Master of Science

Design of Platform for Smart Welding Station Based on RAMI 4.0

The Graduate School of the University of Ulsan

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Design of Platform for Smart Welding Station Based on RAMI 4.0

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ABSTRACT

The emergence of Industry 4.0 (I4.0), which uses smart manufacturing as a strategy to solve industry challenges, is associated with significant research efforts that focus on cyber-physical systems, the internet of things, big data, and artificial intelligence. Utilizing I4.0system performance and decision-making technologies, real-time monitoring, and system control, we developed a smart welding station system. The platform provides guidance for implementing a reliable welding system with a minimal amount of effort using certain characteristics of I4.0 technologies. In this study, a practical guide for the application of Reference Architectural Model Industry 4.0 (RAMI 4.0) and the use of technologies for smartization of welding systems are presented. First, we discuss the conceptual approach of a smart welding station system to create a platform for the station. Enabling technologies of I4.0 and their working functions are then defined. In addition, characteristics of RAMI 4.0 that apply to implement the system into the major architecture of selected RAMI 4.0 areas are analyzed. Finally, a designed platform for a smart welding station system based on five layers and three hierarchy levels of the production of RAMI 4.0 is presented.

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Chapter 1 INTRODUCTION

1.1. Problem statement

Industry 4.0 (I4.0) has widely potential and perspective in starting the new Industrial Revolution in the 21st Century. Several features that support I4.0 are formed into an ecosystem in the 21st century industrial that has many characteristics for future assessment as shown in Figure 1.1. Many advanced technologies have been developed in the manufacturing industry to face global competitiveness and produce value creation, such as connecting digital and physical worlds in which sophisticated hardware combined with innovative software, sensors, massive amounts of data and analytics.

Significantly, I4.0 technology has been developed in many fields, especially in industrial manufacturing to improve process performance, reduce downtime, and ensure maximum productivity. Among the benefits offered by I4.0 technology in its application, is the infrastructure to utilize ICT (Information and Communication Technology) into smart manufacturing with the aim of developing a fully integrated production system. Smart manufacturing systems are "fully integrated, collaborative manufacturing systems that respond in real-time to meet changing demands and conditions in the factory, in the supply network, and customer needs" [1].

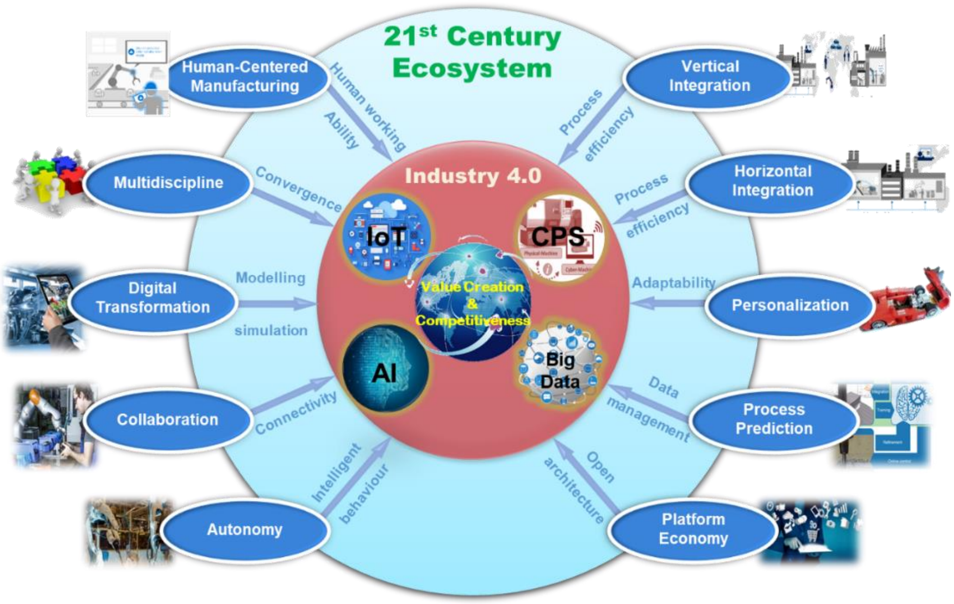

Figure 1.1. Characteristics of the Industry Ecosystem in the 21st Century

With the development of ICT in I4.0 technologies, this has laid down to a paradigm shift in several manufacturing stations to be an integrated production system, such as in welding station: from an automated welding station to a smart welding station system. The smart welding station system requires reliable technologies to integrate the welding system information at the desired function. Digitalized welding is one of the functions that could be developed in a welding station with I4.0 technologies as shown in Figure 1-2. Digital information about the design component, the filler metal, the protective gas, etc. is necessary for this function to be able to determine an optimal set of welding parameters automatically and real-time requirements must be met [2]. In order to realize this function, it is essential to see the full chain which includes I.40 technologies and the origins of the components needed for the smart welding station system. Therefore, a platform that consists of the infrastructure and operating system of the smart welding station should be developed as a system design based. A platform model for I4.0 is developed with a potent combination of technologies that adds accuracy, efficiency, productivity to be realized in the real factory based on architecture standardizations. 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) [3]. Architecture is widely used as a reference to describe the main structure and internal relations of complex systems. Some emerging reference architectures such as RAMI 4.0 and IIRA have been developed by the German I4.0 and the US-led Industrial Internet Consortium (IIC), respectively.

Figure 1.2. Digital Twin of Welding Process

A Reference Architecture Model Industry 4.0 (RAMI 4.0) has been developed by BITCOM (the German Association for IT, Telecommunications and New Media), VDMA (Mechanical Engineering Industry Association) and ZWEI (German Electrical and Electronic Manufacturers' Association) for providing a guideline for the interdisciplinary I4.0 technologies and describing the connection between IT, manufactures/plants and product lifecycle [4]. Another major reference architecture is the Industrial Internet Reference Architecture (IIRA) developed by the US-led Industrial Internet Consortium (IIC) to encourage the adoption of IIoT (IoT Industry) and relies on the OMG (Object Management Group) [5]. These two reference architectures are respectively shown in Figure 1-3. Moreover, the reference architecture standardization in the fields of smart manufacturing has been studied by a large number of published works. Moghaddam et al. [6] identified two actionable plans to enable smart manufacturing through conceptual analysis of service orientation ideas, several key challenges, and capabilities needed for the design, development, and deployment of SOA in manufacturing by investigating various architectural references for smart manufacturing systems. Li et al. [7] presented a systematic standardization solution for smart manufacturing by analyzing and comparing the architectures, then developing the reference model and finally providing a standards framework. However, the aforementioned studies have not concentrated on one specific manufacturing process. Therefore, an effective approach is necessary to develop the platform for smart welding station system.

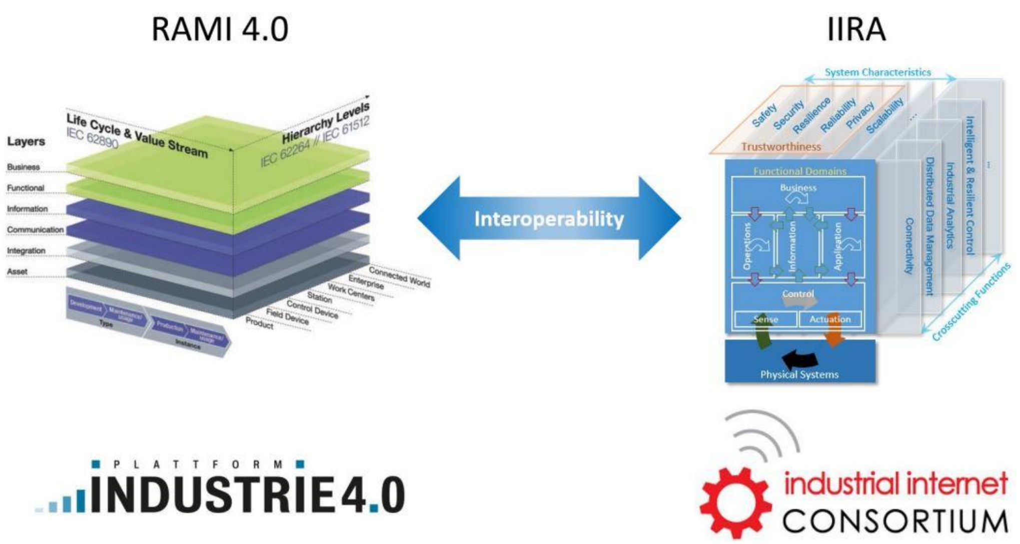

Figure 1.3. IIC and I4.0 are working together to map architectures [5]

The platform model designed should be satisfied with the following requirements:

- The platform model should be adapted to the different types of welding process.
- The important aspects of the platform are necessary to expand the functional framework.
- The architecture layers should be easily changed to adapt to different I4.0 technology components 4.0
- The function should be derived by each layer to classifying the tasks of the system
- The platform should be flexible, adaptive and easy to implement and operate.

1.2. Research objectives

The purpose of the present study is to design a platform model to classify the tasks of smart welding station system using enabling technologies of I4.0 by identifying RAMI 4.0. The technologies were applied to the system while RAMI 4.0 is analyzed to be modeled into a platform of smart welding station system. To achieve a specific understanding of RAMI 4.0 standardization, the characteristics of the RAMI 4.0 core idea are analyzed to select the area in line with the smart welding station system and serving as a basis for the discussion of its interrelationships and details. Three main aspects are selected, but two main aspects are expanded in detail to create major architectures and to classify the location of functionalities. Afterward, a two-dimensional model was designed using the selected functions and then mapped in terms of essential components and services.

1.3. Significance of the study

This work focuses on designing a platform of smart welding station system by applying Digital Twin, Industrial Internet of Things (IIoT), Robot as an Agent, Cloud Computing, Big Data and System Integration to create the function in smart welding station. In the proposed smart welding system, strategic decision-making is determined on each task of the welding process. This thesis is expected as a contribution to improve the implementing of a smart welding station system in an efficient and effective but more important with a practical way which is easy. The research contributions are listed as followings:

Firstly, based on the advantages of I.40 technologies and disadvantages of the automated welding system, we proposed the conceptual design of the smart welding station system to satisfy the standard requirements of the platform model. The characteristics of I4.0 enabling technologies were investigated to verify the working function of the welding process. Then, the functional of the smart welding station is analyzed by describing the working functions architecture with selected technologies.

Secondly, the platform of the smart welding station system was designed. The major frameworks of RAMI 4.0 were analyzed to determine which area that covers the working functions. Moreover, the main tasks for operating a smart welding station were derived based on the functional framework RAMI 4.0. The two-dimensional platform showed that the smart welding station system adequately met the structures and functions of what is termed I4.0 components as well as the system design specifications.

1.4. Organization of the thesis

The remainder of this thesis is organized into six chapters. Chapter 2 presents the literature review related to the present study, including smart manufacturing, the welding system, and its challenges, RAMI 4.0 as well as technologies of Industry 4.0 for smart manufacturing. Chapter 3 contains the strategy for designing a platform, core technology of the platform model designed in the present study to classify the tasks and essential components using enabling technologies of I4.0 by considering RAMI 4.0. Chapter 4 presents the results of the architecture in classifying tasks and essential components for operating a smart welding station system. Chapter 5 discusses the classification function of the platform model to determine the platform architecture in mapping. Lastly, Chapter 6 presents concluding remarks and suggests several considerations for future studies.

Chapter 2 LITERATURE REVIEW

2.1. Smart manufacturing

Smart manufacturing is a technology-driven approach generally applied to a movement in manufacturing practices towards integration up and down the supply chain, integration of physical and cyber capabilities, and taking advantage of advanced information for increased flexibility and adaptability, such as to monitor the production process [8]. The study about smart manufacturing has been a tremendous increase in interest to some researchers who reported their findings in a large number of publications in the fields of I4.0. Many disruptive technologies, such as cloud computing, Industrial Internet of Things (IIoT), big data analytics, and artificial intelligence permeate the manufacturing industry with making it smart and capable of addressing current challenges. With the use of disruptive technologies, smart manufacturing has become a key aspect of I4.0, which has the potential to make significant contributions through some features such as horizontal and vertical integration, life cycle management, stream value coordinated by a human, and security for assuring data [9].

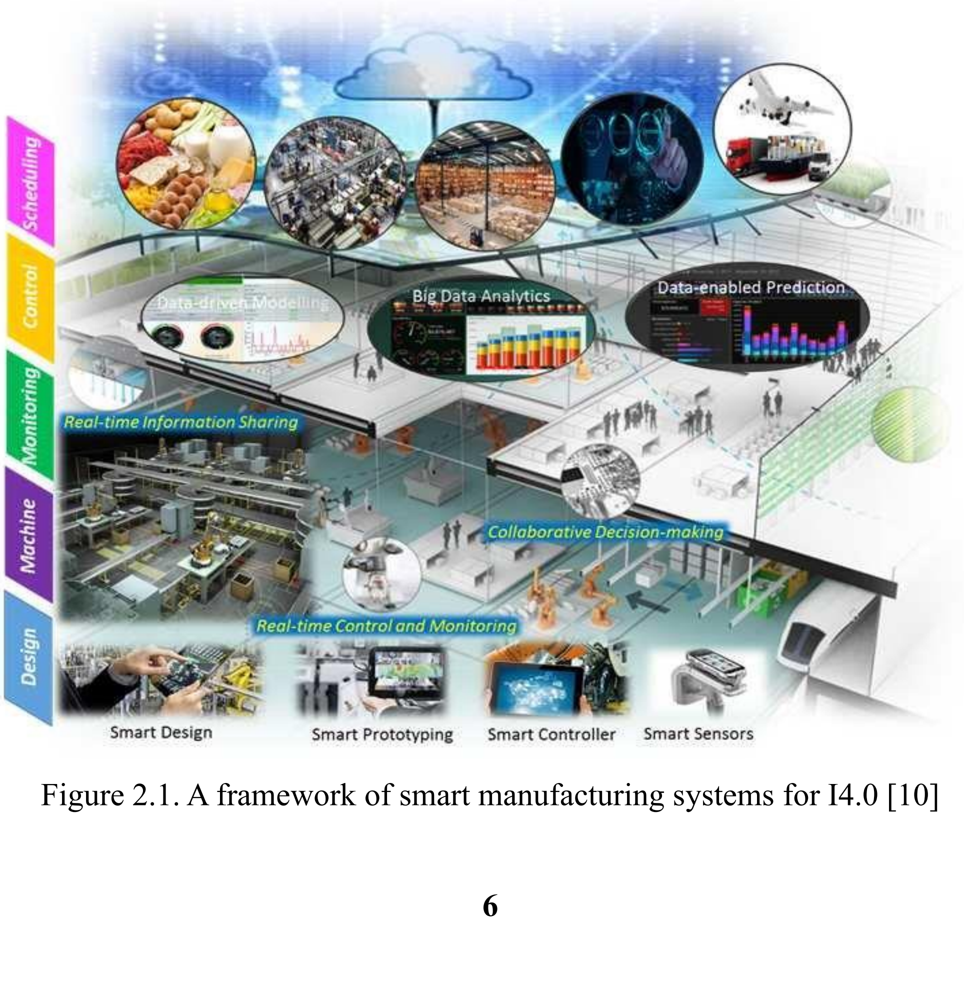

Figure 2.1. A framework of smart manufacturing systems for I4.0 [10]

The rise of new digital industrial technology, known as Industry 4.0 is an industrial transformation associated with the smart manufacturing revolution. Associated with this, the digital solutions enable smart manufacturing is based on subsystems, including data collection and storage, internet/intranet connectivity for data exchange, data analysis, and decision-making, decision implementation mechanisms, and human-machine interfaces, as illustrated in Figure 2.1.

An important aspect that differentiates smart manufacturing from many other initiatives is the specific emphasis on human ingenuity within the framework, but their abilities must be improved by smartly designing a customized solution for a specific area [11]. A systematic standardization could be considered to enhance the smart design in a manufacturing system with the main objectives, such as production optimization, sustainable production, and agile supply chains. 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 [10]. Some developed and developing countries have a systematic standardization of manufacturing strategies to support manufacturing industry transformation and update. Standardization is an important part of smart manufacturing strategies, due to it is a way to change the system from traditional manufacturing to smart manufacturing gradually. Based on the development of the published standards landscapes and standardization construction for smart manufacturing are divided into NIST, DIN, MIIT&SAC to provide useful definitions and taxonomies of services. While emerging reference architectures are based on a CPS-based 'automation network' such as RAMI 4.0 and IIRA. In March 2017, the International Electrotechnical Commission (IEC) adopted RAMI4.0 as a Publicly Available Specification for Smart manufacturing (IEC PAS 63088:2017).

2.2. Development of welding system and related challenges

Welding has been a large part of a fabrication industry that joints materials with a high heat process which melts the base material, typically with the addition of filler material. As is known, welding has been widely introduced more than 3000 years, particularly manual welding operation system. However, the manual welding operation system is not reliability and consistency of welding quality depends on welder's skills and experiences and the efficiency of welding production is also limited. Therefore, the robotic welding industry has become more important in the welding operation system as it allows rapid production and higher quality parts to be produced while reducing labor costs. So far there has been much research on welding systems conducted to provide both greater productivity and enhanced quality for welding in the manufacturing environment.

The research includes welding methods, welding techniques and components, welded structures, welding processes, and quality as well as the technology that is related to system development. With the development of modern manufacturing, welding is ideally suited for implemented as a smart manufacturing system. This development is intended for an advance from the industrial revolution in the manufacturing field. Due to this, some significant differences can be seen in each type of welding system. For instance, a schematic diagram between a manual metal arc welding system and the welding robot system with an additional feature that is visual sensing, as shown respectively in Figure 2-2 and Figure 2-3.

There are many types of welding systems that have been developed until now, further development which is one of the most widely used is combining human welders and automated welding robots, as known as intelligent welding. Chen et al. [12] discussed the framework for science and technology for the manufacture of intelligent welds by considering the important elements of intelligent welding such as sensing and control design, process modeling, and artificial intelligence. The development of intelligent robot welding needs to study and simulate the action and function of intelligent welder' operations [13]. Based on this, an intelligent weld manufacturing is intended to increase the performance of the production of welding automation uses the robot. Development of other welding systems which more advanced than intelligent welding which are systems that use the technology of the industrial revolution. Albrecht et.al [14] 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. So, the welding sector is successfully exploiting the new technologies of the industrial revolution, using network-connected industrial welding robots to develop smart welding systems. To implement a smart, reliable, and easy-to-operate welding station system, a clear understanding of emerging manufacturing technologies, reference architectures, and required capabilities is needed. Information and industrial technology integration supply the ability to outline and control specific elements of an entire system.

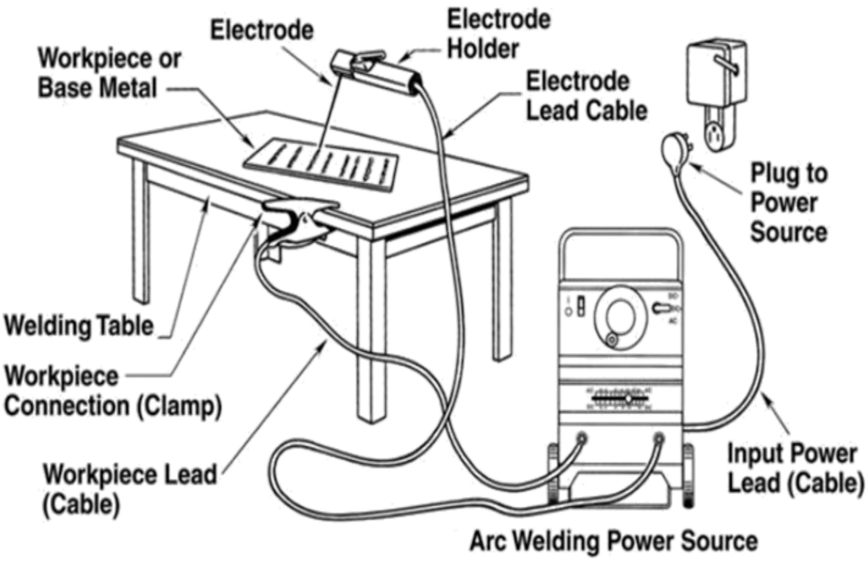

Figure 2.2. A schematic diagram of manual metal arc welding (https://www.weldingis.com/)

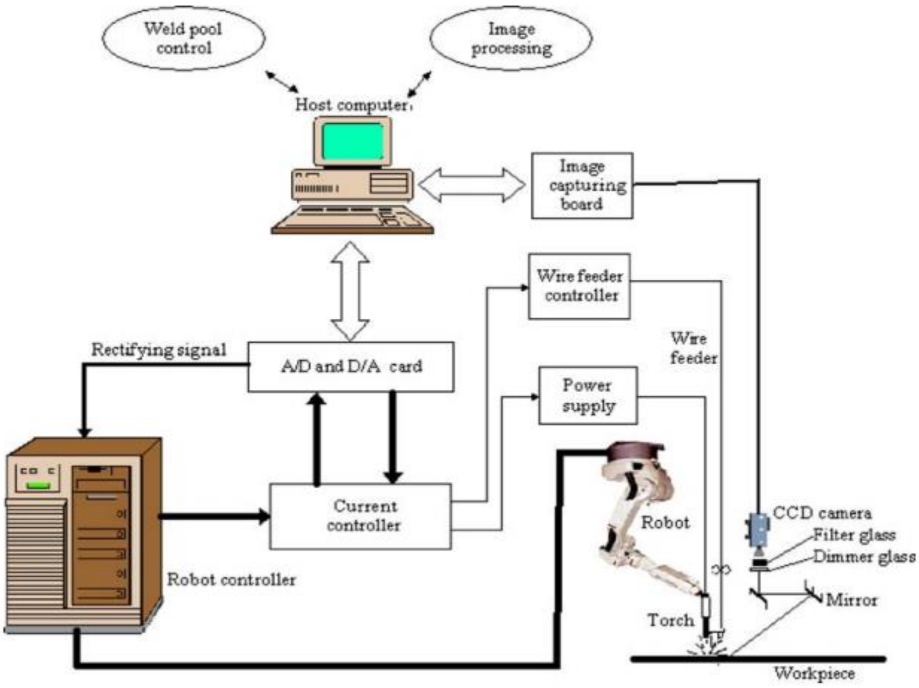

Figure 2.3. A schematic diagram of the robot welding system with visual sensing [15]

2.3. RAMI 4.0

The RAMI 4.0 is a reference architecture model that describes the fundamental aspects of I4.0 and aims to achieve a common understanding of what standards and use cases are required for I4.0 [16]. In general, the RAMI 4.0 provides a basic reference architecture that includes three-dimensional to define the domains of I4.0, as shown in Figure 2-1. RAMI 4.0 has been developed and introduced by several industrial associations located in Germany, BITKOM, VDMA, and ZVEI. Created by several German associations and institutions, the reference architecture model describes the development of a shared language and structural framework that intended to assist in the I4.0 technologies implementation[17, 18]. The reference architecture consists of a set of guidelines and rules that have the scope to structure, organize, and classify technical content [19]. With RAMI 4.0, platform I4.0 has defined an architecture that makes production, products and services, and their usage and complexity manageable from an industrial perspective. Moreover, it shows how to approach the issue in a structured manner and allows all participants in I4.0 to use a common frame of reference for exchanging and understanding data & information efficiently. RAMI 4.0 incorporates all the crucial aspects of I4.0 that divided into three axes: (1) hierarchy levels; (2) architecture layers; and, (3) lifecycle value stream.

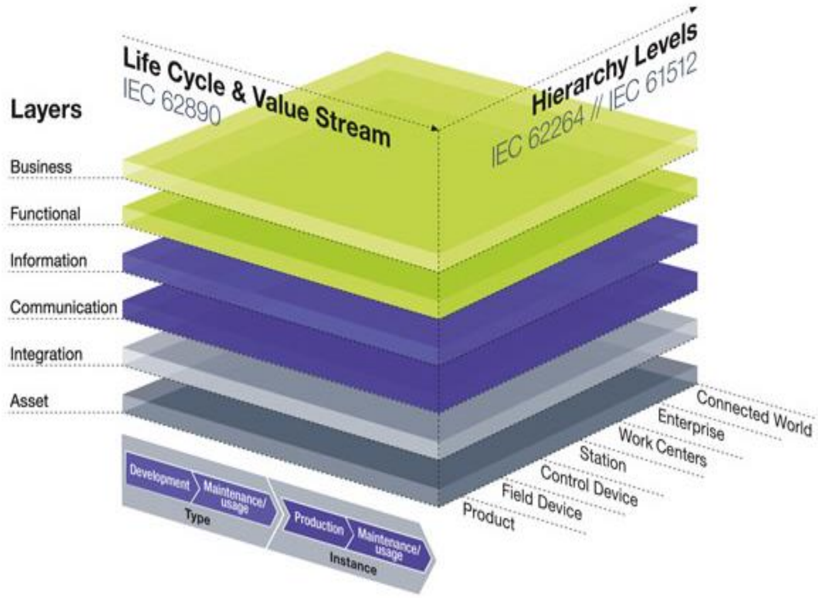

Figure 2.4. Reference Model RAMI 4.0 [16]

2.3.1 Hierarchy levels

The hierarchical levels from the ISO/IEC 62264 and 61512 standards are showed in the right axis, representing the functional characteristics of the components for enterprise-control system integration. To classify as many sectors as possible within a factory, a uniform consideration from the process industry to factory automation has been defined in hierarchy levels. Based on the 1991 Purdue Enterprise Reference Architecture, the hierarchy levels represent a rather orthodox approach architecturally [20]. RAMI 4.0s hierarchy levels are described in Figure 4-1.

Starting from the lower levels, the product and field device levels represent real-time functions and the information required to perform the manufacturing activity. Then, this activity is respectively described in four next levels, such as the control device, station, work centers, and enterprise levels to identify information of assets related to different levels in the enterprise. At the last level, the connected world is added to describe the group of factories, and the collaboration with external engineering firms, component suppliers and customers, etc. This level is the most extended level which identifies the information of assets that is meant to be shared between different enterprises (or companies).

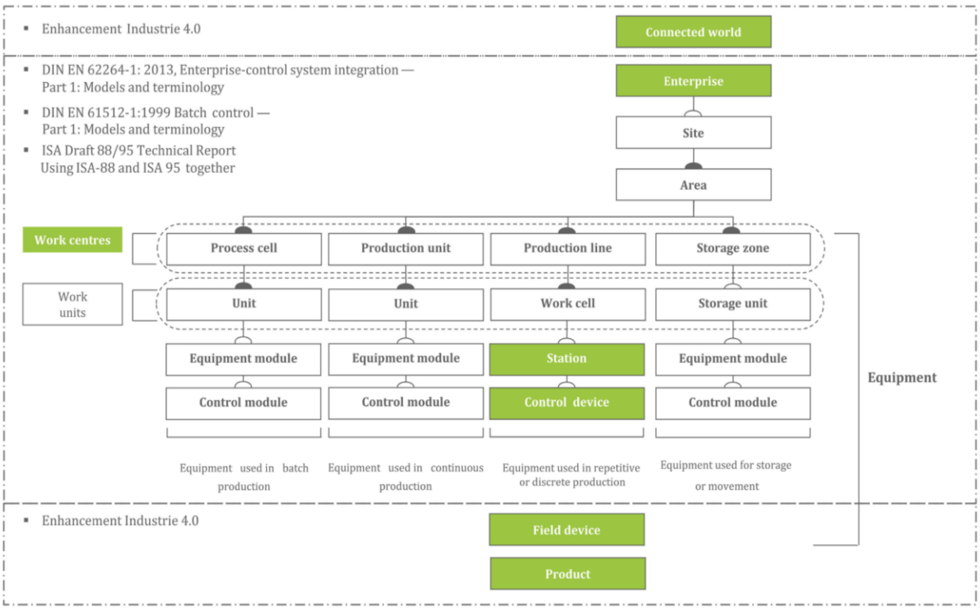

Figure 2.5. Hierarchy levels RAMI 4.0 [16]

2.3.2 Architecture layers

The architecture layers consist of six layers describe the IT representation of the I4.0 component in a structured way in the left vertical axis. This part represents a reminder to integrate all aspects of the enterprise digitalization [17]. Each layer enables the development of I4.0 software solutions in a consistent way so that different and interdependent manufacturing operations are interconnected by considering the physical and the digital world. The architecture layers of the organized describe functions in different perspective and levels of control in the manufacturing system [6, 21]:

- *Asset layer*: Functions that are physically performed by an I4.0 component or virtualize the component. This includes system actors, applications, physical components as well as documents, ideas and human beings [22];
- *Integration layer*: Functions that provide processed information for the digitalization of assets that enable computer-aided control, event-generation, connectivity, and component virtualization. In the virtual domain, each significant event is mirrored through the enabler [18];
- *Communication layer*: Functions that support communication and provide control services with standardization. It makes use of uniform data format and predefined protocols, providing services for the "Integration Layer" [18, 23];
- *Information layer*: Functions that process and integrate consistently the different available data into useful information [23]. This information is being used and exchanged between functions, services, and components, as well as supports event pre-processing, execution of rules, data analysis, and quality assurance [22];
- *Functional layer*: Functions that formally describe, model, and integrate services including their relationships from an architectural viewpoint. It creates a horizontal integration platform of several functions that can be with remote access, resulting from the necessity of data integrity. It generates the logic of the rules and decision;
- *Business layer*: Functions that map business models/processes and links between different business models, define rules and regulations and arrange services. RAMI 4.0 can be used to map regulatory and economic (market)

structures and policies, business models, business portfolios (products & services) of market parties involved, as well as business capabilities and business processes [22];

2.3.3 Life cycle value stream

I4.0 offers great potential for improvement throughout the life cycle of products, machines, factories, etc [16]. the last axis of RAMI 4.0 represents the life cycle and associated value streams with the aim are to visualize and standardize relationships and links. The life cycle value stream defines from the IEC 62890 standard facilities and product life cycle with the correspondent value stream are showed on the left horizontal axis. This section is the lifecycle management for systems and products used in industrial-process measurement, control, and automation. The special characteristic of the RAMI 4.0 is its combination of the life cycle and value stream with a hierarchically structured approach for the definition of I4.0 Components [24].

The draft standard is divided into “type” and “Instance” which respectively are the initial idea and the real and usable product. Type is divided into development and maintenance/usage, while the instance is divided into production and maintenance/usage. Platform I4.0 covers the complete life cycle of the corresponding assets, as described in Table 2-1 [22].

Table 2.1. Draft of life cycle value stream

Life Cycle	Description
Type Development	This stage relates to the first idea of a product. Every aspect around the product is displayed, from commissioning to development, testing and the generation of the first prototypes.
Type Maintenance	Representing the result from the development stage, this stage shows the first model or prototype of the machine or product.
Instance Production	After specifying the requirements and generating a type, this stage represents the development of a single part before being unique.
Instance Maintenance	The final product or machine is represented here. To meet the needs of this stage, the part has to be unique and in usage.

2.2. Industry 4.0 Technologies for Smart Manufacturing system

2.2.1. Digital Twin

The concept of the digital twin was first introduced by Michael Grieves at the University of Michigan in 2002 [25]. Since then, the digital twin is one of the enabling technologies for system intelligence and develop with the advent of Industrial IoT (IIoT) technology. The digital twin could be part of a cyber-physical system, due to the functions are similar in the use of data to enable understanding, learning, and reasoning. In this case, virtual models are created for physical objects in the digital way to simulate their behaviors and provides an effective way for the cyber-physical integration of manufacturing. Moreover, The vision of a digital twin calls for incorporating a business, contextual and sensor data from physical systems (or processes) into the virtual system model of the digital twin to facilitate analysis, avoid problems and develop informed technology roadmaps [26]. ISO 10303 STEP standards are candidates to support the digital twin design.

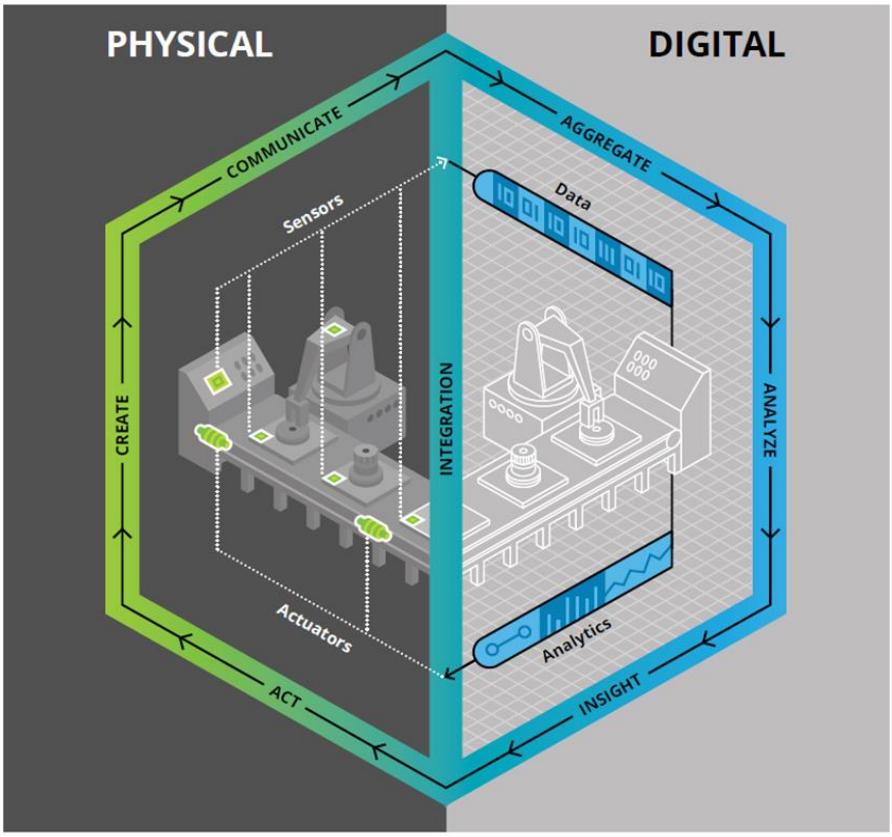

Figure 2.6. Manufacturing process digital twin concept (*www2.deloitte.com*)

To create a fully functional digital twin, there are six steps that can be carried out concurrently or in a different sequence are as follow: create, communication, aggregate, analyze, insight and act as shown in Figure 2.6. Furthermore, the digital twin capability supports three of the most powerful tools in the human knowledge tool kit, these are conceptualization, comparison, and collaboration [25]. A new method for product design is conducted based on a digital twin approach by generating a comprehensive design framework that focuses on the connection between the two data sources [27]. Furthermore, with the use of various big data in the entire product lifecycle, the detailed application methods and framework of digital twin-driven product design, manufacturing, and service are investigated [28]. It generated nine smart services that have the opportunity to improve the intelligence level of products, reduce the product failure rate, improve maintenance effectiveness, and improve product utilization efficiency. However, digital twin services can be used in product design, production planning, manufacturing execution, and other applications [29]. In the step of manufacturing execution, digital twin provides an effective method to draw up the functions of the manufacturing system and how the execution process should be implemented. Firstly, the manufacturing system is determined to generate service management and analysis of key technologies is carried out to define enabling technologies. Then, based on the real-time status of physical resources (e.g., robot arms), a functional smart manufacturing system is drawn up. Based on this, it proved that digital twin has provided a promising opportunity to implement smart manufacturing and industrial 4.0. Zhuang et al. [30] proposed four core techniques embodied in the framework of digital twin-based smart production management and control for complex product assembly shop-floors. Another specific manufacturing process that applies a digital twin concept in order to ensure the completion of process on-time is smart injection molding [31]. All the stages in injection molding such as mold design, mold making, and injection molding processes are linked and communicated with each other through Internet-of-Things (IoT) and Cyber-Physical System (CPS). Overall, digital twin technology enables the manufacturing process to be conceptualized visually and collaborate with other manufacturing sections by obtaining benefits such as finding out the potential failures before even during the actual manufacturing process, evaluate production decisions based upon data analytics, provide early warnings.

2.2.2. Industrial Internet of Things (IIoT)

The IoT is a group of interconnected objects that allow for remote management and access to the data they generate, one in which connected objects are “sensor(s) and/or actuator(s)” that carry out a specific function and can communicate with other equipment [32]. Smart manufacturing is a specific application of the Industrial Internet of Things (IIoT). The industrial internet of things (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 [33]. The IIoT is the part of the IoT that operates machines semi-independently or with minimal human intervention, focusing on devices that improve operational efficiency. Smart manufacturing is a specific application of the Industrial Internet of Things (IIoT). Moreover, the application of CPS in manufacturing also uses the IoT as a core technology, so that CPS components can communicate with each other and work together in real-time, including with humans. The collection of data by IIoT technologies is one of the categories of data generated by manufacturing processes in smart factories [34].

Due to the IoT, IIoT, and I4.0 are closely related concepts, the architecture about IIoT has been created in those areas. For instance, Boyes et al. [33] proposed a framework for IIoT components as a basis for analyzing the use and deployment of IoT technologies in industrial settings. It explained the definition of IIoT and analyses related to enumerate and characterize IIoT devices when studying system architectures and analyzing security threats and vulnerabilities.

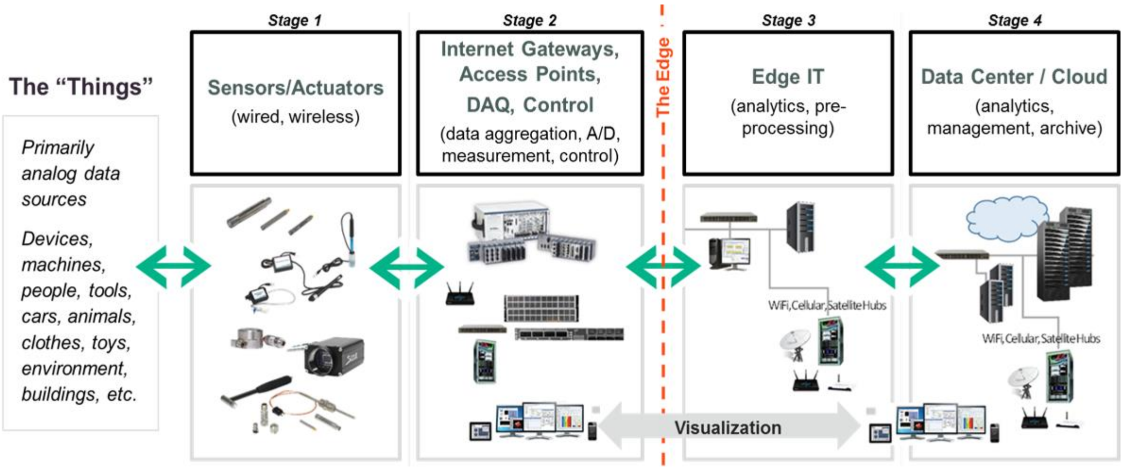

Figure 2.7. A 4-stage IoT solutions architecture (*www.community.hpe.com*)

Figure 2.7 shows an IoT model that directly related to Industrial application, it is divided into four distinct stages: (1) sensors/actuators, (2) data acquisition and control systems, (3) Edge IT, and (4) data center and cloud. The first stage contains sensors and actuators to capture analog data as the primary data of IIoT. In reverse, control data and signals are connected to things for controlling and actuating it. Then, the second stage consists of systems that digitalize the analog data and convert it into bits and bytes. Afterward, stage three provides analytics and prognostics from the IT systems data that take place at the edge, closer to the point of data capture. The final stage is the stage where the data center or cloud will be used by most IIOT applications, which enables in-depth processing, along with a follow-up revision for feedback and the data from other sources may be included here to ensure an in-depth analysis.

Furthermore, Sisinni et al. [35] proposed some foundational aspects that can be highlighted for a systematic overview of IIoT, such as the architecture, the connectivity, and the standardization. The IIoT architecture provides a three-tier pattern that consists of edge, platform, and enterprise tire connected by proximity, access, and service networks. The edge describes the components of IIoT that interact with each other, then platform provides a secure as well as performs data collection and transformation, and tier that is the level of the network services to establish a link with the company that implements the level of domain-specific applications and provides the end-user interface. Then, the connectivity that is illustrated by the protocol heterogeneity of the IIoT is mirrored in an hourglass-shaped stack. These layers consist of networking, connectivity, and information. Networking in the lower layer provides the physical link and IP networking, then there are the framework and transport to exchange messages in the connectivity layer and application of information is placed on the top layer. Furthermore, the most important basic aspect to support technology widely and is well accepted is through the establishment of standardization. For this IIoT technology, the International Electrotechnical Commission (IEC) is used to provide relevant parts of communication by providing a glossary of industrial automation requirements throughout the life cycle of the installation.

2.2.3. Artificial Intelligence (AI)

Operating, monitoring, and controlling a manufacturing system generates data that can be used to determine which controls and configurations result in the best performance and make strategic and necessary decisions in real-time. These functions can be created by applying Artificial Intelligence (AI). AI is a computer technology that makes machines work in an intelligent manner, similar to how the human mind works. Therefore, AI is implemented in the manufacturing field to lead the way to be a smart manufacturing system because this technology is considered as a fundamental way to possess intelligence. 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 [34]. According to a smart manufacturing system that implements CPS and Digital Twin, AI will be a powerful tool to handle this large amount of and somehow interdependent parameters. It will collect a large volume of data from the physical system and this should be considered together with process parameters, machine tool properties, machine conditions, and machining environment in order to make a more accurate prediction in system optimization, monitoring, and diagnostics.

Typically AI that integrated with information communications, manufacturing, and related products in the smart manufacturing technology system, AI consists of a resources/capacities layer, a ubiquitous network layer, a service platform, and an intelligent cloud service application layer, as well as security management and standard specification system [36]. From this information, rules governing the decision-making of smart manufacturing systems can be generated utilizing AI for services that support manufacturing processes and a platform for horizontal integration. A functional and information layer should be developed to obtain services that provide a core intelligent-decision support system and as a user interface. To develop this layer by optimally coordinating manufacturing resources augmented with AI methodology, the four technologies that enable the AI industry are put in the context of the Cyber-Physical Systems (CPS), as illustrated in Figure 2.8 [37, 38]. These four technologies that enabled for achieving success in Connection, Conversion, Cyber, Cognition, and Configuration, or 5C consists of DT, AT, PT and OT.

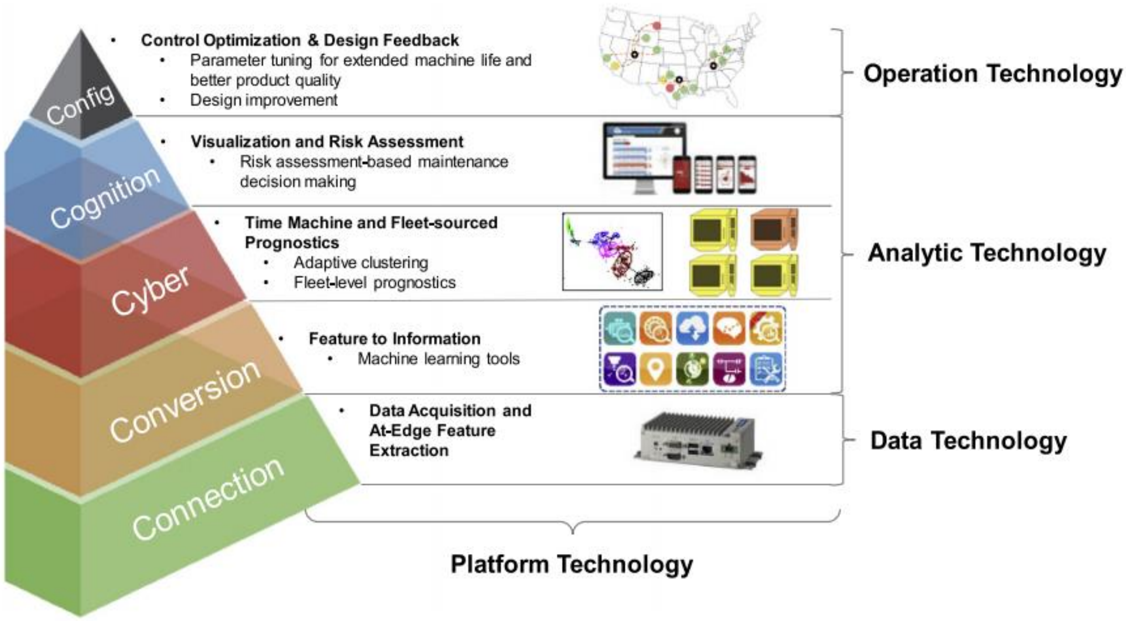

Figure 2.8. Enabling technologies for the realization of CPS in manufacturing

In Platform Technology (PT) of the architecture is divided into Data Technology (DT), Analytic Technology (AT) and Operation Technology (OT) [38]. DT represents the connection that generates information, knowledge, and insight by identifying the appropriate equipment and mechanism to acquire useful data. Then, AT provides conversion, cyber and cognition that changes the data of sensors into useful information that can be used for machine prognostics and health management. Data visualization tools are an important element of analytic technology to facilitate the interpretation and use of graphs, charts, and reports. The last technology is OT represents the configuration that generates a series of the decision made and actions taken based on information extracted from data or provided insight. OT enables characteristics to smart manufacturing for I4.0 like self-configure, self-adjust, and self-optimize which finally improve flexibility and resilience throughout the whole production system and lead to higher efficiency and economic impact. In conclusion, this 4-stage architecture provides strategies from initial data collection to final value creation taking into account the use of AI technology. Lee et al. [37] applied this architecture by presenting a case study in intelligent spindle system, it provided a full solution for real-time monitoring and performance prediction of a machine tool spindle. The system is designed to minimize maintenance costs and optimize product quality.

2.2.4. Big data

Big data technologies can play an essential role in smart manufacturing by equipping machines with sensors that measure data in their environment. Big data involves information assets characterized by high volume, velocity, and variety, and requires specific technologies and analytical methods to transform data into useful and valuable products [39]. Generally, the value chain of big data refers to the sequence of activities from data generation, and acquisition to storage and analysis [40]. In smart manufacturing, the big data involve a large amount of real-time data (e.g., machine operation data and sensor data) and unstructured multimedia data (e.g., video and audio) from the system. Therefore, regular data tools could not be collected, stored, managed, shared, analyzed, and computed within a tolerable time [41].

Big data has four characteristics abbreviate in "4V" which is volume, variety, velocity, and value. Volume represents a very large scale of data, ranging from several PB (1000 TB) to ZB (one billion TB) [42]. Then the size, content, format, and applications of the data that diversified are defined as variety. Data structured (e.g., digit, symbols, and tables), semi-structured data (e.g., trees, graphs, and XML documents) and unstructured data (e.g., logs, audios, videos, documents, and images) are the examples of the variety [43]. As for velocity is the speed of data transfer and accuracy of data processing. While the value is the significance of big data in the huge value, it refers to the process of discovering huge hidden values from large datasets with various types and rapid generation [29].

Nowadays, due to the rapid development of new-generation information and communication technologies, such as the Internet of things (IoT), cloud computing, and artificial intelligence (AI), the use of big data is widely applied in manufacturing systems that are integrated with new paradigms for various smart systems. Tao, et al. [28] investigated the detailed application methods and frameworks of digital twin-driven product design, manufacturing, and service in order to solve the problems about data in the product lifecycle. Three use cases also are illustrated by the application of a digital twin driven the three phases of a product respectively. Another framework is developed based on big data analytics that is an optimization of the maintenance schedule through condition-based maintenance (CBM) and improvement of the prediction accuracy to quantify the remaining life prediction uncertainty [44]. This framework is developed for analyzing CBM policy costs more accurately and finding probabilistic covariate threshold values that correspond to the lowest price of predictive maintenance costs. Before this, a study about cloud-based predictive maintenance for intelligent manufacturing has been conducted. It investigates a cloud-based predictive maintenance paradigm based on mobile agents to enable information acquisition, sharing and timely utilization to improve accuracy and reliability in fault diagnosis, prediction of service residuals, and maintenance schedules [45]. Associated with it, big data and cloud computing are distributed network technologies that integrated. In addition, cloud computing is one of the most significant changes in modern ICT and services for large-scale and complex computing. Cloud computing is a model for allowing ubiquitous, convenient, and on-demand network access to a number of configured computing resources such as networks, servers, storage, services and applications that can be rapidly provisioned and released with minimal management effort or service provider interaction [46]. The use of cloud computing in big data is illustrated in Figure 2.9 [47]. It shows a large data source from the cloud and web that stored in a distributed fault-tolerant database, then processed by a programming model and transferred in data visualization to view analytical results presented through different graphs for decision making.

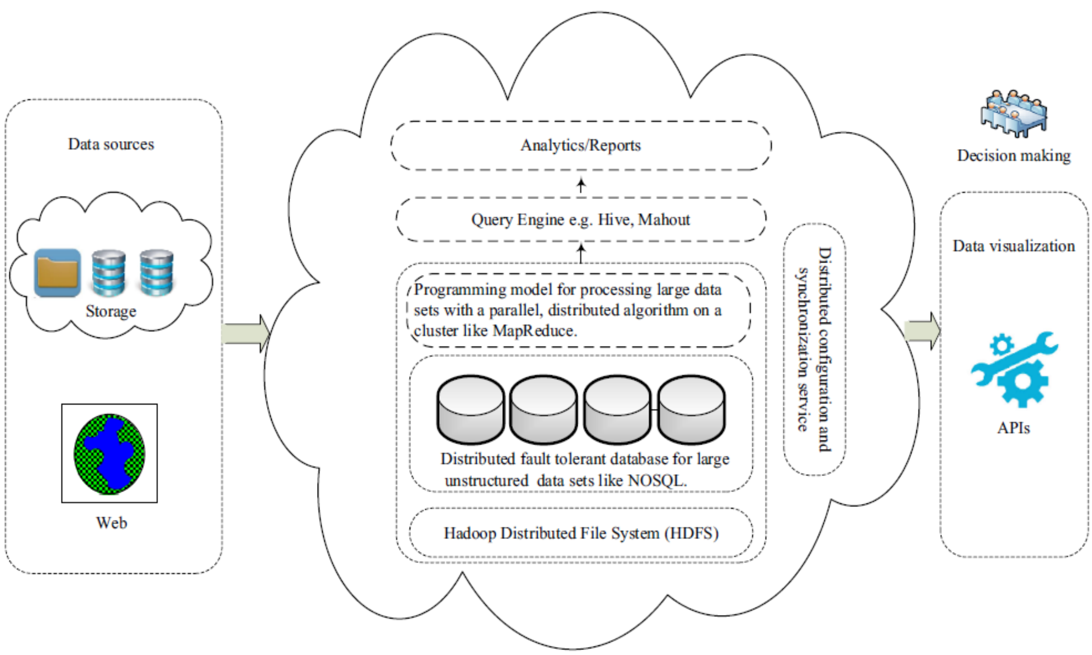

Figure 2.9. The use of cloud computing in big data

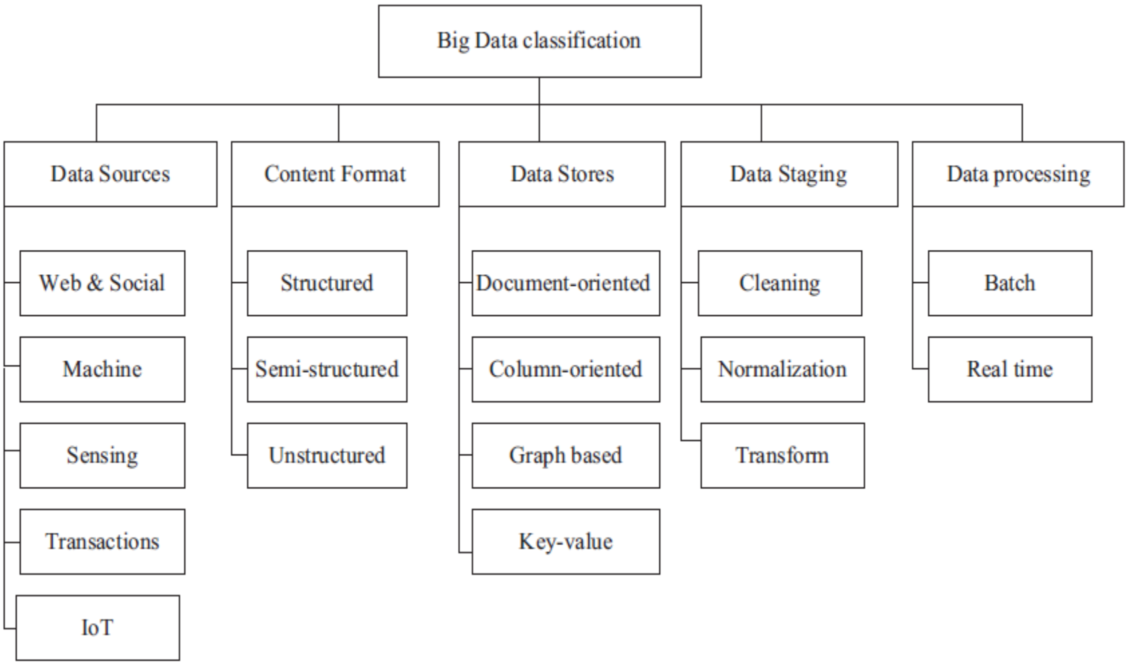

Figure 2.10. Classification of big data

Since the classification of big data characteristics is important to be stored in the cloud, Figure 2.10. shows the five categories of big data: (1) data sources, (2) content format, (3) data stores, (4) data staging and (5) data processing. All these categories of big data are offered features and benefits by cloud computing through the ease of use, access to resources, low costs in utilizing resources for supply and demand, and reducing the use of solid equipment [48].

Based on the role of big data and cloud computing technologies that explained above, smart manufacturing needs to implement these technologies. The integration and networking of smart manufacturing components and services within a factory will seamless exchanging of information with program language that understandable by all the systems involved in cloud computing. Smart manufacturing leverages that value chain in manufacturing and applies big data analytics to improve process performance and identify variables that affect production and drive decision-making. Putting big data in the cloud will make both the source of the information (data) and a platform for AI essential components in the smart manufacturing system. These visible and invisible problems in smart manufacturing can be reflected in the data. Big data brings more efficiency, sharper insight and more intelligence to manufacturing.

Chapter 3 CONCEPTUAL DESIGN

3.1. Strategy for designing a platform of the smart welding station system

The purpose of doing research is to get a solution to the problem being faced. The solution must be proven theoretically and analytically so that it can be accounted for. To fulfill this, the research must be carried out in a structured and systematic manner in its implementation. Therefore, a strategy for developing a platform for a smart welding system implementation was created, as shown in Figure 3.1. With the endeavor of implementing a Smart Manufacturing, 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 I4.0 technologies we would implement in our platform.

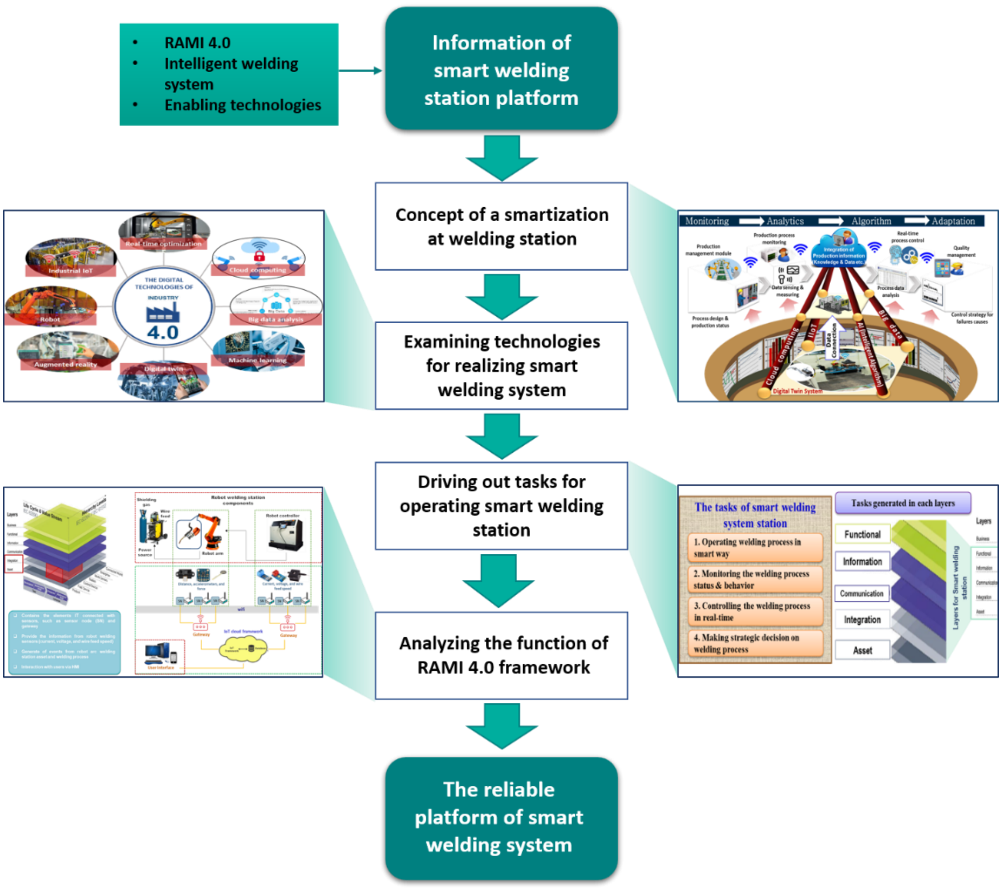

Figure 3.1. Strategy for developing a platform of a smart welding system

3.2. The core technology of smart welding system

Smart manufacturing aims to transform raw data across a product's life cycle into knowledge to make a positive impact on manufacturing [49]. One of the main pathways of development is through a smart welding system. The development of smart manufacturing in the welding station has exhibited remarkable growth, suggesting a bright future for current manufacturing industries interested in improving welding processes and quality control of the resulting products. In a welding station system, the welding is performed and controlled by robotic equipment, also known as smart welding machines, which operate autonomously and can communicate directly with larger manufacturing systems. Through these technologies, real-time smart welding station system data can be obtained and shared to facilitate rapid and accurate decision-making. We investigated the potentials of smartization to address emerging capabilities of smart manufacturing, as well as the barriers to upgrading current systems.

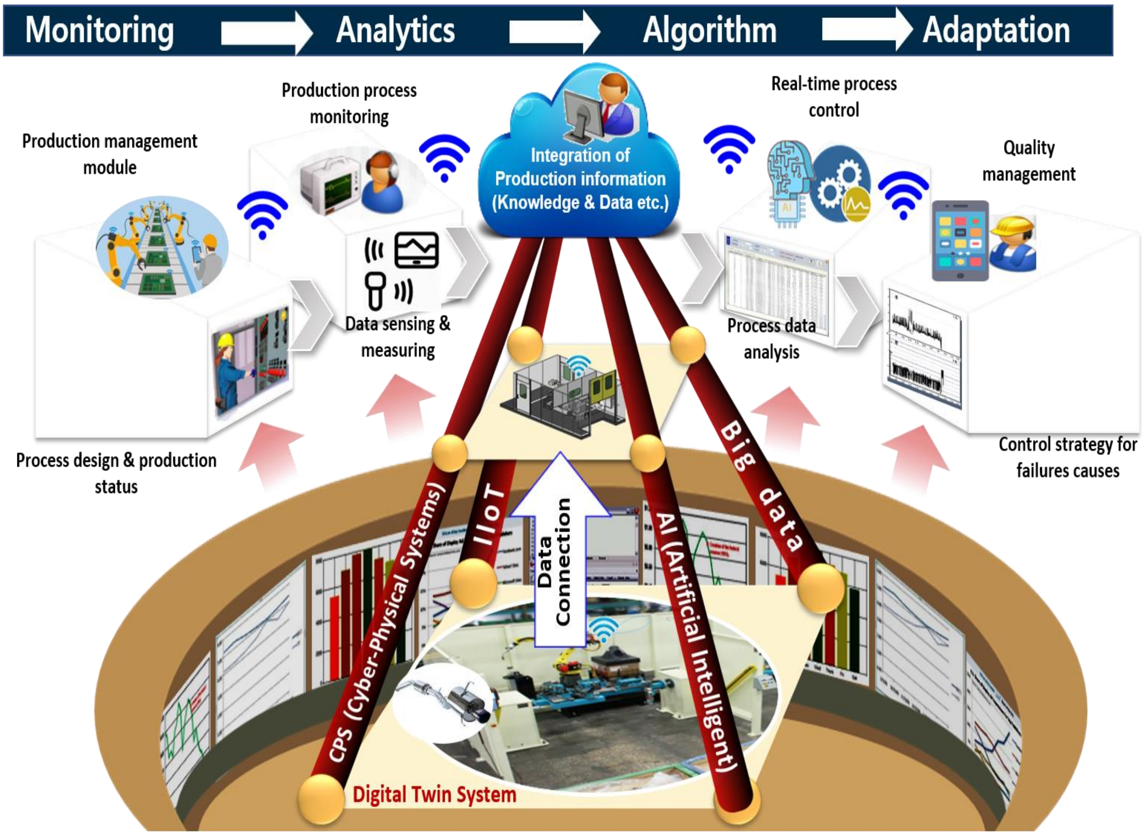

Figure 3.2. The smart welding station system concept

A concept of a smartization of the welding station system is presented in Figure 3.2. Process design and production status, data sensing and measuring, process data analysis, and control strategy of failures are the functions of the Intelligent manufacturing system. Smartization here refers to an evolutionary shift of welding station toward smart behavior through this stage: monitoring, analytics, algorithm, and adaptation which consecutively the key features of the Smart welding station system. While four key technologies of I4 — CPS, IIoT, big data, and AI (shown in Figure 3.2) — are applied to a welding station.

An IT system is necessary for communication in smart manufacturing and requires a reliable network of industry assets. The interactions between the IT system and the robot welding machine can be designed with enabling technologies to create a smart welding station system, with IIoT ensuring efficiency in communications and integration. Through this integration, a digital twin (DT) system is formed in the cyber system and all necessary data from the welding process in the physical system are generated. Data can then be collected and documented, and it is possible to be used for eliminating production errors through intelligent quality control, should they arise. High-performance data analytics are needed after all welding data are transmitted to the cloud for the integration of production information. Cloud computing has been implemented in manufacturing systems, and traditional manufacturing systems can be upgraded with the help of IIoT and big data, resulting in decision-making concerning which manufacturing data can be shared and used to operate in autonomous mode [9]. Artificial intelligence is used to generate the algorithm for real-time process control with process data analysis. Neural network models are the most AI techniques used to conduct research to overcome challenges related to smart manufacturing. Evaluation of weld quality through the cloud-based on seam-edge detection and holographic projection has been tested; the cloud service, with the help of an artificial neural network, evaluates the captured images by comparing them with a reference image for weld defects and sends the evaluated results back to the weld cell [50].

Such a system consists of welding physical components with computational functionalities and mechanisms controlled or monitored by algorithms running on a computer. It can provide increased capabilities, allowing manufacturers to monitor the welding process in real-time and accumulate data that can be analyzed. Analyzed and structured data are transferred to a cloud server for permanent storage, where different data mining and machine-learning algorithms can be executed for knowledge extraction [51]. This knowledge is used to make strategic decisions on each task, which refers to all kinds of tasks and algorithms established in the smart welding station system, such as operating welding processes, monitoring the welding process status and behavior, and controlling the welding process in real-time. Analyzed and structured data can be critical to the success of a smart system. Data-mining methods can be designed for welding process decision-making through machine-learning algorithms that can understand real-time process monitoring, interact with the environment, and intelligently adjust behavior.

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. To implement a welding system using this conceptual research methodology, three actionable plans were identified: (1) establishment of a strategy for building a smart welding station system based on a welding process problem, (2) development of an intelligent process control module by applying the core technology of the I4.0, and (3) development of a smart welding operation system that enables process control in the IoT-based connection environment beyond the existing manufacturing execution system.

3.3. Enabling technology for the system function

The proposed smart welding station system involves monitoring and controlling the welding process using the core I4.0 technology to ensure quality. Monitoring includes identifying the welding process behavior based on an evaluation of failure causes related to process parameters. A monitoring process has two parts: (1) sensing, with appropriate signals for process behavior monitoring obtained from sensors, and (2) monitoring, composed of signal processing and decision-making [52]. Real-time process monitoring will make it easier for the operator to determine whether the manufacturing process is running correctly or if there is an error, using different parameters. Welding parameters include voltage, current, wire-speed, and welding speed. Big data make it possible to observe these parameters continuously and in real-time, over system-cycle periods. Because all data relevant to the process are available, users have the opportunity to configure the monitoring of the welding process behavior in ways and features generated by AI for certain applications. I4.0 technologies are developed to enable flexible decisions in smart welding station system production. In I4.0, most of the operational decisions are made according to the experience of managers. However, how to analyze the collected information, it helps users make better decisions is a crucial issue in current welding systems. Although data collection is simple with the use of smart sensors, the collected data are useless without analysis. It is necessary to acquire, store, and analyze big data to make them meaningful. By a big data analysis and cloud computing, the digital system and decision support system can transform the information into visualizations. To enable the smart welding station system, the core technologies of I4 are introduced in Table 3.1.

Table 3.1. Characteristics of I4.0 enabling technologies

Characteristics of enabling technologies	**Description**
Industrial Internet of Things (IIoT) for welding station	• Ability to connect and manage welding hardware and software • Detect welding failures and place orders for welding process parameters • Monitoring the welding process in real-time
Cloud Computing for welding data	• A model managing, storing and processing welding data • Real-time communication for operating welding process • Sharing welding parameters for reducing failures
Big Data Analytics of welding data	• Collecting welding data such as current and voltage • Improving the welding processes performance • Ensuring the quality of welding characteristics, such as surface cracking and penetration
Robot Welding as an agent	• Communicating the welding power supply and sensors • Performing the weld and handling the part • Automating a welding process by maintaining a torch orientation that follows the desired trajectory
Digital twin for monitoring and controlling	• Monitoring the behavior of the welding process • Managing and executing welding data algorithm • Improving the welding process and control welding system
System Integration for welding station	• Allows for different smart welding station to be linked together • Enables actual welding station communication and passing on of welding data between systems

3.4. Functional analysis of the smart welding operating system

The following case study is taken from a welding process in an automobile muffler or exhaust system. Like many components in automotive engineering, mufflers are assembled by a robot. The goal is high productivity, shorter process times, and minimum welding defects. To achieve these things, the working function of the welding process is classified here based on the characteristics of I4.0 enabling technologies that investigated in the previous section. Based on the chosen product, the working function of the welding process is intended to face challenges for welding consumables. High welding speeds with low feed power, even feed force, and high tolerance range are required for this product. Furthermore, welding that can be consumed has to meet mechanical and chemical requirements as well. Therefore, because some materials will be exposed to high temperatures and corrosion when used, a combination of base material and selection of the right welding method is needed. The operation of the intelligent welding station system makes it possible to improve this condition.

Digital twin as the new simulation modeling paradigm, which is often referred to as a component of the CPS vision is developed in this working function. The goal is to allow robot welding to synchronize its processes on the production line while making it part of a smart welding station system. Artificial intelligence technology is used for simulating intelligent behaviors and functions of welder's sense, brain and body activity in the welding process. Furthermore, the general constitution of smart welding station, functions, and its systems were developed in an intelligent process control based on big data analytics. It is the technical approach imitating welder's decision-making functions. Intelligent control methods that could be developed for welding technical condition such as plate-based welding such as the muffler is a self-learning fuzzy neural control and adaptive fuzzy neural. This method has been developed for the penetration, the width of the upside and backside pool and seam, face reinforcement and fine forming of the weld seam during the arc welding process [53]. The advanced autonomous expert system for real-time and control of the welding process is another important part of smart welding systems that could be developed through system interaction. This would create a welding process that operates in an essentially intelligent way, monitoring and controlling the welding process in real-time, as shown in Figure 3.3.

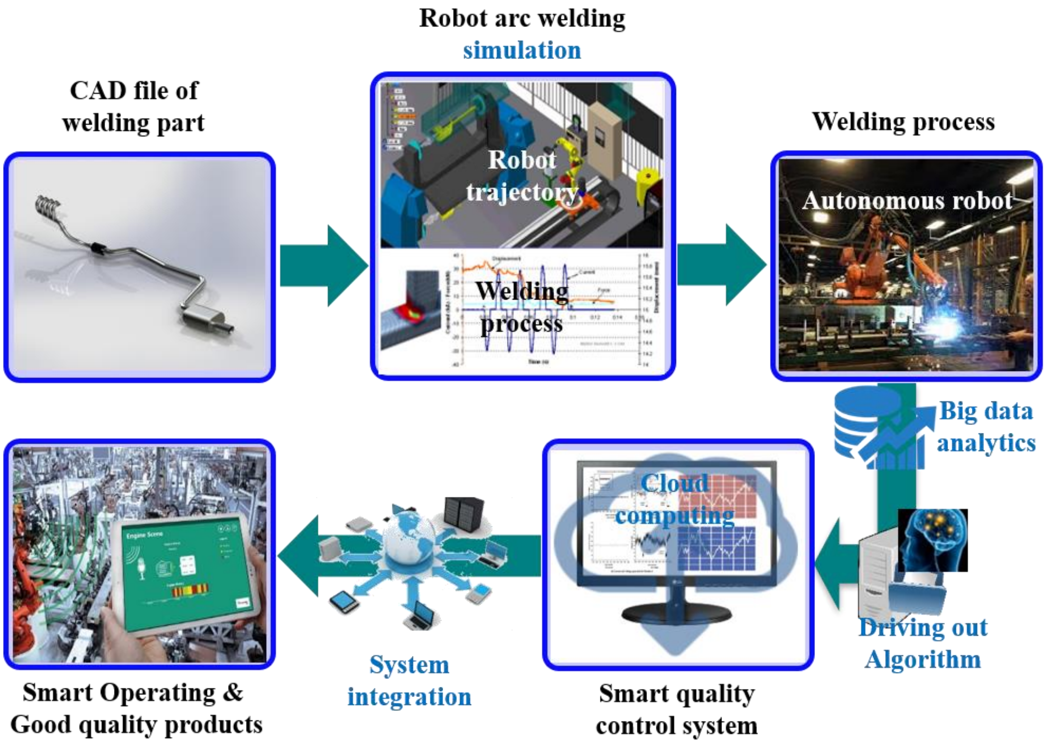

Figure 3.3. Working functions of a smart welding station system

Operating the welding process in a smart way means a system connects the physical network and the cyber system through autonomous control in real-time, and big data analysis directs the decision-making for taking actions. I4.0 technologies, including IIoT, that can collect data and analyze it, automatically detect abnormal failures, and share information can be easily and reliably applied to smart systems in a welding station to prevent welding failures and enhance process performance. During the welding process, different feed speeds and arc types can be used to evaluate performance and yield based on different requirements identified by the big data collected and analyzed.

3.5. Major frameworks of RAMI 4.0

A platform for implementing a smart welding station system based on RAMI 4.0 is studied, analyzing the characteristics of this reference model in line with the smart welding station system architecture. The selected area of RAMI 4.0 for platform creation includes three aspects: product life cycle, hierarchy levels, and architecture layers.

- Hierarchy levels: Field device, control device, and station represent the smart welding station system. This aspect shows entities that are grouped differently based on functional properties and represent all levels of the hierarchy of the company or factory. “Station” is the final stage, which uses the IoT to connect all components of the station.
- Architecture layers: On the vertical axis are asset, integration, communication, information, and functional, which represent the tasks of the smart welding station system. The contents of the asset layer represent the real world and the rest of the layers constitute a virtual map of the physical installation of the welding station.
- Life cycle and value stream: On the horizontal axis are staged from production to maintenance/usage defines “instance” as a completed concept design that is available as an object to be applied and used. The process of designing this platform for the smart welding station system includes “production” from the “instance” section.

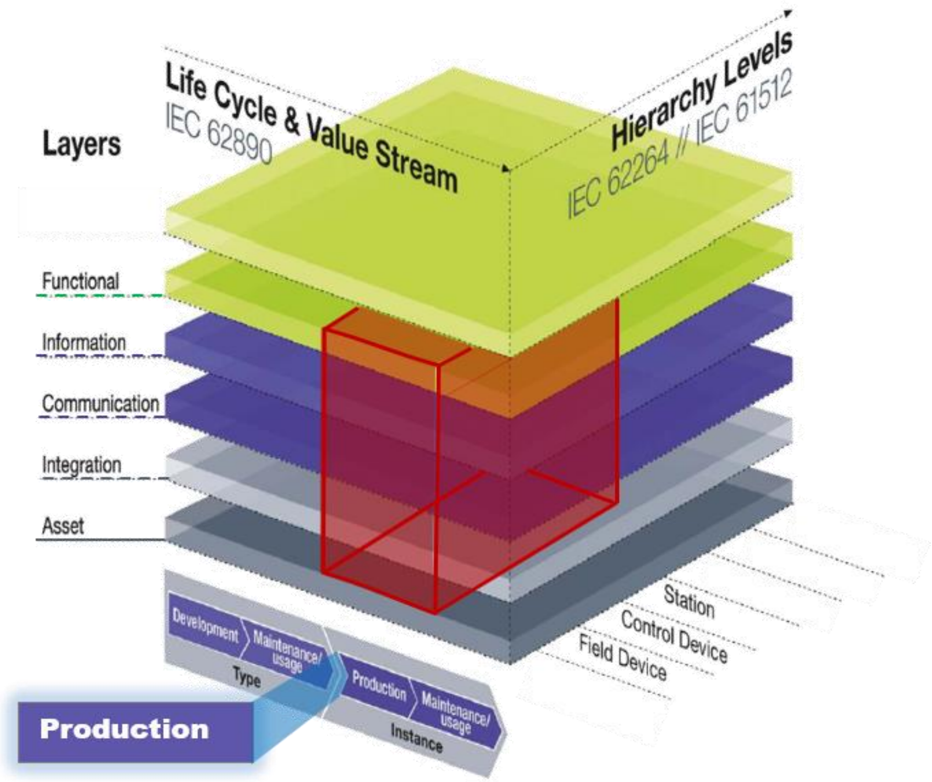

Figure 3.4. Smart welding station system tasks visualized in RAMI 4.0

The smart welding station system represented in the layers of the RAMI 4.0 framework consists of building a network for the smart welding station system, implementing communication in the cloud network and performing cloud computing.

These tasks are created in the “instance” phase of the life cycle on the x-axis of RAMI 4.0, that is, “production.” Based on the characteristics of each aspect of RAMI 4.0 and the proposed main tasks, a platform for the smart welding station system follows the selected area visualized in RAMI 4.0 framework, as shown in Figure 3.4. Before mapping the essential components on a two-dimensional platform consisting of three levels of hierarchy on the y-axis and five IT layers on the z-axis, classification of the smart welding station system tasks is first clustered in terms of IT layers and hierarchy levels.

The left vertical axis in Figure 3.5 includes five clustered IT layers ranging from the lowest (asset) through integration, communication, information, and the highest (functional). Brief descriptions of tasks generated in each layer are shown in Table 3.2. Figure 3.6 depicts the right axis-hierarchy in terms of classification of a smart welding station system considering RAMI 4.0. These hierarchy levels represent the location of functionalities and responsibilities within the smart welding station system’s physical architecture. The structure covers three sectors, from data-collecting to process automation; the terms “station,” “control device,” and “field device” were selected from the listed options.

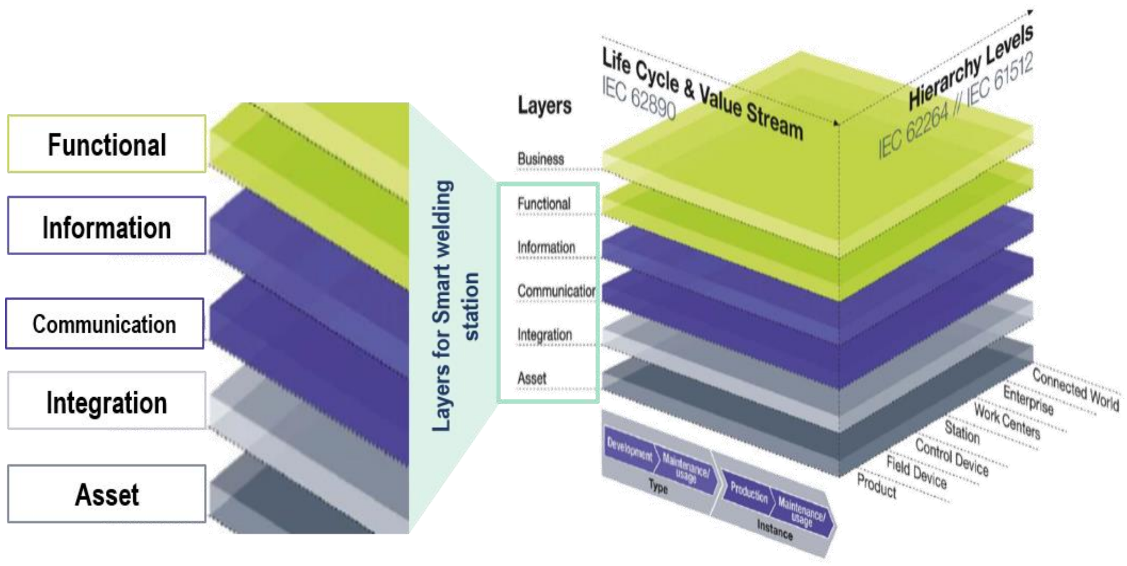

Figure 3.5. Clustered IT layers

Table 3.2. Tasks generated in each IT layer

IT layer	Description
Asset	Interact directly with standardized physical and digital elements of a smart welding station, such as the robot arm controller, power source, and wire feeder via cable
Integration	Model communication requirements between the welding station and control server in digital forms that can be processed by computer in the cloud
Communication	Control the connecting access point and cloud computing using HTTP/FTP in the direction of the information layer to manage the data collected
Information	Correlate sensor signals of welding process failures and process variables as well as a digital twin–based process status monitoring
Functional	Set up welding process parameters such as current and voltage on a welding controller to respond in real-time to failures that occur in the welding process

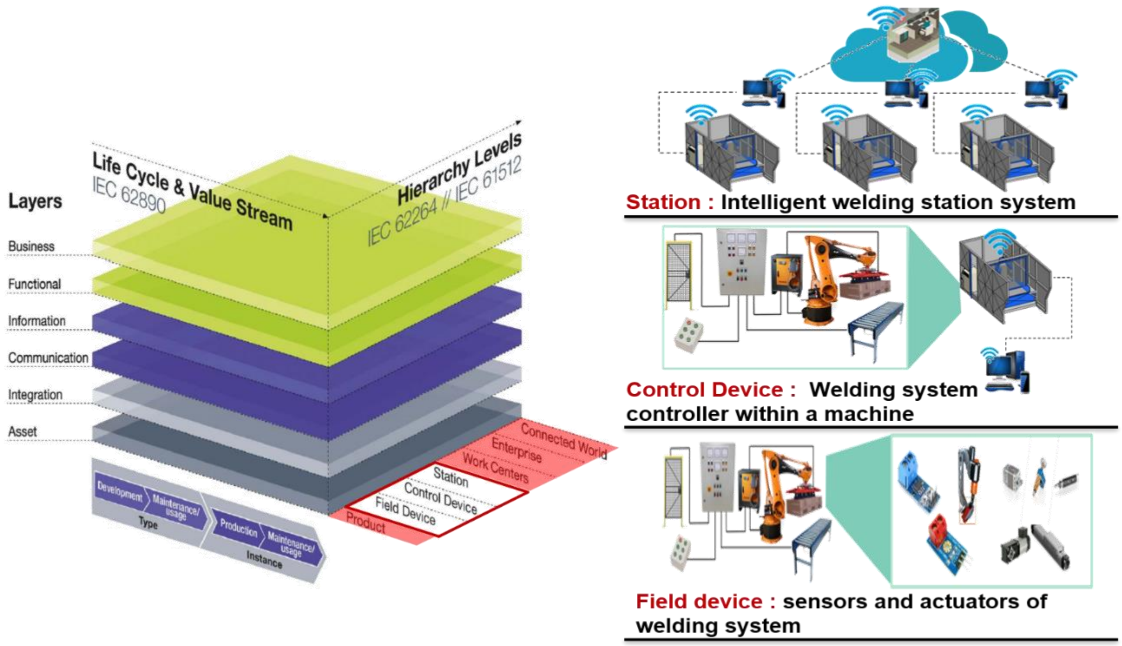

Figure 3.6. Clustered hierarchy levels

This hierarchy starts from the field device, which consists of a set of sensors and data collectors embedded in the smart welding station system. At this level, data on the welding process (voltage, current, and wire-feed speed) are collected and then processed by a computer. The control device facilitates direct automatic control of the welding process using industrial controllers such as 'Siemens' Simatic automation system. Finally, the station level is designed to connect or display data on the welding process and manage various welding station units.

Chapter 4 DEVELOPMENT OF A PLATFORM

4.1. The main task in the functional framework RAMI 4.0

The main tasks of the smart welding station system proposed in a five-layer description of functions differ in perspective and levels of control. Three main tasks are involved in smart welding: monitoring the welding process status and behavior, controlling the welding process in real-time, and making a strategic decision on the welding process. These tasks define the essential components of the smart welding station system that will be described later. As shown in Figure 4.1, tasks for each function generated in each layer were proposed. To achieve effective collaboration between the robot and the welding process, the physical network functions must be correctly structured. Following a conceptual approach, the functional components of the welding station and their interactions are synchronized. Layers include a hardware concept of IIoT as an asset layer, network integration as an integration layer, implementation of communication in direction of cloud computing as a communication layer, DT-based monitoring and controlling as information layer, and physical configuration as the functional layer.

In the asset layer, physical networks of a complete smart welding station were designed along with an AI system on the cloud to control welding. The operator can monitor the welding process status and behavior using a physical interface influenced by actuators. Sensors and actuators play important roles in the welding station asset by sensing the welding process environment and collecting data. The integration layer connects its IT elements with a sensor node and gateway. Network integration also provides information, such as current, voltage, and wire-feed speed, from robot welding sensors, and users interact with the welding machine through a human-machine interface. On this communication layer, a standardized communication interface for the smart welding station system is provided. The gateway functions as a signal amplifier and middleware node in the wireless network. A communication protocol (e.g., IP, TCP, or HTTP/FTP) is selected for managing information on the welding process. Decision-making about welding process control is analyzed based on the structured data of welding process parameters delivered by service interfaces.

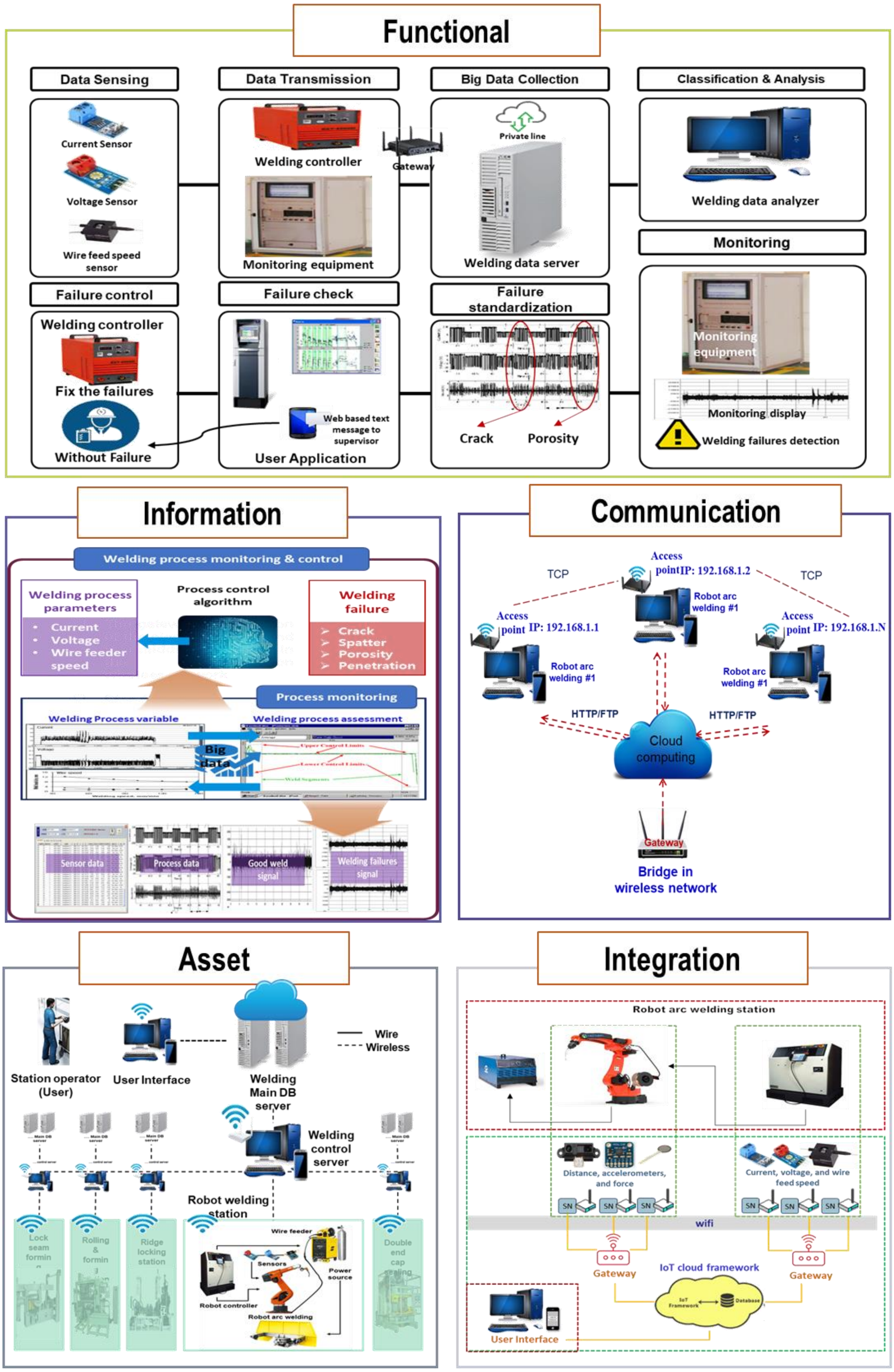

Figure 4.1. Architectures generated in each layer for operating the system

However, this information must be pre-processed, executed, and analyzed. A DT-based process monitoring and control system, similar in concept to CPS, is used in the information layer. Dynamic and kinematic structural analysis of the welding process and robot welding machine are conducted. If sensor signals, process parameters, and DT-based process status monitoring are correlated, process parameters and failures are derived by a control algorithm. Implementation of DT-based process monitoring and controlling will be carried out by an AI through the derived algorithm.

The last functional layer describes the model and integration services of the smart welding station system by generating decision-making strategies for welding and controlling. With IIoT as the network technology, real-time data from the welding process are collected by sensors and the welding station, which are system inputs. Later, a welding data analyzer is connected directly through the internet to a welding data server to analyze the process. Monitoring equipment and a user application detect welding process failures based on standardization. The system then makes decisions based on the inputs and immediately performs an automatic control, such as failure detection or directly fixing the failure. It can also simultaneously send alert messages to supervisors and operators about the situation.

All described layers define which functions should be given and how the interaction with the surrounding components overall in the interoperability layer. Additionally, a study related to one of the production systems has been conducted by producing a road map. Assembly 4.0 (A4.0) which is the assembly system transformed by I4.0 technology integration proposed a framework to understand and assess how they impact on performance in terms of overall flow time and ability to handle a wide variety of end products with three impact levels include: strategic, tactical, and operational [54].

4.2. Mapping the essential components of I4.0 in RAMI 4.0

Some studies that analyze and compare reference architectures and frameworks relating to smart manufacturing standardization, in general, are available. However, little attention has been paid to guidelines based on reference architecture to realize a system in a practical way. A study of reference architectures based on a critical review of smart manufacturing systems has been conducted that divides fundamental architectural elements into three architectures: physical architecture that describes the components that create a system, functional architecture that describes the required functions of the system, and an architecture that integrate the physical architecture and functional [24].

Similarly, this study divides the three main aspects to be modeled into a platform. To complete the platform modeling process, I4.0 components of the proposed architecture needs to be allocated to each aspect of RAMI 4.0 to provide a full explanation of the design of the smart welding station system, including the physical network functional architecture, enabling technology for realizing the whole system, interface architecture that has been integrated to cloud, and complete documentation of the design architecture of main tasks. We propose using our platform to better understand and enhance the smart welding station system based on RAMI 4.0, and to identify I4.0 component specification and the potential of I4.0 technology.

The main task of the smart welding station system in the RAMI 4.0 framework was addressed in previous sections. Figure 4.2 depicts a platform architecture that covers the three aspects of a RAMI 4.0 device relevant to operating and control a welding station intelligently. Also described are the life cycle and value chain of the I4.0 components for executing the welding process at the station. For the layers in the vertical axis, the corresponding functions are physical elements, system integration and internetworking, communication interface, integration welding parameters for cloud computing using AI, and integration services for decision-making. The hierarchy level in the horizontal axis provides references for allocating different levels of smart welding station physical components. This platform provides guidelines and standard requirements for the successful implementation of the smart welding station system.

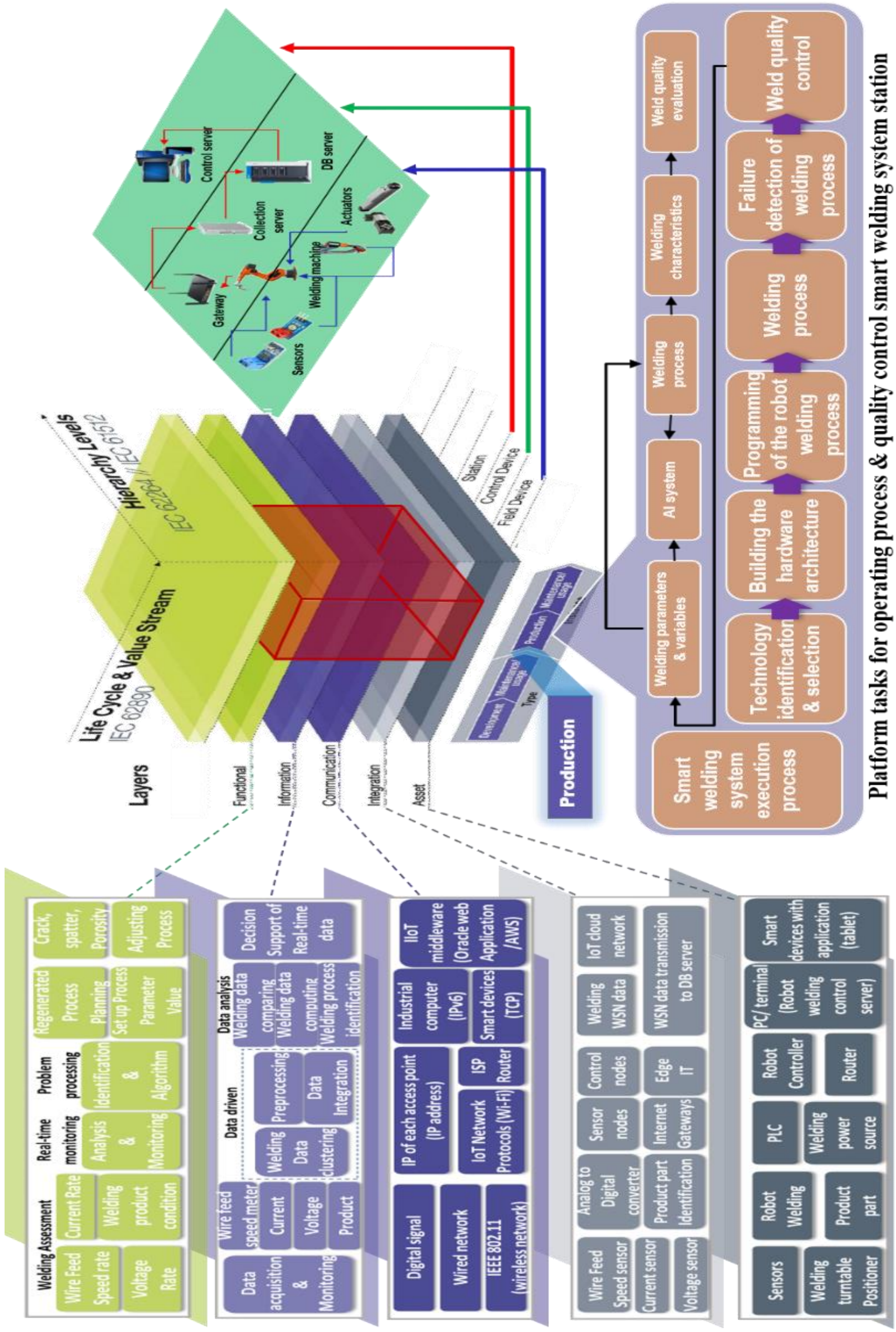

Figure 4.2. A platform architecture for a smart welding station system

4.3. A platform of smart welding station system

For a manufacturing enterprise, how best to use smart manufacturing technology (industrial technology, information technology, and management technology) to link manufacturing processes together is a core consideration [25]. Intelligent manufacturing systems involve physical devices that are flexible, self-aware, and autonomous. This kind of challenge requires a complex network of multiple interacting layers associated with the functional, physical, and value-network aspects of the manufacturing system. Rigorous mechanisms and analytical techniques need to be developed to guide, optimize, and regulate interactions between human and non-human agents from simple data exchange to high-level cognitive collaboration [26]. The design of interaction rules and architectures must conform with open communication and self-description standards such as OPC-UA [27].

This study designed a platform for a smart welding station system categorized by manufacturing systems at the station level. Based on the concepts system and the modeling of a platform architecture described in the previous section, this welding system is intended to meet that challenge. This section shows how smart manufacturing technology is used. After designing the platform architecture with I4.0 to create the smart welding station system, a model of the platform for implementing that system is shown in Figure 4.3. This two-dimensional platform identifies the essential components of enabling technology in I4.0 for the proposed system. It is aimed to provide a guideline and standard requirements in the aspects of RAMI 4.0. Figure 4.4 shows a global view of the topological approach of three-dimensional for a smart welding station system platform, which consists of the important aspect depicted from RAMI 4.0. This case study refers to specific but common challenges in operating and controlling welding processes.

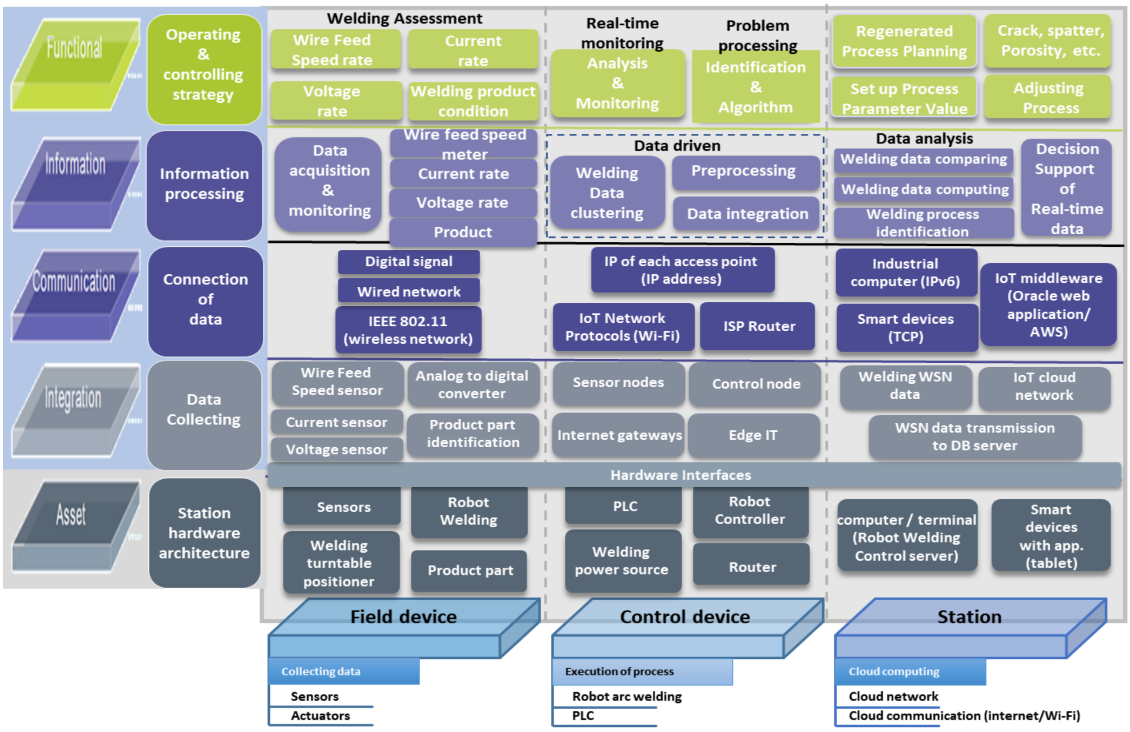

Figure 4.3. The smart welding station system platform in terms of production

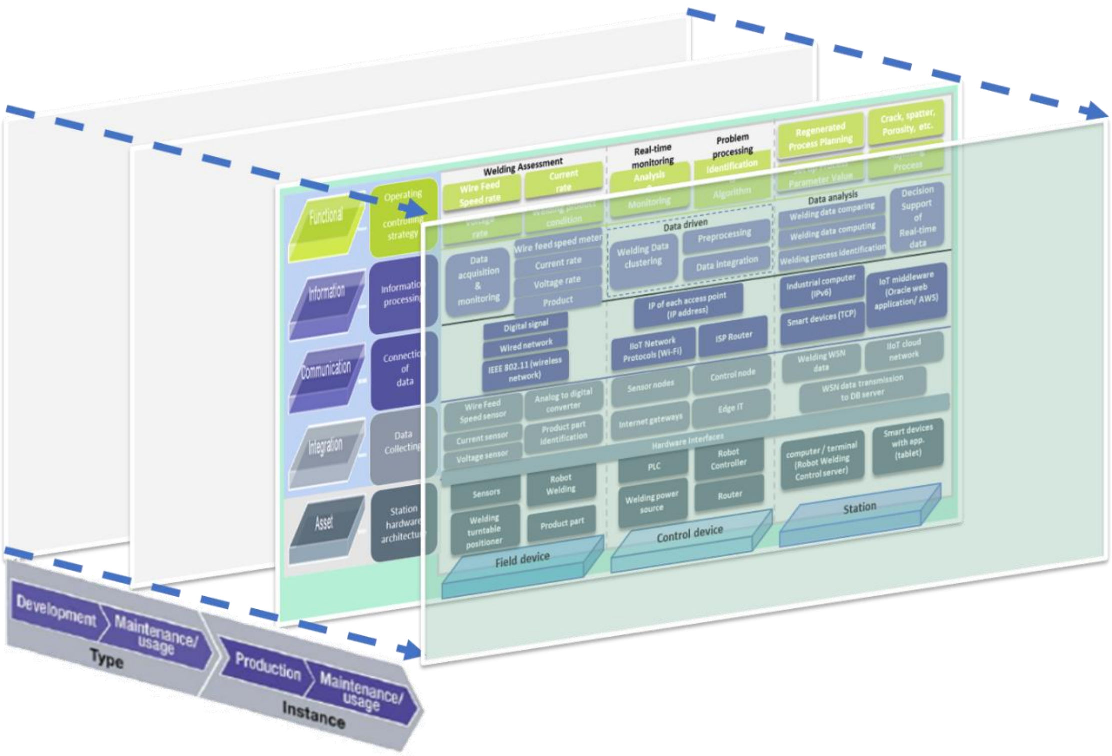

Figure 4.4. A global view of a smart welding station system platform

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 I4.0, such a value-added service is required for cloud-based, smart manufacturing system platforms that can be flexibly managed and interlocked. The value-added services come from the application areas, such as data acquisition, condition monitoring, sensor data processing, data exchange, and welding process simulation. For clarity, a determination of the hierarchy levels, as well as the layers, of the product lifecycle phases of instance and production is performed in this platform. Its elements represent relevant technologies for the respective product lifecycle phases of the welding station. Each layer shows the functions of technology and components arranged on a platform consisting of hardware architecture, data collection, the connection of data, information processing, and operating and controlling strategy. Hierarchy levels show the required components to support the proposed approach concept.

Using a RAMI 4.0 approach with enabling technologies of I4.0, users receive a solid sense of the platform I4.0 landscape. Guidelines (including components, formats, and services) on how to operate and control a smart welding station system with enabling I4.0 technologies are provided in the platform to help manufacturers create smart welding systems at the station level, sequentially and as needed.

Chapter 5 DISCUSSION

A platform model identifying functional of RAMI 4.0 was designed to classify in detail the tasks of smart welding station system using enabling technologies of I4.0. The smart welding station system concept is created by enacting core technology to deploy some features of smartization. Furthermore, six enabling technologies of I4.0 were derived to determine the working functions of the smart welding station system. In addition, the working functions were illustrated into a series of processes for establishing a smart welding station system by considering the manufacturing network design to detect failures in the welding process through digital technology. The platform model developed in this study presents a guide to discover and select elements to process operations requested by a smart welding station system, which is performed by the interaction of the physical and virtual worlds.

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. The right axis of the hierarchy levels is decided on three levels in sequence from below by getting through the product level. Then, the architecture layer in the left vertical axis selects five of the six layers without considering the business layer. Subsequently, a draft standard for life cycle management is combining those two axes and arranged in one life cycle that is "production" in the instance phase. Since a platform consists of I4.0 components, the architecture of the smart welding station system was designed by providing components for communication between the machines and users, and the service offered by the system is a mechanism for processing operations.

The architecture layer also is known as an interoperability layer in RAMI 4.0 aspects, which can be described by architecture in each layer. The architecture depictured the main task of a smart welding station system in which arranged in 5 layers. These layers defined which functions should be given and how the interaction with the surrounding components overall in the interoperability layer. Smart welding system architecture in the framework of RAMI 4.0 is applicable at field device, control device, and station level. In this sense, the smart welding system capable of interacting and communicating across the hierarchy levels through a network.

Architecture layers and hierarchical levels detailed in interrelated functions are included in the "production" category with the understanding that this section is included in the development of a system before it is implemented in the industrial environment. The interconnection of all interconnected vertical and horizontal axis elements within each layer is crucial and has to be defined when planning a new smart factory or upgrading an existing factory [55]. Therefore, the smart welding station system is mainly supported by the core technology of I4.0 technology; thus, the workflow of the welding operation system is modeled in an intelligent way to be able to provide continuous control of welding operations, systems, and processes.

The tasks of a smart welding station system were classified into a function along with its essential components which mapped at each layer. Components in the hierarchy level will be automatically generated after a function is illustrated into an architecture. Architectures generated in each layer for operating a smart welding station system. The final platform is made in two-dimensional because it focused on one life cycle to be the reference guide of the welding system in this study; while a “reference model” of architecture is a stable model commonly used and recommended from which are derived specific and concrete architectures [56]. In addition, the architecture layers in this study were responsible for production rules, actions, processing, and system control in the welding station; on the other hand, the role of ‘Functional’ layer provides a service and components to exchange information between real and virtual worlds [57]. Therefore, it is implied that tasks of smart welding station system modulate each architecture layer integrated into hierarchy level with the function which contains service and components for two worlds and placed into a two-dimensional platform

The proposed RAMI 4.0-based smart welding system platform design can be applied to the development of a system that can identify the essential components of enabling technology in I4.0. The platform model developed in the present study showed a guideline and standard requirements in two-dimensional aspects of RAMI 4.0; thus, it might be used for implementing a smart welding station system in an efficient and effective but more important with a practical way which is easy. For instance, the hardware and software components and information can be obtained from the architecture generated from each layer of the RAMI 4.0 framework. The architecture provides standardized communication interfaces between physical elements and cloud computing.

Through a specially created platform, the core I4.0 technology can be easily implemented to create a smart welding station system. This not only focuses on the development and adoption of technology I4.0, but also embraces management, I4.0 components, and other aspects. This case study refers to specific but common challenges in operating and controlling welding processes.

However, there is a lack of the proposed methodology addressing the role of the business layer, product level, work centers, enterprise and connected world level that not selected for this platform. It is required specific products and ERP at the hierarchy level. Although the step of selecting the essential elements can improve the accuracy of a platform model by each function to a smart welding station system, the complete learning step takes time to expand each information technology related to manufacturing systems to provide the information exchange between IT products and machines.

Chapter 6 CONCLUSION

The present study proposed a Platform model to classify the task of smart welding system based on RAMI 4.0 by taking into account the enabling technologies of I4.0. The aim was to enhance and ensure results in a practical way without iterations. First of all, the establishment of a smart welding station concept was conducted to adjust the core technology of I4.0 in the responses of the standard requirements in the RAMI 4.0 framework. Then, six enabling technologies of I4.0 were determined for each task by analyzing its characteristics to adjust the working function of the welding process. Afterward, the framework of RAMI 4.0 was analyzed using a designed working function to discover the essential element in the smart welding station system. As a result, the classification welding function of the platform model showed a guideline and standard requirements in two-dimensional aspects of RAMI 4.0. The platform model enables users to easily implement smart welding station with all the necessary systems and to study the communication links between them. The architectural model of each function between layers shows very clearly how the communications within systems take place, where it is necessary to acquire and capture data for digital twin planning. Then the data is analyzed to determine strategic decision-making on each task of the welding process and which layers can be accessed by users in taking action for fixing the failure, etc. This can generate insights in which RAMI 4.0 standardization covers working functions to create a smart welding station system.

Future studies are suggested to improve the applicability of the proposed Platform model in the development of a smart system. First, an in-depth evaluation of diverse welding types and product groups is required to completely understand the relationship between the welding system and the enabling technology of I4.0. Second, further implementation is needed to test the effect of implementing platforms on the steps of building a smart welding system. Third, the welding task classification model in this study is suggested to be applied to a real-time assessment system of the welding process. Lastly, a field study is necessary to confirm our finding due to the platform in the present study was accomplished based on reference architecture by which I4.0 was created and several studies on intelligent welding systems that carried out both in the simulation and industry field.

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PUBLICATIONS

I. Journal paper

1. Preform Optimization of Functional Deep Side Gear (Bevel Gear) for Warm Forging Process, Risky Ayu Febriani, Hong Seok Park, Saurabh Kumar and Chang Myung Lee, *International Journal of Automotive Technology (SCIE)*, Published on Vol. 21, No. 5, October, 2020.
2. An approach for Designing a Platform of a Smart Welding Station System, Risky Ayu Febriani, Hong Seok Park and Chang Myung Lee, *The International Journal of Advanced Manufacturing Technology (SCIE)*, on publishing.
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II. Conference Papers

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