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Integrated and Intelligent Manufacturing: Perspectives and Enablers

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ABSTRACT

With ever-increasing market competition and advances in technology, more and more countries are prioritizing advanced manufacturing technology as their top priority for economic growth. Germany announced the Industry 4.0 strategy in 2013. The US government launched the Advanced Manufacturing Partnership (AMP) in 2011 and the National Network for Manufacturing Innovation (NNMI) in 2014. Most recently, the Manufacturing USA initiative was officially rolled out to further "leverage existing resources... to nurture manufacturing innovation and accelerate commercialization" by fostering close collaboration between industry, academia, and government partners. In 2015, the Chinese government officially published a 10-year plan and roadmap toward manufacturing: Made in China 2025. In all these national initiatives, the core technology development and implementation is in the area of advanced manufacturing systems. A new manufacturing paradigm is emerging, which can be characterized by two unique features: integrated manufacturing and intelligent manufacturing. This trend is in line with the progress of industrial revolutions, in which higher efficiency in production systems is being continuously pursued. To this end, 10 major technologies can be identified for the new manufacturing paradigm. This paper describes the rationales and needs for integrated and intelligent manufacturing (i^{2}M) systems. Related technologies from different fields are also described. In particular, key technological enablers, such as the Internet of Things and Services (IoTS), cyber-physical systems (CPSs), and cloud computing are discussed. Challenges are addressed with applications that are based on commercially available platforms such as General Electric (GE)'s Predix and PTC's ThingWorx.

1. Introduction

It is well-known that manufacturing is the most important resource for today's wealth-generating process. Manufacturing is a critical element of economic growth in all regions. With the introduction of the concept of Industry 4.0 by Germany, there has recently been a great emphasis in advancing manufacturing technologies around the world, in developed and developing countries. This advance is being achieved by joint effort between government and private sectors, and through the close collaboration of industry and academia. It has spearheaded a strong movement toward a brighter manufacturing future.

This paper provides a study of the manufacturing technology trend and of the two unique features of integrated manufacturing and intelligent manufacturing. Aspects of the technical enablers for advanced manufacturing systems are described, and potential future directions and challenges are discussed.

1.1. The Fourth Industrial Revolution

Looking at the historical advancement of manufacturing system technology, three fundamental measurements are often used: quality, productivity, and cost. These three critical measurements are both related to each other and integrated together. However, early industrial revolutions focused more on the measurement of productivity than on the other two measurements. In other words, manufacturing productivity and efficiency are the focal points for manufacturing technology advancement, while quality and cost are

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the constraints. In this circumstance, the question of how to improve the productivity and efficiency of manufacturing systems has been the critical issue in industrial revolutions.

Fig. 1 depicts the progress and characteristics of the industrial revolutions. During the First Industrial Revolution, with the introduction of Walter's steam engine technology at the end of the 18th century, the method of production was changed from manual craftsmanship to mechanical production, leading to a great improvement in productivity. In the Second Industrial Revolution, with the introduction of electrical power and the transfer line, pioneered by Henry Ford at the beginning of the 20th century, high-speed mass production became the standard manufacturing practice. As a result, productivity was significantly improved and reached a whole new level. During the Third Industrial Revolution, manufacturing efficiency and productivity have been further enhanced by the combination of information technology (IT) and automation systems, such as flexible manufacturing systems (FMSs) and robotic technology. Now, as we consider ourselves to be experiencing the dawn of the Fourth Industrial Revolution, the Internet and smart devices are being widely used to further improve the productivity and flexibility of manufacturing systems.

1.2. Manufacturing initiatives in different regions

In 2013, Germany unveiled its Industry 4.0 strategy, which directed a great deal of global attention to the advances in manufacturing systems technology [1]. In the United States, the government launched the Advanced Manufacturing Partnership (AMP) in 2011. Since then, many other initiatives have been rolled out, including the Advanced Manufacturing Partnership Steering Committee "2.0" in 2013; the National Network for Manufacturing Innovation (NNMI) in 2014; and the Revitalize American Manufacturing and Innovation Act, which was signed into law by the President of the United States in December 2014 [2]. Most recently, Manufacturing USA was officially launched by the US government in order to further "leverage existing resources... to nurture manufacturing innovation and accelerate commercialization" by fostering close collaboration between industry, academia, and government partners [3]. In 2015, the Chinese government officially published a 10-year plan and roadmap toward manufacturing: Made in China 2025 [4]. The largest international collaborative program, Intelligent Manufacturing Systems (IMS), which is led by Japan, is also rolling out a roadmap for its next step with its IMS2020 project.

2. A new paradigm: Integrated and intelligent manufacturing

Among the many features characterizing today's modern manufacturing system technology, such as lean, virtual, and rapid-response systems, two features stand out and are sure to be carried over into the next generation of manufacturing: integrated manufacturing and intelligent manufacturing. As shown in Fig. 2, the market and process demands have driven technology from an information-intensive focus to a knowledge-intensive paradigm, in which big data analytics and knowledge bases play an important role in the current manufacturing environment.

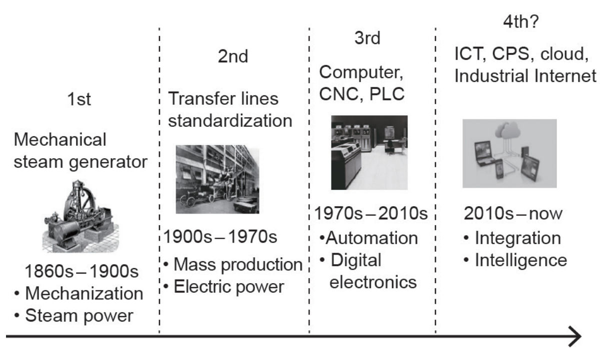

Fig. 1. The progress and characteristics of industrial revolutions. CNC: computer numerical controller; PLC: programmable logic controller; ICT: information and communications technology; CPS: cyber-physical system.

The evolution of integrated and intelligent manufacturing (i^2M) technology is driven not only by the market demand, but also by technological advances. There are 10 major technologies that can be identified as the key elements of the new manufacturing paradigm. As shown in Fig. 3, these technologies include six supporting elements: three-dimensional (3D) printing or additive manufacturing, robotic automation, advanced materials, virtual or augmented reality, the Industrial Internet, and cyber-physical systems (CPSs). They also include four foundational elements: big data analytics, cloud computing, applications, and mobile devices. The ways in which these elements impact advanced manufacturing systems and, more specifically, how they affect i^2M, are described in the following sections.

2.1. Integrated manufacturing

The introduction of the concept of manufacturing systems began with advances in digital computing capability in the 1960s; at that point, some kind of integration started to emerge within manufacturing. Under this scenario, the machines and devices in a manufacturing process are no longer isolated. Rather, they are parts of a system, and all the components can be effectively coordinated in order to achieve improved productivities. For example, the computer-integrated manufacturing system (CIMS) has been widely adopted by companies.

The Internet of Things (IoT) and CPS technologies opened the door for tremendous opportunities in advancing such integration to a whole new level, making integration wider, deeper, and more open. As a result, manufacturing system controls are no longer limited to dealing with physical things and devices such as materials and machines; they are now able to process a large range of data, information, and knowledge in real time. This processing is realized by three levels of integration in manufacturing: vertical integration, horizontal integration, and end-to-end integration [1].

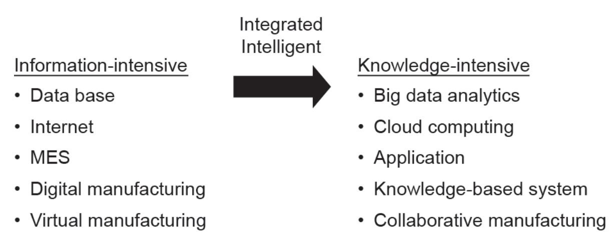

Fig. 2. The new trend in manufacturing systems. MES: manufacturing execution system.

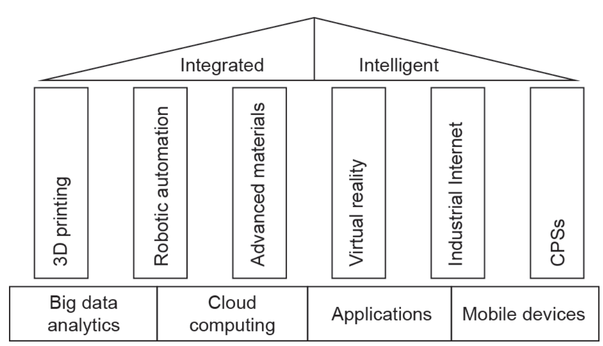

Fig. 3. Ten major technologies for i^2M.