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Summary of Research on Digital Twin Workshop

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Global overcapacity, resulting in increasingly fierce competition between enterprises, improve the production efficiency of the manufacturing industry is the key problem. Workshop is an important part of manufacturing industry. In order to improve the intelligent level of workshop and realize the digitization of production process, the current focus is how to use digital twin technology. Although the traditional virtual shop and digital shop design can realize intelligent shop, there are some problems such as non-real-time interaction and low data utilization. Digital twinning technology can effectively improve the transparency of workshop production process and optimize the production process. Establishing digital twin workshops and realizing the interconnection and further integration of workshop information and physical space will become the development trend of workshops and the only way to realize intelligent production and control of workshops. This study describes the definition of digital twin shop, system architecture and supporting technology, and summarizes the applications of digital twin shop in six aspects: shop equipment fault prediction and maintenance, shop production scheduling optimization, production process planning, intelligent control of shop equipment, shop energy consumption analysis and optimization, and real-time control of shop manufacturing process. This will provide reference for later digital twinning workshop researchers.

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1. INTRODUCTION

With the widespread application of big data, Internet and artificial intelligence in traditional manufacturing industry, people's demand for personalization is becoming more and more urgent, and the application process of intelligent manufacturing, a production mode, is also accelerating. Therefore, it has become an important trend of the development of manufacturing industry to greatly reduce the product repetition rate. In this context, in order to meet and adapt to the needs and trends of socialized, personalized, service-oriented, intelligent, green manufacturing development, the construction of intelligent factories and intelligent workshops, to achieve real intelligent manufacturing, intelligent workshops have been widely applied and developed in the world. Germany is one of the important countries in the global manufacturing industry and a leader in intelligent manufacturing. The German government has put forward the goal of promoting intelligent manufacturing in the "Industry 4.0" strategy, and encourages enterprises to carry out intelligent transformation. At present, Germany's smart shop applications have become a global model. The Chinese government has put forward the goal of promoting intelligent manufacturing in the "Made in China 2025" strategy, and has invested a large amount of funds and resources to encourage enterprises to carry out intelligent transformation. At present, the application of intelligent workshops in China has covered various fields of manufacturing.

Workshop is the basic unit of manufacturing industry. It is urgent to realize the digitization and intelligentization of workshop. With the in-depth application of information technology, the workshop has achieved rapid development in real-time data acquisition, information system construction, data integration, virtual modeling and simulation. In the future, the trend of workshop development will be to realize the interconnection and deep integration of workshop information and physical space, which is the only way to realize intelligent workshop production and management [1-4]. Therefore, the digital twin technology research team of Beihang University introduced the digital twin technology into the workshop and put forward the concept of digital twin workshop. The purpose of digital twin shop is to realize real-time interaction and deep integration of shop information and physical space [5]. Driven by the fused twin data, each part of digital twin shop can realize iterative operation and bidirectional optimization, so as to achieve the optimal state of shop management, planning and control. Aiming at the concept of digital twinning workshop, the research team of digital twinning technology of Beihang University has systematically studied its operation mechanism, key technologies, implementation methods, as well as the theory and technology of information physical fusion, and discussed the related technologies and methods of equipment health management, multidimensional analysis and optimization of energy consumption, dynamic production scheduling and real-time process control in digital twinning workshop [6-7].

2. THE CONCEPT OF A DIGITAL TWIN WORKSHOP

Digital twinning is an important concept, first proposed in 2003, but it did not attract the attention of scholars at home and abroad until 2011. From 2016 to 2018, digital twin has been listed as the top strategic technology development direction by Gartner, the world's most authoritative information technology consulting company. In November 2017, Lockheed Martin ranked digital twin at the top of its list of six top technologies for the future defense and space industry. In December 2017, the Intelligent Manufacturing Academic Association of China Association for Science and Technology listed digital twin as one of the top ten scientific and technological advances of intelligent manufacturing in the world at the World Intelligent Manufacturing Conference . [8].

Digital twinning is an advanced technology that combines a digital representation of an object, system or process in the physical world with its actual form. Digital twinning can be used to simulate, optimize, and predict situations in the real world, thereby increasing production efficiency, reducing costs, and improving product quality. A technique that combines the digital representation of a physical object, system, or process with its actual form to simulate, optimize, and predict it. Digital twinning can be used in a variety of fields, including manufacturing, construction, healthcare, energy management and more. The basic principle of digital twinning is to digitize various parameters and characteristics of a physical object, system, or process and then correspond them to entities in the real world. Digital twinning can use a variety of techniques, including computer-aided design (CAD), computer-aided manufacturing (CAM), computer-aided engineering (CAE), and computer-aided testing (CAT), among others.

Most of the research on digital twinning technology in shop floor focuses on production management and product operation and maintenance, such as digital twinning shop, equipment life prediction, product condition monitoring and fault diagnosis, predictive maintenance and so on. As a technology that makes full use of models, data and intelligence and integrates multiple disciplines, digital twin is oriented to the whole life cycle process of products, plays the role of bridge and link between the physical world and the information world, and provides more real-time, efficient and intelligent services.

Tao et al. [9-11] proposed a conceptual model of digital twin shop, including physical shop, virtual shop, shop service system and shop twin data. Through the bidirectional mapping and real-time interaction between physical shop and virtual shop, the integration and fusion of all factors, all processes and all business data are realized, so as to achieve the goals of shop production factor management, production activity planning and production process control driven by shop twin data. Driven by new generation information technology and manufacturing technology, digital twin shop consists of four parts: physical shop, virtual shop, shop service system and shop twin data. They run iteratively among physical shop, virtual shop and shop service system to achieve the goal of optimal shop production and management [12-13].

3. ARCHITECTURE OF THE DIGITAL TWIN WORKSHOP

The architecture of digital twin workshop mainly includes 5 layers:

1. Perception layer: This layer is mainly responsible for collecting and sensing the data of various equipment, facilities and production process in the factory. This data can be collected through sensors, smart devices, machine vision and more.
2. Transport layer: This layer is mainly responsible for transmitting the data collected by the perception layer to the cloud platform or local server. Data transfers can be made over wired or wireless networks.
3. Data processing layer: This layer is mainly responsible for processing and analyzing the data transmitted by the transmission layer, including data cleaning, data mining, data modeling, etc. This layer can use artificial intelligence, big data and other technologies to process and analyze data.
4. Application layer: This layer is mainly responsible for applying the data processed by the data processing layer to the production process, including production planning, quality control, equipment maintenance and other aspects. This layer can simulate and optimize the production process using virtual reality, augmented reality and other technologies.
5. Service layer: This layer is mainly responsible for providing various services of digital twin workshop, including data storage, data security, system management, etc. This layer can use cloud computing, blockchain and other technologies to manage and optimize services [14].

4. KEY TECHNOLOGIES OF DIGITAL TWINNING WORKSHOP

The key technologies of DTW can be divided into five main categories according to its main system composition:

(1) "human-machine-object-environment" interconnection and integration technology between materials and vehicles. It mainly includes: heterogeneous manufacturing resource protocol analysis and data acquisition technology; Heterogeneous multi-source and multi-mode data fusion and encapsulation technology; Multi-source heterogeneous sensor collaborative measurement and optimal layout technology; Heterogeneous multi-source data communication and release technology; Distributed cooperative control technology of heterogeneous resources; Development of sensing access technology and device for heterogeneous manufacturing resources; Real-time intelligent monitoring and optimization control technology of physical shop [15-16].

(2) Virtual workshop technology, including multi-dimensional and multi-scale modeling and simulation technology, model integration and fusion technology,

production planning/process simulation and optimization technology, virtual reality and augmented reality application technology, etc.

(3) Workshop twin data management technology, including multi-type, multi-time scale, multi-granularity data planning and cleaning technology, heterogeneous data fusion technology, data structured cluster storage technology, virtual-real fusion and data collaboration technology, etc [17-18].

(4) DTW operation technology, including virtual-real real-time interaction technology, multi-source data collaborative control technology, self-organization and adaptive dynamic scheduling technology, production factor management, production plan, production process and other iterative operation and optimization technology, DTW operation standards, protocols and technical specifications, etc.

(5) Intelligent production and precision service technology based on DTW, including workshop equipment health management technology and service, real-time product quality control and analysis technology and service, workshop energy consumption optimization and forecast technology and service, intelligent material tracking and allocation technology, collaborative production process analysis technology, intelligent production operation optimization technology and service, workshop precision control technology and service, etc.

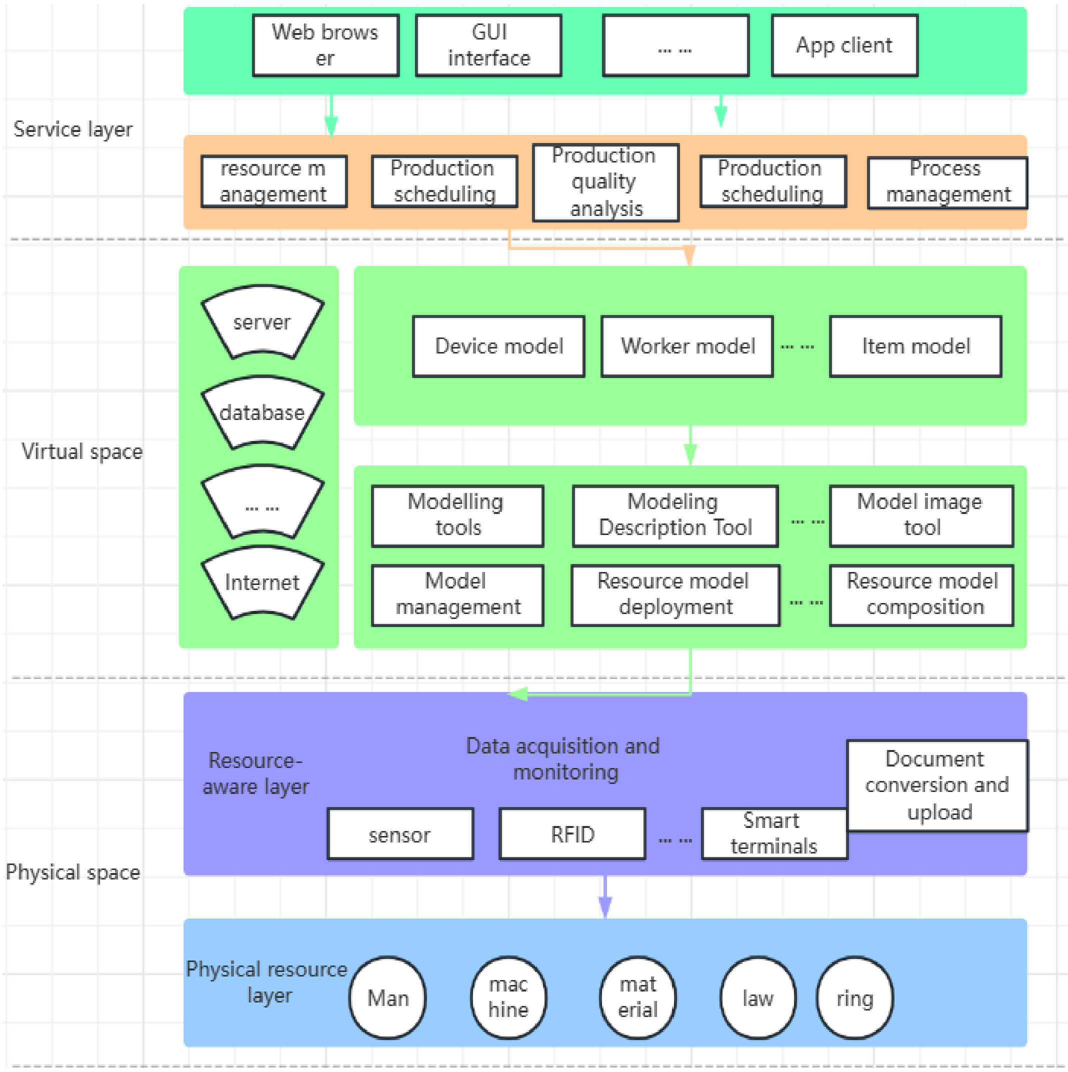

Fig. 1. Architecture of the digital twin workshop

5. APPLICATION OF DIGITAL TWINNING WORKSHOP

5.1 Fault Prediction and Maintenance of Workshop Equipment

The digital twin workshop can monitor the equipment in real time through the sensor, collect the data such as the running state and working parameters of the equipment, and transmit the data to the cloud for analysis and processing. By analyzing and modeling the data, you can predict the time and cause of equipment failure and take maintenance measures in time to avoid the impact of equipment failure on production [19-22]. In order to use digital twin technology to predict and maintain equipment faults, it is necessary to establish 3D model first. Then, according to the analysis of the external data of the equipment, the typical high-frequency failure modes are determined, and the product failure modes and cause classification database are established. Then, considering the multi-physical structure of the product, the simulation model under multi-physical and multi-stress at the system level was established. According to the test results, the key characteristic parameters, stress and mechanism models of the equipment were modified, and finally the digital twin reference model was formed [23]. In the process of use, sensors constantly exchange virtual and real data, and modify the virtual model based on the data, and finally realize the accurate description of the physical equipment. At the same time, by updating the physical entity usage data, failure data and maintenance data, the loss is calculated, the remaining life of the equipment is predicted, and the maintenance decision is guided [24].

5.2 Workshop Production Scheduling Optimization

Workshop production scheduling optimization refers to making the production process more efficient, stable and controllable through reasonable production planning and scheduling arrangement, so as to maximize production benefits. It is the orderly, stable and efficient operation pillar of the production workshop [25]. With the support of digital twinning system, digital twinning technology is used to optimize and improve the scheduling process. It can accurately simulate physical systems in the real world, including production lines, equipment and products. Through digital twin technology, the data in the production process can be monitored in real time, the production efficiency and quality can be analyzed, the production bottleneck and failure can be predicted, and the optimization plan can be proposed [26]. In the digital twin-driven scheduling model, the mapping between physical shop and virtual shop enables the scheduling elements to be optimized cooperatively in two Spaces. The formation of the collaborative optimization network not only enables the physical shop to actively perceive the production state, but also enables the virtual shop to analyze the scheduling state, adjust scheduling schemes and evaluate scheduling decisions by means of self-organization, self-learning and self-simulation. In this way, the dispatching system can quickly determine the scope of exceptions, respond quickly, make intelligent decisions, and have better adaptability to changes, disturbance response ability and exception resolution ability. In addition, in the digital twin-driven scheduling mode, real-time monitoring, remote control, intelligent forecasting and other functions can be realized, so as to further improve the production efficiency and quality [27].

5.3 Planning of Production Process

Process procedure is a document that formulates the process flow, technical requirements, operating procedures, inspection standards and other contents required in the production process of products. It is an important document in the production process, can ensure the quality of the product and production efficiency. The main contents of process procedures include the following aspects: Digital twin-driven process planning is to realize process design and continuous optimization for production site by establishing highly simulated virtual models, including products, resources and process flow. In this process design mode, the simulation model of virtual space maps to the actual physical space, forming an iterative collaborative optimization mechanism of virtual and real symbiosis, and fully realizing the virtual and real mapping and interactive integration of all elements and processes. The process design mode driven by digital twinning is shown in Fig. 2. The digital twinning driven process design mode brings the following new changes to process design and optimization: (1) In the aspect of process design based on simulation, it realizes the process modeling and simulation oriented to the production site and the predictable process design in a real sense; (2) In the aspect of knowledge-based process design, the process knowledge modeling, decision-making and optimization based on big data analysis are realized. (3) In the aspect of active response to process problems, the original passive response to active response to process problems has been changed to realize the independent decision-making of process problems [28].

The process design method around digital twinning drive still has many shortcomings:

(1) Digital twin process model construction research on the theory and method of physical entity digital twin model construction based on the integration of geometric and multiple physical quantities, as well as the process modeling and simulation technology based on digital twin model.
(2) Research on process innovation design methods based on digital twinning knowledge modeling, knowledge extraction and knowledge optimization methods based on big data analysis, as well as independent process design, process optimization and process decision methods based on enhanced learning, deep learning and independent learning.
(3) Process continuous optimization method based on digital twinization Research process continuous improvement method and process change response mechanism based on massive data, and process problem prediction, parameter dynamic adjustment, process iterative optimization and decision making, evaluation and evaluation based on real-time data theory and method.

5.4 Intelligent Control of Workshop Equipment

The control system of workshop equipment is the brain of workshop equipment. The correctness of its control function and control strategy directly affects the function and performance of workshop equipment. Digital twinning can provide multi-dimensional support for the design of control system, debugging and optimization of control function and performance, and decision-making ability of control system based on virtual and real mapping [29-30]. In the design stage, the integrity check of the control function and the optimization of the control algorithm are realized by virtual model simulation and debugging, and the iterative mechanical system and the control system are improved at the same time. In prototype debugging stage, the actual control effect is evaluated by virtual-real mapping, and the design of control system and physical prototype is improved. In the operation and maintenance stage, the state of the physical prototype and the processed object can be fully sensed to meet the real feedback of the real time state and historical state of the physical entity in the real-time autonomous decision control. With digital twinning technology, the control system can achieve precise control, efficient algorithm, reliable operation and economic cost. The control advantages of digital twinning include: 1) During the equipment design stage, digital twinning synchronously matches the design of the control system, so that the control system and physical equipment can be integrated and matched earlier, and the burden of real machine debugging can be reduced; 2) In the debugging phase, digital twinning promotes the comprehensive matching of control system and equipment, improves design defects and reduces design redundancy; 3) In the running stage, the physical real-time state presented by digital twinning can provide objective and effective data support, and provide control feedback information for the autonomous decision-making of the algorithm [31].

The above content involves the application of digital twinning technology in the control system, which needs to make breakthroughs in the following aspects:

(1) Interface interaction: Seamless interaction is required between the digital twin and the control system, and it is key to solve the problem of driving interaction and state feedback between the model and the control system. Unified interface standards and protocols can be considered to ensure efficient and stable data exchange and communication between the digital twin and the control system.
(2) Control simulation: Digital twin model requires control simulation based on physical properties and dynamic characteristics to achieve a real description of physical devices. Advanced simulation techniques and algorithms combined with real-time data acquisition and processing can be used to ensure accurate and reliable behavior simulation of digital twin models driven by control data.
(3) Autonomous decision making: Digital twin model can provide a large amount of timely and multidimensional data, and control the effectiveness and accuracy of self-decision making from the data source. Advanced machine learning and artificial intelligence

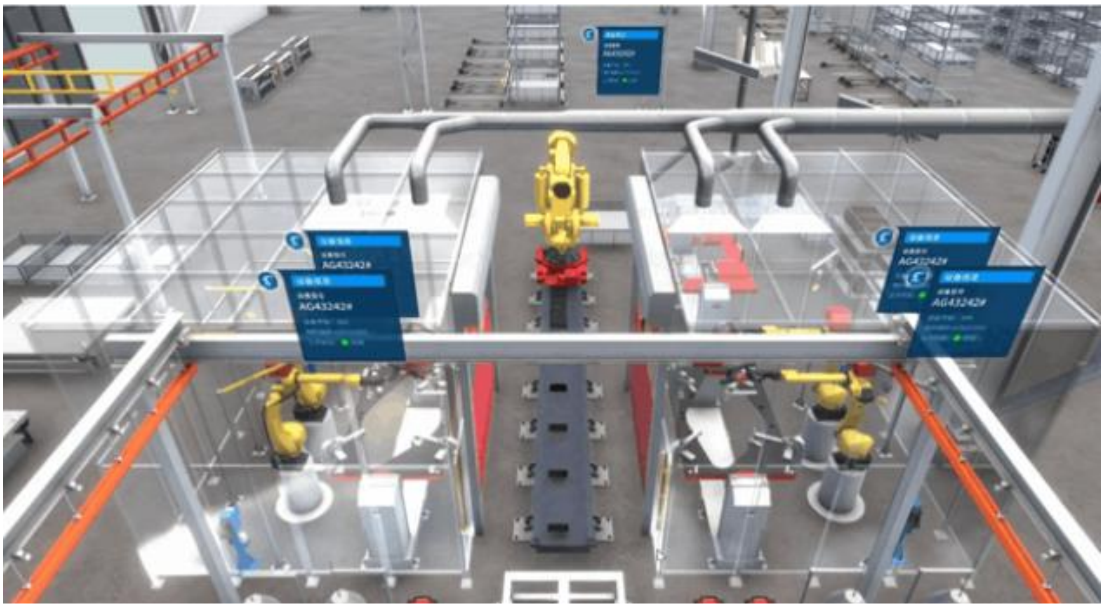

Fig. 2. Process design mode driven by digital twinning

technologies, combined with data from the digital twin model, can be used for autonomous decision-making and intelligent control to improve the efficiency and performance of the control system.

In general, the application of digital twin technology can bring brand new ideas and methods for the design, debugging and operation mode of control system, which requires continuous exploration and breakthrough in the aspects of technology, standard and application.

5.5 Analysis and Optimization of Workshop Energy Consumption

In terms of energy consumption analysis, the mutual calibration and fusion of information and physical data can improve the accuracy and integrity of energy consumption data, so as to support comprehensive multidimensional and multi-scale analysis. In terms of energy consumption optimization, real-time simulation based on virtual model can reduce the energy consumption of the workshop through iterative optimization of equipment parameters, process flow and personnel behavior. In the aspect of energy consumption evaluation, the dynamic updating rules and constraints based on twin data mining can be used to conduct multi-level and multi-stage dynamic evaluation of actual energy consumption [32-34].

5.6 Real-time Control of Workshop Manufacturing Process

The real-time and comprehensive state perception of the production process is carried out to meet the data requirements of the virtual model's real-time autonomous decision-making. The corresponding control strategy is generated through the evaluation and prediction of the control target, and the simulation verification is carried out. When the actual production process is inconsistent with the simulation process, the reasons are analyzed and mined based on the fusion data, and the synchronization and bidirectional optimization are realized by adjusting the physical equipment or correcting the virtual model.

6. CONCLUSION

As a key technology in the field of intelligent manufacturing, digital twin will play a key role in improving product quality, production level and enterprise profitability in the manufacturing industry. The concept of digital twin workshop is proposed here, combined with the theory of digital twin and the reality of workshop manufacturing, the system architecture and key technologies of the digital twin workshop are elaborated, with the aim of actively promoting the transformation of the manufacturing industry development mode, upgrading the technical structure, transforming the growth momentum, developing in the direction of intelligence, greening and high-end, greatly improving operating efficiency and production capacity, and playing a demonstration role and reference significance for the intelligent upgrading of the manufacturing industry.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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