Survey on Industrial Wireless Network Technologies for Smart Factory

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Abstract

Recently, smart factories are being developed in and around advanced countries. With the rapid progress of ICT, the studies on new manufacturing systems using ICT are being carried out actively. Therefore, it needs to develop a technology to handle flexibly and intelligently complex systems such as distributed control of industrial process as well as factory automation. Accordingly, the need to develop an industrial network technology for real-time factory monitoring & controlling and connecting the inside and outside of a factory is also growing. In this study, based on the analysis of the global trend of smart factory and standardization of industrial network and the survey on future development of smart factory and its expected effects, we propose the direction of future research on industrial network.

***Keywords**: Factory monitoring, ISA100.11a, Smart Factory, Wireless HART, Wireless industrial networks*

1. Introduction

The reason why the importance of manufacturing industry is rising recently is because the countries in which manufacturing industry has looked bullish since the global financial crisis have recovered their economy rapidly. However, the avoidance phenomena of low-pay manufacturing industry and the economic structure focusing on the service industry are deepening the hollowization of manufacturing industry. In addition, the decreasing of birthrate and the aging of people in manufacturing industry are urging the development of new systems to overcome the problem of productive population decline and to increase productivity. The continuous social and political changes such as globalization, urbanization, population structure change, and energy type change represent the need to pursue new technological change in the manufacturing industry. Historically, the industrial revolution was done according to the technological advancements, as shown in Fig. 1. Like this, it is anticipated that the advancements of ICT enabling the construction of automated production and intelligent system in industrial process will cause the advent of the fourth period of industrial revolution. Furthermore, through complete fusion of manufacturing industry and ICT, the existing factories will be changed into perfect smart factories in which not only automated production but also control and maintenance of overall processes and safety management are possible[1, 3].

If we say that the ways of monitoring and control in the existing factories are On-Site management, a smart factory can be monitored and managed in real-time via Internet regardless of our location. The development of IoT (Internet of Things) enables the exchange of information between production equipments as well as between inside and outside of a factory by establishing a network, and the technology of big data · cloud can provide a base for collecting and using data. Industrial network is a concept to operate production facilities effectively for automating production. In the existing wire

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communication-based fieldbus, there exist various problems such as space utilization, limited mobility of production facilities, and difficulty of reinstallation. Therefore, it needs to study real-time data processing technologies and industrial wireless network technology which enables the interconnection between devices [1-4].

In this paper, we first analyze smart factory technology, current situation of its related standardization, and current situation of industrial network technologies, and then, based on these analyses, we present the direction of development of industrial network technologies and the problems to solve. In Section 2, we introduce the situation of current technologies and the related standardization trend. In Section 3, industrial network technologies and current situation of standardization are discussed. In the last section, Section 4, the expected effects of smart factory and the research direction of industrial network are presented as conclusion.

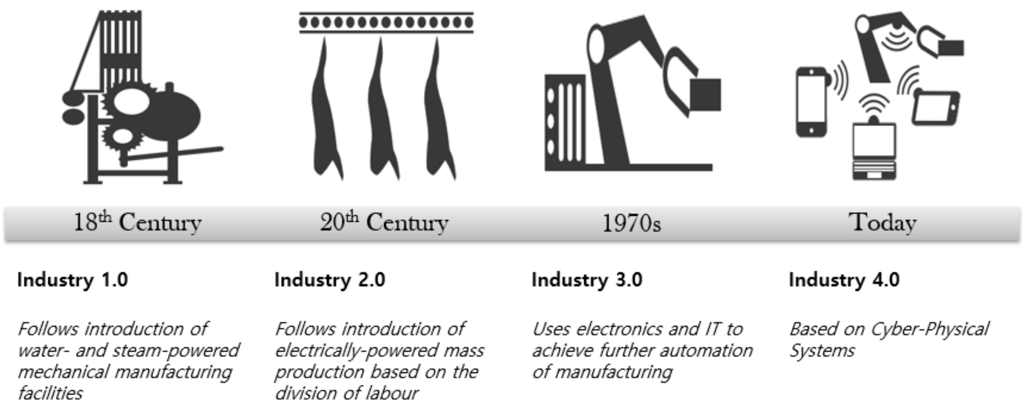

Figure 1. Technological Changes and 4 Stages of Industrial Revolution
(Source: Recommendations for implementing the strategic initiative Industry 4.0 – The Industrie 4.0 Working Group)

2. Overview of Recent global technology trends in Smart Factory

Smart factory is different from the general automated one the production facilities of which operate passively, in that it decides its work mode for itself [2]. In case of Germany that carries forward Industries 4.0 policy, their final target is to realize a smart factory which has the fusion of ICT and automated production system of manufacturing industry by grafting ubiquitous technologies such as RFID (Radio Frequency Identification), USN (Ubiquitous Sensor Network), wireless network, and mobile devices onto manufacturing factories from the early of 2000s. SMLC (Smart Manufacturing Leadership Coalition) in USA is focusing on realizing 'the 21st century Smart Manufacturing' case by utilizing industrial Ethernet, hardware & software, and sensors & actuators [5]. In this section, we introduce global trend of the core technologies of smart factory such as CPS (Cyber-Physical Systems), ICT-fused smart processing system technology and industrial internet technology which can all the devices with network, and the current situation of the standardization of smart factory technologies.

2.1 CPS (Cyber-Physical-Systems)

CPS is a system which controls autonomously with reliability physical systems such as sensors, actuators, mobile devices, and people in real world through cyber systems like computing devices, and enables integration of value chain of a smart factory from production process to management of inventory and customer [5, 6]. Because unlike the existing vertical manufacturing factories, data for production are exchanged through CPS and production processes in the whole factory can be controlled in smart factory, flexible manufacturing environment and optimization and individualization of product are possible in a smart factory [2]. While general embedded systems are focusing on the operation of mobile phones and information appliances, it is expected that CPS will be applied not only to manufacturing environment but also to the wide areas of healthcare & medical fields, energy, and national defense, by aiming to control autonomous systems [7].

2.2 Smart manufacturing system

Smart manufacturing system is a manufacturing system to produce high value products and to build a smart factory, based on various ICT technologies for real-time monitoring, sensor networking, facility condition diagnosis and equipment operation. Recently, the need of flexible manufacturing platform is increasing in order to respond to the rapid change of trends and various demands of customers. Therefore, ICT-based smart manufacturing systems which can overcome the limit of accuracy and production efficiency through grafting new control technologies onto the existing processing systems are required [2, 8]. In addition, the need to develop bi-directional smart manufacturing system using the technologies of sensor networking and real-time monitoring, together with developing a cloud-based operation system which can share status information, processing information, and production information of machine tools, is being raised [8].

2.3 Industrial networks

As the communication environment of factory automation field is converted from the analogue method to the digital, the need of network configuration to manage factory facilities efficiently came to the fore. The concept of industrial network was emerged from this situation [4]. The development of wireless network technology has enabled the wireless communication between machines in a factory and the collection of data related to production facilities, and this technology is also being grafted onto the safety control and real-time monitoring in a factory [5]. Industrial network is a technology which can exchange data even with a different access protocol and improve factory productivity through establishing a network of intelligent equipment and sensors. Therefore, it is required to propose wireless industrial network standards suitable for smart factory and to conduct a study for improving integrated wireless communication technologies [2, 5].

2.4 Global standard trends for the smart factory

To establish a smart manufacturing factory, the equipment in a manufacturing factory is required to be connected with various elements and services in and out of the factory [2]. Therefore, it is important to standardize communication protocols including means of communication and data format. From the existing IEC TC 65 and ISO TC 184 to IEC SG8 for standardizing smart factory-related technologies, various activities of International Organization for Standardization related to smart standardization are proceeding actively. IEEE P2413 project of IEEE is carrying on standardization work with the aim of establishing a framework that can ensure the interoperability between the connected devices and an application in an environment such as industrial system through configurating IoT architecture [5]. In IoT area, IEEE takes the lead of standards, and CoAP(Constrained Application Protocol) for transferring sensor information, a low power-oriented protocol, comes into the spotlight as a leading international standard. EU is carrying on ETSI M2M (Technologies & Clusters Committees & Portals Machine to Machine) standard, focusing on telecommunications companies [2].

3. The global standards for wireless industrial network

Most of wireless communication technologies used in the field of industrial automation are based on IEEE 802.11 Standard–based WLAN (Wireless Local Area Networks) or IEEE 802.15 Standard-based WPAN (Wireless Personal Area Networks). IEEE 802.11 Standard has higher communication speed and broader communication range compared to other standards, but consumes more energy [9]. From the perspective of wireless sensor network for which energy efficiency is important, we discuss the standards aiming for wireless industrial network based on IEEE 802.15 which consumes lower energy than IEEE 802.11. In this paper, our description will be focusing on IEEE 802.15.1 standard-based WISA, IEEE 802.15.4 standard-based WirelessHART™, and ISA100.11a.

3.1 IEEE 802.15.1 based standards

IEEE 802.15.1 based standards(Bluetooth) which has medium-communication speed and lower energy consumption compared to standards of IEEE 802 and IEEE 802.15.4 are suitable for the applications requiring real-time and higher communication speed [9, 10]. These are Bluetooth SIG(Special Interest Group)'s standards for wireless communication between home appliances, use ISM band of 2.4 GHz, and communicate based on PicoNet architecture.

3.1.1 WISA (Wireless Interface for Sensor and Actuators)

WISA is a new factory communication system published by ABB Group, which aims to transmit data of the level of devices related to factory automation by providing high reliability and low delay [11]. WISA has been developed in terms of not only wireless communication protocol (WISA-COM) but also wireless power supply (WISA-POWER). WISA-COM, wireless communication area, is based on the physical layer of IEEE 802.15.1 [10, 11]. For real-time communication of many devices with high density, it is very important to use bandwidth efficiently. Therefore, in WISA, cellular network topology including the reuse of frequency is used, and one module or base station composes one cell and one cell is composed of local sensors and actuators (SA) (Fig. 2). Each base station accommodates up to 120 devices, and parallel data transmission/reception is possible. Network Manager communicates between cells through wire fieldbus [9, 10].

MAC layer of WISA uses TDMA (Time Division Multiple Access) and FDD (Frequency Division Duplex). By using FDD, it transmits data in parallel through sorting downlink communication from base station to SA and uplink communication from base station to SA with frequency. In downlink communication, SA transmits data only from one assigned slot. Downlink superframe is TDMA frame, and one frame is 2.048ms long and divided into 16 double slots each of which is 0.128ms long. In case of double slot, identification number of slots and payload data for 8 SAs are continuously transmitted for superframe configuration and time synchronization. In uplink communication, data are transmitted only when SA has data to be transmitted to base station or module, and its uplink superframe is also TDMA frames and divided into 32 slots each of which is 0.064ms (Fig. 3) [9-11].

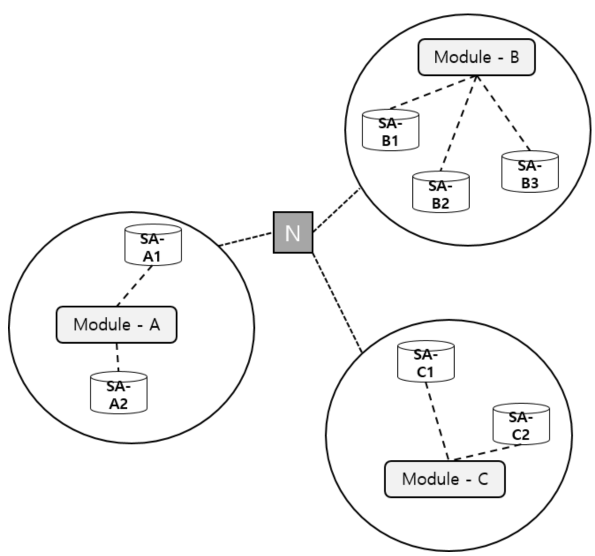

Figure 2. Network topology and elements of WISA [9]

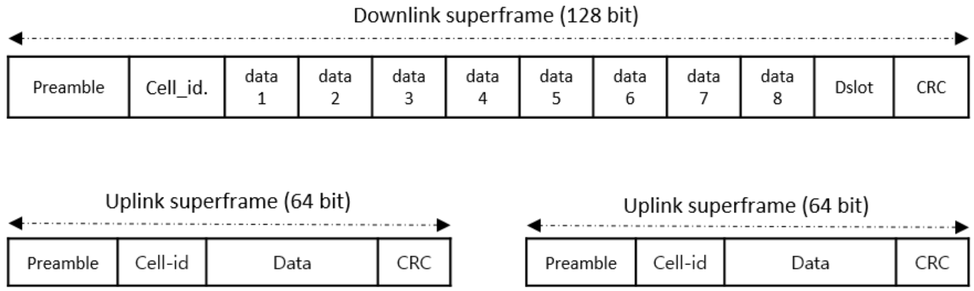

Figure 3. Superframe structure of WISA [10]

3.2 IEEE 802.15.4 based standards

IEEE 802.15.4 based standards have lower transmission speed and energy consumption, compared to IEEE 802.15.1 based standards. They use ISM band of 2.4GHz and are used to establish low-cost and low-power wireless communication. Accordingly, they are suitable when data are transmitted frequently in a factory application which needs many sensors and continuous monitoring though the quantity of data is small [9].

3.2.1 WirelessHART™

WirelessHART™ which was published by HART Communication Foundation in 2007 is an open protocol improved to wireless standard from the existing HART(Highway Addressable Remote Transducer) protocol to make suitable for process measurement and control applications [9, 13]. The process devices in the field which have the same function with the nodes of wireless sensor network send and receive signals to and from neighboring instruments by using router [9]. Basically, the devices of WirelessHART network include field devices(FD), Wireless field devices(WFD), router devices(RD), wireless hand-held devices(WHH), access point(AP), gateway(G), network manager(N), and security manager(S) (Fig. 4) [12, 13]. Field devices are devices having the functions of sensors and actuators. Hand-held devices can be used while users in a factory such as factory engineers are moving, and are used for installation, configuration, monitoring and management of devices. Gateway functions as a bridge to host application, and can accommodate up to 80 devices. Network manager manages all the things related to WirelessHART wireless network. It is responsible for network configuration, resource scheduling, and network path setting, and transmits query to the field instrument related to specific information through gateway [9, 12, 13].

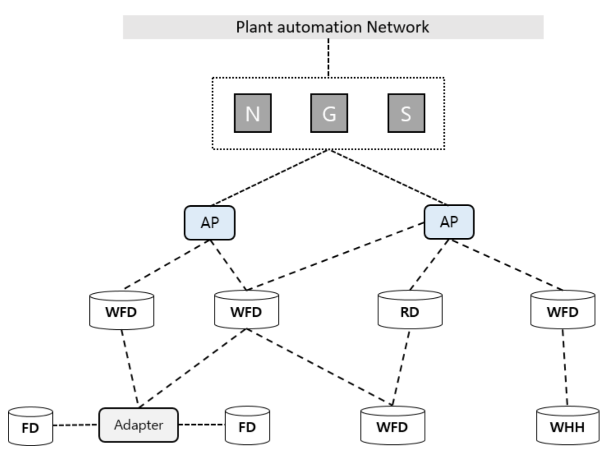

Figure 4. Network architecture of WirelessHART™ [13]

Because the physical layer of WirelessHART is based on IEEE 802.15.4 standards, it operates in 2.4GHz frequency band, and uses 15 channels from 11 to 25 excepting channel 26 [12]. In data link layer, one slot is assigned to each device by using TDMA method integrated with frequency hopping, or CSMA/CA method is used. The former is used to minimize delay and the latter to maximize the utilization of bandwidth. In case of using TDMA method, network manager is responsible for the allocation of time slot [9, 12]. WirelessHART has a structure in which one or more superframe is repeated, and the length of superframe can be adjusted to be suitable for an application (Fig 5) [9].

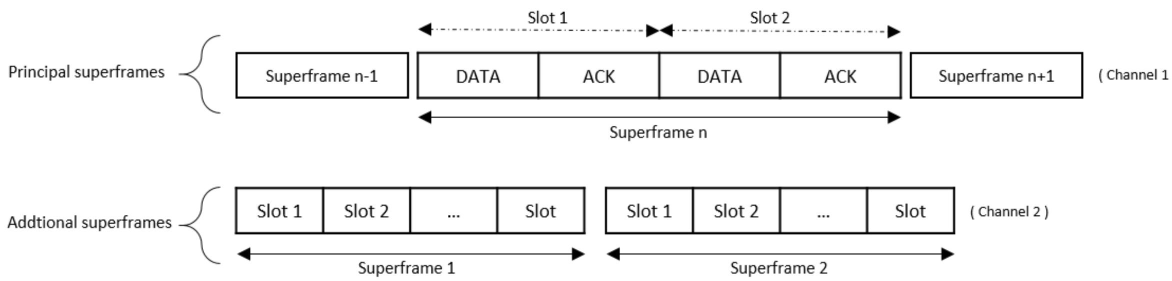

Figure 5. Superframe of WirelessHART™ [9]

3.2.2 ISA 100.11a

ISA100.11a wireless network standards were developed by International Society of Automation (ISA) for industrial automation and process control. ISA is a non-profit organization composed of about 20,000 experts in automation area. ISA100.11a standards address a wide range of issues such as factory automation including wireless industrial plant, RFID, and process automation [9, 13].

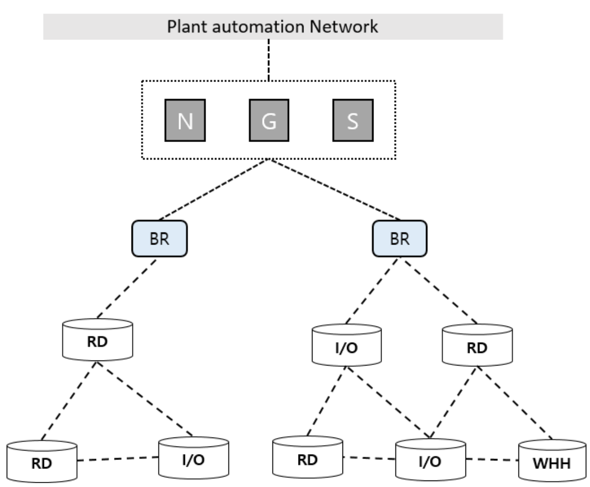

Figure 6. Network architecture of ISA100.11a [13]

Typical network architecture of ISA100.11a is as shown in Fig. 6. It supports mesh, star-mesh, and star topology [13]. There are I/O device (I/O) indicating a sensor which provides data or an actuator which uses data from other devices and writer device (RD) separately responsible for the function of data path setting. Backbone router (BR) is responsible for the function of data transmission with backbone network. Gateway (G) of ISA100.11a is a device to provide interface which connects wireless field network and plant network or enables to connect with end application.

Because it is based on IEEE 802.15.4 standards, like WirelessHART, it also operates in 2.4GHz frequency band and uses 15 channels from 11 to 25 [12]. In addition to the contents of IEEE 802.15.4

standards, ISA100.11a supports frequency hopping and frequency blacklisting [9]. Data link layer uses TDMA method and composes time slot and superframe. There are two methods in composing time slot; one is slotted channel hopping method and the other slow channel hopping method. The former is a method which can make the best use of bandwidth, and the latter is a method in which flexible time synchronization with neighboring node is possible. In ISA100.11a, 5 preprogrammed hopping patterns are provided [9, 12].

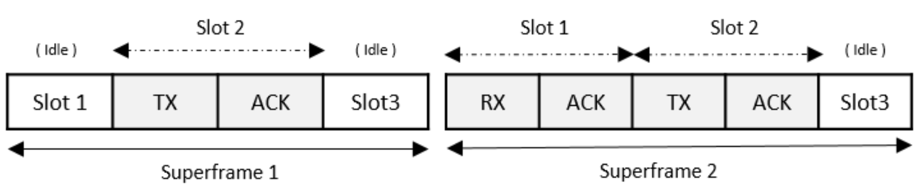

Figure 7. Superframe of ISA100.11a [9]

4. Conclusion

In this paper, we described the current situation of smart factory technologies and the standardization technologies of industrial network. To put it concretely, we described CPS (Cyber-Physical-Systems), ICT-based smart manufacturing system, and industrial networks technologies, and analyzed the current situation of the standardization of related technologies. Judging from our research results, it is expected that smart factory will have ripple effects on the industry such as productivity improvement of an automated and advanced factory, protection against industrial disaster, and creation of new jobs for running smart factories (though simple labor jobs will be decreased). Further development of smart factory will need, together with policy support, the establishment of international standards for various areas such as manufacturing process, facilities, hardware & software, engineering and safety management, and various researches according to those standards.

After that, we looked at the standards of industrial wireless network used in the area of industrial automation, and described IEEE 802.15.1 standards-based WISA system, IEEE 802.15.4 standards-based WirelssHART™ and ISA100.11a standards. While industrial network has resolved the existing problems such as the complexity of wiring, cost of construction, and the difficulty of reinstallation by using wireless network technologies in the existing wire fieldbus, it is still required to improve problems such as more error occurrences than wire channels and defects. In addition, it needs to study on integrated wireless protocols which can coexist with the existing installed network by minimizing its interference.

5. Acknowledgments

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