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# Internet of Things for Manufacturing in the Context of Industry 4.0

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**Abstract.** Internet of Things (IoT) can be defined as “a world where physical objects are seamlessly integrated into the information network, and where the physical objects can become active participants in business processes. Services are available to interact with these ‘smart objects’ over the Internet, query their state and any information associated with them, taking into account security and privacy issues.” The Internet of Things itself is enabled by a few key technologies which have had extensive progressive in the last few years. As the well world-wide spread of Industry 4.0, IoT-enabled manufacturing plays an important role in supporting smart factory, intelligent automation, and real-time adaptive decision-makings. This paper comprehensively review related technologies and world-wide movements so that insights and lessons could be useful for academia and practitioners when contemplating IoT technologies for upgrading and transforming traditional manufacturing into a Industry 4.0 future.

**Keywords.** Internet of Things, Manufacturing, Industry 4.0, Technology.

## 1. Introduction

Industry 4.0, well-known as ‘smart factory’, was proposed in Germany with the modular structured smart factories, Internet of Things (IoT), and other technologies for creating a virtual version of the physical world so as to make decentralized decisions [1]. Industry 4.0 is referred as the 4<sup>th</sup> Industrial Revolution, with prior three industrial revolutions being mechanization powered by the introduction of mechanical production facilities using water and steam between 1784 and mid 19th century, the mass production based on the division of labor using electric energy from late 19th century to 1970s, and automation powered by computers since 1970s. Today, driven by information and communication technology (ICT) in particular the Internet and embedded systems technology, the seamless integration of the physical (real) and digital (virtual) worlds is made possible, giving rise to IoT. The widespread application of IoT marks the transition of industrial production to its fourth stage - Industry 4.0 [2]. Industry 4.0 thus enables companies to cope with the challenges of producing increasingly individualized products with a short time to market and ultimately enhances companies’ competitiveness [3].

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IoT is the internetworking of physical devices, vehicles (also referred to as "connected devices" and "smart devices"), buildings, and other items—embedded with electronics, software, sensors, actuators, and network connectivity that enable these objects to collect and exchange data [4]. It allows objects to be sensed and/or controlled remotely across existing network infrastructure, creating opportunities for more direct integration of the physical world into computer-based systems, and resulting in improved efficiency, accuracy and economic benefit in addition to reduced human intervention [5-7]. Radio frequency identification (RFID) technology as one key elements in IoT was initially proposed to uniquely identify interconnected objects through radio waves [8]. Due to its identification advantages, RFID has been widely used in various industries to supporting data collection and objects distinguishment [9-12].

IIoT (Industrial Internet of Things) is termed as the adoption of IoT technologies in industry [13]. IIoT integrates machine learning and Big Data Analytics for smart machining and advanced decision-makings. Decisions based on such data are prone to be errors, which may bring negative impacts on manufacturing efficiency and customer satisfaction [14]. Manufacturing industry has used RFID for data capturing for a decade [15]. For example, an affordable approach to shop floor performance improvement using RFID or auto-ID technology with wireless manufacturing was presented [16]. This paper attempts to firstly review the IoT technologies and world-wide movements so that insights and lessons could be useful for academia and practitioners when contemplating IoT technologies for upgrading and transforming traditional manufacturing into a Industry 4.0 future.

The rest of this paper is organized as follows. Section 1 presents related technologies such as RFID, Bar-code, and wireless communication standards. Section 2 shows the world-wide movements from North America, European Countries, and Asia Pacific Area. Section 3 highlights the insights and lessons from this research and indicates the future implementation. Section 4 concludes this paper.

## 2. Related Technologies

### 2.1 RFID

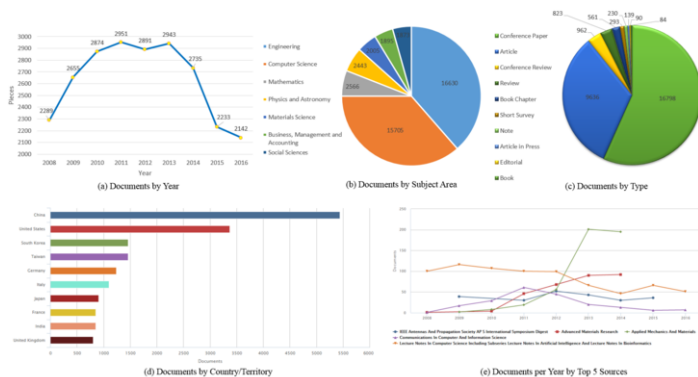


Figure 1. Statistics Analysis on RFID Research.

RFID technology uses electromagnetic fields to automatically identify and track tags attached to objects, which can stored electronic information [8][17][18]. Two types of tags are included: passive tags collect energy from a nearby RFID reader's interrogating radio waves and active tags have a local power source such as a battery and may operate at hundreds of meters from the RFID reader [19]. Unlike a barcode, the tags need not be within the line of sight of the reader, thus it could be embedded in the tracked object. RFID is one method for automatic identification and data capturing without any human intervenes so that it could be used widely in industry.

RFID research has been placed particular attention in recent years [9-11, 20-28]. From Figure 1 (a), it could be observed that, from the year of 2008 to 2016, the total documents published are 23,713 with the average of 2635 documents per year. The major subject areas are shown in Figure 1 (b) from where Engineering and Computer Science take up 39% and 36% respectively. From Figure 1 (c), most of the documents are from conference papers and articles. RFID books are quiet few (only 84) compared with other types such as notes and review. As shown in (d), the most active research countries/territories are China, United States, South Korea, Taiwan, and Germany where RFID research in terms of technologies and its applications are popular. (e) presents the top 5 sources about the keyword 'RFID'.

2.2 Bar-code

Bar-code technology is an optical and machine-readable data presentation by varying the widths and spacings of parallel lines [29]. It has one and two dimensional codes which use linear and rectangles, dots, hexagons and other geometric patterns in two dimensions [30]. Bar-code usage in industrial context was sponsored by the Association of American Railroads in the late 1960s when it was developed by General Telephone and Electronics (GTE) and called KarTrak ACI (Automatic Car Identification), which involved placing colored stripes in various combinations on steel plates which were affixed to the sides of railroad rolling stock. Then in 1981, it was used by the united States Department of Defense to labelling all the products sold to the military from where a logisitics applications of automated marking and reading symbols has been used for a long time [31]. Figure 2 presents a statistics report in different views such as documents by year, by subjects, by type, etc, from Scopus database where keyword 'Bar-code' is used for obtaining the results between 2008 to 2016.

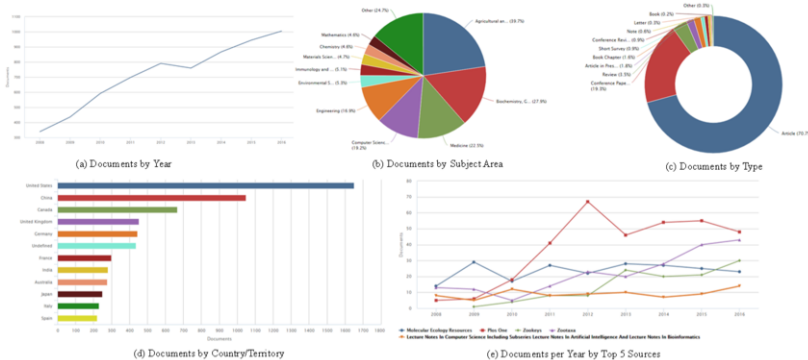


Figure 2. Statistics Analysis on Bar-code Research.

Figure 2 (a) presents the published documents related to this technology by yearly. It could be seen that around 350 documents were published in 2008 and over 1000 was

in 2016, which is three times more than the year 2008. And the numbers increase stably recently. From Figure 2 (b), the top subject areas used Bar-code are agricultural and biological science (39.7%), biochemistry, genetics and molecular biology (27.9%), medicine (22.5%), computer science (19.2%) and engineering (16.9%). These areas used Bar-code to identify various objects to through labelling a numbering code whatever linear lines or 2D shapes. Figure 2 (c) shows the types of documents most of which are articles that takes up of 70.7%. And then, conference papers rank at the top second with 19.3%. From the view of county/territory, United States, China, and Canada are the top three countires which used this technology most from Figure 2 (d). Over 1,600 documents are from United States that because it is firstly proposed in U.S. and now widely used in various industries. Figure 2 (e) shows top 5 resources for producing these documents.

### 2.3 *Wireless communication standards*

In IoT-enabled manufacturing, wireless communication standards are very important since all the manufacturing objects should be identified, connected and reacted. Wireless communication is a way to send data or information between two or more points which are not connected physically by any conductors such as cables or wires [32]. Wi-Fi is a wireless local area network that enables portable computing devices to connect easily with other devices, peripherals, and the Internet, which uses tandardized as IEEE 802.11 [33]. Wi-Fi approaches speeds of some types of wired Ethernet for accessing in manufacturing shopfloors, industry sites, and at public hotspots [34-36]. Wi-Fi wireless communication technology was used in a cyber-physical system in industry to process automation and control with some sensors [37-39].

Another wireless communication is cellular data service which offers coverage within a range of 10-15 miles from the nearest cell site whose speed have increased as technologies have evolved, from earlier technologies such as CDMA and GPRS, GSM, to 3G networks such as W-CDMA, EDGE or CDMA2000 [40]. Wireless sensor networks are responsible for sensing vibrations, interference, and activity in data collection networks for example in manufacturing stations or working machines. This allows the manufacturing system to detect relevant quantities, monitor and collect data, formulate clear user displays, and to perform decision-making functions [41]. Wireless data communications are used for spanning a distance beyond the capabilities of typical cabling in point-to-point communication [45].

Bluetooth, a well-known wireless communication method, is for exchanging data over short distances by making full use of short-wavelength UHF radio waves in the ISM band from 2.4 to 2.485 GHz from fixed and mobile devices and building personal area networks (PANs) [46]. Invented by telecom vendor Ericsson in 1994, this technology was conceived as a wireless alternative to RS-232 data cables which are able to connect up to seven devices, overcoming problems that older technologies had when attempting to connect to each other [47, 48]. It is managed by the Bluetooth Special Interest Group (SIG), which has more than 30,000 members in the areas of telecommunication, computing, networking, and consumer electronics, which are used in industry [49]. ZigBee is an IEEE 802.15.4-based specification for a suite of high-level communication protocols which are used for creating private area networks with small, low-power digital radios, such as for shop floor automation, manufacturing device data collection, and other low-power low-bandwidth needs [50]. It is specially designed for small scale projects which need wireless connection. The technology was

defined by the ZigBee specification which is intended to be simpler than other wireless personal area networks (WPANs), such as Bluetooth or Wi-Fi [51]. Its low power consumption limits transmission distances to 10–100 meters so that power output and environmental characteristics have great impacts on the technology [53].

## 2.4 Smart Sensors

Smart sensors play important roles in supporting the IoT-enabled manufacturing or IIoT. Sensors for capturing the temperature, humidity, force, vibration, etc have been widely used to get the real-time data [54]. For instance, vibrating fork level sensors are used due to its switch reliable, cost effective, and efficient principle. The tuning fork detecting components are placed into vibration by establishing motion in the sensing fork. So that the machine vibrations or moving objects could be detected and such information is important for decision-makings such as machine maintenance.

When implementing different sensors in manufacturing, the integration of heterogeneous sensors are crucial, especially in real-time basis. Thus, an online real-time quality monitoring system using heterogeneous sensors for additive manufacturing processes was reported [55]. These sensors have been deployed on various manufacturing objects such as machines, materials, shopfloor buffers, etc [56]. After that, the real-time data could be captured and collected for further decision-makings. More sensors technologies, implementations, and review could be observed from [57–59].

## 3. World-wide Movements

This section reviews the current world-wide movements of IoT-enabled manufacturing so that industry practitioners are able to get some ideas and insights from reading their successful cases or governmental policies which are going to promote this field under the Industry 4.0 era. United States is of course one of key countries in IoT-enabled manufacturing. US government launched several programs to improve manufacturing such as Advanced Manufacturing Partnership Plan (2011) and Industrial Internet (2012). 35% of US manufacturers are currently collecting and using data generated by smart sensors to enhance manufacturing/operating processes. And 34% believe it is “extremely critical” that US manufacturers adopt an IoT strategy in their operations. 38% currently embed sensors in products that enable end-users/customers to collect sensor-generated data. GE in the US proposed the concept of Industrial Internet that aims to connect manufacturing facilities, people, and data analytics through IoT application in most of their companies in 2012 [60]. Three major parts of the Industrial Internet are smart facilities, smart systems, and smart decision-making.

In 2013, Germany introduced an Industry 4.0 program which covered one core, two topics, three dimensional integration, and eight plans. IoT is one of the key elements in this program. Industry 4.0 creates what has been called a smart factory where modular structured smart factories, cyber-physical systems monitor physical processes, a virtual copy of the physical world and decentralized decisions could be achieved [61]. Over the IoT, cyber-physical systems communicate and cooperate with each other and with humans in real time, and via the Internet of Services, both internal and cross-organizational services are offered and used by participants of the value chain [62]. There is a working group on Industry 4.0, aiming at implementing the

recommendations from German federal government. This group members are the founding fathers and driving force behind industry 4.0.

In China, a strategic plan called Made in China 2025 was proposed with the Guidance of the State Council on Promoting Internet + Action and 13<sup>th</sup> Five-year Plan on national Program for Science and Technology Innovation. Made in China 2025 has a clear goals, guidance and road map for 30 years. There are nine missions ten major development fields and give major programs [63]. Recently, Japanese government initialized an Industry 4.0 plan which aims to create standards for technology to connect factories and to combine efforts to internationalize industrial standards from Japan. Mitsubishi, Fujitsu and Panasonic, some of the initiative's founding members, plan and act global this initiative to make a difference. Nissan Motor is also a member, which looks for areas of collaboration instead of understanding this as a competing model to Industry 4.0.

#### **4. Insights and Lessons**

Several lessons could be obtained from the review investigation. Firstly, IoT key technologies like RFID, Bar-code, and wireless communication standards are quite mature in industry applications. However, their integrations such as technical and data integration are scarcely reported. That may result in isolated technology implementation in entire manufacturing sites. For example, parts being produced communicate with machines by means of a product code, which tells the machines their production requirements and which steps need to be taken next and all processes are optimized for IT control, resulting in a minimal failure rate.

Secondly, successful cases are seldom reported since most of the implementation of IoT-enabled manufacturing is still in the initiative stage. Best practices and case studies require more implementations of IoT technology in the industry so that manufacturing could be better transformed and upgraded [64].

Thirdly, the IoT-enabled manufacturing is still led by developed countries like US and Germany. For example, most of the top IoT technology providers are from these countries. Few of them are from developing countries like China and India. Developing countries like China are chasing with rapid step due to the government plans or programs. In the near future, these countries may be the biggest market for IoT technology and their applications.

Manufacturing worldwide is on the cusp of a revolution where new information technologies are suddenly offering not only to make the management of manufacturing more effective from early versions of plant and enterprise software, but the work itself smarter [64]. Technologies based on the Internet of Things have the potential to radically improve visibility in manufacturing to the point where each unit of production can be "seen" at each step in the production process. Batch-level visibility is being replaced by unit-level visibility. This is the dawn of IoT-enabled manufacturing which requires a healthy dose of technology to ensure machines work together, material flows visibly in real time, and teams of knowledge workers orchestrate the entire manufacturing process [66]. The IoT-based environment enables this possible, for example in plant floor applications, it can create a network linking a range of manufacturing assets from production equipment to parts being produced, from sensor-embedded automation controls to energy meters, from trucks to a warehouse's smart shelves [67].

With the IoT, manufacturers can give each of their physical assets a digital identity that enables them to know the exact location and condition of those assets in real time ubiquitously throughout the manufacturing sites or even the whole supply chain. Very importantly, IoT-enabled manufacturing also requires proactive and autonomic analytics capabilities, making manufacturing an intelligent and self-healing environment. With IoT-enabled manufacturing, companies can predictively meet business needs through intelligent and automated actions driven by previously inaccessible insights from the real world. It transforms manufacturing businesses into proactive, autonomic organizations that predict and fix potentially disruptive issues, evolve operations and delight customers, all while increasing the bottom line.

## 5. Conclusion

This paper reviews the current Internet of Things for manufacturing in the context of Industry 4.0 where IoT-enabled manufacturing is about creating an environment where all available information from within the plant floor is captured in real-time, made visible and turned into actionable insights. IoT-enabled manufacturing comprises all aspects of business, blurring the boundaries among plant operations, supply chain, product design and demand management. Enabling virtual tracking of capital assets, processes, resources and products, IoT-enabled manufacturing gives enterprises full visibility which in turn supports streamlining business processes and optimizing supply and demand.

Some key technologies and world-wide applications are reviewed so that some critical insights and lessons could be obtained. Such important insights could be used for guiding practitioners and academia in their applications and research in the near future due to the development of Industry 4.0.

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