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PROTOTYPE OF IOT ENABLED SMART FACTORY

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Abstract. *A disruptive paradigm shift is under way in the manufacturing environment globally. The main sources of this big change are IT, machine intelligence, AI and Internet of Things (IoT). The adoption of IoT is crucial for the next generation manufacturing, namely smart factory. The IoT enabled manufacturing system is often referred to as Industry 4.0. In this paper, IoT enabled smart factory is reviewed and a prototype is tried in the laboratory level. In the smart factory environment, most microprocessors are embedded and connected via wireless and wired based on cyber-physical system. A company producing industrial vinyl film with high defective ratio is chosen to implement IoT enabled smart factory. By adopting wireless devices, the proposed IoT concept is implemented in the laboratory level.*

Keywords: Internet of Things (IoT), Smart factory, Wireless, Cloud computing, Reference architecture, Cyber-physical system

1. Introduction.

Today's business environment is highly affected by new smart and mobile technologies such as smart phone, Bluetooth, Universal Mobile Tele-communications System (UMTS), PDA's, and wearable devices, to name a few. In the production environment, complexity prevails in customer requirements, business processes, planning and operations. In the future manufacturing system, global competition, shorter product life cycle, frequent model change and continuous improvements in quality, cost and style are required challenges.

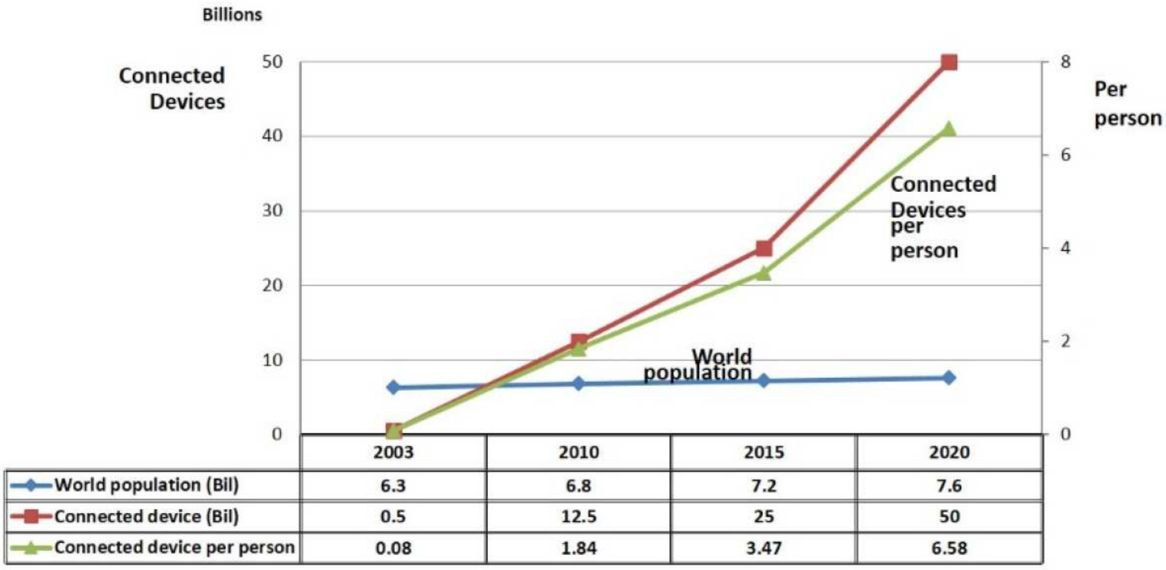
The Internet of Things (IoT) describes a system where objects, sensors and software are connected to the Internet via wireless and wired network. It enables added value and service by exchanging data with the manufacturer, operator and/or other connected devices. ITU (International Telecommunications Union) defines IoT as a global infra-structure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies [2].

The IoT generates a paradigm where everything is interconnected and redefines the way people interface with machines and the way they interact with the environments.

A smart factory is implemented on the basis of a Wireless Local Area Network (WLAN), Radio-Frequency Identification (RFID), Ubiquitous Sensor Network (USN), ZigBee, Bluetooth, General Packet Radio Service (GPRS) and Ultra-WideBand (UWB). The smart factory enables supervisory communication, decentralized process control, wireless device networks, failure messaging and localization utilizing the above mentioned sensors.

A German manufacturer refers the next wave of manufacturing with IoT-enabled systems as Industry 4.0. Industry 1.0 was depended on mechanical system powered by water and steam. Industry 2.0 was the period of mass production based on division of labor powered by electrical energy. Electronics and control systems contributed to the emergence of the Industry 3.0, and Industry 4.0 is peer-to-peer communication between products, systems and machines based on cyber-physical system [3]. Industry 4.0 includes smart production with high precision and superior quality, green production with clean and sustainable, and urban production with smart factories close to the consumer and employee [5].

In 2010, the number of Internet-connected devices surpassed the number of human beings on the planet. By 2020, Internet-connected devices are expected to number up to 50 billion [1]. The increase of Internet-connected devices compared to the world population is shown in Figure 1.



	2003	2010	2015	2020
◆ World population (Bil)	6.3	6.8	7.2	7.6
■ Connected device (Bil)	0.5	12.5	25	50
▲ Connected device per person	0.08	1.84	3.47	6.58

FIGURE 1. Internet-connected devices and the future evolution (Source: [1])

Considering these big changes in the IoT environment, it is crucial to combine the sensor technologies with the network infrastructure. Also, it is more important to demonstrate the feasibility of IoT technologies in the factory environment of manufacturing system.

The purpose of this paper is to review the State of the Art of an IoT and smart factory, and propose a simple prototype implementing IoT enabled smart factory in a laboratory level. Section 2 investigates reference architecture of IoT and smart factory. Section 3 proposes a framework of prototype, and Section 4 performs implementation for the problem. Section 5 summarizes conclusions and future research directions.

2. The IoT and Smart Factory.

2.1. **IoT.** The basic usage model of IoT is to manage people, to monetize things, to operate information, and to extend places. A cyber-physical system or embedded systems are located on the edge of IoT. They bridge the gap between physical world and cyber space.

The fundamental characteristics of the IoT are [4]:

- Interconnectivity: With regard to the IoT, anything can be interconnected with the global information and communication infrastructure.
- Things-related services: The IoT is capable of providing thing-related services within the constraints of things, such as privacy protection and semantic consistency between physical things and their associated virtual things.
- Heterogeneity: The devices in the IoT are heterogeneous, and they can interact with other devices or service platforms through different networks.
- Dynamic changes: Both the state of devices and the number of devices change dynamically.

- Enormous scale: The number of devices that need to be managed and that communicate with each other will be at least an order of magnitude larger than the devices connected to the current Internet.

Three dimensions of IoT are enabling technologies, functions and application domains. The details of three dimensions are illustrated in Figure 2.

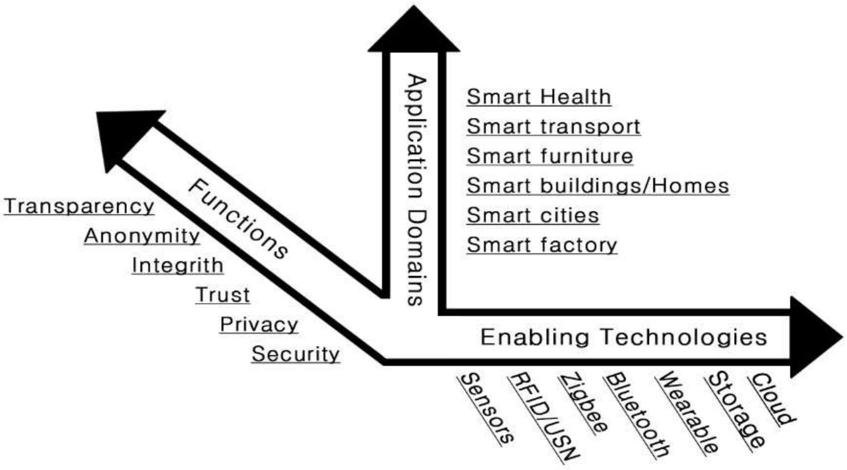


FIGURE 2. Three dimensions of IoT

2.2. **Smart factory.** In order to be competitive, a production system should be an ecosystem where efficient and lean production can be implemented upon the network of interconnected sensors and devices. For this purpose, an IoT should be embedded in the manufacturing and production facility.

The big challenge for the future factory aims at design, setup and maintenance of highly complex and efficient systems in terms of quality, cost, responsiveness and customer satisfaction. In order to reach this goal, the user interface in the future factory needs to transform from local access to nomadic access, from fixed dialogue to multiple dialogue, from limited functions to complex functions, from known location to fuzzy locations with longer lifetime and higher flexibility.

In the smart factory, various wireless technologies are implemented based on new protocols. They are supervisory communication using WLAN, decentralized process control based on RFID, wireless device network based on ZigBee and Bluetooth, failure messaging using GPRS and localization by UWS.

During the last three decades, the technology supporting the production system has been developed rapidly in the communication device. In the 1980s, automation via electrical signal was a main focus. In the 1990s, bits and bytes technology is supported by micro technology and advances in digital signal processing contributed for the factory automation. In the 2000s, functional modularity driven by decentralized PLC's played a big role. In the 2010s, the concept of service supported by standardization of communication interfaces and integration of business and production systems attracts huge interests [6].

In the smart factory environment, smart machine predicts failure and malfunction in the system and triggers maintenance process automatically based on IoT. IoT delivers added value by connecting people, process and big data with higher visibility. Some of the use cases in the IoT enabled smart factory include factory visibility, proactive maintenance and monitoring, automation, connected supply chain, energy management, and sustainable manufacturing.

The next generation of smart factory is semantic-based by collaborating knowledge, service and context. It can handle flexibility, adaptability, complexity control and cognitive behavior of the future factory. The future scenario will be described as everything is mobile, networked, semantic services. A virtuality in the cyberspace merges with reality in the physical world.

3. Prototype Architecture of Smart Factory.

3.1. Prototype architecture of IoT enabled smart factory. The sensor network installed in the factory is defined as sensor node. The sensor nodes are wireless communication standards based on open international IEEE 802.15.4. They can be configured into IoT via point-to-point, tree or mesh type connection. Real time control is possible using the data collected from the sensor nodes.

Actually, in the areas of digital order picking and stock management, a use case of IoT combined with RFID has been reported. Also, automatic classification and data management of freight on the conveyor belt is feasible by combining QR-code and QR-code scanner. Various sensors and combined production information enable real time control of product quality which is under production. Through the real time control, unnecessary loss is minimized and productivity is improved by reducing defects and mistakes of work.

Processing results from the real time control level can be combined automatically with information system such as ERP/SCM. This process can reduce manual work and make the precise information control possible. Both the real time data from sensors and the processed data from ERP/SCM can be adopted for the new knowledge discovery in the industry field. For example, if defects are found in the production line, the cause of defects will be identified by comparing the sensor data and machine status.

The new knowledge discovered from data mining could be applied in the real time control level. When defects are foreseen in the production line from the real time sensor data, the information can be transferred to the field manager in advance in the real time control level. By applying data mining techniques for defects control in all levels of business, business intelligence can be accelerated. Figure 3 shows the architecture of IoT enabled smart factory proposed in this paper.

3.2. Problem domain. The problem domain to implement IoT enabled smart factory is a company producing industrial vinyl film such as High-density Polyethylene (HDPE) and Low-density Polyethylene (LDPE). As the consumer goods are used mainly for wrapping in the household, factory and farming, the defective ratio is relatively high with 15% during production and refund ratio from the defects is 3%. The main defect appears in

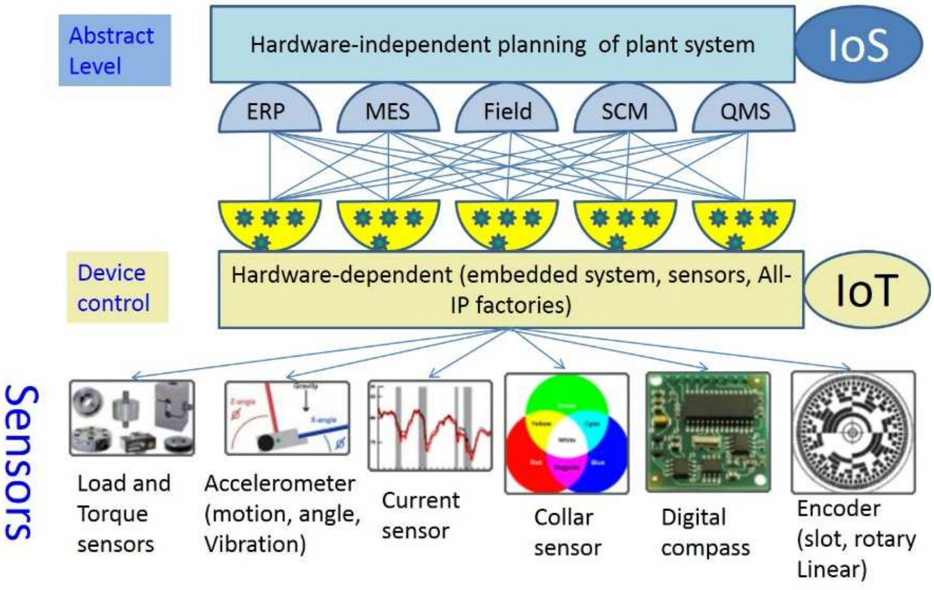
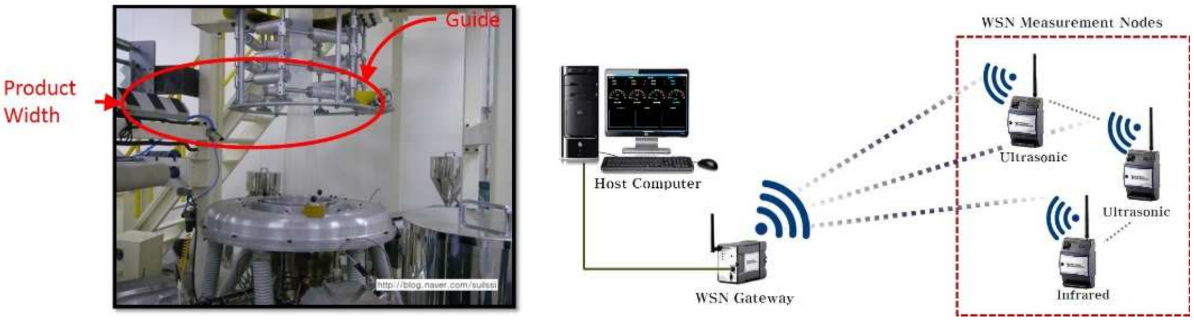


FIGURE 3. Prototype architecture of IoT enabled smart factory



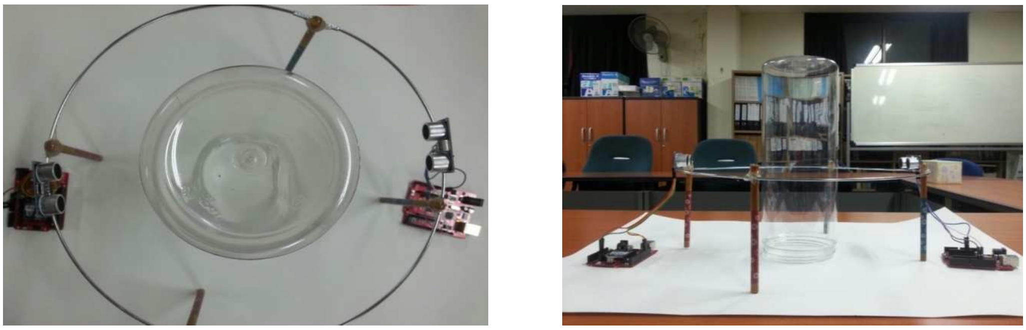
(a) Machine producing HDPE and LDPE (b) USN network

Figure 4. Factory machine producing the product and USN network

the dimension of the product. An idea is generated to reduce the defects using USN and ZigBee. Figure 4 shows the factory machine producing the vinyl film and USN network to implement the wireless error reducing system.

4. Implementation of Smart Factory.

4.1. **Implementation.** In order to reduce defects problem, a test bed simulating the real factory is devised. The simulated line is composed of one steel guide, one transparent water bottle, two Arduino boards, three Xbee and two ultrasonic sensors. The laboratory concept for the simulated line is shown in Figure 5.

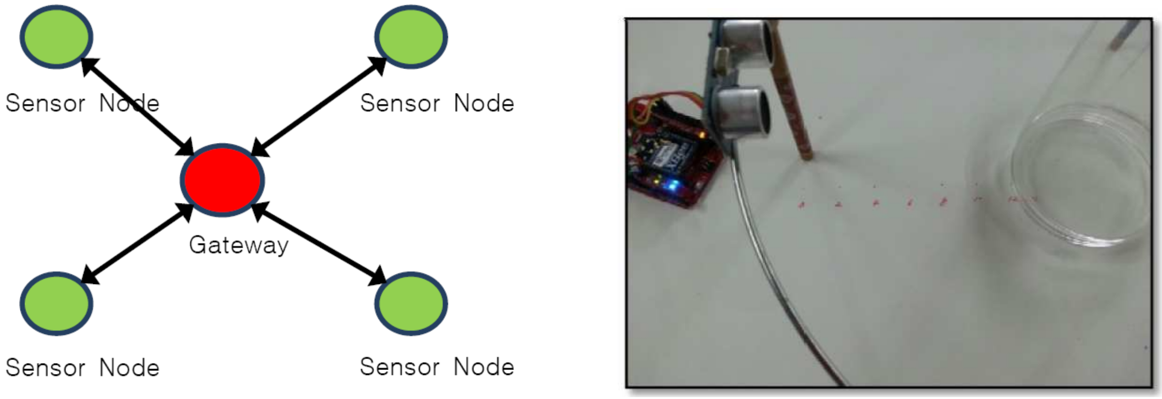


(a) Steel frame simulating the factory (b) Transparent plastic water bottle

Figure 5. Test bed simulating the factory production line

4.2. **Result.** For implementation, ZigBee network should be configured. In the ZigBee network, Star, Mesh and Tree type is available. In this paper, star-type ZigBee is adopted for a network model. The goal of laboratory prototype is to measure the diameter of injection product. As the diameter of guide is known in advance, the diameter of injection can be calculated if we know the distance from guide to the edge of injection product. Test result shows that distance measure is accurate in the range of from 2cm to 180cm. The ZigBee with star-type and distance measure concept is shown in Figure 6.

5. **Conclusions.** IoT is a buzz word not only in the technology but also in business model. Internet and wireless communication technology transformed a dream into a reality in every aspect of industry and life style. Many people watch and search smart phone while they are walking, moving, riding or even driving. This paper tried to survey The State of the Art of IoT and smart factory. IoT plays a basic role for the realization of smart factory. A prototype of IoT enabled smart factory is proposed and is implemented in the laboratory level. The result showed the feasibility of IoT applied in the factory.



(a) Star-shape ZigBee network (b) Distance measure from injection and guide

Figure 6. ZigBee network and distance measurement

Overall, there are many research topics in the IoT. They are identification technology, architecture, infrastructure, applications, SOA (Service Oriented Architecture), software algorithms, hardware, interoperability, security, privacy, trust, governance and material technology, etc.

If we focus on the future research directions in the IoT enabled smart factory, the following could be suggested. First, in order to add value to the smart factory, semantic knowledge is needed in the IoT data. For this purpose, data mining and process mining technology are required to be combined with IoT data. Second, with regard to the smart factory, a new paradigm named smart-X about manufacturing needs to be developed.

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