Utilizing the Internet of Things (IoT) Technologies in the Implementation of Industry 4.0

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Abstract. The first Industrial Revolution took place in the 17^{th} and 18^{th} centuries. Since then, the evolution of the industrial revolution has continued. At present, Industry 4.0 a new industrial paradigm is already creating euphoria among technology professionals. The implementation of Industry 4.0 will significantly rely on Internet of Things (IoT) technology. IoT is poised to become the next big thing in the IT arena. However, the use of IoT technology to implement Industry 4.0 will require a collaborative efforts. There are many aspects that all stake holders both in IT world and Industry 4.0 will need to consider; these multiple aspects can be defined (i) smooth integration of the newly developed IoT sensors (things) into existing industries. (ii) Transparent secure communication channel and software layer to link manufacturing data with cloud based SW platforms. (iii) Developing a standard IoT architecture; Open standard is vital to guarantee hundreds of millions of Internet-connected things are inter-operable and being able to communicate with each other. (iv) Big Data storage and management capability. (v) Development of energy efficient IoT sensors and devices. The objective of this study is to explore the role IoT and related technologies such as cyber-physical systems (CPS) will play in the implementation of Industry 4.0. The paper begins with an introduction that gives an overview of IoT and Industry 4.0. The rest of the paper is divided as follows; integration between Industry 4.0 and IoT, Cyber physical system and industry 4.0, prerequisites of IoT technology, challenges and a conclusion.

Keywords: Internet of Things (IoT) · Industry 4.0 · Cyber-physical system (CPS)-intelligent things · Sensors · Big data

1 Introduction

Advancement of technology over the past decade has given rise to Industry 4.0, sometimes referred as industrie 4.0, a strategic research initiative of Germany

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that seeks to radically transform the manufacturing and production industry [1]. Germany seeks to implement Industry 4.0 as a strategy to remain competitive [2]. Industry 4.0 is concerned with the use of different technologies and mainly the Internet of Things (IoT) technology to establish a communication media between people, products, sensors and control systems. The world of Information Technology is already referring to key technologies such as IoT and CPS as the technologies for the future that will revolutionize communication and computation [3,4] the time frame of the four industrial revolution is described in Fig. 1.

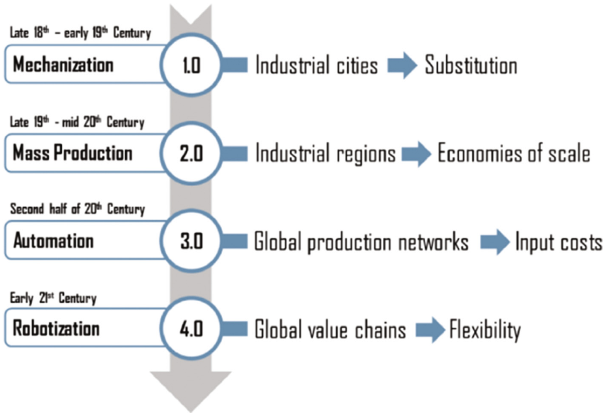

Fig. 1. Time frame of the four industrial revolutions

Internet of Things (IoT) refers to intelligent objects (things)having the ability to seamlessly connect together, share data, information and be able to react to changes in the environment [5]. The connected objects will be intelligent meaning that they will be able to sense the environment around and communicate. Industrial systems will be able to predict failures, initiate self-maintenance processes, and scheduled production activities [6]. Users and operators will be able to communicate remotely through the internet with systems in Industry 4.0 [7]. For instance, IoT technology has made it possible to connect to remote sensors for metering purposes and then perform the needed control action in industrial, agricultural and environmental applications [8]. Through pervasive healthcare, it will possible to offer any patient medical services anytime regardless of the location. Sensors are being embedded in T-shirts to help measure different physical and bio activities [9]. It will be possible to offer smart city services such as controlled water supply networks, power plants smart grid, smart metering, smart building, smart mobility and transportation, smart logistics, vehicle tracking in real time and smart factories [8,10,11]. Industry 4.0 and Internet of Things will enable the integration of advanced control systems with Internet technology. Through IoT technology, it will be possible to attach sensors and controllers to different manufacturing tools such as saw machines and conveyors and collect relevant data. IoT will provide smart systems that can go a step further and synchronize and analyze the collected data [12]. The two technologies (Industry 4.0 and IoT) will provide a common infrastructure that will enable communicating, intelligent and self- controlled systems. Industry 4.0 from this prospective is characterized by four conceptual approaches including: Cyber-physical systems, Internet technology, Communication between different components and security protection of data being transferred [1].

2 Integration Between Industry 4.0 and IoT

Industry 4.0 is a German concept introduced in 2011 in Hanover fair; sometimes referred as (Industrie 4.0). Germany, a super house in the manufacturing and production industry initiated Industry 4.0 implementations to make the country a high-tech hub by 2025. The German government aims that the introduction of Industry 4.0 will help to handle challenges experienced in the 21^{st} century. Industry 4.0 will provide intelligence and communication for smart systems [1]. Smart systems that includes; smart cities, smart factories, and smart grids; have become the epitome of the modern technology. Smart systems, one of the facets of Industry 4.0, will revolutionize the industrial sector tremendously; see Fig. 2. Recent reports indicate that the economic impact on the German industry will result in an added gross value of 267 billion euros by 2025 after introducing the industry 4.0. However, there will be a need for seamless communication between these smart systems. Internet of Things will provide the requisite communication infrastructure to facilitate communication between the increased number of sensors (things) and systems. IoT will utilize the internet protocol version 6 (IPv6). IPv6 is being preferred because it creates addressing capacity of 2^{128} individual addresses. Therefore, each and every smart device will be assigned a unique IP-address [1,9]. IPv6 will enable allowing the limitless addition of devices on the Internet, which is the idea behind Internet of Things concept. IPv6, which will improve the performance of cyber-physical systems, one of the facets of Industry 4.0. Applying the same idea on manufacturing environment will enable automation system builders to integrate huge number of sensors, controllers and products under one common platform.

The integration of IoT technology and Industry 4.0 will require a software layer that converts the physical conditions of the manufacturing and production systems into intelligent objects. The software layer will be required at the sensor's mechatronic component level. Numerous research is being conducted to come with a software layer that will be compatible and capable to convert mechatronic components into intelligent objects as described in [13]. The software layer will ensure also that the mechatronic components are IoT enabled.

The successful implementation of Industry 4.0 depends on the type of Internet of Things technologies currently being implemented in the IT world. Presently, there are a number of technologies that have made it possible to convert physical objects into intelligent things. These technologies include Radio Frequency Identification (RFID), Internet Protocol (IP), Electronic Product Code (EPC),

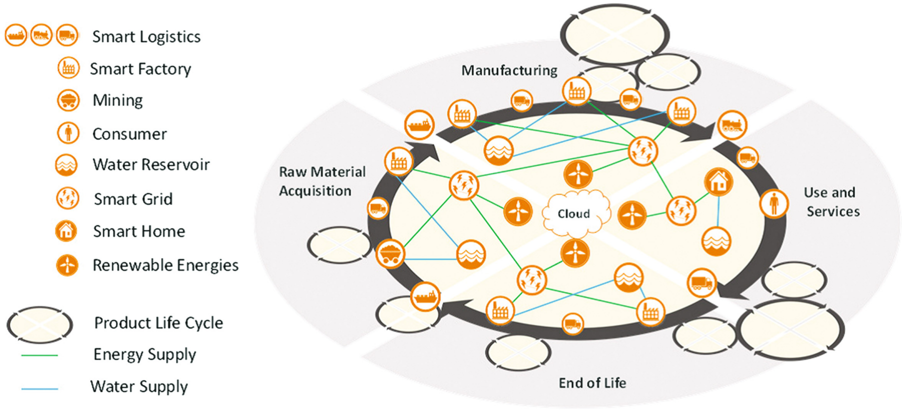

Fig. 2. A model showing how IoT will unify Industry 4.0 facets

Barcode, Wireless Fidelity (Wi-Fi), Bluetooth, ZigBee, Near Field Communication (NFC), and actuators. For example automotive and aerospace companies are using RFID to improve the logistics of their supply chain [11].

As IoT will help the companies to receive detailed and up to date information about their logistics and supply chain. These technologies and others being developed will define how Industry 4.0 will be implemented. IoT technologies also will help developers to develop applications that will provide services that can be used to implement industrial automation systems such as identity-related, information aggregation, collaborative aware and ubiquitous services. Identity-related services will enable the identification of an object through a special identifier such as an RFID tag. Information aggregation services will utilize IoT technology such as ZigBee that can collect data from sensors, process, and transmit it to a desired application. Collaborative aware services make decisions based on the collected aggregated data. Ubiquitous services will enable the deployment of IoT applications anywhere and offer a complete control. IoT technology will ensure systems established in Industry 4.0 are of low cost and have lean operating system. IoT technology also will trigger unprecedented changes in Industry 4.0. Therefore, industry players must take prerequisite actions before Industry 4.0 goals are actualized. A brief comparison between current and Industry 4.0 factories is presented in Table 1. [9,14,15].

3 Cyber Physical System and Industry 4.0

The term Cyber-Physical Systems (CPS) coined in 2006 in a high-level working group composed of selected experts from the USA and European Union, advocates the co-existence of cyber and physical elements with a common goal. CPS explicitly focus on the integration of computation with physical processes [16,17]. CPS also is considered as transformative technologies for managing interconnected systems between its physical assets and computational capabilities.

Table 1. A comparison between Today's factory and Industry 4.0 factory

	Data source	Today's factory		Industry4.0	
		Attributes	Technologies	Attributes	Technologies
Component	Sensor	Precision	Smart sensor and fault detection	Self-aware Self-predict	Degradation monitoring & remaining useful life prediction
Machine	Controller	Producibility & performance	Condition-based monitoring & diagnostics	Self-aware Self-predict Self-compare	Up time with predictive health monitoring
Production system	Networked system	Productivity & OEE	Lean operations: work and waste reduction	Self-configure Self-maintain Self-organize	Worry-free productivity

Beside that; CPS is considered as one of the conceptual approaches that will enable for the implementation of industry 4.0. With the developments in industry 4.0 that will result in higher availability and affordability of sensors, data acquisition systems and computer networks, also the tendency to apply high-tech methodologies in today's industry leads to an ever growing use of sensors and networked machines that has resulted in the continuous generation of high volume data which is known as Big Data. In such an environment, CPS can be further developed for managing Big Data and facilitate the interconnectivity of machines to reach the goal of intelligent, resilient and being a self-adaptable machines [18].

Looking at the manufacturing automation system; we can realize that manufacturing automation, markets are imposing strong changing conditions, where the customization of products requires the use of flexible automation infrastructures. Moreover, the application of flexible automation cannot completely guarantee respecting the time to market requirements, compared with the usual short time on the market of the manufactured products. This situation lies to the necessity of developing and implementing, in a complementary manner to the addressed flexibility, fast and manageable configurability of the automation systems. This means, the configurability of mechatronic (physical part of the automated objects) and of the automation software as well [12].

CPS existence in industrial infrastructures deal also with the combination of mechatronics, communication and information technologies to control distributed physical processes and systems; designed as a network of interacting software and hardware devices and system; many of them with a higher level of decision-making capabilities in both aspects: autonomic with self-decision processes and collaborative with negotiation-based decision processes [14,15]. CPS can be considered as smart systems that use cyber technologies embedded in and interacting with physical components, featuring a tight combination of computational and physical elements, integrating computation, communication and control over an information system (integration of computation and physical processes). CPS conceptually extends the concept of embedded systems: in embedded systems the focus is on computational elements hosted in stand-alone devices, while CPS is designed as a network of interacting computational and physical devices. Furthermore by integrating CPS with production, logistics and services in the current industrial practices, it would transform today's factories into an Industry 4.0 factory with significant economic potential as described in Fig. 3 [17].

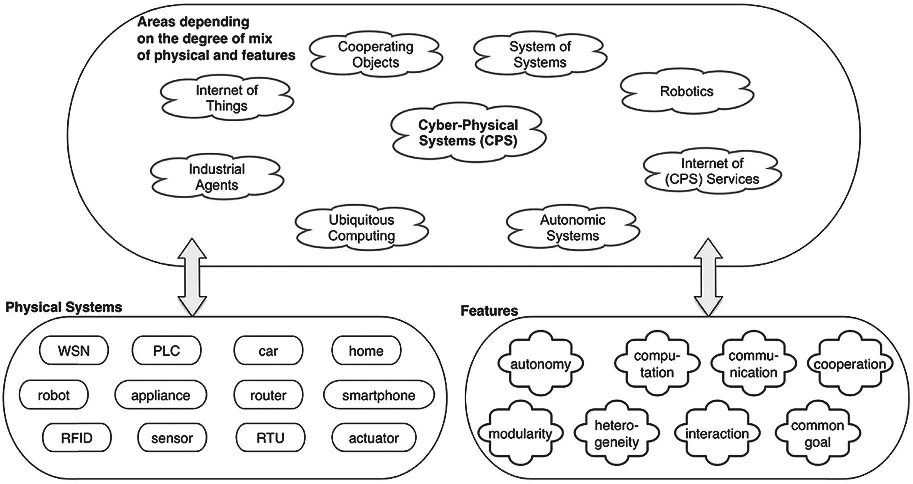

Fig. 3. The mix of physical systems and features as a basis for CPS

According to different research articles; a number of different concepts and architectures have become apparent in the context of CPS such as collaborative systems, service-oriented architectures (SOA), networked embedded devices and systems, cloud computing. [17]. The details of CPS concepts and integration into industry 4.0 is out the scope of this paper; however we'll present to one of the key concepts of CPS which is the implementation of Service-oriented architecture (SOA) into the industrial automation system architecture as a step towards the implementation of industry 4.0.

As a result of application of both CPS and IoT; accordingly millions of devices, not all time smart, are interconnected, providing and consuming information available on the network and are able to exchange capabilities collaborating in reaching common goals. As these devices need to interoperate both at cyber and physical levels, the service-oriented approach seems to be a promising solution, i.e. each device should offer its functionality as standard services, while in parallel it is possible to discover and invoke new functionality from

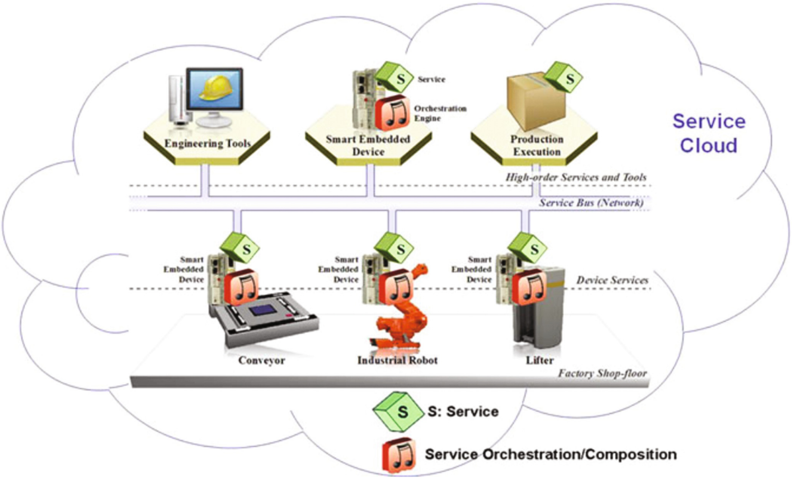

Fig. 4. A service-oriented view of an industrial system

other services on-demand. The use of device-level service-oriented architecture contributes to the creation of an open, flexible and agile environment by extending the scope of the collaborative architecture approach through the application of a unique communication infrastructure, down from the lowest levels of the device hierarchy up into the manufacturing enterprises higher level business process management systems [18]. The result of having a single unifying application-level communication technology across the enterprise, labelled as service bus (network) in Fig. 4, transforms the traditional automation archi-

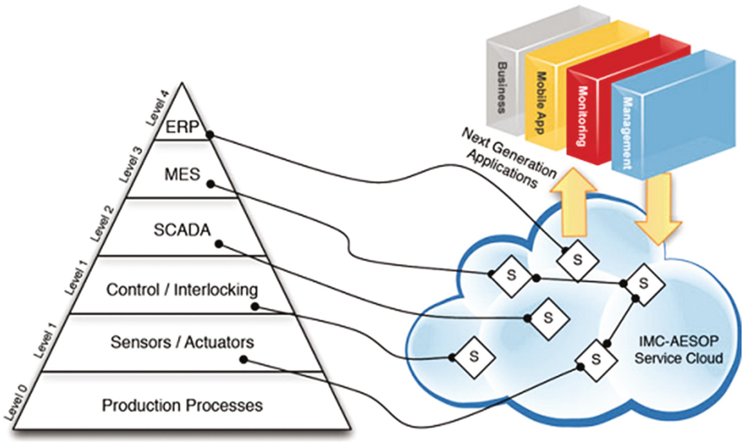

Fig. 5. Conversion of ISA automation structure into a service-oriented apps

tecture from the physical device control level up to the higher levels of the business process management system, as defined in ISA-95 (www.isa-95.com) as compliant Production Enterprise Architecture into a flat automation, control and management infrastructure as in Fig. 5. That is, devices and systems located at different levels all have the same web service interface and are able to interact smoothly. This functional interaction is completely independent of the physical location in the traditionally implemented enterprise hierarchy.

4 Prerequisites of IoT Technology

This section describes factors that IT professionals should consider while implementing IoT, which will significantly affect the adoption of Industry 4.0. The successful implementation of Industry 4.0 will depend on the current IoT infrastructure foundation that is being established in the IT world. IT professionals need to put into consideration certain prerequisites while implementing IoT technology. There will be a need for an open and inter-operable cloud system. Open cloud system will ensure users have the freedom to move from public to private cloud and vice versa. IT professionals also need to build inter-operable cloud systems that will ensure components can work together without developing incompatibility issues. IoT interoperability will enable seamless integration of cyber-physical systems, which are critical in cyber-based manufacturing [12]. Interoperability in IoT technology can be addressed through the use of open standard protocols such as SOS over CoAP, OGC Sensor Things API, and Tiny SOS [19]. Thirdly, IoT applications need to be efficient in power consumption. Fourthly, IoT applications will need to be flexible and available anytime. There will be need for hardware that is made up of sensors, actuators, IP cameras, CCTV and embedded systems. There will also be a need to have middle-ware with computing tools that can handle the analysis of data both in cloud and Big Data systems. IT professionals will also need to enforce mechanisms that will provide data protection and user privacy. Since IoT will connect numerous devices to the Internet and thus there will be a pervasive collection and movement of data from different applications. This will create privacy concerns that need to be addressed. Considerations needed for both applications and devices can be summarized on the need to have features such as reliability, robustness, low cost, low power, secured, simple for use, adaptive and optimal, standardized from operation and communication points of view, easy for integration in existing system and to be in industrial grade from the operation prospective. Therefore, IT professionals need to consider the mentioned prerequisites and also work with players in the manufacturing industry because the IT systems they are presently implementing will significantly shape Industry 4.0 [20].

5 Challenges

This section outlines the challenges that the IoT technology and Industry 4.0 will experience, which may influence the implementation of Industry 4.0. Also, the development of IoT applications, that will provide the required services to implement Industry 4.0, will encounter challenges. The first of them is the lack of a standardized architecture. Presently, there exist a number of IoT architectures that have been proposed such as architectures issued by European FP7, ITU, IoT Forum, Qian Xiaocong, Zhang Jidong Architecture, Kun Han, Shurong Liu, Dacheng Zhang and Ying Hans Architectures [5,21]. The two common reference architectures available for IoT namely IoT-A and IIR-A. Academic researchers and Industry players are putting more efforts to develop other architectures as indicated in [22–24]. Secondly, there will be a large number of devices connected to the Internet. Industry experts estimate that by 2020 there will be around 100 billion devices connected to the Internet that requires smooth interoperability among the variety of systems and things [21].

Other challenges include heterogeneity and different life cycle phases. It is believed in the next decade, billions of devices will be connected to the Internet. However, there is a concerted effort from industry players to come up with IoT standard protocol that will be able to accept new devices in a smooth and flexible manner on plug and play basis. Other challenge related to the volume of data generated from the massive number of sensors and devices. This raw data will require a capable system for data storage, monitoring and analysis in order to have a useful information from this row data. Adaptive data handling, processing and data combination methods are required; also a new methods to monitor and inform about the real data in manufacturing environment and to be correlated to the data of existing automation and control system. Beside all, special care should be given to data management in terms of security [20]. IT professionals need to consider that IoT applications will operate in an overly heterogeneous environment that consists of devices that have different characteristics. IoT applications will also operate in an environment that has thousands of devices from different vendors. The development of IoT applications will also have different life cycle with distinct tasks associated with each of the phases [24]. On the other hand, Industry 4.0 requires a smart analytics tools that will enable mass customization at mass production cost, which is one of the objectives of industry 4.0. It is pertinent for IT professionals to engage players in the manufacturing and production sectors and address issues of concern that may emerge between IoT and Industry 4.0.

6 Conclusion

From the above discussion, it is quite apparent that Industry 4.0 is a reality. The implementation of Industry 4.0 depends entirely on how key technologies such as IoT and CPS are implemented. With IoT technology, it will be possible to convert the traditional manufacturing environment into a smart, cloud based, customer supportive and able to offer range flexible products. The expected added value; was defined as (1%) of global industry outcome; is worth enough to encourage different stack holders to invest in industry 4.0 and IoT technologies. Although the realization of IoT and industry 4.0 technologies are still in its early stages, it is apparent that Industry 4.0 will radically transform the manufacturing industry. However, there issues of concern that needs to be addressed such as interoperability, heterogeneity, data protection and privacy, large number of devices, and different life cycle phases. IoT and Industry 4.0 will unlock many opportunities in the coming years.

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