A REFERENCE ARCHITECTURE BASED ON INDUSTRY 4.0 TO DESIGN SMART WELDING STATION

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Abstract: *Improving the productivity of the welding process as well as its product quality requires an evolutionary shift toward intelligent behaviour from the conventional welding process. The 4th industrial revolution, also called Industry 4.0, can take this welding process to the whole new level which introduced customized and flexible production technologies along with smart elements. This whole revolution would create a welding station operating in an intelligent way and reliable to do monitoring and controlling the welding process in real-time. These functions generate strategic decision-making based on the algorithm of welding process parameters which can be controlled and measured through welding process variables. Moreover, the Industrial Internet of Things (IIoT) is leading to architectural changes to a welding station, including greater connectivity to industrial systems to improve quality production. Development of a reference architecture is the imperative guideline for production experts to make easier and more exact planning of smart welding station by using all the key technologies of Industry 4.0. In this paper, we proposed this reference architecture with the aim to implement this smart welding station and determine what is needed to realize it in a structured way. It will provide greater efficiency to welding implementation and eventually improve cost-saving, and iterative improvements of a physical prototype.*

Key words: *Smart welding station; Industry 4.0; Reference architecture, Monitoring and controlling*

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1. Introduction

Smart manufacturing (SM) systems have been defined as “fully integrated, collaborative manufacturing systems that respond in real-time to meet changing demands and conditions in the factory, in the supply network, and in customer needs” [1]. Industry 4.0 has widely potential and perspective in industrial manufacturing with several technologies that lead to this smart manufacturing system. The conventional welding operation is not reliability and consistency of welding quality depends on welder’s skills and experiences and the efficiency of welding production is also limited. Development of smart manufacturing in a conventional welding process for improving the welding performance and quality of the product is one of the implementations of Industry 4.0 concept in a manufacturing system that will be operating welding station in a smart way. Smart welding station is a set of welding equipment for operations that performed and controlled by smart element system.

It requires reliable technologies to integrate the welding system information at the desired function. Industry 4.0 technologies would be upgrades existing conventional welding process so that a better performance can be issued in the face of process and product failure, such as welding monitoring, which gives the operator ability to monitor their machines in real-time and accumulates data which can be analysed later. Development of welding systems in an intelligent way which are systems that use the technology of the industrial revolution. Albrecht et.al [2] developed an architecture that integrates cloud services to the welding unit where the cloud system allows a two-way communication where the welders are allowed to download the welding data and upload the updated results.

The Industrial Internet of Things (IIoT) is a component, necessary for communication of Smart Manufacturing System essentially relies on a reliable network of industry assets. The IIoT can be defined as certain IoT technologies and smart objects within cyber-physical systems in an industrial setting that promotes goals specific to industry [3]. Some foundational aspects that can be highlighted for a systematic overview of IIoT, such as the architecture, the connectivity, and the standardization [4]. This connectivity developed in digital twin technology system intelligence for enabling its function in the use of data to enable understanding, learning, and reasoning of the smart manufacturing.

Then, the big data involve a large amount of real-time data (e.g., machine operation data and sensor data) is collected from the system for driving out algorithm. Generally, this big data is developed to cloud server as a private cloud computing for operating smart manufacturing and generating strategic decision. Furthermore, The decisions based on analysis of historical and ongoing data provided by the module can be made to overcome problems that are happening and prevent similar problems from happening in the future [5]. Artificial Intelligence (AI) will be a powerful tool to handle this large amount of and somehow interdependent parameters. The mentioned technology above is some of Industry 4.0 concept that could be implemented in manufacturing process such as welding station.

Architecture is a description (model) of the basic arrangement and connectivity of parts of a system (either a physical or a conceptual object or entity) [6]. Architecture is widely used as a reference to describe the main structure and internal relations of complex systems. To provide a common base around the Industry 4.0, a group of collaborators from different European enterprises and R&D institutions suggested a “reference architectural model” for Industry 4.0 (RAMI 4.0), whose purpose is the grouping and representation of different aspects of the industry in a common model [7]. RAMI 4.0 describes the fundamental aspects of Industry 4.0 and aims to achieve a general understanding of what standards and use cases are required for Industry 4.0 [8]. In order to guide academic research and industrial implementation, a systematic framework has been created that covers smart design, smart machining, smart monitoring, smart control, smart scheduling, and industrial implementation [9]. Designing the reference architecture of smart welding station is one of the important models that outline fundamental elements for operating welding station. RAMI 4.0 is used for standardization that is able to cope with the rapid ramp-up of implementation in an efficient way.

2. Systematic procedure of the inspection system

In order to design the reference architecture for smart welding station based on RAMI 4.0, there are some aspects to study, the systematic procedure is shown in Fig.1. With the endeavour of implementing a smart welding station, we started a literature collection from different academic sources like reference books, handbooks, reference papers, as well as reports from the industrial development to define the fundamental of intelligent welding system, RAMI 4.0 and Industry 4.0 technologies we would implement in our reference architecture. Then, the concept of smart welding station is presented by explaining the core technology of the reference architecture model designed in the present study. Next, classification the tasks using enabling technologies of Industry 4.0 by analyzing the function of RAMI 4.0 framework. Subsequently, the results of the architecture were generated for operating a smart welding station system by outlining the essential elements. As for the final step, the reference architecture of smart welding station is mapped that showed the system adequately met the structures and functions of what is termed Industry 4.0 components as well as the system design specifications.

Fig. 1. Systematic procedure for designing reference architecture of smart welding station.

3. Development of reference architecture for smart welding station

3.1 Implementation of core technologies

The characteristics of the designed reference architecture are to create the operating system of welding station in a smart way. A depiction of this research overarching vision for the smart welding station is shown in Fig. 2. Smart welding station enables operators to extract actionable insights from welding process data, to quantify the impact of their decisions and welding process behaviour and to identify opportunities for increasing welding productivity by eliminating failures. The data and condition from the welding station reach operators devices with software through the IIoT. The digital twin process and intelligent quality control are provided in this system. The core technologies of Industry 4.0, IIoT, big data, and AI are able to collect welding data and analyze it, automatically detect abnormal failures, and share information can be easily and reliably applied to smart welding station to prevent welding failures and enhance welding process performance. During the welding process, different wire feed speeds, current rate, and voltage rate can be used to evaluate welding process performance and yield based on different requirements identified by the big data collected and analyzed. It starts from a welding station which consists of robot welding machine will generate sensors in monitoring equipment, while the welding process will generate process data. Through digital twin system, welding process monitoring is developed and generate welding process valuable in real-time in towards risk assessment. Then, the derived algorithm from welding process parameters to control welding failure with the result is optimal proactive actions. This result is directly given to control command and give notification through the operators. Through a conceptual approach to a smart welding station, several key challenges and required capabilities for design, development, and deployment of functions in the system are identified and discussed.

3.2 The main task in the functional framework of RAMI 4.0

A reference architecture for implementing a smart welding station based on RAMI 4.0 is studied in this research. Analyzing the characteristics of the core technology in line with the welding station architecture is the stage for determining the main tasks. The main tasks of the smart welding station are monitoring the welding process status and behaviour, controlling the welding process in real-time, and making a strategic decision on the welding process. These tasks lead to define the essential components of the smart welding station system that will be designed in the functional framework of RAMI 4.0. In consideration of smart manufacturing that can facilitate realizing smart factories, the reference architecture for the smart welding station has been designed to manage and realize the proposed system approach in an easy, reliable, correct and appropriate way. The RAMI 4.0 framework for smart welding system is shown in Fig. 3 and the selected area of RAMI 4.0 for reference architecture creation includes three aspects: product life cycle, hierarchy levels, and architecture layers. This framework covers the main tasks to create the reference architecture are created in the “instance” phase of the life cycle on the x-axis of RAMI 4.0, that is, “production”. This phase

consists of 3 levels of the hierarchy on the y-axis and five layers of IT-layer on the z-axis. The hierarchy levels define the levels in term of classification of the location of functionalities and responsibilities within the smart welding station in the form of physical architecture in the industry level. The structure for smart welding station was covered by three levels from data collecting to process automation, the terms of “Field device”, “Control device”, and “station” were selected. The IT-layer defines the five layers of RAMI 4.0 in considering the tasks of smart welding station that makes it possible to operate the system it is started from the lowest with the asset, integration, communication, information, and highest one with the functional. Following a conceptual approach, the functional components of the welding station and their interactions are synchronized.

Fig. 2. Conceptual Design for Operating Smart Welding Station.

Fig. 3. Tasks of smart welding station visualized in RAMI 4.0.

4. Design of Reference Architecture for smart welding station

This study designed a reference architecture for a smart welding system categorized by manufacturing systems at the station level. Based on the concepts system and the modelling of a RAMI 4.0 and tasks of smart welding station described in the previous section, the reference architecture was developed in 2-dimensional form as shown in Fig. 4. This two-dimensional reference architecture identifies the essential components of enabling technology in Industry 4.0 for the proposed system. It is aimed to provide a guideline and standard requirements in the aspects of RAMI 4.0 for smart welding station. This reference architecture consists of the infrastructure and operating system of the smart welding station should be developed as a system design based on Industry 4.0 concept. The hierarchy levels are simply model which describes the different levels or castes of what is needed in the smart welding station or components in a station or simply describe the breakdown structure of welding components. A brief description of each hierarchy is given:

- **Field device** is the sensors and actuators of welding station which is a set of sensors and data collectors embedded in smart welding station for collecting data of welding process (voltage, current, and wire-speed feeder).
- **Control device** is welding station controller within a machine that facilitates direct automatic control of welding process using industrial controllers like Siemens such as Simatic, etc.
- **Station device** is designed to connect /display data in the welding process and undertake the complex management of the welding station.

The five layers of IT-layer that make it possible to operate the smart welding station with the core technology of Industry 4.0 is defined perpendicular from the hierarchy level. A brief description of each layer is given:

- **Asset layer** represents all the standardized physical things of the smart welding station that interacted, such as welding station components (Robot welding arm, power source, wire feeder via cable, etc.), network devices, and sensing things, the operator is also included in this category.
- **Integration layer** is responsible for Connecting the data of smart welding station from the asset and provide into computer base processable information.
- **Communication layer** provides the network connection of IIoT that consist of the Internet and other relevant communication technologies. This layer also controls the connecting access point and analytic computing using data format in the direction of the information layer to manage the data collected.
- **Information layer** generates information collected from the welding process behaviour in strategic decision-making for carrying out processes and controlling them on a welding station. Correlation between sensor signals of the welding process parameters is monitored based on the digital twin system.
- **Functional layer** provides optimal proactive action to manage welding process performance and welding product in operator's devices through handling knowledge which is driving out from the information layer. This action such as set up welding process parameter on welding controllers such as current and voltage rate to respond to the failures.

Fig. 4. Conceptual Design for Operating Smart Welding Station.

RAMI 4.0 standardizes directory services, which are an efficient system of automated services based on cloud-based production with interfaces that are transparent to the user. In Industry 4.0, such a value-added service is required for cloud-based, a reference architecture that can be flexibly managed and interlocked. Therefore, the tasks of a smart welding station system were classified into a function along with its essential components which mapped at each IT-layer. Components in the hierarchy level will be automatically generated after a function is illustrated into an architecture. Guidelines (including components, formats, and services) on how to operate and control a smart welding station system with enabling Industry 4.0 technologies are provided in the reference architecture to help manufacturers create smart welding systems at the station level, sequentially and as needed.

5. Conclusion

The design of the proposed system is to operate a welding station which functions able to monitor, collect, and analyze the welding process performance. The IIoT of a welding station monitoring provides an alarm notification system for detecting the failures in controlling product quality while the welding process, as well as welding process parameters. The hardware architecture provides standardized communication interfaces between physical elements and analytic computing. Implementation of such smart welding station will not only enhance the welding productivity but also improve the working efficiency of engineer and operator. Smart welding station a revolutionary technology in the manufacturing industry integrates database into a digital model

which provides a visualized way in all welding production cycle management. From the analysis of RAMI 4.0, a reference architecture was developed to a practical guide for implementing a smart welding station system in an efficient and effective which can identify the essential components of Industry 4.0 technology. The main framework of RAMI 4.0 is derived in each aspect to find out which areas are part of the smart welding station system. The area selected on these three aspects of RAMI 4.0 in this study is selected based on its characteristics and conceptual design of the smart welding station system. This is not only focused on the development and adoption of Industry 4.0 concept, but also embraces welding station management, smart elements, and other aspects. The proposed reference architecture will manage the approach systems to create in an easy, reliable, and exact way. The demand for the industry 4.0 concept interacted with an existing system can be successfully met if the engineers implement smart welding station in a successful manner. It will lead to reducing of effort and expenses for building a reference architecture of the new system resulted in huge savings and increase the efficiency of carrying out the process as well as reduction of the planning effort. Future work related with this invention is the implementation of this system approaches for the conventional fusion welding station and in a later phase to extend the reference architecture into a different system, some stations, and a whole factory with more smart sensors.

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