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SMART FACTORY USE CASE MODEL BASED ON DIGITAL TWIN

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Abstract. *Connectivity is essential in the success for the smart factory as the rise of the fourth industrial revolution 4.0 and the convergence of digital and physical worlds. Digital twin refers to a digital replica of physical assets, processes and systems that can be used for various purposes. In this paper, smart factory use case framework and model are presented based on digital twin concept. A reference model and a specific use case are presented which can be widely applied in various manufacturing system and real life domain.*
Keywords: Smart factory, Digital twin, Internet of Things (IoT), Big data analytics

1. **Introduction.** The National Institute of Standards and Technology (NIST) defines the smart factory as fully-integrated, collaborative manufacturing systems that respond in real time to meet changing demands and conditions in the factory, in the supply network, and in customer needs. The key features are real or near-real time, self-optimization, self-adaptation and automation. Smart factory can operate not only within the four walls of the physical factory, but also connect to a global network of similar production system or cyber world based on IoT (Internet of Things) infrastructure [1]. In order to realize the smart factory, connectivity and sensor network is essential in the physical and cyber world. The concept of digital twin plays a key role for the connection and sensor network.

Digital twin refers to a digital replica of physical assets, processes and systems that can be used for various purposes. The digital twin concept model contains three main parts: a) physical products in real space, b) virtual products in virtual space, and c) the connections of data and information that ties the virtual and real products together [2].

The digital twin may enable companies to solve physical issues faster by detecting them sooner, predict outcomes to a much higher degree of accuracy, design and build better products, and, ultimately, better serve their customers. With this type of smart architecture design, companies may realize value and benefits iteratively and faster than ever before [3].

On the physical side, we now collect more and more data from the machines and processes that perform operations on the physical part to understand exactly what operations, at what speeds and forces, were applied. On the virtual side, numerous methodologies have been developed to simulate and visualize the product and processes with the technologies of sensor network, IoT and big data analytics.

The purpose of this research is to propose a smart factory use case model based on digital twin. The proposed architecture is tested and applied to other domains in manufacturing and environmental issues.

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2. **Literature Review.** Smart factory, which is the factory ecosystem of the future, has attracted much attention from the manufacturers and industrial leaders. Smart factory is a powerful trend, building on readily available hardware and software to take production operations to the next level of performance.

In order to implement smart factory, there are some requirements in technologies. Technological challenges and needs are connectivity and interoperability, seamless factory of the future system integration, architecture for integrating existing systems, modeling/simulation, and security/safety. Enabling technologies for smart factory are proposed as [4].

- IoT and machine-to-machine communication
- Cloud-based application infrastructure and middleware
- Data analytics
- Smart robotics
- Integrated product-production simulation
- Additive manufacturing/3D printing
- Additional factory of the future technology

Members of Industrial Internet Consortium (IIC) have suggested the benefits of smart factory as [5]:

- Increased shop floor visibility
- Intelligent supply chain management
- Decreased total cost of ownership
- Streamlined human resources
- Reduced environmental impact
- Increased profitability

Recent research tried to combine smart factory and digital twin. Alam and Saddik [6] present a digital twin architecture reference model for the cloud-based CPS (Cyber Physical System), C2PS, where they analytically describe the key properties of the C2PS. The model helps identify various degrees of basic and hybrid computation-interaction modes in this paradigm.

Most recent papers and publications focus on overall review of smart factory or specific application for the chosen domain. More research is required for the generic framework in the smart factory applications.

3. **Methods.** With the rapid development of ICT, network and sensor technologies, there is high demand in the realization of smart factory in the industry. However, the real situation is far behind for the implementation of smart factory in the manufacturing cell and production line because the production line is based on the physical world with many real and physical constraints. In this respect, we can propose a few points to realize the smart factory. They are as the following.

1) What are the key features of smart factory?
2) What are the components and technologies that comprise the smart factory?
3) What is the methodology?

Key features of smart factory are connectivity, optimization, transparency, proactivity and agility [7]. Smart factories require the underlying processes and materials to be connected to generate the data necessary to make real-time decisions. The optimized smart factory can increase yield, uptime, quality, and reduce costs and waste. A transparent network can enable greater visibility across the facility and ensure that the organization can make more accurate decisions by real-time alerts and notifications, and real-time tracking and monitoring. The proactive features enable advance identifying and warning

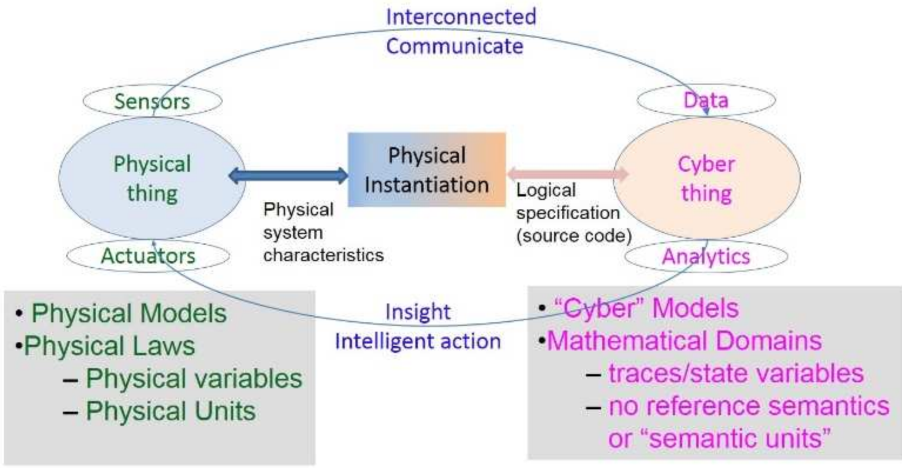

FIGURE 1. Digital twin architecture

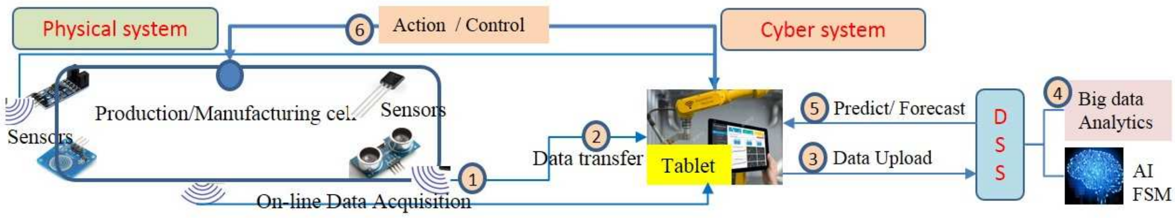

FIGURE 2. Smart factory control and monitoring based on digital twin

of anomalies, quality issues, safety and maintenance concerns. Self-adaptation to schedule and product changes is available by agile features. Figure 1 represents digital twin architecture composed of physical thing and cyber thing.

The implementation step of smart factory based on digital twin is sensor data creation, communication between physical process and digital platform, data aggregation, analysis and visualization, insights from analytics, and action back to the physical world. The above steps are repeated over different processes or operations.

Figure 2 represents the scheme of smart factory control and monitoring system based on digital twin. All the features of smart factory with sensors, network, and legacy system are mirrored in the Tablet or PC which is integrated with big data analytics in the cloud or main server. All the actions and tasks in the production and manufacturing cell are monitored transparently in the Tablet or PC with real time. For the uploaded sensor data, big data analytics are performed such as data mining, artificial intelligence, and finite state machine to name a few. Prediction and forecast for the domain problems have been tried and fed forward back to domain. Based on big data analytics, quality issues or facility problem is forecasted or prevented proactively.

Digital twin is a near real-time digital image of a physical object or process that helps optimize business performance. Two concepts of IoT and IoS (Internet of Service) are combined to realize the smart factory based on digital twin. IoT consists of various sensors that gather data from the factory shop floor and transfer them through wireless sensor network. IoT corresponds to physical world which is hardware dependent processes with embedded system, sensors, and all-IP factories. IoS consists of ERP (Enterprise Resource Planning), MES (Manufacturing Execution System), SCM (Supply Chain Management), QMS (Quality Management System) and data analytics. This constitutes cyber world, where legacy system works for hardware-independent planning & control of factory and process monitoring. The architecture of digital twin composed of physical and cyber world is shown in Figure 3.

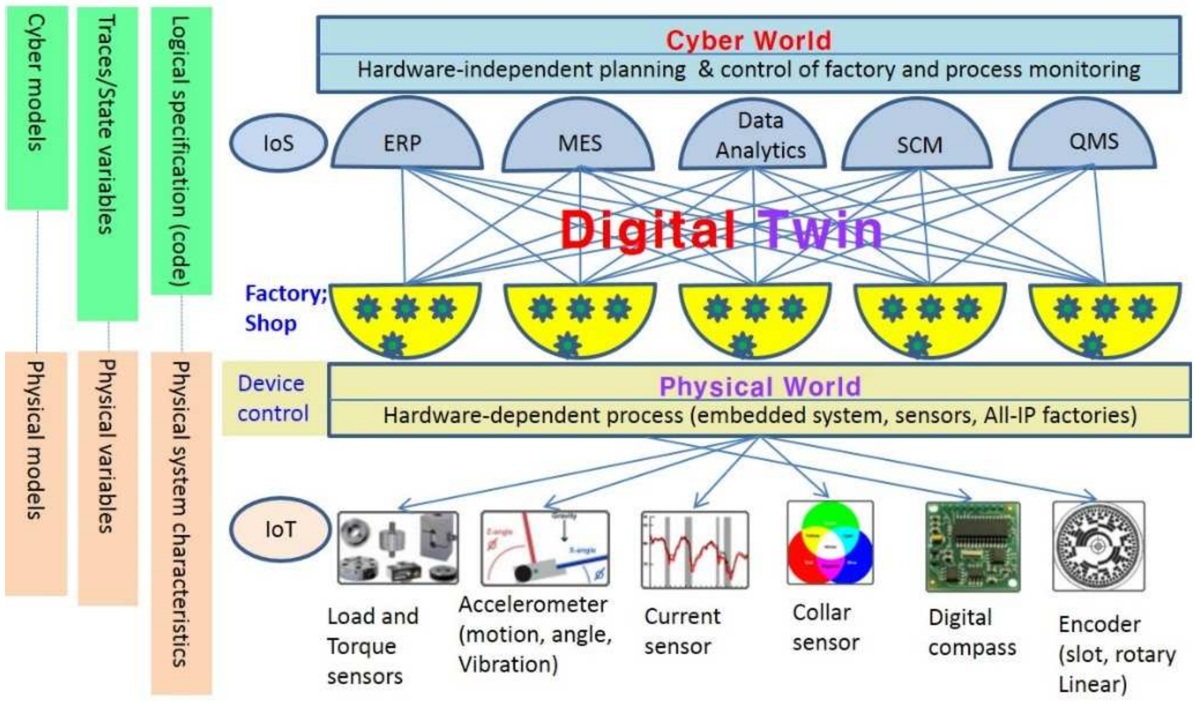

FIGURE 3. Architecture of digital twin with IoT and IoS

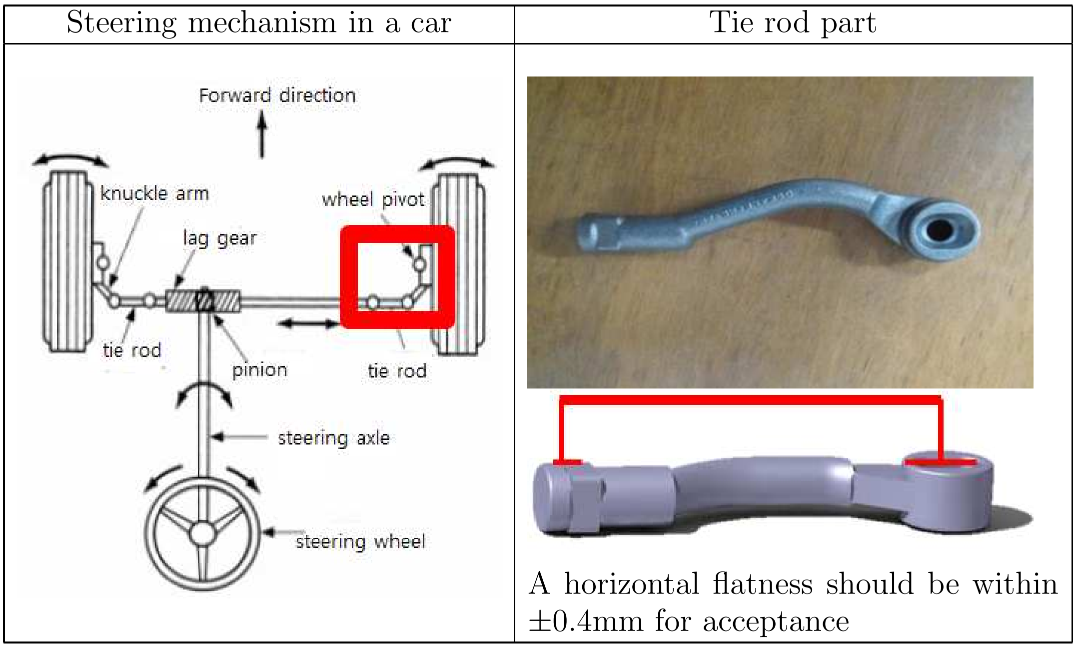

FIGURE 4. Problem domain of steering system, tie rod part and its quality requirement

4. **Smart Factory Use Case.** A smart factory use case model utilizing the concept of digital twin is presented to tackle a practical problem in the real world. Two use cases are presented with implementation.

The first case is related with auto parts. The problem domain to implement smart factory use case is a tie rod used in steering system of an automobile [8]. The required quality specification of the part is a horizontal flatness within ±0.40mm. The steering system and the part of tie rod and its quality requirement are shown in Figure 4.

In order to measure the horizontal flatness of a tie rod, distance and proximity sensor are adopted to measure the accurate distance. In this study, we used distance sensor (VL6180) and proximity sensor (VCNL4000) at the same time.

Experimental setup for checking horizontal flatness is established for implementation. From the distance and proximity sensors, the distance and proximity are acquired, and then a regression model is applied for checking the flatness of the tie rod. Data analysis program was developed using a single board computer Raspberry pi2 with version lazarus0.9.8, which is a cheap processor.

The second use case is related with an environmental problem. The application of use case is managing water resources of 'Four Major Rivers' in Korea. After making dams to collect water resources in the reservoir, water pollution and green algae have been generated, which causes a social and environmental problem. A pilot system has been implemented to monitor water quality, color and real-time status from a remote place. A wireless, low power WAN, which is LoRa has been adopted for long distance sensor networking. IoT and sensor networking have been integrated to develop the use case. The use case of river monitoring system is shown in Figure 5.

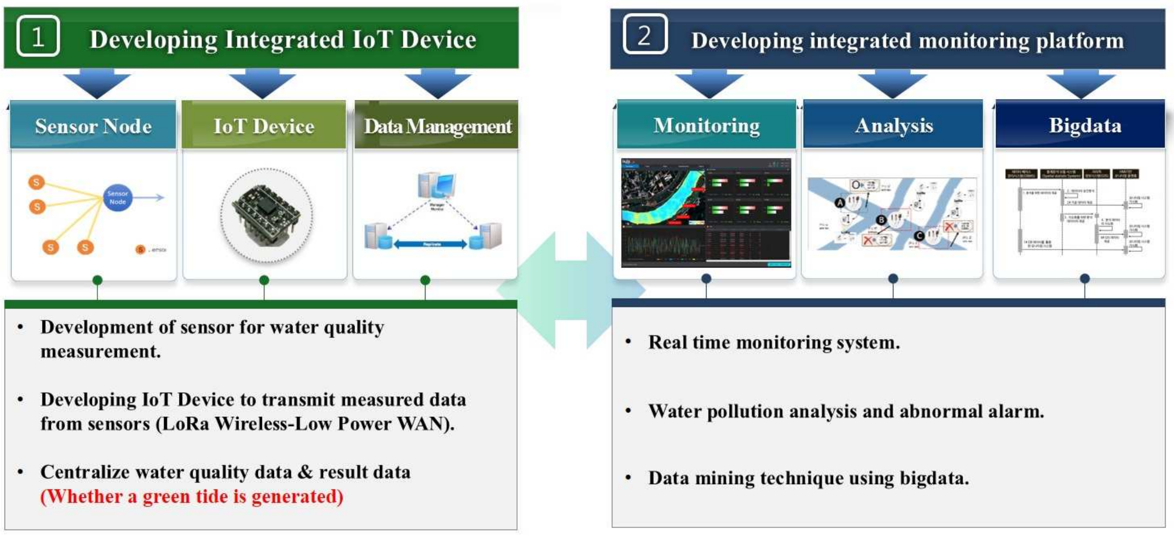

FIGURE 5. Use case of water resource management of 'Four Major Rivers'

5. **Conclusions.** Smart factory is not only a buzz word but also a practical methodology to solve emerging problems in the real fields. In this paper, a framework and an architecture of smart factory utilizing digital twin are proposed as a reference model. Then two practical use cases realizing the smart factory are presented.

The contribution and significance reside in the fact that a generic pictorial framework of smart factory model based on digital twin is proposed. Also, practical use cases following the framework are presented covering different domains. This paper does not focus on a mathematical model but rather propose a practical and working framework of a smart factory. The key features of smart factory are connectivity through sensor network and intelligent data analytics. In the use case application, connectivity and intelligence have been attempted to tackle.

The following could be suggested for a further research. First, more clear reference model combining digital twin with smart factory should be developed for generic application. Second, in order to add value to the smart factory, semantic and AI application are needed in the data analytics module. Third, if the application result can be verified independent of its domain, the value of the proposed model can be enhanced much higher.

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