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Research
Intelligent Manufacturing—Perspective

Toward New-Generation Intelligent Manufacturing

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ABSTRACT

Intelligent manufacturing is a general concept that is under continuous development. It can be categorized into three basic paradigms: digital manufacturing, digital-networked manufacturing, and new-generation intelligent manufacturing. New-generation intelligent manufacturing represents an in-depth integration of new-generation artificial intelligence (AI) technology and advanced manufacturing technology. It runs through every link in the full life-cycle of design, production, product, and service. The concept also relates to the optimization and integration of corresponding systems; the continuous improvement of enterprises' product quality, performance, and service levels; and reduction in resources consumption. New-generation intelligent manufacturing acts as the core driving force of the new industrial revolution and will continue to be the main pathway for the transformation and upgrading of the manufacturing industry in the decades to come. Human-cyber-physical systems (HCPSs) reveal the technological mechanisms of new-generation intelligent manufacturing and can effectively guide related theoretical research and engineering practice. Given the sequential development, cross interaction, and iterative upgrading characteristics of the three basic paradigms of intelligent manufacturing, a technology roadmap for “parallel promotion and integrated development” should be developed in order to drive forward the intelligent transformation of the manufacturing industry in China.

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1. Introduction

Countries around the world are actively engaging in the new industrial revolution. The United States has launched the Advanced Manufacturing Partnership [1,2], Germany has developed the strategic initiative Industrie 4.0 [3], and the United Kingdom has put forward the UK Industry 2050 strategy [4]. In addition, France has unveiled the New Industrial France program [5], Japan has a Society 5.0 strategy [6], and Korea has started the Manufacturing Innovation 3.0 program [7]. The development of intelligent manufacturing is regarded as a key measure to establish competitive advantages for the manufacturing industry of major countries around the world. The Made in China 2025 plan, formerly known as China Manufacturing 2025, has specifically set the promotion of intelligent manufacturing as its main direction [8], with a focus on the in-depth integration of new-generation information technology within the manufacturing industry.

Since the beginning of the 21st century, new-generation information technology has shown explosive growth. The broad application of digital, networked, and intelligent technologies in the manufacturing industry and the continuous development of integrated manufacturing innovations have been the main driving forces of the new industrial revolution. In particular, new-generation intelligent manufacturing, which serves as the core technology of the current industrial revolution, incorporates major and profound changes in the development philosophy, manufacturing modes, and other aspects of the manufacturing industry. Intelligent manufacturing is now reshaping the development paths, technical systems, and industrial forms of the manufacturing industry, and is thereby pushing the global manufacturing industry into a new stage of development [9–13].

2. Three basic paradigms of intelligent manufacturing

Intelligent manufacturing is a general concept that covers a wide range of specific topics [10,14]. New-generation intelligent manufacturing represents an in-depth integration of new-generation

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artificial intelligence (AI) technology and advanced manufacturing technology. It runs through every link in the full life-cycle of design, production, product, and service. The concept also relates to the optimization and integration of corresponding systems; it aims to continuously raise enterprises' product quality, performance, and service levels while reducing resources consumption, thus promoting the innovative, green, coordinated, open, and shared development of the manufacturing industry.

For decades, intelligentization for manufacturing has involved many different paradigms as it continues to develop in practice. These paradigms include lean production, flexible manufacturing, concurrent engineering, agile manufacturing, digital manufacturing, computer-integrated manufacturing, networked manufacturing, cloud manufacturing, intelligent manufacturing, and more [15–23]. All of these paradigms have played an active role in guiding technology upgrading in the manufacturing industry. However, there are too many paradigms to form a unified intelligent manufacturing technology roadmap; this lack of unity causes enterprises to experience many perplexities in their practice of pushing forward intelligent upgrading. Considering the continuously emerging new technologies, new ideas, and new modes of intelligent manufacturing, we consider it necessary to summarize the basic paradigms of intelligent manufacturing.

Intelligent manufacturing has developed in parallel with the progress of informatization. There are three stages in the development of informatization worldwide [24]:

- From the middle of the 20th century to the mid-1990s, informatization was in a digital stage with computing, communications, and control applications as the main features.
- Starting in the mid-1990s, the Internet came into large-scale popularization and application, and informatization entered a networked stage with the interconnection of all things as its main characteristic.
- At present, on the basis of cluster breakthroughs in and integrated applications of big data, cloud computing, the mobile Internet, and the Industrial Internet, strategic breakthroughs have been made in AI; as a result, informatization has entered an intelligent stage, with new-generation AI technology as its main feature.

Taking the various intelligent manufacturing-related paradigms into account and considering the characteristics of the integration of information technology and the manufacturing industry through different stages, it is possible to generalize three basic paradigms of intelligent manufacturing: digital manufacturing, digital-networked manufacturing, and new-generation intelligent manufacturing (Fig. 1).

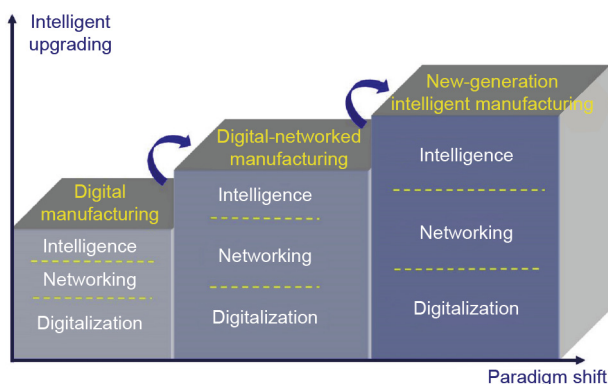


Fig. 1. The evolution of three basic paradigms of intelligent manufacturing.

2.1. Digital manufacturing

Digital manufacturing is the first basic paradigm of intelligent manufacturing; it may also be referred to as first-generation intelligent manufacturing.

The concept of intelligent manufacturing first appeared in the 1980s [10,25–27]. Because the first-generation AI technology that was in application at that time could hardly solve specific engineering problems, first-generation intelligent manufacturing was essentially digital manufacturing.

Starting in the second half of the 20th century, as demand for technological progress in the manufacturing sector became increasingly urgent, digital information technologies were widely applied in the manufacturing industry, driving forward revolutionary changes in the industry. Against a background of the integration of digital technology with manufacturing technology, digital manufacturing undertook the digital description, analysis, decision-making, and control of product information, process information, and resources information; in this way, digital manufacturing remarkably shortened the time required for designing and manufacturing products to meet specific customer requirements [15,16,26,27].

The key features of digital manufacturing are as follows: ① Digital technology is widely used in products, forming a “digital generation” of innovative products; ② digital design, modeling and simulations, and digital equipment information management are widely applied; and ③ production process integration and optimization are achieved.

The point that needs to be clarified here is that digital manufacturing is the foundation of intelligent manufacturing. Digital manufacturing continues to evolve, and runs throughout the three basic paradigms and all the development processes of intelligent manufacturing. The digital manufacturing being defined here is the digital manufacturing of the first basic paradigm, which positions digital manufacturing in a relatively narrow sense. On an international level, several types of positioning and theories on digital manufacturing have also been developed in a broad sense [28].

2.2. Digital-networked manufacturing

Digital-networked manufacturing is the second basic paradigm of intelligent manufacturing; it may also be referred to as “Internet + manufacturing” or as second-generation intelligent manufacturing [29].

In the end of the 20th century, Internet technology started to gain popularity. “Internet +” has continuously pushed forward the integrated development of the Internet and the manufacturing industry. The network connects humans, processes, data, and things. Through intra- and inter-enterprise collaborations and the sharing and integration of all kinds of social resources, “Internet +” reshapes the value chain of the manufacturing industry and drives the transformation from digital manufacturing to digital-networked manufacturing [17,30–33].

The main characteristics of digital-networked manufacturing are as follows [34]:

- At the product level, digital technology and network technology are widely applied. Products are connected through the network, while collaborative and shared design and R&D are achieved.
- At the manufacturing level, horizontal integration, vertical integration, and end-to-end integration are completed, thereby connecting the data flows and information flows of the entire manufacturing system.

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