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Cyber-Physical System Platform and Applications for Smart Manufacturing in Global Automotive Industry

Jinho Yang¹[0000-0002-9946-4432], Jonghwan Choi¹[0000-0001-9193-9379], Joohee Lym¹[0000-0002-6135-529X], Sang Do Noh^{1*}[0000-0002-5610-5560], Yong-Shin Kang², Sang Hyun Lee³, Hyung Sun Kim⁴, Je-Hoon Lee⁵, and Hyun-Jung Kim⁵

¹ Sungkyunkwan University, Suwon 16419, Republic of Korea

² Advanced Institutes of Convergence Technology, Suwon 16229, Republic of Korea

³ Yura, Seongnam 13494, Republic of Korea

⁴ Dexta Inc., Suwon 16677, Republic of Korea

⁵ Korea Advanced Institute of Science and Technology, Daejeon 34141, Republic of Korea
sdnoh@skku.edu

Abstract. The modern manufacturing industry ought to solve various problems amid increasingly fierce competition. Particularly, the supply chain network of the manufacturing industry is expanding globally. Therefore, there is an increasing necessity for smart manufacturing. Smart manufacturing is an integrated manufacturing system that applies information and communication technologies to manufacturing, rendering the entire manufacturing process smart, for obtaining real-time responses to internal and external variations in factories, supply networks, and customer requirements. Although there are several technologies that promote smart manufacturing, the cyber-physical system (CPS), introduced into the manufacturing environment is the primary technology. Global manufacturing enterprises have limitations in that it is difficult to collect information generated at distributed manufacturing sites with independent applications, and it is impossible to make quick decisions. To build smart manufacturing at such global manufacturing scales, a platform that integrates information and provides various applications in a distributed environment using the CPS ought to be built. This paper proposes an integrated platform for smart manufacturing implementation. The primary components and functions of the platform are defined. Finally, the effectiveness of the proposed platform is verified through a case study.

Keywords: Cyber-Physical System (CPS), Platform, Smart Manufacturing.

1 Introduction

The modern manufacturing industry is required to solve various problems, such as dynamic global market demand, short product life cycles, greater product variety, and lower production costs [1, 2]. These requirements increase the complexity of manufacturing systems and promote the introduction of various information and communication technologies (ICTs) into the existing manufacturing system. Starting with industry 4.0, which was proposed by Germany, various advanced manufacturing countries, such as

the United States, Korea, and Sweden, are trying to attain a competitive edge in manufacturing [3-5]. Various technologies, such as smart manufacturing [3], the cyber-physical system (CPS), internet of things, and big data, are commonly considered essential [3, 5] and believed to promote the fourth industrial revolution in the manufacturing field. When these technologies are applied to manufacturing, the entire manufacturing process can become smart and respond to the internal and external variations in systems such as factories, supply networks, and customer requirements in real time [4, 6]. The CPS is a core technology of the industry 4.0 architecture. It is a concept for managing systems connected to physical resources in the cyber world through communication networks [5, 7]. The cyber-physical production system (CPPS), which corresponds to the CPS in the manufacturing environment, constitutes autonomous and cooperative elements and subsystems, based on information obtained from the overall production site and logistics system, intelligence, connectedness, and responsiveness toward internal and external variations as its primary features [8].

Global manufacturing companies dispersed in several countries ought to overcome obstacles such as differences in cultures, languages, regulations, policies, and manufacturing units [9]. Particularly, the automotive parts industry is a representative assembly industry in which a small number of automakers procure tens of thousands of parts from a large number of automotive part makers to produce automobiles. It constitutes highly complex and extensive value chains [10, 11]. Therefore, the collection of information in a distributed field with an independent application is difficult. Moreover, localized platforms exhibit limitations toward acceptance and distribution in the industry [12]. To facilitate cooperation among different enterprises and responsiveness to global competition, a standardized open platform, in lieu of existing independent platforms, is needed.

This paper proposes an integrated platform for the efficient implementation of smart manufacturing for global manufacturing companies. Various ICTs used in the CPS platform are discussed, and the applications provided through this platform are introduced. Finally, industrial case studies are performed by applying this platform to the assembly and production line of a Korean automotive part manufacturing company.

2 Research Background

The CPS is an innovative technology that enables data access, processing, analysis, and utilization between physical assets and computational entities through an interconnected system [8, 13, 14]. The CPPS can configure the production environment more flexibly, in addition to providing more differentiated management and control processes than conventional manufacturing systems do [8, 15]. To effectively implement the CPPS, the most important consideration is the integration of analytics technology and a simulation-based approach for big data collected in large quantities at the manufacturing site [8]. Particularly, the most core technology among the various elements constituting the CPPS is the digital twin (DT), defined as a virtual model that enables the analysis, evaluation, optimization, and prediction of the current situation by syn-

chronizing and simulating real-time information and functions collected at the production site [16]. The core technical functionality of the DT is simulation. Additionally, it is essential for deriving the performance indicators of various production control techniques [17]. To provide various services by integrating information in a distributed environment using the CPS and DT technologies discussed, a platform that provides a large-scale service system ought to be constructed [18]. In a smart manufacturing environment, this platform is a middleware technology that delivers information collected from devices to services and applications. The platform builds various services and applications by converging technologies such as CPS, big data, and cloud computing. Through this platform, people, things, and systems can be connected [5]. In particular, the CPS platform, with ICT technologies, provides intelligent capabilities to predict various situation at production sites, and encapsulate and virtualize distributed manufacturing resources into cloud manufacturing services to support tasks such as product design, simulation, testing, and management [19–21]. Accordingly, we propose an integrated platform using the DT and various ICTs to construct an efficient CPS environment.

3 CPS Platform and Applications

3.1 CPS Platform

The proposed technology in this study is a CPS platform for building a smart assembly system for automotive part makers through converging with legacy systems, such as the manufacturing execution system, or enterprise performance management using various ICT and applications for production site application. The purpose of this platform is to support various services such as production quality prediction and production management for the development of a smart manufacturing system. Fig. 1 depicts the architecture of the proposed platform.

The proposed CPS was classified into the automotive part assembly line (corresponding to the physical world) and the platform (corresponding to the virtual world). The definitions of the components composing the CPS are as follows.

- **Automotive part assembly line:** It is an assembly line that produces various automobile parts and is a manufacturing site comprising resources such as workers and assembly parts. Information with respect to workers, equipment, and products on the assembly line are transmitted to the CPS platform and legacy system through media.
- **Core technologies of the platform:** It is the core basis of basic functions and application services for engineering in the platform. The functions comprise the DT, which can perform various functions by configuring a virtual model using real-time data collected from the manufacturing site, and can perform advanced analytics to analyze and utilize the collected data. Finally, it comprises big data management for manufacturing, which processes and refines the data collected at the manufacturing site.

- **Basic functions:** These are provided by the platforms utilizing core functions. The basic functions available on the platform were real-time monitoring, simulation, visualization, prediction, and analysis.
- **Application services:** These are services that can be utilized according to the characteristics and circumstances of the manufacturing site using the basic functions described previously.

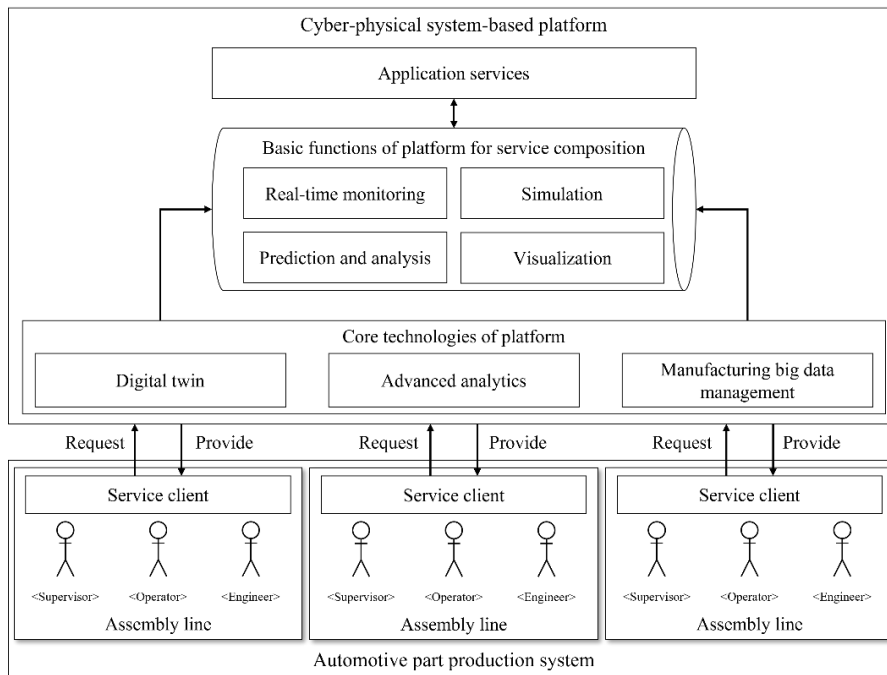


Fig. 1. Conceptual architecture of the proposed platform.

Fig. 2 shows the driving screens of the basic functions of a platform implemented in a cloud computing environment. The CPS platform dashboard allows service clients to check and respond to the status of the system based on real-time data from various manufacturing sites. Using this data, real-time monitoring can generate a DT model at the manufacturing site and monitor the situation of a particular production line or factory. The simulation on this platform provides more accurate results than existing simulation models by utilizing the generated DT model. Additionally, the platform facilitates the visualization of various production-related data such as simulation, prediction, and diagnosis results. This function includes charts, reports, and visualization of 3D models. Table 1 summarizes the relationship between the core technologies used in basic functions. The basic functions of the platform are built by combining one or more core functions. The application services can be built using these basic functions. Although various application services can be configured on the platform, based on the requirements of a global manufacturer, this paper introduces smart production management and smart quality prediction systems.

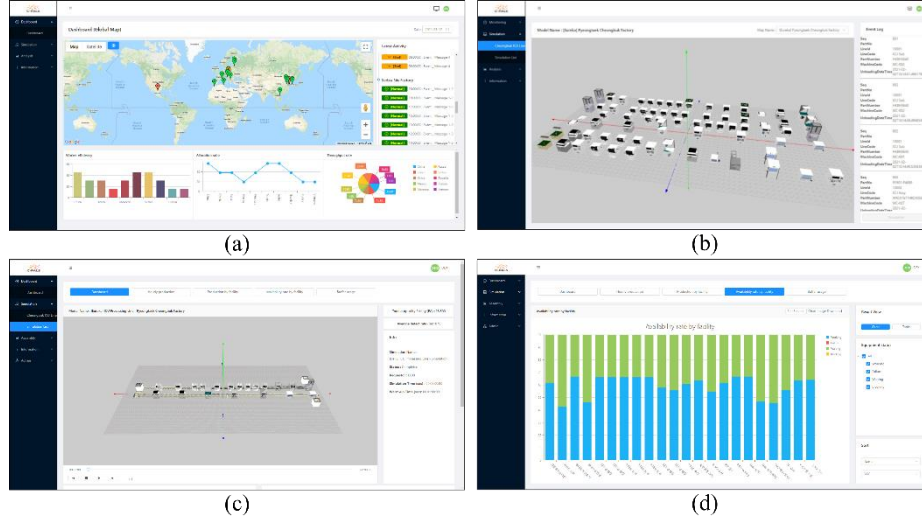


Fig. 2. Snapshots of the CPS platform (a) dashboard [22] (b) real-time monitoring [22], (c) simulation, and (d) visualization.

Table 1. Relationship between basic functions and core technologies.

Basic function	Core technologies
Real-time monitoring	Digital twin; big data management
Simulation	Digital twin; big data management; advanced analytics
Prediction and analysis	Big data management; advanced analytics
Visualization	Digital twin; big data management; advanced analytics

The platform shown in Fig. 2 applied a standardized information model for data collection from the distributed manufacturing sites to ensure versatility. The information model was defined based on international industry standards [22]. We have omitted the detailed descriptions in this paper for conciseness.

3.2 Applications of the CPS Platform

Various service applications can be implemented using the functions of the proposed platform. To build a smart assembly line, this platform primarily comprises two service applications. The first application is a smart quality prediction system that can predict the quality of products in advance by analyzing the quality impact analysis between the processes. The core function of this system is advanced analytics; the algorithms are implemented by preprocessing and training data using various machine learning models. The second application is a smart production management system, which utilizes an optimization algorithm to provide an optimal task allocation function considering the skill of workers at the production site and the amount of work required for each production line. The periodic verification of the working status of workers on the production line facilitates the relocation and optimization of the work process for problems

caused by workers for various reasons. Fig. 3 is a screen for these service applications provided by the platform.

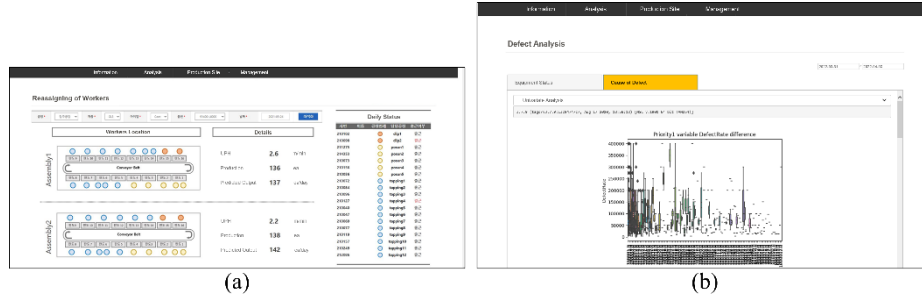


Fig. 3. (a) Smart production management and (b) smart quality prediction systems.

4 Industrial Case Study

To validate the proposed CPS platform and applications, they were applied to an actual industrial site of a global automotive parts manufacturer in Korea. The target factories located in Vietnam, China, and Korea were virtualized using the platform. Research is currently underway toward applying the developed technologies to the smart factory test bed located in Sweden. This study was conducted as a part of the international joint research of Korea and Sweden. Fig. 4 shows the DT models of the target factories for which the proposed technology was applied. The proposed platform and services application results for the three target production lines were as follows.

- The average performance calculation accuracy of the DT model virtualized on the platform agreed with more than 90% of the observations in the real production line.
- With optimized assembly process control, the productivity of the assembly line was improved by more than 3%.
- The average quality prediction accuracy was more than 90% on average, for the identification of defects and responding in advance, contributing toward productivity improvement.

The details of the application results are not completely disclosed, owing to the confidentiality conditions of the manufacturer applying the technologies.

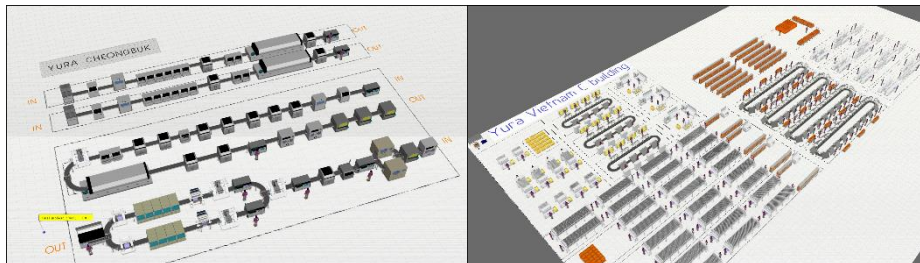


Fig. 4. Digital twin models of target factories.

5 Conclusion

This paper proposed a CPS platform and application for the systematic management and efficient operation of a Korean-based global automotive part manufacturer. For the smartization of the manufacturing system, we discussed advanced technologies, such as the DT and advanced analytics. The contributions of this study are as follows. First, the architecture of the CPS platform was presented, and the primary components were defined. Based on this, the practically implemented technologies were introduced. In addition, service applications that can be utilized in the CPS environment were explored. By applying the proposed technology to the actual manufacturing site, improvements over the existing manufacturing system were derived. However, the proposed platform exhibited the following limitation: there is a large gap in the technology that can be applied depending on the required level of virtualization and automation of the production line. Therefore, in the future, it is necessary to identify a method that can reflect the various levels of the production site and to develop a platform technology tailored for the site.

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