density are defined; geometric variables which describe the changes of the body, internal forces and their relation with external influences are considered. The correlation between internal forces (stresses) and geometric changes (deformations) are taken from the experiment. Consequently, the theory of elasticity is a phenomenological theory [12].

Real solids are considered as a model that only has their basic and common properties which are characteristic on certain conditions.

Depending on the features of the accepted model of elastic solids the theory of elasticity is subdivided into linear and non-linear.

The non-linear elasticity theory has a more general character than the linear elasticity [4, 10], and solves a rather wide range of problems, which are continually and inevitably raised by the modern technologies.

The linear elasticity studies longitudinal waves (where particles displace in the direction of wave propagation) and transverse waves (on which the displacements are perpendicular to the propagation direction). In the non-linear theory of elasticity the strain evolution occurs by singular moving surfaces – shock waves and simple waves.

The medium nonlinearity leads to combined character of waves: one and the same front can change both the volume and the shape of the medium simultaneously.

The shock wave is the strong discontinuity of the first kind in the solving of the differential model equations system (the rupture of first derivatives). The weak wave is the discontinuity of the second derivatives of displacement. A Riemann wave is bounded by two weak discontinuities band, where continuous changes in displacements and their first derivatives obey the motion equations [9].

THE CONCEPT OF FLAT SELF-SIMILAR PROBLEM

Now we move on to the concept of flat self-similar problem of non-linear theory of elasticity. We consider this concept by defining the two components: self-similar problem and flat problem.

The boundary value problems are flat if unknown functions depend on two independent coordinates.

The self-similar problem is a special case of dynamic boundary value problems. Mathematically self-similar problems are the simplest, in different branches of mechanics they can be solved first. For the construction of a self-similar solution we find a necessary form of self-similar variable (combination of independent variables) by which a partial differential equation system is reduced to ODE system. The numerical integration of ODE is much easier than solving the original partial differential equation numerically. Self-similar solutions give some quality knowledge about the process, while partial differential equation fully describes the physical process [7].

In the general case, a flat problem is described by the system of partial differential equations presented in the works [2, 5, 15].

CLASSIFICATION OF FLAT SELF-SIMILAR PROBLEMS

The works consider different classes of plane self-similar problems. Among them the following problems can be distinguished:

- problems of the reflection of a plane shock wave from the boundary of non-linear elastic half-space;
- problems of the collision of elastic solids with plane boundaries.

In the first class, two types of problems are solved, since the half-space boundary can be free (Fig.1 b) or rigidly fixed (Fig. 1, a).

The next class consists two cases: only one body is deformed (Fig 2); both bodies are deformed (Fig. 3).

Since these classes of problems assume a transition to a self-similar formulation, the non-uniqueness of their solution arises.

For each class mathematically possible wave patterns can consist of different combinations of plane shock waves and Riemann waves, But the self-similar way of solving does not give the only true combination, and it is also not known how the wave fronts are located.

That is why, after having obtained all mathematically possible solutions to the problem, it is necessary to compare them with one another and examine the implementation of the following criteria.

Firstly, every shock wave is tested on the implementation of thermodynamic compatibility condition [15]. If given correlation is not satisfied on some shockwave, than such a formulation is excluded from the number of possible solutions.

One more restriction on the existence of shock waves is its evolutionary condition. If the comparison of two solutions reveals that shock wave front (occupies the intermediate position) mediates inside the fan of the plane wave, than that kind of a wave is considered to be non-evolutionary, and the solution with the Riemann wave is chosen.

In the general case, the model of the process of wave reflection is the mixed system of differential and algebraic equations in different combinations.

Fig.1 Reflection of a plane shock wave from the (a) rigid and (b) free boundaries of non-linear elastic half-space

Fig. 2 Oblique impact of the moving rigid body with flat boundary on elastic nonlinear half-space

Fig. 3 Collision of two nonlinear elastic half-spaces

Additional difficulties arise in determining the anterior and posterior simple wave fronts, in determining the stoppage of the calculation, when the boundary of the medium is free.

The final characteristics are the parameters of the stress-strain state. On the basis of the initial problem formulation [2, 5], we determine the displacement vector components, velocity and acceleration of the medium points, the components of the strain tensor and stress tensor, the correlation of the material densities in the final and current state.

Carrying out computational experiments in solving of the mentioned problems is laborious work, that is why it is urgent for the researchers of such problems to an adequate software package, which allows of automating this process, partially at least.

The methods for solving every specific class of flat self-similar problems must underlie this package. All that a user needs to do is to set up the initial parameters of the body and the shock wave.

According to the problem formulations described above we can see that when solving, for example, the problem of shock wave reflection from a rigid boundary, we must give a specific problem formulation depending on a prescribed set of parameters. For this reason the algorithm must include the implementation of the search for a specific problem formulation with the checking the evolutionary criterion and the thermodynamic compatibility condition of discontinuities on shock waves, and also finding a numerical solution of the problem for given parameters.

CHOOSING THE ENVIRONMENT

For the software implementation of the complex, MATLAB® [3, 11] is chosen. It is a high-level language and an interactive environment for programming, numerical calculations and visualization of results [5]. In addition to this environment, the products Mathcad® [16], Wolfram Mathematica® [8, 14] and Maple® [1, 6] were also considered. The variant with the development of the complex in the high-level programming language was not considered, because computer algebra systems offer a number of predefined functions that implement various numerical methods. The choice of this package of mathematical modeling was based on its following advantages among other systems of computer algebra:

MATLAB® includes tools that allow an engineer to interactively construct a graphical user interface to create a complete application;

MATLAB® includes MATLAB Compiler tool, with which it is possible to package the MATLAB application into an independent application;

lower threshold entry;

it is effective for numerical model simulation;

student version of MATLAB is available;

open source code of the predefined functions.

SUMMARY

Since the studying of the deformable material properties is connected with solving of boundary value problems with various parameters, then the researchers need to carry out different computational experiments.

However, the labor-intensive problem testing process is not automated. We don't have a software tool, which is supposed to solve the flat self-similar problem in a specific formulation (application of a particular numerical method for a corresponding system of equations), and to select this formulation depending on some initial parameters. That is why the problem of developing a software package for conducting experiments is urgent.

The main purpose of the study is the computing schemes implementation for solving plane self-similar problems in the form of software tool.

Within the scope of this work we will need to solve the following tasks:

1) development of a general form of the algorithm for solving a particular boundary value problem chosen from a given class of plane self-similar problems, which includes a two-criteria search procedure for a single solution;

- selection of the necessary numerical methods [7] and numerical solution of the chosen problem for the given parameters;

- modification of the developed algorithm, taking into account the specifics of the formulation of each of the problems of the class considered;

- directly implementation of the program complex.

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ANALYSIS OF THE INTERVAL OPTIMAL CONTROL PROBLEM IN A HILBERT SPACE

V.O. Filippova
Far Eastern Federal University
Vladivostok, Russia
Filippova.vo@dvfu.ru

Abstract — An optimal control problem for a system involving an interval parameter is considered. The concepts of a p -universal optimal state and a p -universal optimal control are introduced. The existence and uniqueness of a p -universal solution to the interval optimal control problem is proved, and an algorithm for its determination is presented. The interval optimal control problem for a system described by the boundary value problem for a second order differential equation is solved as an example

Keywords— interval parameter, optimal control problem

INTRODUCTION

Optimal control problems for systems with interval parameters are of interest from a practical point of view in connection with the uncertainty of data underlying the construction of corresponding mathematical models. On the other hand, interval optimal control problems are interesting from a theoretical point of view, since the arising optimization problems are nonlinear even if the control system is linear for particular values of uncertain parameters.

In this paper, we consider an interval optimal control problem for operator control in Hilbert space. A solution of the problem is proposed that is based on averaging of the objective functional with the L^p norm over the domain of admissible parameters. The main result of this paper consist of a proof of the existence and uniqueness of p -universal solutions.

A similar approach for solving a wide range of problems related to the choice of optimal control was discussed in the author's article [1]. In addition, variants of the 1-universal solution with different weight functions are proposed. As an illustration of the proposed algorithm, we consider the problem of boundary control for a second-order differential equation.

The concept of a *p-universal* solution for a interval quadratic function in a Hilbert space is considered in the author's article [2]. The basis for studying universal solutions of interval problems was the monograph [3]. This concept is close to various variants of defining solutions of ill-posed problems [4]. Note that finite-dimensional interval optimization problems were investigated in [5] - [9].

STATEMENT OF THE INTERVAL OPTIMAL CONTROL PROBLEM

Consider real Hilbert spaces V and H , $V \subset H \subset V'$, with a dense compact embedding $V \subset H$. Here, V' — is the dual of the space V . Let $\|\cdot\|$ and $|\cdot|$ denote the respective norms in V and H , and let $((\cdot, \cdot))$ and $(\cdot, \cdot)$ be the corresponding inner products. By (f, z) we denote the value of a functional $f \in V'$ at an element $z \in V$, which coincides with the inner product in H if $f \in H$.

Let $A : V \rightarrow V'$ be a linear continuous operator with the properties

$$\begin{aligned} (Ay, y) &\geq \alpha \|y\|^2, & \alpha > 0, & & (Ay, z) &= (Az, y), \\ (Ay, z) &\leq \tau \|y\| \cdot \|z\|, & \tau > 0 & \end{aligned}$$

By the Hilbert–Schmidt theorem, the eigenelements w_j of the operator A ,

$$Aw_j = \lambda_j w_j, \quad j = 1, 2, \dots \quad (w_i, w_j) = \delta_{ij}, \quad 0 < \lambda_1 \leq \lambda_2 \leq \dots$$

form a basis for H and V , $\lambda_m \rightarrow +\infty$ as $m \rightarrow \infty$. The above properties of A imply the existence of an inverse operator $A^{-1} : V' \rightarrow V$,

$$A^{-1} f = \sum_{j=1}^{\infty} (f, w_j) w_j, \quad f \in V'.$$

The interval optimal control problem is formulated as follows.

Let a control space - Hilbert space U and the mapping $B : U \rightarrow V'$ — a continuous linear operator. For each control $u \in U$, the state y is defined as the solution of an equation of the form

$$aAy = Bu, \tag{1}$$

where $y \in V$, and a is an undetermined coefficient from the closed interval

$$0 < a_1 \leq a \leq a_2. \tag{2}$$

The problem is to minimize the functional:

$$J(u, y) = \frac{1}{2} |y - y_d|^2 + \frac{N}{2} |u|^2 \rightarrow \inf, \tag{3}$$

over the solutions of Eq. (1), where $y_d \neq 0$ is a given element from H and $N > 0$.

Remark. Optimal control problems for systems of elliptic equations with boundary conditions are reduced in a natural manner (see [9]) to control problems of form (1) – (3). The interval nature of the parameter a in (1) models the uncertainty in physical characteristics of the control system, such as thermal conductivity, diffusivity or viscosity.

Before introducing the concept of a universal solution of the optimal control problem, we reduce problem (1) – (3) to an interval minimization problem for a functional depending only on $u \in U$. Substituting $y = \frac{1}{a} A^{-1} B u$ into (3) yields:

$$J(u, y) = \frac{1}{2} ((b^2 M + N I) u, u)_U - b (B^* A^{-1} y_d, u)_U + \frac{1}{2} |y_d|^2 \rightarrow \inf, u \in U \quad (4)$$

The operator $M : U \rightarrow U$ is defined by the equality: $(Mu, v)_U = (A^{-1} B u, A^{-1} B v)$, $\forall v \in U$, I is the identity operator. The parameter b satisfies the constraints

$$0 < b_1 \leq b \leq b_2, \quad (5)$$

where $b_1 = \frac{1}{a_2}$ and $b_2 = \frac{1}{a_1}$.

Note that $M : U \rightarrow U$ is self-adjoint, prove its compactness. Let $u_j \rightarrow 0$ weakly in U . Then $A^{-1} B u_j \rightarrow 0$ weakly in V and strongly in H . From the definition of the operator M we obtain the following inequality

$$\|M u_j\|_U \leq C \|B\| \|A^{-1}\| |A^{-1} B u_j| \rightarrow 0,$$

where C is the embedding constant of V in H . Hence the compactness of the operator M .

Note that the operator $(b^2 M + N I) : U \rightarrow U$ is continuous and coercive, since $((b^2 M + N I) u, u)_U \geq N \|u\|_U$. Then, by the Lax-Milgram theorem, there exists a unique element $u \in U$ such that $((b^2 M + N I) u, u)_U = (w, v)_U$. Since the operator $(b^2 M + N I)$ is symmetric, therefore there exists a bounded operator $(b^2 M + N I)$ such that $u = (b^2 M + N I)^{-1} w$.

For problem (4), (5), we define the concepts of a minimum and a minimizer and describe procedures for finding them.

Any number b from interval (5) is called *admissible*. Note that, for every admissible b , the minimum of J is reached at the point

$$\hat{u} = b (b^2 M + N I)^{-1} B^* A^{-1} y_d.$$

The corresponding value of the functional is given by

$$J(\hat{u}) = -\frac{1}{2} b^2 ((b^2 M + N I)^{-1} z_d, z_d)_U + \frac{1}{2} |y_d|^2,$$

where $z_d = B^* A^{-1} y_d$.

The main idea of the approach used in this paper is as follows. Let it be required to solve the interval problem on an extremum

$$J(b, u) \rightarrow \min, u \in U, \quad (6)$$

where $b \in [b_1, b_2]$. Denote by J_* the function $b \in [b_1, b_2] \rightarrow J_*(b) = \inf J(b, u)$ and assume that $J_* \in L^p(b_1, b_2)$, $p \geq 1$. In the Lebesgue space $L^p(b_1, b_2)$ we consider the set of functions

$$K = \{b \in [b_1, b_2] \rightarrow J(b, u) : u \in U\}.$$

The problem of interval optimization can now be considered as the problem of finding the projection of the function J_* in the space $L^p(b_1, b_2)$ onto the set K , that is, we will search for an element $u \in U$ such that

$$\|J(\cdot, u) - J_*\|_{L^p(b_1, b_2)} \rightarrow \inf, \quad u \in U.$$

Note that the choice of various properties ≥ 1 and various metrics in $L^p(b_1, b_2)$ will lead to different algorithms for solving the interval problem (6).

The application of this approach to the interval problem (1) – (3) leads to the following notion of the *p-universal* solution.

Definition. The element $u_p \in U$ minimizing the functional

$$\frac{1}{2} \int_{b_1}^{b_2} \rho(b) \left(\left((b^2 M + NI) u_p, u_p \right)_U - 2b(u_p, z_d)_U + b^2 ((b^2 D + NI)^{-1} z_d, z_d)_U \right)^p db \rightarrow \inf \quad (7)$$

is called the *p-universal* optimal control of problem (1) - (3), $p > 1$. Here the function $\rho : [b_1, b_2] \rightarrow (0, +\infty)$ is the given weight.

By the *p-universal* optimal state in the interval problem (1) - (3) is defined as

$$y_p = \frac{2}{a_1 + a_2} A^{-1} B u_p, \quad (8)$$

where u_p solves optimization problem (7). A pair $\{y_p, u_p\}$ is called the universal solution of problem (1) - (3).

Note that expression (8) is, in fact, the universal solution of the interval problem

$$aAy = Bu_p, \quad a \in [a_1, a_2],$$

i.e., the element $y \in V$ satisfies the condition $\|aAy - Bu_p\| \leq \varepsilon$ for all $a \in [a_1, a_2]$ with the smallest $\varepsilon > 0$.

EXISTENCE AND UNIQUENESS OF P-UNIVERSAL SOLUTION

The correctness of the introduced concept of the *p-universal* solution of problem (1) - (3) follows from the theorem.

Theorem 1. Let $1 \leq p < +\infty$. Then there exists a unique *p-universal* solution of the interval problem (1) - (3).

Proof. The finding of the *p-universal* solution reduces to the problem of minimizing the functional

$$F(u) = \int_{b_1}^{b_2} \rho(b) \left(\left((b^2 M + NI) w, w \right)_U \right)^p db, \quad u \in U, \quad (9)$$

where $w = u - b(b^2 M + NI)^{-1} z_d$.

Calculate the Gateaux differential of the functional F :

$$F'(u, \varphi) = 2p \int_{b_1}^{b_2} \rho(b) \left((b^2 M + NI) w, w \right)_U^{p-1} \left((b^2 M + NI) w, \varphi \right)_U db, \quad u \in U. \quad (10)$$

Note that the map $F'(u, \varphi)$ is linear and continuous in $\varphi \in U$, since

$$\|F'(u, \varphi)\|_U \leq C \|\varphi\|_U,$$

where $C = 2p \int_{b_1}^{b_2} \rho(b) \left((b^2 M + NI) w, w \right)_U^{p-1} \|(b^2 M + NI) w\|_U db$ does not depend on φ .

To prove the strict convexity of the functional F , we compute the second Gâteaux differential:

$$F''(u, \varphi, \varphi) = 2p \int_{b_1}^{b_2} \rho(b) \left(2(p-1)((b^2M + NI)w, w)_U^{p-2} ((b^2M + NI)w, \varphi)_U^2 + \right. \\ \left. ((b^2M + NI)w, w)_U^{p-1} ((b^2M + NI)^2\varphi, \varphi)_U \right) db, \quad u \in U. \quad (11)$$

Suppose that there exist $u_0 \in U, \varphi \in U, \varphi \neq 0$, such that $F''(u, \varphi, \varphi) = 0$. Then $w_0 = 0$, that is, $u_0 - b(b^2M + NI)^{-1}z_d = 0$, which is false for any b from the admissible interval. Therefore, F is a strictly convex functional.

The functional F is lower semicontinuous, since it is convex and differentiable in the sense of Gâteaux.

The functional F is coercive, since by the triangle inequality $\|w\|_U \geq \|u\|_U - \|b(b^2M + NI)^{-1}z_d\|_U$. Hence $F(u) \rightarrow +\infty$, for $\|u\| \rightarrow +\infty$.

From these properties of F it follows that the problem (1) - (3) has a unique solution.

FINDING THE 1-UNIVERSAL SOLUTION OF THE INTERVAL PROBLEM

Find the p -universal solution for $p = 1$ with different weight functions.

First, choose $\rho \equiv 1$. Then problem (7) reduces to the following:

$$\frac{1}{2} \int_{b_1}^{b_2} \left(((b^2M + NI)u, u)_U - 2b(z_d, u)_U + b^2((b^2M + NI)^{-1}z_d, z_d)_U \right) db \rightarrow \inf. \quad (12)$$

Calculating the integral, it is easy to verify that the unique solution of problem (12) is determined by expression

$$u_1 = \frac{b_1+b_2}{2} \left(\frac{b_1^2+b_1b_2+b_2^2}{3} M + NI \right)^{-1} z_d, \quad (13)$$

Call u_1 – the I -universal optimal control of the problem (1) - (3).

The following quantity is meant by the I -universal optimal state in the interval problem (1) - (3)

$$y_1 = \frac{2}{a_1+a_2} A^{-1} B u_1. \quad (8)$$

A pair $\{y_p, u_p\}$ is called the I -universal solution of problem (1) - (3).

Consider now the presence of 1-purpose solutions for the weighting function $\rho \equiv \frac{1}{b^4}$, $b \in [b_1, b_2]$. Then the problem (7) is reduced to the following

$$\frac{1}{2} \int_{b_1}^{b_2} \left(\left(\left(\frac{1}{b^2} M + \frac{1}{b^4} NI \right) u, u \right)_U - 2 \frac{1}{b^3} (z_d, u)_U + \frac{1}{b^2} ((b^2M + NI)^{-1}z_d, z_d)_U \right) db \rightarrow \inf. \quad (14)$$

In this case, simple calculations show that the unique solution of problem (14) is determined by expression

$$\widetilde{u}_1 = \frac{b_1+b_2}{2b_1b_2} \left(\frac{(b_1^2+b_1b_2+b_2^2)NI}{3b_1^2b_2^2} + M \right)^{-1} z_d, \quad (15)$$

Call $\widetilde{u}_1$ – the I -universal with weight optimal control of problem (1) - (3).

The 1-universal optimal weight in the interval problem (1) - (3) is defined as

$$\widetilde{y}_1 = \frac{2}{a_1 + a_2} A^{-1} B \widetilde{u}_1. \quad (8)$$

A pair $\{\widetilde{y}_1, \widetilde{u}_1\}$ is called the 1-universal optimal weight solution of problem (1) - (3).

THE INTERVAL OPTIMAL CONTROL PROBLEM FOR THE 2-DIFFERENTIAL EQUATION

Consider the interval boundary value problem:

$$\begin{cases} -y_{xx} + y = 0, & \Omega \in (0; 1); \\ ay_x(0) = -u, & y(1) = 0, \quad u \in \mathbb{R}. \end{cases} \quad (16)$$

where $a \in [a_1, a_2]$ is an undetermined coefficient.

The optimal control problem is to minimize the functional:

$$\frac{1}{2} \int_0^1 |y(x) - y_d(x)|^2 dx + \frac{N}{2} u^2 \rightarrow \inf, \quad u \in \mathbb{R} \quad (17)$$

at solutions of the boundary value problem (16). Here, $N > 0$ and y_d is a given function from $L^2(0, 1)$.

Problem (16) is reduced in a natural manner to an operator equation of form (1). Let $V = \{v \in H^1(\Omega), v(1) = 0\}$ be the Sobolev space of functions v that belong, together with their derivative v_x , to $L^2(0, 1)$ and vanish on the right boundary.

Let $H = L^2(0, 1)$. The norms in H and V are defined as $|v|^2 = \int_0^1 v^2 dx$, $\|v\|^2 = \int_0^1 v_x^2 dx$. The operator $A : V \rightarrow V'$ is defined by the relation $(Ay, v) = -(y_x, v_x) + (y, v)$, $\forall y, v \in V$. The operator $B : \mathbb{R} \rightarrow V'$ is defined by the equality $(Bu, z) \equiv uz(0)$, then for $B^* : V \rightarrow \mathbb{R}$ the relation $B^*z = z(0)$ holds.

Since in this case the control space is the set of real numbers $\mathbb{R}$, the operator $M = B^*A^{-1}A^{-1}B$ has exactly one eigenvalue, which is defined by the expression $\mu = z(0)$, where $z = A^{-1}\hat{y}$, $\hat{y} = A^{-1}B(1)$.

Therefore

$$\begin{cases} -\hat{y}_{xx} + \hat{y} = 0, & \Omega \in (0; 1); \\ \hat{y}_x(0) = -u, & \hat{y}(1) = 0, \quad u \in \mathbb{R}, \end{cases} \quad (19)$$

i.e:

$$y(x) = u(-th(1)ch(x) + sh(x)).$$

Correspondingly, we arrive at the following nonhomogeneous boundary-value problem:

$$\begin{cases} -z_{xx} + z = y, \\ z_x(0) = 0, z(1) = 0. \end{cases} \quad (20)$$

Then the solution of problem (20) takes the form

$$z(x) = \int_0^1 G(x, s)y(s) ds,$$

where the Green's function

$$G(x, s) = \begin{cases} \frac{-1}{2(e^2 + 1)}(e^s - e^{2-s})(e^x + e^{-x}), & x < s; \\ \frac{-1}{2(e^2 + 1)}(e^x - e^{2-x})(e^s + e^{-s}), & x > s. \end{cases}$$

Thus, we find the eigenvalue $\mu = z(0) = \frac{e^4 - 4e^2 - 1}{2(1 + e^2)}$. In this case, the following results are consequences of the abstract Theorem 1.

Theorem 2. *Let $0 < a_1 < a_2$. Then there exists a unique 1-universal control of the problem (16), (17):*

$$u_1 = \frac{b_1 + b_2}{2} \left(\frac{(b_1^2 + b_1 b_2 + b_2^2)(e^4 - 4e^2 - 1)}{6(1 + e^2)} + N \right)^{-1} z_d,$$

where $z_d = B^* A^{-1} y_d$.

Taking into account the definition (8), we obtain the universal optimal state of problem (16) - (17):

$$y_1 = \frac{2}{a_1 + a_2} A^{-1} B u_1$$

where u_1 is the unique 1-universal control of problem (16) - (17) with unit measure.

Now consider the finding of the 1-universal solution to the problem (16) - (17) for the weight function $\rho \equiv \frac{1}{b^4}, b \in [b_1, b_2]$.

Theorem 3. *Let $0 < a_1 < a_2$. Then there exists a unique 1-universal with weight control of the problem (16), (17):*

$$\widetilde{u}_1 = \frac{b_1 + b_2}{2b_1 b_2} \left(\frac{(b_1^2 + b_1 b_2 + b_2^2)N}{3b_1^2 b_2^2} + \frac{e^4 - 4e^2 - 1}{2(1 + e^2)} \right)^{-1} z_d,$$

where $z_d = B^* A^{-1} y_d$.

Taking into account the definition (8), we obtain the universal optimal state of problem (16) - (17):

$$\widetilde{y}_1 = \frac{2}{a_1 + a_2} A^{-1} B \widetilde{u}_1,$$

where $\widetilde{u}_1$ is the unique 1-universal control of problem (16) - (17) with measure $\rho \equiv \frac{1}{b^4}$.

Example 1. Let $a_1 = 1, a_2 = 1.1$. Figure 1 shows the values of the functions $J(u_1, y_1)$ and $J(\widetilde{u}_1, \widetilde{y}_1)$ and the graph of the objective function y_d and 1-universal optimal state y_1 and 1-universal with the weight of the optimal state $\widetilde{y}_1$ for different values of the parameter N .

$$N = 1$$

$N = 0.1$

$N = 0.01$

Fig. 1. Functions y_d , y_1 and $\widetilde{y}_1$ for different N .

These graphs illustrate the effect of reducing the influence of uncertainty on *1-universal* optimal states by reducing the weight parameter N . Note that with a small uncertainty interval, the 1-universal and the 1-universal with weight optimal states in this example almost coincide.

Example 2. Let $a_1 = 1$, $N = 0.01$. In Fig. 2 there is a graph of the objective function y_d and the 1-universal optimal state y_1 and the 1-universal with the weight of the optimal state $\widetilde{y}_1$ for different values of the parameter a_2 .

$a_2 = 2$

$a_2 = 5$

Fig. 2. Functions y_d, y_1 and $\widetilde{y}_1$ for different a_2 .

Thus, the solution of the interval control problem on the basis of the proposed concept of the 1-universal optimal state makes it possible to compensate for the influence of uncertainty due to the choice of the regularizing parameter N .

Example 3. Compare the values of the functional $J(y, u)$ by 1-universal and 1-universal with the weight of optimal solutions. Let $a_1 = 1, a_2 = 1.1$ and $N = 0.01$. Having carried out a numerical experiment, obtain

$$J(u_1, y_1) = 0.3644, J(\widetilde{u}_1, \widetilde{y}_1) = 0.3644;$$

As we noticed from the first experiment, for a small interval, 1- universal and 1-universal with weight solution and, correspondingly, the value of the functionals coincide. Let a_1 and N remain unchanged, take $a_2 = 2$:

$$J(u_1, y_1) = 0.7740, J(\widetilde{u}_1, \widetilde{y}_1) = 0.6996;$$

Hence it follows that with an increase in the uncertainty interval, it is preferable to use a 1-universal with weight optimal solution. With an even larger increase in the interval, the value of the functionals $J(u_1, y_1)$ and $J(\widetilde{u}_1, \widetilde{y}_1)$ increases, but nevertheless, the use of 1-universal with the weight of the optimal solution leads to a better result. This is illustrated by the following example.

$$J(u_1, y_1) = 2.5641, J(\widetilde{u}_1, \widetilde{y}_1) = 2.0834;$$

The indicated calculations show that in this example it is preferable to use the 1-universal with weight optimal solution.

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MODELING OF COMMUNICATIVE INTERACTION

Smekhun Ya. A., Artemieva I.L.

Far Eastern Federal University

Vladivostok, Russia

Artemeva.il@dvfu.ru

Abstract - This article devoted to human communication modeling. Communicative interaction is very complicated process which has many different features for proper modeling in the computer. Here is described several of them.

Key words – modeling; communicative interaction; culture; language; ontology

INTRODUCTION

Human languages are extremely complex systems. It is very complicated for the computer to understand the meaning of communications through the text, having not enough information about all details of communicative interaction. Communicative interaction is very complicated process which has many different features for proper modeling in the computer. Here is described several of them.

COMMUNICATIVE INTERACTION

Our research started from working up project devoted to designing the prototype of education system in intercultural communication based on text-processing methods.

First of all we chose essential terminology from the vocabulary of intercultural communication [4] which will lead us through our research.

We used the most general of them.

Culture- cumulative conduct of life of certain people groups.

Communication - contact, information transfer through system of signals between a source of information and the receiver.

Intercultural communication - exchange of information between representatives of different cultures.

Communicant – a person with his own world view, taking or delivering information

In this three meaning we can found a great number of factors which influenced into the result of communication. Among these factors could be: different culture types of communicant, the purpose of communication, the meaning of communication and others.

Communicative situation has it's own structure:

1. communicants (source of information and receiver)
2. place of communication
3. time of communication
4. relationships between communicants
5. purpose
6. meaning of communication

At the same time every part of above structure has it's individual characteristics. Communicants have such nature as nationality, country of residence, culture, standards of behavior, religion, world view, thinking model, values and ideals.

Our problem is to create a detailed model of each features of communicative interaction.

MODELLING

A. Linguistic approach

The object of linguistic processors are the texts of the Natural language (NL). Texts have several levels:

1. level of sentences (statements) – syntactic level;
2. level of words – morphological level;
3. level of phonemes – phonologic level.[3]

The formal models of language are considered as components of different application-oriented systems. The system component which realizes the formal linguistic model and realizes semantic processing of texts in a natural language is called the linguistic processor (LP). This LP has three levels of text representation: morphologic, syntactic and semantic. Each of levels is served by the corresponding component of model – an array of rules and dictionaries. The sentence of the text has it's own structure on each level. In general the linguistic processor provide execution of the following conversions: sentence in natural language → morphologic structure → syntactic structure → semantic structure. Morphologic and syntactic structures studded pretty well, but semantic structure needs more investigation.

The main purpose of semantic modeling is to define the text interpretation. In this research modeling can help to categorize information of the text.

Consequently we observed the well known model (1)

MEANING

TEXT

(1)

There are four main components in this model.

1. semantic component
2. syntaxes component
3. morphological component
4. phonological component

For effective representation of knowledge about subject domain the ontology has to provide the description of concepts with complex structure and various semantic links between them. The important requirement to ontology of the portal is the possibility of concepts

forming of subject domain in hierarchy "common - part" and support of inheritance of properties on this hierarchy [3].

Semantic models are less developed. For the semantic analysis of sentences, case grammars and semantic cases (valencies) were proposed, on the basis of which the semantics of the sentence is described both through the links of the main word (verb) with its semantic cases

To represent the semantics of the entire text, two logically equivalent formalism are used:

1. Formulas of the predicate calculus expressing properties, states, processes, actions and relations;
2. Semantic networks - marked graphs, in which the vertices correspond concepts, and the tops - the relationship between them.

B. Mathematical approach

The model (1) effectively uses a large number of data on each word of the considered language. These data can be presented in the special dictionary.

There aren't enough grammar of language knowledge for the successful solution in semantic analysis of texts in a natural language. It is also important to have the knowledge about terminology in specific subject domain. At the expense of information obtained at a stage of the sentence semantic analysis the syntactic tree is corrected that helps to correct mistakes in role structure of the statement. That is why we use the ontology which has such knowledge. The method allows to increase the quality of both the syntactic, and semantic analysis. The ontological model of semantics based on a role sentence structure allows us to abstract from syntactic sentence trees and match up grammar structures with semantic structures.

There are different kinds of methods of both the syntactic and semantic analysis which based on different syntactic structure models of sentences and various understanding of semantics.

Dependency trees design a syntactic sentence structure in the form of words hierarchy. All words are connected by the arches designating syntactic words submission. The submission is caused by a set of the general principles which mean that the dependent word in the sentence is specifying, optional and not important for transferring the sense of the sentence.

The ontological model of semantics based on a role sentence structure allows us to abstract from syntactic sentence trees and match up grammar structures with semantic structures.

An ontology is a formal, explicit specification of a shared conceptualization [1-2].

Conceptualization refers to an abstract model of some phenomenon in the world by having identified the relevant concepts of that phenomenon.

Explicit means that the type of concepts used, and the constraints on their use, are explicitly defined.

Formal refers to the fact that the ontology should be machine-readable.

The ontology defines the basic terms and relations comprising the vocabulary of a topic area as well as the rules for combining terms and relations to define extensions to the vocabulary. Every word could be identified as the link of understanding information in the computer.

Here is an example of Culture types model ontology

Sort Countries: $\{ \} N \setminus \emptyset$

Sort Culture: $\{ \} N \setminus \emptyset$

Sort Culture types: $\{ \} N \setminus \emptyset$

Sort Culture of the country: Country $\rightarrow \{\}$ Culture type

Sort Characteristics: $\{\}N \setminus \emptyset$

Sort Culture characteristics: Culture types $\rightarrow \{\}$ characteristics

Sort Set of characteristics meaning: (Characteristics $\rightarrow \{\}NU \sqcup IU \sqcup R$)

Sort characteristics meaning for the Culture: $((T \rightarrow \text{Culture types}, X \rightarrow \text{Culture characteristics (V)}) \rightarrow \{\}NU \sqcup IU \sqcup R$

This short ontology shows us general characteristics of culture types and their influence on communication.

CONCLUSION

The syntactic and semantic analyses are solved separately: at first the syntactic sentence structure and then the semantic structure which based on previous one. There is a dependence of syntactic mistakes in the normal work of semantic analysis and vice-versa.

In this research the method of the semantic-syntactical analysis is studied. This method has integrated procedure of syntactic dependency trees creation and definition of role structures of statements. For the successful solution in semantic analysis of texts in a natural language there aren't enough grammar of language knowledge. It is also important to have the knowledge about terminology in specific subject domain. That is why we decided to create the ontology which has such knowledge and then design a system based on it.

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KNOWLEDGE BASE CLOUD SIMULATOR FOR DRUG TREATMENT PRESCRIPTION

Krasnov D.¹, Gribova V.V.^{1,2}

¹ Far Eastern Federal University

² Institute of automation and control processes FABRAS

Vladivostok, Russia

mrhantbk@gmail.com

Abstract— This article describes the basic principles of development a computer simulator for drug treatment prescription that do not depend on the area of medicine.

Keywords—intelligent system, ontology, medicine, drag treatment, simulator

INTRODUCTION

Nowadays there is a situation when the volume of medical knowledge is doubled annually, but the means of adaptation of this knowledge to practical use are developed insufficiently.

A sufficiently large number of various intelligent medical systems as well as training simulators are being developed, but most of them are highly specialized systems designed for treatment prescription of a disease or group of diseases. Also, their disparate use significantly worsens the result.

The urgent task for today is the development of a knowledge base cloud simulator for drag treatment prescription using the same resources and having the same interface for efficient development and use.

The purpose of this work is to describe the basic principles of development and the conceptual architecture of a knowledge base cloud simulator for drag treatment prescription in medicine education.

BASIC REQUIREMENTS AND PRINCIPLES OF CREATING A KNOWLEDGE BASE CLOUD SIMULATOR FOR DRAG TREATMENT PRESCRIPTION

The knowledge base management system in a knowledge base simulator is based on a problem-oriented model of representation of knowledge and data that is developed taking the specificity of the domain (medicine) into account. It contains a set of ontologies for building knowledge bases and databases. Each ontology is a concept network understandable by domain experts and a basis for knowledge bases and databases forming without knowledge engineers and system analysts. Ontologies are represented as graphs with cycles and loops.

The simulator was developed with the IACPaaS platform [2]. IACPaaS is a software cloud platform for support of development, control and remote usage of applied and instrumental multi-agent cloud services (primarily intellectual ones) and their components. The platform is based on cloud computing technology and provides users remote access to intelligent systems, and remote access of developers to means of their creation and control. Figure 1 presents conceptual architecture of a simulator.

Fig. 1. Conceptual architecture of a knowledge base cloud simulator for drug treatment prescription

CONCEPTUAL SHELL ARCHITECTURE

The medical simulator for virtual patient prescription of treatment and treatment correction is developed for testing of medical treatment prescription skill, as well as for testing the treatment correction skill, the test results are produced during repeated execution of training and control tasks. Tasks are represented by patient case records with a prescribed diagnosis and a set of observations. One of the most important elements of the simulator is the explanation system for treatments prescribed by students.

Similarly to the case of diagnostic simulator creating a simulator for training the prescription and drug treatment skills consists in reusing ontologies and knowledge bases of the expert system for personalized treatment prescription, prognosis and monitoring. The simulator specific components are also used: the task bank and student information, which are shared by the diagnosis simulator and the simulator for prescription of treatment and treatment correction. The simulator requires the following set of ontologies and matching databases: ontology for pharmacological reference book, ontology for bases of knowledge about disease treatment, ontology for bases of knowledge about treatment prognosis, ontology of medical treatment and correction, ontology of the explanation of the prescribed treatment and correction, ontology for bases of case records, ontology for the task bank, and ontology for information about the student. Additionally, the following ontologies have been developed:

The ontology of medical treatment and correction. The problem solver uses this ontology for creating the structure on the basis of which student's answer to the task that assigned to him is created; the task is prescription of drug treatment and subsequent correction for the given case report.

The ontology of the explanation of the prescribed treatment and correction specifies the information students need for understanding how properly the prescription of treatment for a specific case report was executed and how properly the treatment was corrected. The simulator problem solver uses this ontology for building the result of the task executed by the student.

Figure 2 presents all set of ontologies and knowledge base management system for simulator at all.

Fig. 2. Knowledge base management system

CONCLUSION

The development of a cloud simulator for drug treatment prescription is an urgent problem.

The article describes the most important requirements for the creation of a knowledge base cloud simulator, the conceptual architecture of the simulator and its components is examined in detail. Part of the information resources, such as the ontology of the medical history, and software components.

Work continues the creation of algorithms for problem solvers.

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INTELLIGENT TEACHWARE SERVICE FOR DISEASE DIAGNOSTICS

Ostrovskiy G.¹, Gribova V.V.^{1,2}

¹ Far Eastern Federal University

² Institute of automation and control processes FEBRAS

Vladivostok, Russia

nofu95@gmail.com

Abstract— This article describes the basic principles of development and the conceptual architecture of a specialized shell for creating intelligent diagnostic systems in medicine and education.

Keywords— program shell, intelligent system, ontology, medicine, diagnostic system, simulator

INTRODUCTION

Currently, a sufficiently large number of various intelligent medical diagnostic systems as well as training simulators are being developed, but most of them are highly specialized systems designed to diagnose or teach the diagnosis of a disease or group of diseases. Also, their disparate use significantly worsens the result.

To accelerate and simplify the process of developing intelligent systems, a class of instrumental systems such as universal and specialized software shells of Information systems that are intelligent systems with an empty or partially filled knowledge base are widely used [1]. Universal shells are based on the use of some universal language representation of knowledge. In specialized wrappers, a knowledge-based schema is used to represent knowledge, defined by the ontology of the domain for which the shell is created, which makes it possible to create a knowledge base for the domain expert without the participation of programmers, since the knowledge base is within the competence of domain experts.

Thus, the urgent task for today is the development of a specialized shell designed to create intelligent medical systems for diagnosing and teaching diagnostics using the same resources and having the same interface for efficient development and use.

The purpose of this work is to describe the basic principles of development and the conceptual architecture of a specialized shell for intelligent diagnostic systems in medicine and education.

BASIC REQUIREMENTS AND PRINCIPLES OF CREATING A SHELL FOR INTELLIGENT DIAGNOSTIC SYSTEMS IN MEDICINE AND EDUCATION

The specialized shell is designed to create on its basis two large classes of intelligent systems: a diagnostic system for acute and chronic diseases and syndromes and simulators for

teaching diagnosis. Each of these classes includes appropriate systems designed to diagnose or teach the diagnosis of any disease, regardless of the division of medicine. Thus, ontologies, which are one of the main components of the shell, also should not depend on the division of medicine.

The shell for intelligent diagnostic systems in medicine and education should be implemented as a cloud service. This requirement is due, first, to the maximum availability of intelligent systems created based on the shell for a wide audience of users - doctors and students, and secondly, cloud technologies are an excellent way to preserve the viability of any complex software package, because throughout the life cycle all components are available for maintenance. To fulfill this requirement, the cloud platform IACPaaS [2] is chosen, which is an Internet complex to support the development, management and remote use of application and tool multi-agent cloud services (primarily intellectual) and their components.

CONCEPTUAL SHELL ARCHITECTURE

The architecture of the specialized software shell consists of information and software components. Details of the shell architecture in Fig. 1.

Information components include ontologies, databases and knowledge. Ontologies are necessary for the users of the system - they could create and modify the corresponding knowledge and data bases.

The software components that support the processing of data and data constitute a knowledge management system, task solvers, a knowledge editor and an inductive educator of the knowledge base for diagnosis.

All user users can be divided into the following groups:

- Doctors are a group of users who solve by the diagnostic system the task of obtaining a diagnosis, possible diseases and necessary studies based on the patient's medical history.
Students - a group of users, which solves the problem with the help of training subsystem skills training in various diagnostic situations. In the framework of this task, they should be able to carry out assignments, get acquainted with the results of these assignments, and view personal training statistics.
- Domain experts are a user group that builds a knowledge base on the diagnosis of diseases and the base of observations and provides their modification during the life cycle of the shell: they form a variety of diseases, a lot of observations, determine the links between a disease and a set of observations to be considered in this disease, indicate what value (or a set of values) has this or that observation in a disease.

Figure 1. Conceptual shell architecture

Figure 2. Problem Solver architecture for Learning

- Teachers - a group of users who are responsible for the formation of a bank of tasks and assignment of tasks to students. They should be able to view the general statistics of student learning.
- Administrators - a group of users that maintain information about students in the current state.

Information components

Information components of the specialized shell include the following ontologies, knowledge bases and data on them formed:

- Ontology of medical terminology and observations. It includes a description of medical terms and observations, as well as specific characteristics, factors, events, the name of characteristics, the value of observations. The information resource generated by this ontology - the base of medical terminology and observations is formed by experts of the domain; its contents are used in the formation of knowledge bases on diagnosis of diseases and the database of patient records described below.
- Ontology diagnosis of diseases and syndromes. Ontology defines the structure of terms for describing knowledge about the diagnosis of diseases and syndromes (which includes a description of their clinical pictures), their causes (given by etiologies).
- Ontology of medical history. The ontology of the medical history sets the structure of the description of the patient's specific medical history. As this component in the development of the system used ontology of the medical history. The history of the disease is a description of the patient's condition at the time of the examinations and before entering the clinic: the values of events, signs, and anatomical and physiological characteristics are specified.
- Ontology of tasks. Within the framework of the developed system, the task is understood as the totality of the patient's medical history, the disease (to be determined by the learner) and the identifier of this task (name or number). The ontology of tasks describes the terms needed to describe the specific exercise. This ontology will be described below. The job bank contains the exercises formed based on ontology by the teachers.
- The ontology of the explanation of the diagnosis contains a description of the structure of information for the results of the diagnostic system carried out: the diagnosed or confirmed hypotheses, rejected hypotheses, the necessary studies to clarify the diagnosis.
- Ontology of the student. The ontology of the trainee information describes the information needed to identify the user of the system, such as passport data and job execution statistics. This ontology will be described below.
- The ontology of explaining diagnostic results describes the information that will be provided to the trainees so that they can understand how correctly they have performed the diagnosis of a patient, what observations from the set of them formed, or are not included in the clinical picture of the disease

Software components

The program components of the simulator include the solver of problems for the diagnosis of acute and chronic diseases, the solver of problems for learning the diagnosis, the knowledge base management system, and the inductive diagnostic knowledge base.

The problem solver for the diagnosis of acute and chronic diseases is used directly for diagnosis. Based on the medical history either a specific diagnosis is made, or several possible hypotheses about the diagnosis are put forward, indicating which studies need to be carried out to clarify it.

The solver of tasks for teaching diagnosis is divided into three subsystems: teaching, teaching, and management. Fig. 2 shows in detail what information resources a subsystem uses. It is worth noting that the learning subsystem is not programmed with software and management subsystems, but they use the same information resources.

The training subsystem is used directly for the implementation of training and control tasks for diagnosis, as well as for viewing personal statistics. The learning subsystem consists of two modules: the training module and the control module, which in turn are divided into several submodules: selection, execution and verification of the task, generation and viewing of statistics.

With the help of the task selection module, the trainee from the job bank can choose either an arbitrary job or a teacher assigned to him and then proceed with its execution in the task execution module. When completing a task, the trainee can request an additional set of observations from the observational database. After the trainee, has completed the task (diagnosed), it is sent for verification to the task verification module and explaining the results of the task.

Because of the ontology check-up module explaining the diagnosis, an information resource "Results of the task assignment task and explaining the results" is generated, which can be viewed by the learner and which is subsequently used to generate his statistics.

The management subsystem is used by administrators to support user information in the current state

The teaching subsystem includes modules for the formation and assignment of tasks, the statistics of the trainee. The task generation module is necessary for filling and modifying the job bank. The task assignment module allows you to assign a task or group of tasks to a student or group of students. In the statistics viewer, the teacher can view the statistics of a student or a group.

The knowledge editor is designed to form and modify the knowledge base and data by domain experts. The editor is IWE, which was developed earlier and is part of the IACPaaS platform.

BRIEF DESCRIPTION OF THE ONTOLOGY OF DIAGNOSIS OF DISEASES

A modified ontology for diagnostics of diseases and syndromes is developed, based on the ontology described in the following works [3], [4].

The ontology of medical diagnosis of diseases and syndromes defines the structure of the description of diseases and syndromes, those of their components that are necessary for their diagnosis.

The structure of the disease description consists of a description of diseases and groups of diseases. Each Disease Group may contain diseases of this group, a group of lower-level diseases and a general clinical picture of the disease group.

Each Disease can contain forms of the disease, the necessary conditions for this disease and the overall clinical picture of the disease.

Each Form of the disease may contain variants of the course and a clinical picture of the form of the disease. Each Variant of the course of the disease contains a description of the clinical picture of the variant of the course of the disease.

The general clinical picture of a group of diseases, the general clinical picture of the disease, the clinical picture of the form of the disease, the clinical picture of the variant are several symptoms of the disease. The general clinical picture of the disease also contains the names of the syndromes included in it.

Each Symptom can represent one of the following structures: Characteristics group for dynamics periods, Characteristics group (without dynamics), Simple Symptom without dynamics, Simple Symptom for dynamics periods.

Characteristics group for the periods of dynamics determines the periods of the dynamics of the development of the feature and the conditions for the presence of the trait. Each Dynamic Period contains the upper and lower bounds of the duration of the period, the unit of measurement of the boundaries, and a description of all characteristics of the characteristic in that period. Each characteristic may have several intrinsic characteristics or contain a modality of the entry of characteristic characteristics into the clinical picture, as well as many variants of the dynamics of this characteristic. Each Variant of Performance Dynamics contains a variety of possible characteristic values, as well as a description of the change in the value of this characteristic under the influence of certain events.

A group of characteristics (without dynamics) specifies a description of all characteristic characteristics and conditions for the presence of a characteristic. Each characteristic can have several intrinsic characteristics or contain a modality of the entry of characteristic characteristics into the clinical picture, a set of possible characteristic values, and a description of the change in the value of this characteristic under the influence of certain events.

A Simple Symptom without dynamics contains the modality of the entry of a symptom into the clinical picture and the set of possible values of the trait.

A Simple Symptom for the periods of dynamics sets the periods of the dynamics of the development of the trait, the modality of the entry of the trait into the clinical picture and the conditions for the presence of the trait. Each Dynamics Period contains the upper and lower limit of the period duration, the unit of measurement of the boundaries, and the set of variants of the characteristic dynamics in this period. Each Variant of Dynamics sets a set of possible values for the characteristic.

The structure of the syndrome description consists of a description of syndromes and syndrome groups. Each Syndrome Group may contain syndromes of this group and groups of lower-level syndromes. Each Syndrome contains a clinical picture of the syndrome.

CONCLUSION

The development of a specialized shell for the creation of intelligent medical systems for diagnosis and training is an urgent problem.

The article describes the most important requirements for the creation of a specialized shell for the creation of intelligent medical systems for diagnosis and training, the conceptual architecture of the shell and its components is examined in detail. Part of the information resources, such as the ontology of the medical history, and software components.

To date, described and recorded on the ontology platform of observation and diagnosis of diseases, work continues the creation of algorithms for problem solvers.

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HARDWARE-SOFTWARE COMPLEX FOR EVALUATING THE ROUGHNESS OF THE QUENCHING WHEEL

Chokha I. V.

Far East Federal University

Vladivostok, Russia

ivan_chokha@mail.ru

Abstract—The article describes the device model for estimating the roughness of the copper quenching wheel that is used in the spinning unit. The roughness control methods are considered and the most optimal one is chosen. The developed system allows to quickly estimate the roughness of the side surface of the wheel, during its rotation. The system was based on a laser optical system and a microprocessing unit.

Keywords—spinning unit; surface roughness; CCD ruler; laser; non-contact method; Arduino; quenching wheel

INTRODUCTION

Nanocrystalline materials are polycrystals with an average grain size of less than 40 nm. At present, they are of great scientific and applied interest. The scientific interest is primarily related to the expectation of various size effects in the properties of nanoparticles and nanocrystals whose dimensions are commensurable or smaller than the characteristic correlation scale of a particular physical phenomenon or process (for example, the mean free path of electrons, the coherence length in superconductors, the wavelength of elastic vibrations, the size of the exciton in semiconductors, the size of the magnetic domain in ferromagnets, etc.).

One way to create nanocrystalline structures is the crystallization of an amorphous alloy. Amorphous alloys can be obtained by various methods, which are based on the rapid transition of the alloy components from the liquid state to the solid state. The most common way of obtaining amorphous alloys is spinning. Spinning is the process of producing amorphous alloys

film, by rapidly cooling the melt on a rotating disc or drum [1]. Amorphous and nanocrystalline alloys in the form of tapes are created in the process of rapid quenching on a fast-rotating copper wheel. The resulting tapes are used to study nanocrystalline structures.

Service properties and geometry determine the quality of amorphous and nanocrystalline rapidly quenched tapes. The level of service properties is laid when developing the alloy composition. But it should be borne in mind that it can be achieved only by obtaining ribbons of a certain geometry. The latter is associated with a significant dependence of the cooling rate of the melt and tape on its thickness and the quality of the contact surface [2]. Thus, one of the parameters affecting the quality of the tape is the surface roughness of the wheel. During the quenching process, defects appear on the quenching wheel, which further impairs the casting parameters. To eliminate defects, multi-stage polishing is used, the results of which are evaluated visually by a specialist. Therefore, it is not possible to formalize the parameter of roughness and to establish the functional dependence of the properties of the tape on the quality of polishing of the quench surface. At the current time, there are many methods for monitoring the surface roughness, which allows a very accurate assessment of the microrelief. In most of them, a set of any photoreceiver with a microcontroller is used, which, in turn, estimates the necessary parameter, based on the received signals.

The creation of an automated roughness evaluation system will allow obtaining in a digital form a polishing quality parameter and, thus, setting similar conditions for different experiments.

METHODS ANALYSIS

Review of existing methods

Several works have been devoted to the analysis and development of roughness control methods [3-7]. Most of the methods find practical application, either in production processes or in precise scientific measurements.

The existing methods of controlling the microrelief can be divided into three groups:

- Non-contact comparison method;
- Mechanical contact method;
- Optical method;

In the comparison method, the surface under investigation is compared with a sample that satisfies the requirements of GOST 9378-93.

This method is quite simple and accessible, it provides a reliable surface estimate with a roughness of a few micrometers in size [8]. Comparison microscopes are used to control cleaner surfaces. Typically, modern comparison microscopes have two identical conjugate optical paths with independent illuminators and one common visual bridge, in which images of the sample and the monitored surface are combined. Thus, we can compare two surfaces that are simultaneously or separately seen in the field of view of the eyepieces of the binocular nozzle [9]. The disadvantage of the method is a high measurement error, since the result depends on the subjective skills of the measuring person.

The mechanical contact method is quite common in the implementation of probe devices. This group of instruments includes profilographs that record an enlarged image of the surface profile, and profilometers that display on their scale the arithmetic mean deviation of the R_a profile. When using the contact method for measuring the surface roughness, the diamond needle consistently touches the controlled surface. The needle axis is perpendicular to the surface, and

the needle itself has a conical shape with a very small tip rounding radius ($0.7 \div 1.3 \text{ }\mu\text{m}$) [10]. During the movement of the needle along the surface, it performs micro-displacement in the direction of its axis: it descends into the pits and rises on the protrusions, in accordance with the bent profile. Typically, these micro-displacements are converted into electrical signals using an electromechanical transducer. Then the signal is amplified and enters the recording device, where its parameters are measured, or the corresponding profilogram is recorded in a preselected scale.

The optical method is a non-contact method for measuring roughness. That is, it makes measurement of roughness parameters without mechanical interaction with the controlled surface [11]. Now, the following methods are most widely used for non-contact roughness measurements: light-section methods, laser ellipsometric and triangulation methods and also interferometric method.

In the light-section method, the measurements are made as follows. Through a narrow slit about 0.1 mm wide, light is incident on the controlled surface at an angle α . The reflected rays through the lens transfer the image of the slit to the photodetector. The rough surface distorts the image of the slit and a curved luminous line is observed in the plane of the eyepiece. The height of microroughness is measured by a micrometer from the target line. On modern devices operating on this principle, it is possible to measure irregularities in height from 0.8 to 62.5 μm with an error of 24 to 7.5% [8].

A method based on an analysis of the polarization of light reflected from a controlled surface is called ellipsometric. Usually, in such measurements, a laser is used as a radiation source. The parameters of the reflecting object are measured in terms of the polarization angles [12].

The laser triangulation control method is based on calculating the desired distance through the triangle relationship using known system parameters. It allows to measure both the absolute value of the distance from the sensor to the monitored object, and the relative variation of this distance. Moreover, the controlled distance can have a scale from several micrometers (for example, when controlling the surface of crystals in microelectronics) to several hundred and thousand meters (with geodetic measurements).

The interferometric method is realized by the combination of the Michelson interferometer and a measuring microscope, which makes it possible to increase the image of the interference pattern in the required number of times in the microscope field of view. The source of light is a laser that passes through the separation prism and divides into two beams of equal intensity. The first beam hits the surface under investigation and is partially reflected back to the prism from which it is reflected on the screen. The second beam falls on the mirror and almost everything is reflected back, passes through the prism and falls on the same screen. As a result, an interference pattern is formed on the photodetector screen, along which the unevenness of the sample profile can be measured.

Thus, each of their methods has its own characteristics, which make it possible to use one of them in some cases and unacceptable in other cases.

The choice of the optimal method

For the beginning, it is necessary to make an overview of the installation and to formulate certain requirements for the method of assessing the roughness.

The evaluation system for the roughness of the quenching wheel will be developed for the quick quenching installation Melt Spinning SC manufactured by Edmund Bühler GmbH. One of

the main parts of the spinning unit is the chamber into which the quenching wheel is placed. The chamber is a cylinder with a diameter of about 400 mm. Inside the chamber there is a motor on which a copper wheel with a diameter of 200 mm is attached.

During polishing the wheel rotates and the camera remains open. Evaluation of the surface of the wheel rim should be done promptly, during the rotation of the wheel, and for this, the sensors of the roughness control system must be fixed to the wall of the chamber. Since the control will be performed during the rotation of the wheel, this circumstance makes the application of the contact method impossible, because it is very sensitive to vibrations and is suitable for measuring objects moving at a very low speed. Since the quenching wheel is supplied in one copy, the comparative non-contact method will also be ignored. It remains to consider the optical methods for estimating the surface roughness.

The small space inside the chamber, in which the hardware complex can be placed, imposes certain possibility limitations of using some optical methods. The second requirement is the simplicity of structure implementation. The method of the light section assumes the presence of a slit and an objective in the design, the ellipsometric method - polarization filters, and the interferometric method - mirrors and a semi-transparent prism. In addition, the latter is sufficiently sensitive to vibrations, which requires the presence of certain damping structures. Therefore, the project will use the simplest, triangulation method with some changes.

Schematic diagram of the triangulation meter is shown on Fig. 1. The first part of the circuit is an emissive channel, which consists of a laser diode and an objective that forms a probing beam on the monitored surface. The second part of the triangulation measuring system is a controlled surface. Each surface has the property of reflecting or scattering incident emissive. Scattering of emissive by the surface of a controlled object is used in triangulation as a physical basis for obtaining information about the distance to this surface. The third part of the triangulation meter is the receiving channel, which consists of a projecting lens and a photodetector. The projecting lens forms the image of the probe spot in the plane of the photodetector.

The diagram of the triangulation meter, shown in Fig. 1, works as follows. The emissive channel forms the image of the light spot on the monitored surface. Then the light diffused by the controlled surface enters the receiving channel. Thus, in the photodetector plane, the image of the illuminated portion of the monitored surface is created (light spot). When the controlled surface is displaced by dy (Fig. 1), the light spot in the photodetector plane is displaced by the value dS in

$$dy = \Delta S a_1 / (a_2 * \sin \alpha - \Delta S * \cos \alpha) \quad (1)$$

where α is the triangulation angle between the optical axes of the emissive and receiving channels. a_1 is the distance from the emissive source to the lens of the receiving channel, and a_2 is the distance from the lens to the photodetector.

However, since the roughness is eliminated by sandpapers, with sufficiently large abrasive grains, this circumstance makes it possible to soften the requirements for the roughness measurement accuracy. This allows us to make the design of the system: remove the eyepiece from the receiving channel and use a set of CCD rulers placed at different angles to the monitored surface. Thus, the laser beam reflected from the surface will partially fall on the CCD rulers, and when displacement dy , the points of the intensity of the reflected components on the CCD rulers will also be displaced. Taking the readings from the CCD rulers to the microcontroller at each time, it is possible to calculate the relative displacement of the intensity

points on the rulers. The average value of this displacement will be a characteristic of the wheel surface roughness.

DEVICE MODEL

As a control and data processing device, the Arduino microcontroller was chosen. This platform has a number of advantages over other similar devices:

- Arduino is a cross-platform system - Arduino software runs under Linux, Mac OS X and Windows;

Fig. 1. Schematic diagram of a triangulation meter

- In the Arduino range, there are a large number of available device options that have parameters that vary widely. This allows to choose the most suitable controller for a particular case;
- Free license for hardware and software;
- Currently, the Arduino platform has acquired many fans around the world. Because of the larger community of users, on the Internet it is almost always possible to find solutions to various problems associated with Arduino [13].

For the most accurate measurement of roughness, it is better to use a shortwave laser with sufficient power so that after reflection, the beams falling on the CCD rulers can be fixed. For this, a laser with a power of 500 mW and a wavelength close to 405 nm was selected.

The CCD line should be compact enough and have interfaces that allow it to interact with Arduino. For this, the TCD1201D line, manufactured under the Toshiba brand, was chosen, as it is quite common and showed itself well when working with Arduino in many projects.

The conceptual diagram of the device is shown in Fig. 2. The roughness calculation will be performed by Arduino based on the signals received from the CCD lines. The result will be promptly displayed on the LCD, for example, LCD1602. Signals in the CCD-line are obtained as a result of the photoelectric effect, which arises when the laser hits the ruler. The higher the intensity of the incident beam, the higher the signal level. The Arduino input signal values from 0 to 256, characterizing the roughness (the higher the value, the smoother the surface).

Figure 3 shows the circuit diagram of the CCD-line connection to Arduino. The TCD1201D is a high sensitive and low dark current 2048-elements linear image sensor. The sensor can be used for POS handscanner.

Fig. 2. Device diagram for evaluating the roughness of the quenching wheel

Fig. 3. The circuit diagram of the CCD-line connection to Arduino

The device is operated by only 5V power supply, and mounted in 22-pin cerdip package hermetic sealed optical glass window.

CONCLUSION

In this paper, we analyzed the possible methods of controlling the roughness. The requirements for the methods are assigned and the most optimal one is chosen. Based on the chosen methods, a device model was developed, which makes it possible to quickly evaluate the surface roughness during wheel rotation. This system allows us to formalize the roughness index and use it, for example, to prepare the same experimental conditions.

In the continuation of the study, a roughness evaluation complex will be assembled and the error of this method will be assessed by the experimental method.

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**СТАТИСТИЧЕСКИЙ АЛГОРИТМ ПОСТРОЕНИЯ ГИДРОАКУСТИЧЕСКИХ
ИЗОБРАЖЕНИЙ**

Матафонов А.А., Сущенко А.А.
Дальневосточный федеральный университет

В настоящее время в Институте проблем морских технологий ДВО РАН создан целый ряд автономных необитаемых подводных аппаратов (АНПА). С их помощью

решаются задачи построения карт морского дна, поисковые операции, мониторинг подводных сооружений, поиск полезных ископаемых. Как правило, обработка данных, полученных с АНПА, осуществляется на суше в лаборатории [1].

В работе рассматриваются алгоритмы вычисляющие коэффициент донного рассеяния и полученные с их помощью изображения.

Первый алгоритм [2]:

$$\sigma_d(\pm y_1, Vt_j) = \frac{8\pi}{cl} \tau^3 |y_1| I_j^\pm(y_1) \exp(2\mu\tau),$$

где $I_j^\pm(y_1)$ – значение сигнала в j -ой полосе («сырые» данные), пришедшего с дальности. y_1 .

Второй зарекомендовавший себя у практиков алгоритм временной автоматической регулировки сигнала. Данный метод относится к статистическим алгоритмам обработки данных и заключается в нахождении некоторой обратной функции, на основе информации со всех интервалов зондирования. Для определения обратной функции:

$$y^{-1} = inv[j] = \frac{N}{\sum_{i=1}^N A[i][j]}$$

И для нахождения коэффициент донного рассеяния:

$$\sigma_d(y_{i,j}) = A[i][j] * inv[j]$$

Для построения изображения коэффициент донного рассеяния нужно перевести в промежуток от 0 до 255, для этого используется логарифмическая фильтрация [3]

$$y(x) = 255 * \log_a \left(\frac{a-1}{x_{max}} x + 1 \right)$$

Полученные изображения:

Рисунок 1 – Изображение 1 алгоритм

Рисунок 2 – Изображение 2 алгоритм

Как можно заметить, изображения достаточно похожи, но для более детального сравнения рассмотрим графики частоты цветов. По оси абсцисс располагаются цвета, а по оси ординат частота.

Рисунок 3 – Частота цветов 1 алгоритм

Рисунок 2 – Частота цветов 2 алгоритм

На графике первого алгоритма есть две выраженные вершины, что говорит о большей контрастности изображения, чем у второго алгоритма. Что способствует лучшему визуальному восприятию. Так же первый алгоритм сразу вычисляет коэффициент донного рассеяния, в то время как во втором алгоритме нужно сначала вычислить обратную функцию, что замедляет производительность.

Вывод первый алгоритм имеет более высокую производительность и лучшее визуальное восприятие, но более сложен в программировании, чем второй алгоритм.

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ФОКУСИРОВКА ОБЪЕКТОВ НА ПОВЕРХНОСТИ МОРСКОГО ДНА

Коваленко Е.О., Харченко Н.В., Сущенко А.А.
Дальневосточный федеральный университет
Владивосток

Аннотация - В данной работе рассматривается задача картографирования морского дна гидролокатором бокового обзора, установленного на борту автономного необитаемого подводного аппарата. В основе исследования лежит кинетическая модель переноса акустического излучения.

Основное внимание уделено формулировке и исследованию обратной задачи, заключающейся в определении функции, характеризующей отражающие свойства морского дна, в приближении однократного рассеяния, импульсного источника излучения и узкой диаграммы направленности приемной антенны.

Ключевые слова – картографирование морского дна, моделирование распространения акустического сигнала

ПОСТАНОВКА ЗАДАЧИ

Процесс распространения акустического сигнала на частотах порядка десятков килогерц описывается нестационарным уравнением переноса акустического излучения:

$$\frac{1}{c} \frac{\partial I}{\partial t} + \mathbf{k} \cdot \nabla I(\mathbf{r}, \mathbf{k}, t) + \mu I(\mathbf{r}, \mathbf{k}, t) = J(\mathbf{r}, \mathbf{k}, t), \quad (1)$$

где $\mathbf{r} \in \mathbb{R}^3$, $t \in [0, T]$ и волновой вектор $\mathbf{k}$ принадлежит единичной окружности $\Omega = \{\mathbf{k} \in \mathbb{R}^3: |\mathbf{k}| = 1\}$. Функция $I(\mathbf{r}, \mathbf{k}, t)$ интерпретируется как плотность потока энергии волны в момент времени t в точке $\mathbf{r}$, распространяющейся в направлении $\mathbf{k}$ со скоростью c . Величина μ имеет смысл коэффициента затухания, а функция J описывает источники звукового поля.

Процесс распространения эхосигналов происходит в области, $G := \{\mathbf{r} \in \mathbb{R}^3: r_3 > -l\}$, которая представляет собой верхнее полупространство, ограниченное снизу кривой $\partial G = \gamma := \{\mathbf{y} \in \mathbb{R}^3: y_3 > -l\}$, интерпретируемое как дно океана.

Далее рассмотрим случай точечного изотропного источника звука (функция J), который перемещается с постоянной скоростью V вдоль оси $\mathbf{r}_2$ и испускает посылки длиной Δt с медианой в моменты времени t_i , с мощностью J_i соответственно:

$$J(\mathbf{r}, \mathbf{k}, t) = \delta(\mathbf{r} - Vt) \sum_{i=0}^m J_i \frac{\chi_{[-\frac{\Delta}{2}, \frac{\Delta}{2}]}(t - t_i)}{\Delta}, \quad (2)$$

где δ - дельта-функция Дирака, $\chi_{[a;b]}$ – характеристическая функция интервала $[a; b]$.

Предполагая, что до начала зондирования источники звука в среде отсутствуют, дополним уравнение (1) соответствующим начальным условием:

$$I|_{t=0} = 0. \quad (3)$$

Отражающие свойства границы ∂G определяются диффузным отражением по закону Ламберта:

$$I(\mathbf{y}, \mathbf{k}) = \frac{\sigma_d}{\pi} \int_{\Omega^+} |\mathbf{n}(\mathbf{y}) \cdot \mathbf{k}'| I(\mathbf{y}, \mathbf{k}') d\mathbf{k}', \quad \mathbf{y} \in \partial G, \mathbf{k} \in \Omega^-, \quad (4)$$

где σ_d - коэффициент донного рассеяния, $\mathbf{n}(\mathbf{y})$ - вектор единичной нормали к поверхности γ .

Уравнение (1) с начальными и граничными условиями (3), (4) при заданных μ , σ , σ_d , l , J образуют начально-краевую (прямую) задачу для нахождения неизвестной функции I . Решение задачи будем искать не во всей области G , а только на множестве Γ . Дополним систему (1)-(4):

$$I^\pm(t) = \int_{\Omega} S^\pm(\mathbf{k}) I(Vt, \mathbf{k}, t) d\mathbf{k}, \quad (5)$$

где $S^+(\mathbf{k})$ и $S^-(\mathbf{k})$ определяет диаграмму направленности приемной антенны по правому и левому борту соответственно. Функция $I^\pm(t)$ определяет измеряемую суммарную интенсивность слева и справа по ходу движения носителя антенны. С физической точки зрения приемная и передающая антенны находятся на одном и том же подводном носителе, который перемещается вдоль траектории $\mathbf{r} = Vt, t > 0$. Решение задачи (1)-(5) представим в виде:

$$I^\pm(t) = \frac{1}{\pi \Delta} \sum_{i=0}^m \int_{-\frac{\Delta}{2}}^{\frac{\Delta}{2}} \int_{-\sqrt{1-k_2^2}}^{\sqrt{1-k_2^2}} \sigma_d(y_1, y_2) S^\pm(k) \frac{cl^2 J_1 \exp(-\mu c(t - t_i)) dk_2 dt'}{|Vt' - \mathbf{y}|^2 |\mathbf{y} - Vt| y_1(t - t') |k_2 V - c|} \quad (6)$$

С математической точки зрения уравнение (6) относится к интегральному уравнению I рода относительно функции σ_d . Для его решения введём метод дискретизации. То есть определим области, в которых σ_d константа. Так как σ_d задана на множестве Γ , введём разбиение по осям y_1, y_2 :

$$\{(y_1^p, y_2^q) \in \gamma: y_1^p = ph, y_2^q = qh\}, p \in \overline{1, H}, q \in \overline{1, M} \quad (7)$$

где h - шаг сетки. Таким образом, в области, ограниченной точками $(y_1^p, y_2^q), (y_1^{p+1}, y_2^q), (y_1^{p+1}, y_2^{q+1}), (y_1^p, y_2^{q+1})$ σ_d считается постоянной, и уравнение (6) сводится к:

$$I(t_{ij}) = a_{ijpq} \sigma_d^{pq}, \quad (8)$$

где $I(t_{ij}) = a_{ijpq} \sigma_d^{pq}$, $t_{ij} = t_i + j\tau$, $\tau = \frac{\Delta t}{M}$, $a_{ijpq} = \int_{-\frac{\Delta}{2}}^{\frac{\Delta}{2}} \int_{-\sqrt{1-k_2^2}}^{\sqrt{1-k_2^2}} \frac{cl^2 \exp(-\mu c(t-t_{ij})) dk_2 dt'}{|vt' - y|^2 |y - vt| y_1(t-t') |k_2 V - c|}$,

$\sigma_d^{pq} = \sigma_d(\mathbf{y}^{pq})$, $\mathbf{y}^{pq} = (y_1^p, y_2^q)$. Уравнение (8) представляет собой s-диагональную СЛАУ. Параметр s зависит от ширины диаграммы направленности приёмной и передающей антенн и длительности испускания сигнала.

ВЫЧИСЛИТЕЛЬНЫЕ ЭКСПЕРИМЕНТЫ

Для численных экспериментов применялись параметры из таблицы 1, используемые для построения изображения морского дна на основе реальных данных, получаемых с гидролокатора бокового обзора. Для решения задачи численного интегрирования применялся метод Монте-Карло.

Таблица

Данные для экспериментов

$\mu, \text{ м}^{-3}$	$\Delta t, \text{ с}$	$c, \text{ м/с}$	J	$l, \text{ м}$	β	$y_1, \text{ м}$	$y_2, \text{ м}$
0,018	0,4	1500	1	12	0,1	[0,40]	[0,40]

Поверхность дна описывается функцией

$$\sigma_d = \begin{cases} 0.3, & \sqrt{(y_1 - 27)^2 - (y_2 - 10)^2} < 5, \\ 0.2, & \sqrt{(y_1 - 27)^2 - (y_2 - 25)^2} < 8, \\ 0.1, & \text{иначе} \end{cases} \text{ и изображена на рисунке 1.}$$

Рисунок 1 – Точное решение

На рисунках 2 и 3 представлены вычислительные эксперименты для узкой диаграммы направленности приемной антенны с разным числом вычислительных узлов (10 и 100 соответственно). Стоит отметить, что в данном эксперименте матрица A получилась диагональной.

Рисунок 2 – Решение при $N=10$

Рисунок 3 – Решение при $N=100$

ЗАКЛЮЧЕНИЕ

Таким образом, получена формула для решения обратной задачи, заключающейся в определении функции, описывающей неоднородность донной поверхности, в виде интегрального уравнения. Для его решения был предложен метод дискретизации. Таким образом, задача была сведена к СЛАУ с s -диагональной матрицей. Построена численная схема решения СЛАУ, проведены численные эксперименты в случае узкой диаграммы направленности приемной антенны и импульсного источника.

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КОМПЬЮТЕРНОЕ МОДЕЛИРОВАНИЕ ПЕРЕНОСА ИМПУЛЬСНОГО ИЗЛУЧЕНИЯ В СЛОИСТОЙ СРЕДЕ

Курунтяева К.А., Ковтанюк А.Е.
Дальневосточный федеральный университет

Рассматривается математическая модель, описывающая нестационарный процесс распространения излучения в неоднородной среде с плоскопараллельной и азимутальной симметрией.

Перенос излучения в слоистой среде описывается следующим интегро-дифференциальным уравнением:

$$\left(\frac{1}{c(z)} \frac{\partial}{\partial t} + \nu \frac{\partial}{\partial z} + \sigma(z) \right) f(z, \nu, t) = \sigma(z) \Lambda(z) \int_{-1}^1 p(z, \nu, \nu') f(z, \nu', t) d\nu' + J(z, \nu, t). \quad (1)$$

Уравнение (1) описывает нестационарный процесс распространения излучения в неоднородной среде с плоскопараллельной симметрией. Функция $f(z, \nu, t)$ интерпретируется как плотность потока частиц в момент времени $t \in [0, T]$, в точке $z \in G = (z_0, z_n)$, движущихся со скоростью c в направлении, составляющим с осью z угол, косинус которого равен $\nu \in [-1, 1]$. Функции $\sigma \geq \text{const} > 0$ и $p \geq 0$ имеют смысл сечения взаимодействия и индикатрисы рассеяния, а $J \geq 0$ – плотности внутренних источников. Неотрицательная величина Λ характеризует тип среды: при $\Lambda(z) \leq 1$ – среда не размножающая, в противном случае – размножающая. Область G разбита на n слоев $G_i = (z_{i-1}, z_i)$, объединение которых обозначим через $G_0 = \bigcup_{i=1}^n G_i$.

Обозначим

$$Y = G_0 \times \{[-1, 0) \cup (0, 1]\} \times (0, T),$$

$$\Gamma^\pm = \Gamma_{ext}^\pm \cup \Gamma_{int}, \quad \Gamma_{int} = \bigcup_{i=1}^{n-1} \{z_i \times [-1, 0) \cup (0, 1]\},$$

$$\Gamma_{ext}^+ = \{\{z_0\} \times [-1, 0)\} \cup \{\{z_n\} \times (0, 1]\}, \quad \Gamma_{ext}^- = \{\{z_0\} \times (0, 1]\} \cup \{\{z_n\} \times [-1, 0)\}.$$

К уравнению (1) присоединим условия сопряжения на границах раздела слоев,

$$f^- = Bf^+ \quad \text{на} \quad Y_{int} = \Gamma_{int} \times (0, T), \quad (2)$$

и условия на внешних границах,

$$f^- = h_{ext} \quad \text{на} \quad \Gamma_{ext}^- \times (0, T), \quad (3)$$

где

$$f^\pm(z, \nu, t) = \begin{cases} f(z \pm 0, \nu, t \mp 0), & \nu < 0, \\ f(z \mp 0, \nu, t \mp 0), & \nu > 0, \end{cases}$$

$$f(z \pm 0, \nu, t \pm 0) = \lim_{\varepsilon > 0, \varepsilon \rightarrow 0} f(z \pm \varepsilon, \nu, t \pm \varepsilon).$$

Начальные условия для уравнения (1) имеют вид

$$f^- = h_0 \quad \text{на} \quad Y_0 = G_0 \times \{[-1, 0) \cup (0, 1]\} \times \{0\}, \quad (4)$$

где функция h_0 характеризует распределение плотности потока излучения в среде в момент времени $t = 0$.

В приложениях теории переноса излучения важную роль играют френелевские условия сопряжения, описывающие преломление по закону Снеллиуса и зеркальное отражение на границах раздела сред. В этом случае оператор сопряжения B имеет вид:

$$(Bf^+)(z_i, \nu, t) = R_i(\nu)f^+(z_i, -\nu, t) + T_i(\nu)f^+(z_i, \psi_i, t).$$

Коэффициенты $R_i(\nu)$, $T_i(\nu)$ характеризуют отражательную и пропускную способность поверхности раздела $z = z_i$, $i = 1, \dots, n-1$ [1].

Решение начально-краевой задачи (1)-(4) находилось на основе рекурсивного алгоритма, реализующего метод Монте-Карло [2,3]. Разработанный алгоритм основан на представлении решения в виде ряда Неймана, слагаемые которого являются многократными интегралами. Основная проблема, возникающая при вычислении ряда, это рост кратности интегралов при увеличении количества слагаемых ряда.

Основные расчетные формулы для оценки $f(z, \nu, t)$ при $z \in G_i$ выглядят следующим образом:

$$\begin{aligned} f_j(z, \nu, t) = & \exp\left(-\sigma_i \frac{z - \xi(z, \nu, t)}{\nu}\right) \times \\ & \times \left(R_{l(\xi)}(\nu) f_{j-1}\left(\xi, -\nu, t - \frac{z - \xi}{c\nu}\right) + T_{l(\xi)}(\nu) f_{j-1}\left(\xi, \psi_l, t - \frac{z - \xi}{c\nu}\right) \right) + \\ & + \Lambda_i \left(1 - \exp\left(-\sigma_i \frac{z - \xi(z, \nu, t)}{\nu}\right) \right) \times \\ & \times \frac{1}{M} \sum_{k=1}^M \left(\Lambda(z'_k) f_{j-1}\left(z'_k, \nu_k, t - \frac{z - z'_k}{c_i \nu_k}\right) + J\left(z'_k, \nu_k, t - \frac{z - z'_k}{c_i \nu_k}\right) \right), \quad j = \overline{1, N}, \quad (5) \\ f(z, \nu, t) \approx & f_N(z, \nu, t), \end{aligned}$$

где

$$f_0(z, \nu, t) = \exp\left(-\sigma_i \frac{z - \xi(z, \nu, t)}{\nu}\right) h\left(\xi, \nu, t - \frac{z - \xi}{c_i \nu}\right).$$

Здесь $f_j(z, \nu, t)$ описывает приближение функции $f(z, \nu, t)$ суммой $j+1$ слагаемых ряда Неймана, что соответствует излучению, претерпевшему не более чем j актов взаимодействия со средой (рассеяние, отражение или преломление). Для реализации алгоритма разыгрываются случайные последовательности точек слоя z'_k и направлений ν_k с плотностями, соответствующими весовым функциям интегральных слагаемых ряда Неймана [1]. Функция ξ описывает координату ближайшей границы от точки z в направлении $-\nu$. В каждой из подобластей G_i функция $c(z)$ постоянна и принимает значения $c(z) = c_i > 0$. В выражении (5) функции $\sigma(z)$ и $\Lambda(z)$ также принимают постоянные значения: $\sigma(z) = \sigma_i$ и $\Lambda(z) = \Lambda_i$. Первый член в формуле (5) определяет вклад отраженных и преломленных на границе раздела фотонов. Остальные члены в (5) учитывают вклад рассеянных фотонов. Кроме того, в (5) производится приближенный расчет вклада фотонов, возникающих за счет внутренних источников.

При проведении вычислительных экспериментов рассматривалась трехслойная среда со следующими толщинами слоев: $|G_1| = 1$ mm, $|G_2| = 2$ mm, $|G_3| = 7$ mm. Скорость распространения фотонов $c(z) = 2$ при $z \in G$. Остальные коэффициенты задачи взяты из [4] и соответствуют радиационным характеристикам кожного покрова человека при длине волны излучения 1200 nm. Количество членов ряда Неймана N и количество траекторий M в эксперименте были равны 10 и 1000 соответственно. Функция J , описывающая внутренние источники, полагалась равной нулю. Плотность потока падающего излучения

$$h_{ext}(\zeta, \nu, t) = I_0(z) \exp\left(-4 \ln 2 \left[(t - z/c)/t_p - 1.5\right]^2\right),$$

где I_0 – амплитуда интенсивности излучения, t_p – ширина импульса на половине максимума. Согласно [4], $I_0 = 1000$ Wm⁻². Ширина импульса t_p равна 10⁻¹¹ s. Рассеяние в среде предполагалось изотропным.

На рисунке 1 представлены графики усредненной по направлениям плотности потока излучения для различных точек среды (ось абсцисс – ось времени t):

Рисунок 1 – Профиль усредненной по направлениям плотности потока излучения для различных точек среды: (a) $z = 1$ mm, (b) $z = 3$ mm.

Максимальное значение импульса уменьшается с 80.8 (при $z = 1$ mm) до 2.4 (при $z = 3$ mm). Наблюдается затухание плотности потока излучения с ростом z . Импульсный характер при этом сохраняется. Результаты вычислительных экспериментов свидетельствуют об адекватном поведении решения.

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Раздел III

СТЕНДОВЫЕ ДОКЛАДЫ СТУДЕНТОВ, АСПИРАНТОВ И МОЛОДЫХ ИССЛЕДОВАТЕЛЕЙ

Стеновые доклады конференции-школы рекомендованы к участию Региональной научно-практической конференцией студентов, аспирантов и молодых ученых школы естественных наук (г. Владивосток, 11-30 апреля 2017 г.), секции «Математическое моделирование» и «Информационные и суперкомпьютерные технологии». В данном сборнике приводится список докладов. Тексты докладов опубликованы в материалах Региональной конференции: https://www.dvfu.ru/schools/school_of_natural_sciences/sciences/the-conference/new-page.php

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