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A Categorical Framework of Manufacturing for Industry 4.0 and Beyond

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Abstract

With rapid advancements in industry, technology and applications, many concepts have emerged in manufacturing. It is generally known that the far-sighted term 'Industry 4.0' was published to highlight a new industrial revolution. Many manufacturing organizations and companies are researching this topic. However, the achievement criteria of Industry 4.0 are as yet uncertain. In addition, the technology roadmap of accomplishing Industry 4.0 is still not clear in industry nor in academia to date. This paper focuses on the fundamental conception of Industry 4.0 and the state of current manufacturing systems. It also identifies the research gaps between current manufacturing systems and Industry 4.0 requirements. The major contribution is an implementation structure of Industry 4.0, consisting of a multi-layered framework is described, and is shown how it can assist people in understanding and achieving the requirements of Industry 4.0.

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1. Introduction

Since the first Industrial Revolution, subsequent revolutions have resulted in radical changes in manufacturing, from water and steam powered machines to electrical and digital automated production. Manufacturing processes have become increasingly complicated, automatic and sustainable, which means people can operate machines simply, efficiently and persistently [1].Nowadays modern manufacturing plays an essential role in the word, especially in European countries. About 17% of the GDP is accounted for by industry, which also creates approximately 32 million job positions with several supplementary occupations in the European Union [2]. However, in recent years the industries of European countries are facing many problems; such as an aging population and, competition from developing countries. According to the Economic Policy Committee and the European Commission, the working age population (aged from 24 to 60) is going to reduce about 48 million (16%), while there are 58 million elder people until 2050 [3]. In 2011, the industrial value share of developing countries (such as China, India, and Brazil) was about 40% of € 6,577 billion, which had increased by 179% that in 1990. In contrast, Western European countries industrial value share had decreased by 25% from 36% of €3,451 (8% in Germany, 20% in France, and 29% in the UK). These problems drive the development of industrial technologies for reducing the labour force, shorting the developing time of the product, using resources efficiently, and so on, of which the Cyber-Physical System (CPS) and Internet of Things (IoT) are two state-of-the-art technologies advanced within the last decade.

With the development of these technologies, a new concept, Industry 4.0, was introduced by German during the Hannover Fair event in 2011, which symbolises the beginning of the 4th industrial revolution [4]. Since its first publication, many European manufacturing research organizations and companies have produced work on this topic, which emphasises that under Industry 4.0, manufacturing will consist of exchanged information and controlled machines and production units acting autonomously and intelligently in interoperable. However, researchers hold different opinions of the specific requirements of Industry 4.0 and its accomplishment, acting on their various industrial technology applications [5; 6; 7; 8; 9]. It is obvious that modern manufacturing is a generalised topic, which is elaborated in multi-fields. Therefore, the current understanding of Industry 4.0 cannot claim the principles. In addition, the manufacturing industry is desperate for a

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hierarchical procedure of technology application, which will guide people to fulfil Industry 4.0.

In this paper, relying on the current situation of manufacturing, in section 2, the core requirements and design principles in different dimensions of Industry 4.0 are realised. Then, in section 3, several current manufacturing systems are introduced for presenting the gaps between the current state of manufacturing and Industry 4.0 manufacturing. Section 4 displays a multi-level crossing framework which is created including nine types of manufacturing application that express previous, recent and future industrial implementation. Based on the recent manufacturing application, this framework shows a direction for the research step by step, which would represent a procedure to accomplish Industry 4.0.

2. Industry 4.0

The first three industrial revolutions have brought mechanisation, electricity and information technology (IT) to human manufacturing. As one of the most high-tech manufacturing countries, Germany holds many of the most sophisticated manufacturing companies and factories [10]. Furthermore, the German government provides two of three Research and Development funds to industrial development, which enables industrial technology to grow rapidly. The passive machines and robots have replaced the labour forces, which means they are controlled by a human without consciousness. In 2012, the number of industrial robots was about 273 per 1000 workers in Germany [11]. However, it is still expensive in its use of employees and additional resources required for controlling, checking, or efficient maintenance. Recently, benefitting from the Internet of things (IOT) and Cyber-Physical System (CPS), the industry-relevant items, for example, material, sensors, machines, products, supply chain, and customers, are able to be connected, which means these necessary objects are going to exchange information and control actions with each other independently and autonomously. German engineers realise that manufacturing has been developed into a new paradigm shift, so-called ‘Industry 4.0’, where products tend to control their own manufacturing processing [8]. Since then, the term of Industry 4.0 is one of the most popular manufacturing topics among industry and academia in the world and has also been considered as the fourth industrial revolution with extreme impact on manufacturing in future [12]. At almost the same time, many other industrial countries are aware of this new coming manufacturing era. In China, an industrial development plan was published in 2015, which is called ‘Made in China 2025’. Also, an industry developing plan has been made for the same purposes as the Industry 4.0 [13]. In this section, the future manufacturing vision, the ongoing industry examples, and the system architecture are displayed, according to many various researchers’ research and opinions, to infer the main concepts of Industry 4.0.

2.1. The Vision and concept of Industry 4.0

There is a basic consensus among many researchers that the industrial revisions require a long-time period of development and cover the following four aspects, considered as the future manufacturing visions:

- **Factory.** As one of the main components of Industry 4.0, the future factory is going to involve a new integrative, where not only all manufacturing resources (sensors, actuators, machines, robots, conveyors, etc.) are connected and exchange information automatically, but also the factory will become conscious and intelligent enough to predict and maintain the machines; to control the production process, and to manage the factory system. In addition, many manufacturing processes, such as product design, production planning, production engineering and production and services, are going to be simulated as modular, and then connected closely end-to-end, which means these processes are not only commanded by a decentralized system but also controlled interdependently. This kind of future factory is known as a Smart Factory [14].
- **Business.** Industry 4.0 implies a complete communication network will exist between various companies, factories, supplier, logistics, resources, customers, etc. Every section optimizes their configuration in real-time depending on the demands and status of associated sections in the network, which makes the maximum profit for all cooperatives with the limited sharing resources. In addition, the costs and pollution, raw materials, CO_2 emissions, etc., will be reduced. In other words, the future business network is influenced by each cooperating section, which could achieve a self-organising status and transmit the real-time responses [12].
- **Products.** Benefitting from Industry 4.0, will be a new type of product generated in manufacturing, that of smart products. These products are embedded with sensors, identifiable components, and processors which carry information and knowledge to convey the functional guidance the customers and transmits the uses feedback to the manufacturing system. With these elements, many functions could be added to the products, for example, measuring the state of products or users, carrying this information, tracking the products, and analysing the results depending on the information. In addition, a full production information log can be embedded with product assisting product developer in optimizing the design, the prediction, and the maintenance [15].
- **Customers.** Customers will also have a lot of advantages under Industry 4.0. A new purchasing method is going to be provided to customers. It allows customers to order whatever function of products, with any number even if only one is. In addition, customers could change their order and ideas at any time during production even at the last minute with no charge. On the other hand, the benefit from the smart products enables the customer not only to know the production information of the product but also to receive the advice of utilization depending on their own behaviours [16].

Besides all of these planned visions of manufacturing, many researchers and companies have been working on Industry 4.0 in many fields around these concepts [17; 18; 19; 20]. Two typical examples show the development of the Industry 4.0; which are production line demonstration and smart products.

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