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From Zero to Infinity: Research on the Development Process of Intelligent Manufacturing

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Abstract

Intelligent manufacturing is flourishing in the 21st century. This paper takes the brief history of exploring the development of intelligent manufacturing as a staring point, explains the current intelligent and informative technologies and achievements of intelligent manufacturing by describing the impact of intelligent manufacturing on traditional manufacturing, proposes reflections on the shortcomings and limitations of intelligent manufacturing in China. And our country advocates human-centered intelligent manufacturing, continuously improves the system and innovates technology, while reasonably plans the three directions. Finally, we extend to digital twin technology and explore it in the intelligent manufacturing to promote the further upgrade. Besides, the study shows that the country will continue to use intelligent manufacturing as a traction and the industrial internet as a means to seize new opportunities and create a new ecology of production.

Keywords: smart manufacturing, manufacturing industry, development prospect, human-centered intelligence, combine digital twin

1. Introduction

Manufacturing is the key to a country’s competitive heights and the cornerstone of its development. With the advent of Industry 4. 0, intelligent manufacturing has expanded its scope based on new digital technologies and processes. In 2011, the United States announced the implementation of the Advanced Manufacturing Alliance Program. In 2013, France proposed the New Industry France. And in 2019, German released National Industrial Strategy In 2030. With the trend of intelligent manufacturing sweeping the world, China released the document Made In China 2025, which aims to promote the development directions of intelligent manufacturing. At present, China’s intelligent manufacturing industry is proceeding in an orderly manner, which will further accelerate China’s dream of achieving a great renaissance as a prosperous nation.

2. The History of Intelligent Manufacturing

In the 1860s, the industrial revolution represented by inventions such as the steam engine and the tool machine broke out in central England, gradually changing the form of labor from manual labor to machine production and transitioning the economic form of society from agriculture and handicrafts to industry. In the middle of the 19th century, mankind entered the “electrical age” and launched the second industrial revolution, which led to the further qualitative improvement of the manufacturing industry. Between the 1930s and the 1950s, the industry became a production line, which created the assembly line model of production and the scientific management theory that allowed division of labor to be matched. Immediately afterwards, scientists made major breakthroughs in theories and technology had a basic support. Therefore, human broke out the third revolution.

In 1973, Joseph Harrington proposed the concept of Computer Integrated Manufacturing(CIM) in Computer Integrated Manufacturing. Subsequently, Prof. P. K. Wright of New York University and Prof. D. A. Bourne of Carnegie Mellon University(1988) announced for the first time in their monograph Manufacturing Intelligence that “by integrating knowledge engineering, manufacturing software systems, robot vision and robot control to model the skills and expert knowledge of manufacturing technicians so that intelligent machines can produces small batches without human intervention”, which is intelligent manufacturing. This marked the beginning of digital manufacturing for mankind. Later, British professor Williams further added that “the scope of integration should also include intelligent decision support systems throughout the manufacturing organization”(Ren

Minglun, 2003). At the end of the 20th century, the rapid development of the internet and extensive connectivity, as well as the development of network systems, made intelligent manufacturing into the digital network manufacturing stage. And at the beginning of 21st century, human ushered in the area of intelligence. The fourth industrial revolution will enter the “decentralization”(Wang Xiwen, 2014), in which various new technologies will be combined with manufacturing to realize intelligent production, and the relevant organization will be changed from large factories to virtual-real factories.

3. Intelligent Manufacturing Solve the Drawbacks of Traditional Manufacturing

Currently, intelligent manufacturing figures out some weaknesses about traditional manufacturing. The conventional aspect of design is monotonic and simple, the whole production cycle is tedious. In addition, the process lacks flexibility and it costs more energy. But on the contrary, intelligent manufacturing technology can combine virtualization and reality, achieve dynamic interaction between demand and design, flexibility, individuation, real-time as well as diversification in the industrial chain. For the management and service, it covers the industrial chain and the whole production cycle with the help of computers and more human-computer interaction, which improves the competitiveness in the market, as shown in Table 1.

Table 1. The similarities and differences between intelligent manufacturing and traditional

classification	Traditional manufacturing	Intelligent manufacturing	The impact of intelligent manufacturing
design	Conventional product Functional requirement oriented Long product cycle	Virtual-real combination Individuation and Short period Dynamic monitoring	Change the design of concept、methods Change the value of use、product function
process	Lack of flexibility Semi-intelligent Man-machine separation	Flexibility and full intelligence Networked human-computer interaction A variety of processing and forming methods	Diversification of modes Change of object of labor New technologies and processes emerge
management	Manual management	Computer information management technology Machine and human interactive instruction management	The object, way, means and scope of management have changed
service	Focus on product	Pay attention to the whole cycle of products	Improve the service system

Nowadays, intelligent manufacturing gradually integrates with networked manufacturing, forming a new type of “Internet+Artificial Intelligence+Manufacturing”. In contrast to the traditional manufacturing industry, which is characterized by information isolation, contemporary manufacturing has shifted to direct problem solving by obtaining information from data. The former is based on the versatility of the Internet of Manufacturing Things(IoMT)and other information technologies(Yao Xifan, Lei Yi, Ge Dinyuan & Ye Jing, 2019) that enable data to operate on a large scale, while the latter realizes the synergy between information and physical levels through perceptual analysis and human-computer interaction.

4. The Intelligent Manufacturing Technology and Application of Results

Based on the Industry 4. 0 area, we have started to integrate intelligent manufacturing with other industries. For example, we have implemented “smart city” and “city portal” projects in Beijing and Shanghai with the help of IoMT and other electronic technology. Under the Cyber-Physical Systems(CPS) model of smart grid, our technicians have embedded communication technology and electronic technology to ensure comprehensive coverage of the whole smart grid and realize a series of closed-loop processing. Shandong Century Sunshine company has adopted the innovation results of intelligent manufacturing and realized the upgrade and optimization of System Applications and Products(SAP)system, which includes the majority of management modules of the industrial chain such as production, warehouse and sales, and the production business has changed from fragmented management to automatic inventory management. In terms of assembly line control, the technical department adopts Metso Dynamic Network of Applications (DNA) system, which integrates Machine Control System (MCS), Quality Control System (QCS), and Distributed Control System (DCS) in a unified manner to complete the measurement of paper water content, thickness, energy and other indicators in real time.

The discrete intelligent manufacturing represented by "Industry 4. 0" is being digitally transformed and intelligently upgraded by the new generation of information technology. For example, in the process of studying the autonomous path planning problem of Automated Guided Vehicle(AGV), in order to improve the autonomous path planning capability and navigation freedom of AGV, the above problem can be transformed into a The Markov Decision Process (MDP) model(Bellman Richard， Ronald Howard&David Blackwell, 1957) is built on the basis of an intelligent body and its environment, and consists of five main elements: state, action, policy, reward, and reward. modal environment information as a high-dimensional state space and a two-dimensional action space, incorporating three classical improvements about deep reinforcement learning methods of Double Deep Q Network, Dueling DQN and Prioritized Experience Replay (DQN) for optimal control strategy training of AGVs in complex environments (Guo Xinde & Ding Hongqiang, 2021) . Since the process industry is different from the discrete industry and the discrete industry smart manufacturing model is not applicable to the process industry, we need to develop a smart manufacturing model suitable for our process industry. Knowledge is the core element of intelligent manufacturing in process industry(Gui Weihua, Zeng Zhaohui, Chen Xiaofang, Xie Yongfang & Sun Yubo, 2020) . Although we have regular mining method, statistical learning method, deep learning method, evolutionary algorithm, example-based reasoning method, symbolic intelligence or computational intelligence based acquisition method(Gui et al, 2020) etc already in the early stage, industry process involves various mechanism changes as well as association associated representation, dynamic uncertainty cause-effect graph, fuzzy awareness graph representation, Petri net representation, semantic Different knowledge representation methods such as network representation. Therefore, we can build a knowledge-driven intelligent manufacturing system for the process industry to automatically complete processing knowledge (Gui et al, 2020) , achieve seamless information exchange at all levels in each enterprise, and finally meet the requirement of efficient and green intelligent manufacturing in the process industry.

5. The Future of Intelligent Manufacturing

5.1 Deep Reinforcement Learning

One important factor in the future of smart manufacturing is the ability of deep reinforcement learning. On this basis, for example, we can consider reflecting on intelligent robots sequentially. Traditional robots can only be programmed to perform inherent actions through existed programming systems and devices, and if there are variations in the work, the robot needs to be reprogrammed. For example, Inoue proposes a recurrent neural network-based Deep Reinforcement Learning (DRL) algorithm model for the complex problem of conventional robot programming, which shows better robustness in a partially observable Markovian decision process (Kong Songtao, Liu Chi-Chi, Shi Yong, Xie Yi & Wang Kun, 2011) and also achieves good experimental results with several missing frames. MIT CSAIL focuses on deep learning (Hinton et al, 2006) to develop new collaborative learning methods for sensor placement and representation of complex tasks, designing a PSFE network architecture using point-cloud-based learning and probabilistic sparsification. The main contributions of the new architecture are the measurement of strain and strain rate, a minimal set sparse probabilistic sensor representation for downstream tasks, an algorithm that goes beyond automated and manual baselines, and a collaborative demonstration of task learning and sensor placement in soft robotics.

5.2 Steel Process Industry

The iron and steel industry is a representative process industry with numerous and chaotic processes. And the process parameters are nonlinear, multivariate, and strongly coupled (Yao Lin & Wang Junsheng, 2020) . By using industrial smart manufacturing and reshaping the value chain of the production process system, we can attain the maximization of benefits. As shown in Figure 1, the completion of a steel smart factory needs to relate to the characteristics of production process continuity, equipment reliability, process complexity and diversity, high safety index, and comprehensive management coverage, etc. Therefore, based on the informationization of steel enterprises, we integrate independent "information islands" into one "information set" through the “business + data” approach. We choose communication technology (e. g. 5G) to connect field devices and achieve the "Internet of Things" model. We also apply CPS to connect the Industrial Internet and the Internet of Things to form a digital twin model. Among these foundations, we build a connection between the virtual and the real. For steel big data processing, we break the monopoly of information control at all levels, build cross-level information reporting channels, form an integrated information sharing of production information flow, material flow, and energy flow (Zhang Qi & Cai Jiuju, 2021), and realize the synergy between production processes.

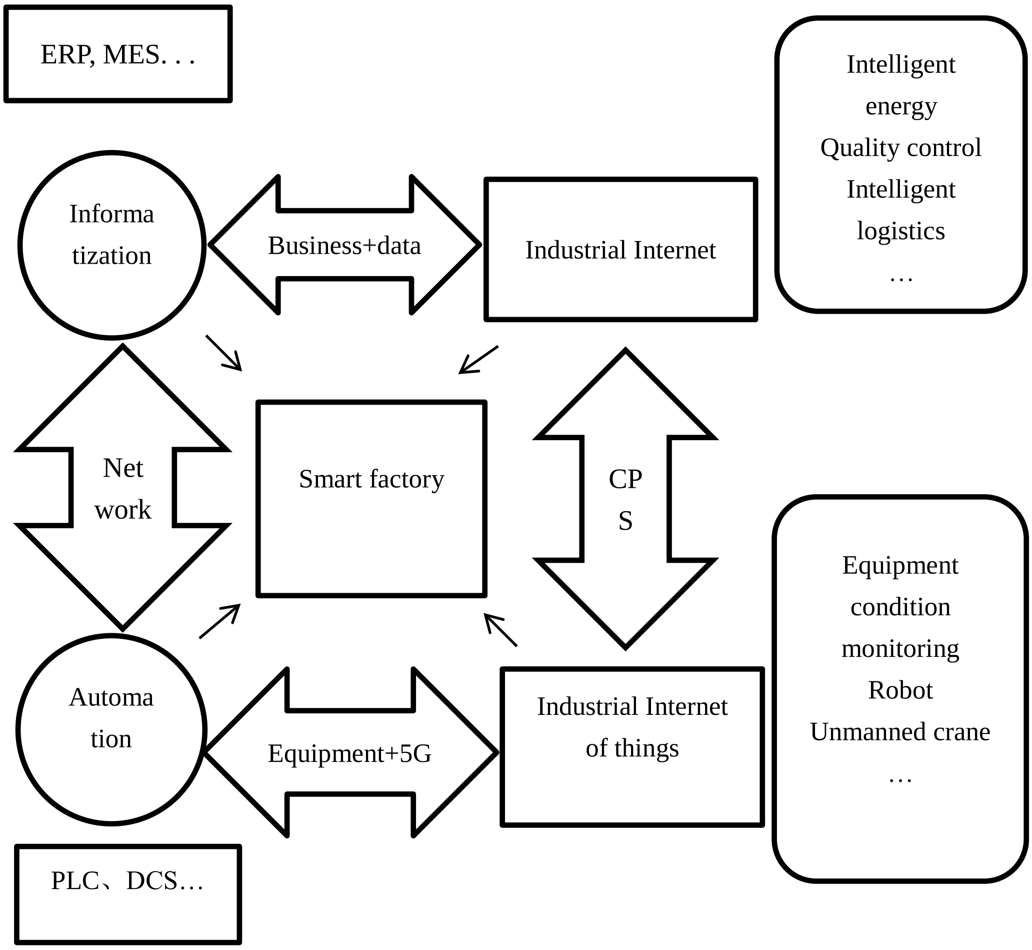

Figure 1. The completion of the steel smart factory

5.3 Electronic Information Engineering

For the intelligent manufacturing of electronic information engineering, we can consider the single integrated operation, which encapsulates the intelligent change gear and driveless movement technology. The mechanical systems automatically match the working state to improve efficiency, and in some dangerous work, we can apply it to reduce the accident rate. But electronic information engineering in the event of failure is often manual maintenance processing, time-consuming and slow efficiency. If we break through the intelligent sensing technology, we can combine sensors, mechanical collection of fault information to achieve rapid locking, and finally complete the repair. Therefore, the combination of electronic and intelligent related industries such as intelligent vehicle equipment, intelligent security, intelligent wearable devices, intelligent medical electronic devices, etc. will also become the object of consideration for intelligent manufacturing.

6. Current Thinking About Intelligent Manufacturing

6.1 Human-based Intelligent Manufacturing

At present, based on the development theory of intelligent manufacturing of Human-Cyber-Physical system (HCPS), human-centered intelligent manufacturing (Wang Baicun, Xue Yuan, Yan Jianlin, Yang Xiaoying & Zhou Yuan, 2020) has gradually attracted the attention and consideration of academic circles. People are the most dynamic influence factor in the manufacturing production process. The ultimate service goal of intelligent manufacturing should be attributed to people, but not separated from the actual population. What the people-oriented intelligent manufacturing reflects is an important concept of sustainable development. It represents a future development direction of intelligent manufacturing (Wang et al, 2020) . At present, it is based on digital network technology, and plays the respective advantages of human and machine to meet the demands of society. However, in the future, human-centered intelligent manufacturing is not a single manufacturing model or form. On the contrary, some new innovative forms will appear in the process of its development and evolution, etc. Hence in terms of policy, the state should dovetail human-centered intelligent manufacturing with relevant strategies in a timely manner, strengthen publicity and training, systematically consider the human factor, and deepen the concept of human-centeredness into the assessment and evaluation system of intelligent manufacturing. In terms of enterprises, they should reasonably use intelligent manufacturing instead of just replacing it, and strengthen the ideological training of employees so that they can accept machine replacement, while also allowing employees who are not capable to continue to make contributions, and it also make new employees more willing to engage in occupation. In terms of research, HCPS and human-centered intelligent manufacturing and human factors engineering need to be further honed. We attach great significance to the system on structure and improvement of HCPS (Wang et al, 2020), and apply the human-centered concept to the related research, in order that science and natural humanities can fit each other, and finally realize the good development of human-centered intelligent manufacturing.

6.2 Intelligent Manufacturing Evaluation and Technology

At present, there are certain problems in the evaluation research of smart manufacturing, such as the evaluation specification and system. The current intelligent manufacturing evaluation research is quite successful, but there are still shortcomings in terms of different standards and disorganized methods, and intelligent manufacturing is a broad concept, not just a design field, so experts from various industries understand it differently, and there are "a hundred schools of thought". However, multiple systems will lead to indicators that are not objective, dimensions that are not comprehensive, insufficient research and other shortcomings, which hinder the in-depth research of intelligent manufacturing. In addition, there is also a problem of new technology and technology integration, evaluation and research is based on theory rather than practical application, we are still weak in solving practical problems and application capabilities, for example, the application of big data is weak, can not fully collect data at the same time can not be efficiently docked to the application, resulting in data waste; the data collected by enterprises and the required indicators do not match, resulting in value can not be reflected. And these questions and shortcomings in intelligent manufacturing need to be solved as soon as possible at some stage in the future to break through.

7. The Digital Twin in Intelligent Manufacturing

Digital twin technology, with its system description based on physical entities, enables the mapping of data and information across the entire life cycle, as shown in Figure 2. In the 21st century, the U. S. and Germany proposed Cyber-Physical System(CPS), the goal of which is to achieve the integration of the physical and virtual worlds, and the digital twin is a better interpretation of CPS. Intelligent systems first need to sense and model in order to analyze and solve problems, and the digital twin can provide an accurate description of the real production system. For the field of smart manufacturing, NASA pioneered the use of the digital twin concept. In the Apollo project, NASA used digital twins of space vehicles to simulate and analyze the vehicles in flight (Zhang Xinsheng, 2018). Nowadays, digital twin technology is highly valued by related academia and enterprises at home and abroad. Tao Fei et al. of Beijing University of Aeronautics and Astronautics proposed the concept of digital twin workshop based on digital twin (Xiao Tangwei, Meng Biao & Qiao Xinghua, 2021); ABB developed digital twin of material staging yard with the help of CAD/CAE/VR and other technologies; in the European Union led European Research and Innovation Program project, researchers developed digital twin of machine tools to optimally control the machining process of machine tools. Throughout its development, the digital twin has evolved from a simple product or piece of equipment to a production line and finally to an organization or a city, whether it is the National Development and Reform Commission or the Central Internet Office, which issued a notice in April 2020 on the implementation plan to promote the action of "going to the cloud and using digital intelligence" to foster the development of a new economy. In April 2020, the National Development and Reform Commission and the Central Internet Information Office issued the Implementation Plan on Promoting the Action of “Fostering the Development of New Economy through Cloud and Data Empowerment", which listed digital twin with big data, artificial intelligence, 5G, etc. and dedicated The repudiation chapter talks about "carrying out the digital twin innovation program"(Liu Zhen, 2020) ; or the Ministry of Industry and Information Technology has released the "Guide to the Construction of Intelligent Ship Standard System (Draft), the construction of the "digital twin" is included in the key technology applications (Liu Zhen, 2020). There is no denying that the digital twin is a key technology in manufacturing and a frontier direction for smart manufacturing. It will go further in value creation, production cycle, and finished product performance, driving smart manufacturing to the next new stage.

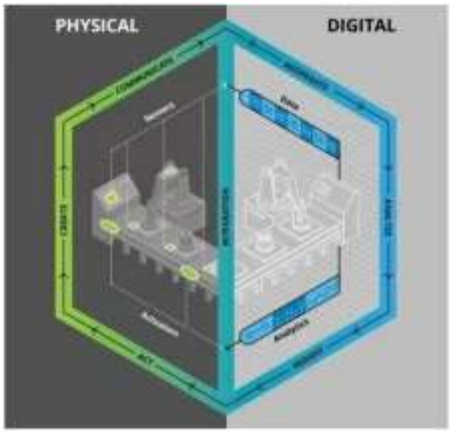

Figure 2. Schematic concept of the digital twin

8. Conclusion

Through an elaboration of smart manufacturing as a whole, we understand the convenience it brings to the country, society, enterprises and economic production. For the discrete industry, smart manufacturing promotes the quality enhancement of the industry and strengthens the intelligent upgrade of the industry; for the process industry, smart manufacturing promotes the sustainable and high-quality development of the whole industry. However, the development of intelligent manufacturing is still a long road, with weak awareness at the top, imperfect information system, emphasis on automation rather than intelligence, and incomplete digital transformation. Therefore, in terms of policy, the state should improve the standard system of intelligent manufacturing as soon as possible, carry out relevant pilot projects and implement the "14th Five-Year Plan" development plan. Society should optimise the layout of digital infrastructure and build a solid foundation for the digital transformation of manufacturing. Enterprises should strengthen the core of key technologies, further enhance the driving force of innovation and provide power support for smart manufacturing. We hope that in the future, we can continue the digital and intelligent transformation, and deepen the institutional reform to burst into new vitality, so that intelligent manufacturing can take a new step forward.

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