An Overview of Industry 4.0 Technologies and Benefits and Challenges That Incurred While Adopting It

V. M. Gobinath

Abstract The so-called Industry 4.0 is expected to be the Fourth Industrial Revolution and is to have a huge impact on the manufacturing industry. The ultimate aim of Industry 4.0 is to improve the manufacturing process by combining the virtual and physical world which can help us achieve fully automated manufacturing with adaptability while improving the product quality. The thesis also talks about the establishment of connectivity between various devices in an environment (factory) and also between humans and machines which helps us in collecting and analysing the data to come up with a latent solution for a complicated problem. By this way, customized products can be manufactured easily within the short time. However, challenges such as difficulty in adaptability of the current industries to this revolution are also mentioned in the following paper.

Keywords Internet of things (IOT) · Internet of services (IOS) · Cyber-physical system · Cloud manufacturing

1 Introduction

The First Industrial Revolution which included the transition of muscle power to the establishment of machines that was sourced by steam power was a big leap for the man kind. Followed by the Industry 1.0, the second revolution occurred after the invention of combustion engines and electricity. Third Industrial Revolution occurred after the invention of computers and its ability to minimize the time for an operation and also other advancement such as social media and artificial intelligence. Finally, we are in the verge for the initiation of Industry 4.0. The focus of Industry 4.0 depends on two technologies, which includes human–machine interface (HMI) and connectivity. HMI is a link between humans and machines which helps in guiding the operator towards the solution of the problem [1]. Connectivity includes the communication between the machines and tools or between a machine and another. The ultimate aim

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of Industry 4.0 is to improve quality, cost efficiency, delivery time, flexibility and ergonomics. The fourth revolution is mainly based on the benefits of effective data acquisition. The Fourth Industrial Revolution is expected to bring more sophisticated process into manufacturing by the concept of digitalization.

2 Cyber-Physical System (Cps)

CPS is the base for the evolution of Industry 4.0. Cyber-physical system is a concept of creating a digital replica of the physical resources and then linking them together for augmentation of the efficiency of the output of the physical resources [2, 3]. In other words, CPS can be defined as the technology that helps the physical resources via digitalization. CPS can also be implemented in supply chains management to optimize the processes based on the real-time situations. CPS also enables for the self-con‘uration and self-optimization of the machines based on the changing environmental conditions (Fig. 1).

The cyber-physical system consists of five levels:

- The first level is smart connection which includes the collection of data from the machines and devices through controllers, sensors and other secondary components.
- The second level involves data conversion where the raw data are converted into meaningful information.
- The third level is the cyber level where all the acquired information is taken to a common platform where it can be compared with other acquired information to identify any deviations and then to establish a countermeasure to correct the deviation.
- The fourth level is the cognition level in which interaction between the machines and humans takes place. In this level, various suggestions are brought up by the

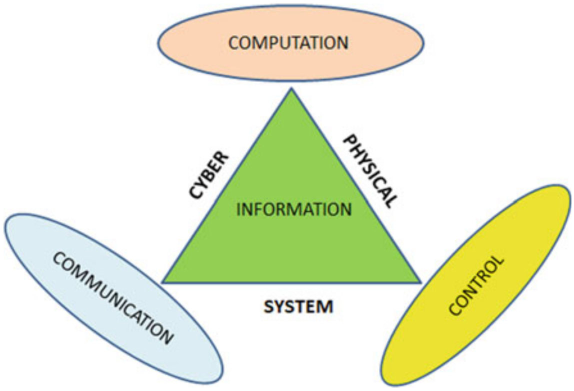

Fig. 1 Structure of cyber-physical system

machine for the humans to perform accordingly so as to increase the efficiency of the manufacturing process and also to improve the quality of the product.
- The fifth level of CPS includes self-configuration of the system based on the environment in such a way it remains as optimized as possible.

3 Vital Concepts and Technologies in Industry 4.0

As discussed earlier, the two main concepts that Industry 4.0 focusses on HMI and connectivity. These two bundles of technologies do not work alone but it works as a combination of technologies.

3.1 Connectivity

This includes linkage of machine with another machine/s for efficient collection and monitoring of the data. Efficient communication of information is the foundation for Industry 4.0. Connectivity plays a dominant role in the industries where the quality and efficiency of the product are vital in the production logic. The degree of connectivity can be of three types, namely one-to-one, one-to-many and many-to-many.

ONE-TO-ONE: Individual usage of machine data to monitor, control and optimize individual devices

ONE-TO-MANY: Networked machine parts allow collective usage of machine data to monitor, control and optimize all devices

MANY-TO-MANY: Integrated usage of machine data connecting machine data to processes.

The primary job of the connectivity concept is to communicate the data and information (both transmit and receive). Communication of information can be done using wired and wireless modes. Implementation of wired communication system is more powerful and sturdy but it is not flexible if the factory has to undergo any chance in infrastructure. However, wireless communication is easy to install but it lacks stability when it comes to large data transfer. The main theme of the connectivity between the machines is cyber-physical systems (CPS) [2]. Internet of things (IoT) is a network of devices that is linked with the CPS. IoT helps the machines and units to communicate with each other and its supply chain and thereby providing clear, accurate and timely data transfer to achieve co-ordination in supply chain. The data and information generated by the machines are collected and processed in the cloud where the performance and risk factors are calculated in real time. As a result of this, cloud computing will become an emerging concept in Internet.

Fig. 2 Structure of Internet of Things

3.1.1 Internet of Things (Iot) and Internet of Services

One of the recent developments of IT is IoT [4]. This technology has completely changed the face of supply chain management by improving the connectivity between the humans and machines [4, 5]. To summarize, IoT refers to a network of digitally connected devices that has the capability to interact within the factory and also between the factory and the supply chain. IoS helps in the enhancement of the product based on the market demand. This technology helps the manufacturing firms to communicate closely with the customers and understand their emotional needs through the products. Hence, a lot of time and resource are reduced that is spent on aggressive market research before the product reaches the market (Fig. 2).

3.1.2 Machine to Machine Interface (M2m)

As the name suggests, we can understand that this technology involves the creation of link between the machines so that data can be communicated among them [6]. One of the examples of M2M interface is the creation of digital link between the machines involved in product development and the machines involved in manufacturing process. Any changes in the product are captured in the database, and it is then transferred to the manufacturing strategy. This provides more flexibility in the creation of mass customized production. In future, robots are expected to be the complete serving entity in the factory system.

3.1.3 Big Data Analytics (BD)

Big data analytics is the glue that holds the concepts of connectivity and HMI. Big data refers to the collection, storage and analysis of a very large amount of data that is acquired from various devices [7]. Since this revolution is mainly driven by automation, a large amount of data is transferred, stored and processed. In order to do this, big data technology is very helpful. The main characteristics of big data include 4Vs: volume, variety, velocity, veracity. Volume refers to the amount of data generated, stored and processed. This characteristic determines whether the data generated can be considered as big data or not. Variety represents the type of data generated. It can be a text, drawing, audio or a visual representation. Data velocity denotes the speed at which the data are generated and analysed. Veracity represents how accurate is the data generated. This characteristic is directly linked to the quality of the generated data.

3.1.4 Cloud Computing

A cloud represents the common space in the Internet where the information can be stored and can be accessed anytime we want. Therefore, any data in the cloud can be accessed by any devices connected to the Internet [8]. The cloud data can be private or public. A public cloud involves storage and access of data and applications via Internet by the public (anyone can have access). Gmail is one of the best examples of public cloud computing where the applications and services launched by Google can be accessed by anyone through any device via Internet. In case of private cloud, data and services within the cloud are secured by a firewall. Private clouds are usually used by corporate and ITs to store, transfer and access data without any security breach. Microsoft Exchange is one of the examples of private cloud as it can be accessed only via VPNs (Fig. 3).

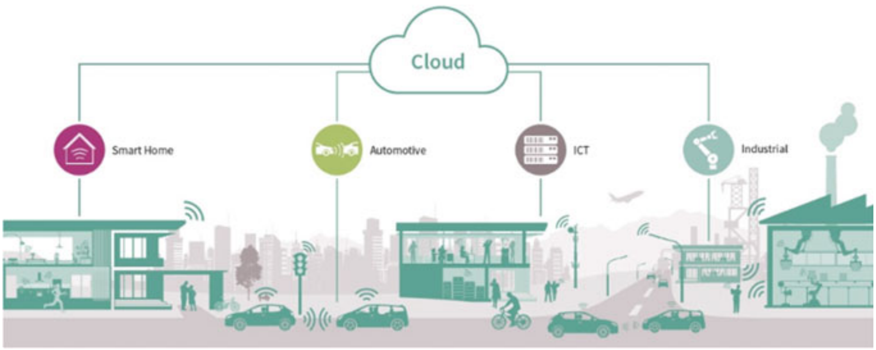

Fig. 3 Cloud storage

3.1.5 Cloud Manufacturing

Cloud manufacturing is a technology that developed after the advancement of cloud computing, IoT and several service-based technologies [9]. The aim of cloud manufacturing is to share the manufacturing resources and capabilities conveniently in order to provide suitable services for the required consumers. Here, all the resources and tools required for manufacturing are stored in the cloud. These resources can be accessed anytime from the cloud. Cloud manufacturing is broadly classified into two categories. The first category involves the storage of manufacturing software into the cloud. The second category involves the integration of real-time devices such as computers, CNC and other machines to the cloud. When all the physical resources in a factory are connected to the cloud, the unused or rarely used machines in the factory can be used for the benefits of other consumers as they will be aware about the availability of the machines they require via the data in cloud space. By this way, the unused machines can be utilized more effectively, and the initial cost of machines can be reduced.

3.2 Human–Machine Interface

As the name indicates, this technological bundle involves the interaction between the humans (Operators) and machines [1]. Though the whole concept of Industry 4.0 is to completely automate the manufacturing process via self- optimization, there are few challenges that are to be met. To overcome these challenges, human interaction with the machines is required now and then. HMI technology is usually preferred in the firms where flexibility is a key characteristic. Here, the operator is the flexible factor in the factory set-up who interacts with the machine manually. As they will be the primary problem-solvers and decision-makers, they must be provided with suffice data and information through devices such as mobiles and context sensitive devices. Through Industry 4.0, it is believed that the concept of automation brings us to a point called “mixed automation” where both humans and machine (robots) work together in the factory environment without any partition between them [1]. Various robot manufacturing firms have pointed out that collaborative robots have the capacity to interact and guide the operators rather than just to stop when the operators get close to them.

3.2.1 Augmented Reality (AR)

Augmented reality is a technique used to combine the actual scene viewed by the user in real time with the virtual scene generated by the computer [10]. This technique is very useful in easy interpretation of data from the machines, especially during human–machine interface (Fig. 4).

Fig. 4 Augmented reality via tablet

3.2.2 Collaborative Robots

Collaborative robots or cobots are the future serving entities in the factories in Industry 4.0 [11]. The key functions of these robots include autonomous operation in a collaborative workspace with humans and establishment of safety design features to protect humans from injury in factory environment. Collaborative robots are also capable of the concept of hand guiding where humans can guide the robots with hand-operated devices. These robots are provided with highly sensitive sensors which help them to stop moving if they find any operator close to the safety level [11, 12]. However, these robots are not very powerful nor very quick when compared to traditional factory robots and they need not be as their primary task is to work along with the humans. Therefore, they work at the speed and magnitude of an average human being (Fig. 5).

3.2.3 Exoskeletons

Exoskeletons are the mechanical gadgets that are worn by the operator which can act as a limb or muscle and can work in co-ordination with the movements given by the operator [13]. They are commonly used as an amplifying and assisting device. The concept of exoskeleton initially originated in defence department, however it is recognized that it might add significant value in manufacturing industries (Fig. 6).

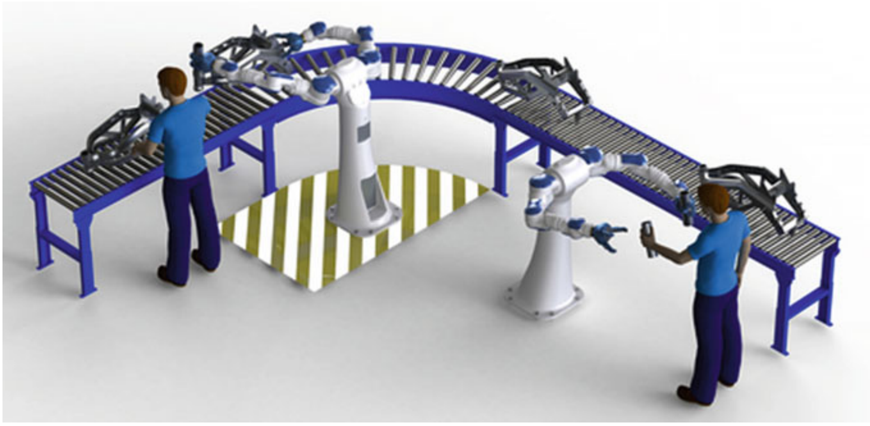

Fig. 5 Collaborative robots in action with humans. *Source* Yaskawa.eu.com

4 Smart Factory and Smart Production

Smart factory and smart production are the two vital areas in Industry 4.0. Smart factory represents the factory that is accompanied with technologies such as CPS, IoT, big data analytics, augmented reality and artificial intelligence. It mainly comprises the physical resources integrated with the local industrial network which in turn is connected to the cloud space. This cloud space is provided with terminals to access, control and supervise the manufacturing system. The physical resources include the real-time appliances and machines. These machines are actuated or operated from the cloud via the industrial networks to which they are connected. The cloud is the store house of all the data that is acquired from the physical resources. These data and information in the cloud could be accessed by the people via the terminals to which the cloud data is connected.

5 Key Features of Industry 4.0

The key feature for the successful establishment of Industry 4.0 is to integrate various domains in the supply chains. This integration of domains can be horizontal or vertical or end-to-end integration [14]. Horizontal integration involves the integration of two firms that are in the same stage and produces same or similar product/output in the supply chain. Through this integration communication between same stages of the supply chains within the firm or with other firms is possible. Vertical integration involves the integration of two firms that are at the different stages in the supply chain. This integration helps us to have better communication through all the domains in all the hierarchical flow. Vertical integration can either be forward or backward integration. When a company in the initial stage of supply chain controls or owns a company in the farther stages along the supply chain, then it is called forward integration. In contrast, when a company in the farther stage of the supply chain owns or controls a company in the beginning stage of the supply chain, then it is called as backward integration. The combination of the horizontal and vertical integration results in the formation of end-to-end integration that has the benefits of both types of integration.

6 Benefits of Industry 4.0

The benefits and outcomes of Industry 4.0 can be classified into three main categories

- New business models
- Efficiency
- Customization.

6.1 New Business Models

A business model is a template of all the processes happening within a firm. The new business model involves more interaction with the customers when compared to the current models. The technical advancement in Industry 4.0 enables increase in efficiency in the way by which data can be created and captured.

6.2 Efficiency of Operation

New technologies such as big data analytics and CPS help us to improve the operational capabilities through predictive and preventive maintenance, self-optimization of the machines, improved visualization of supply chains and quick decision-making. Due to this, the downtime of the machine can be cut or eliminated; hence, the operational efficiency of the firm will be improved.

6.3 Customization

The third benefit of Industry 4.0 is improved customer satisfaction. New technologies of Industry 4.0 help to learn more about their customers and receive real-time feedback. Through the feedback from the customers, mass personalized production is possible. Direct input and feedback from the customers will help the companies to design and produce more customized products for which shorter cycle time and low cost are sufficient when compared to standardized mass production. By this, both the producer and the customer will share the new value that is created.

7 Challenges in Adopting Industry 4.0

7.1 Cyber-Physical System

The lack of complete framework and physical resources is one of the big challenges in the implementation of CPS in current factories. Other external factors such as noise and vibrations also influence in the measurement of inputs from the devices which interrupts the entire cycle of data transfer. CPS may also face issues related to scalability, robustness and its complexity due to its need to fetch real-time data. Still studies have been carried out on how to error free interface between physical and digital world.

7.2 Internet of Things and Internet of Services

This involves the integration of various technologies from different domains which is the primary challenge. The main challenges in implementation of IoT and IoS are the lack of scalability, robustness, security, privacy breach and quality [5]. The existence of various working platforms for various devices makes it difficult for the researchers to integrate all the devices into one. For example, both Android and iPhone have different working platform. Under this case, the combination of these two devices to access a common data from the cloud is difficult as each device platform has its own privacy. Scalability is another challenge during the implantation of Industry 4.0 via IoT. As the number of device integrated to each other increases, large amount of resources for data storage and management is required. Security breach is one of the main challenges in the IoT as the potential attackers of the secured data increase due to the availability of global access to Internet; therefore, anyone can have access to devices connected to IoT.

7.3 Big Data Analytics

Since the whole concept of Industry 4.0 is digitalization and automation, a large amount of data reception and storage and processing is required. In order to do so, large amount of resources are required to maintain and process the data. Since these data are stored in a common space called as cloud storage, the question of how secured the data will be maintained will be raised. This storage of large amount of data with high confidentiality is again a challenge for adoption of Industry 4.0.

7.4 Cloud Manufacturing

Cloud manufacturing is a big challenge for the small and medium-scale enterprises (SME). The primary challenge that SME faces is the development of complex design via cloud manufacturing as it involves integration of highly advanced software, application and machines. The second challenge is the lack of follow-up actions as most of the company do not have the ability to offer that. The third challenge is the cost of the technology. Since cloud manufacturing involves advanced techniques and machines, the cost of the overall technology is high which is difficult for the small and medium-scale firms to adopt [9].

7.5 Augmented Reality

Augmented reality faces four main challenges. The first challenge is the exact overlay of the real-time information with the virtual environment. Very high accuracy in positioning and co-ordination of the reality and virtual environment are necessary for the efficient design and manufacturing process. The second challenge faced by AR system is registration. There are two possible errors in this concept, namely static and dynamic error [3]. The static inaccuracy is caused due to the errors present in the sensing devices, algorithms and other secondary devices. Dynamic errors are caused due to delays in synchronization and computing process. Dynamic errors are mainly due to latency problems.

7.6 Collaborative Robots

The primary challenge of installation of cobots is that they require separate working area. Though they are programmed to work alongside humans, the concept of human safety hinders the complete elimination of boundary between the robots and operators [12]. As these robots are collaborative, they always require human's assistance to work.

8 Conclusion

The primary aim of this paper is to bring awareness about the technology that will be used in Industry4.0. Through this paper, it is understood that Industry 4.0 will have a huge impact on the manufacturing industry that will drive us to the most advanced future where digitalized world will work in parallel with the physical world. Though this adaptation might be a challenge, we will be forced to adapt it due to the emerging technology and increased demands from the consumers.

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