

Summary of Research on Digital Twin Workshop

ABSTRACT

Global overcapacity leads to increasingly fierce competition among enterprises. How to improve production efficiency and shorten product cycle has become a concern of all countries in the world. Workshop is the basic component of manufacturing industry. How to improve the intelligent level of workshop and realize the digitalization of production process is the focus of current attention. However, the intelligent workshop designed by traditional virtual workshop and digital workshop has some problems such as non-real-time interaction and low data utilization rate. Based on digital twin technology, it can effectively improve the transparency of workshop production process and optimize the production process. Building digital twin workshops and realizing the interconnection and further integration of workshop information and physical space will be the development trend of workshops, as well as the only way to realize intelligent workshop production and management.

Key words: digital twin, workshop, manufacturing.

1. INTRODUCTION

In recent years, with the rapid application of new generation information technologies such as big data, cloud computing, Internet of Things, and mobile Internet in traditional manufacturing industry, the demand for large-scale personalized customers is becoming more and more urgent, and the application process of intelligent manufacturing, the production mode, is also accelerating. In this context, in order to meet and adapt to the needs and trends of socialized, personalized, service-oriented, intelligent and green manufacturing development, build intelligent factories and intelligent workshops, and realize real intelligent manufacturing, various countries have introduced corresponding advanced manufacturing development strategies, representative of which are "Industry 4.0" in Germany and "Industrial Internet" in the United States. In 2015, The State Council officially promulgated Made in China 2025 as an action program for China to implement the strategy of becoming a manufacturing power in the next 10 years and a cornerstone for China to become a leading manufacturing power in the world in the next 30 years.

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 collection, information system construction, data integration, virtual modeling and simulation, etc. On this basis, it will be the development trend of the workshop to realize the interconnection and further integration of the information and physical space of the workshop, and also the only way to realize the intelligent production and management of the workshop. Therefore, the research team of digital twinning technology in Beihang University introduced digital twinning technology into the workshop and

proposed the concept of digital twinning workshop, aiming at realizing real-time interaction and deep integration of workshop information and physical space. Driven by the twin data fusion, each part of the digital twin shop can achieve iterative operation and bidirectional optimization, so as to achieve the optimal 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.

1. THE CONCEPT OF A DIGITAL TWIN WORKSHOP

The concept of digital twin was first proposed in 2003, and it was not until 2011 that scholars at home and abroad paid great attention to it. From 2016 to 2018, it was listed as today's top strategic technology development direction by Gartner, the world's most authoritative information technology consulting company. Lockheed Martin, the world's largest arms manufacturer, ranked digital twin at the top of its list of six top technologies for the future defense and space industry in November 2017. 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 in the world intelligent manufacturing Conference. Until now, the definition of digital twin widely accepted by the industry was given by Glaesegen and Stargel in 2012: "A complex product simulation model that integrates multi-physical, multi-scale and probabilistic properties to reflect the real product status in real time". It can be extended from this definition that the purpose of digital twin is to add or extend new capabilities to physical entities by means of virtual-real interactive feedback, data fusion analysis, decision iterative optimization, etc. 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. At present, 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.

Tao et al. first proposed a conceptual model of digital twin shop, which mainly includes four parts: physical shop, virtual shop, shop service system and shop twin data. Through bidirectional mapping and real-time interaction between physical shop and virtual shop, the model can realize the integration and fusion of all elements, processes and business data of physical shop, virtual shop and shop service system. Driven by workshop twin data, workshop production factors management, production activity planning, production process control and so on are realized. Digital Twin Workshop (DTW) is driven by the new generation of information technology and manufacturing technology, through the two-way real mapping and real-time interaction between physical workshop and virtual workshop, to realize the integration and fusion of all elements, processes and business data of physical workshop,

virtual workshop and workshop service system. Driven by shop twin data, the iterative operation of shop production factor management, production activity planning and production process control among physical shop, virtual shop and shop service system is realized, so as to achieve the optimal shop production and control under the premise of meeting specific objectives and constraints. DTW is mainly composed of Physical Workshop, Cyber Workshop, Workshop Service System, WSS and Workshop Digital Twin Data.

2. ARCHITECTURE OF THE DIGITAL TWIN WORKSHOP

The architecture mainly includes five layers: physical layer: it mainly refers to the physical workshop entities such as people, machines and objects in the workshop, as well as the collection of corresponding production activities in the physical workshop, which is responsible for the realization of the physical space of product production and processing, and has the functions of self-sensing, self-decision-making, and underlying data collection and transmission. Model layer: It mainly refers to DTS virtual workshop and its corresponding virtual production activities, including various models, rules and knowledge of virtual workshop, and is responsible for simulation, analysis, optimization and decision-making of production activities in virtual space. Data layer: refers to the workshop twin data service platform, which is responsible for providing data support services for the operation of physical workshop, virtual workshop and workshop service system of DTS, and has data life cycle management and processing functions such as the generation, processing, integration and fusion of workshop twin data. Service layer: responsible for providing intelligent production scheduling, collaborative process planning, product quality management, production process control, equipment health management, energy efficiency optimization analysis and other workshop production services. Application layer: It mainly refers to the application requirements of intelligent manufacturing tasks such as intelligent production, accurate control and reliable operation and maintenance involved in the processing and production of specific products.

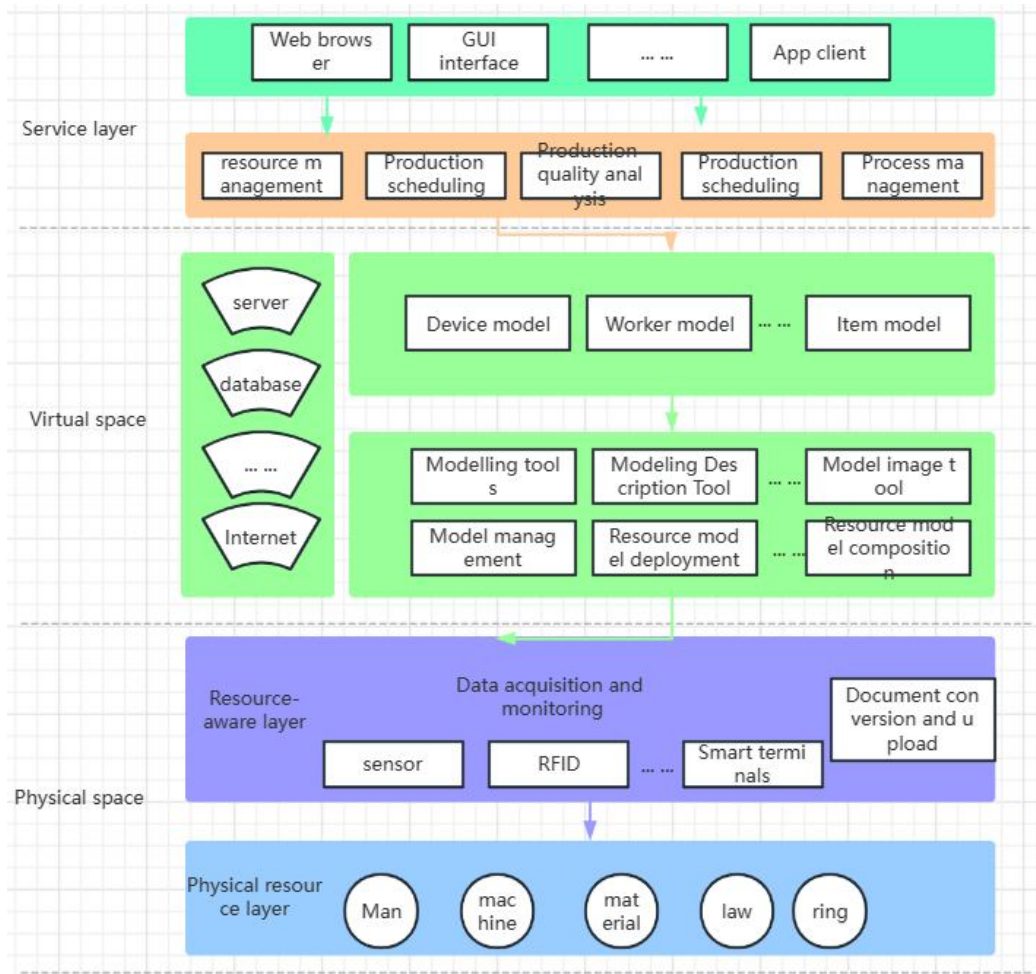


Fig 1 : Architecture of the digital twin workshop

3. 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.

(2) Virtual workshop construction, simulation operation and verification technology. It mainly includes: virtual workshop modeling technology, such as multi-dimensional and multi-scale modeling and simulation technology of workshop "essential element - line - rule"; Multidimensional and multi-scale model integration and fusion technology; Operation

mechanism and evolution law of virtual workshop; Production planning/production process simulation operation, verification and optimization technology; Workshop virtual reality and augmented reality application technology.

(3) Workshop twin data construction and management technology. It mainly includes: multi-type, multi-time scale, multi-granularity data planning and cleaning technology; Interpretable, operable and traceable heterogeneous data fusion technology; Data structured cluster storage technology; DTW virtual-real fusion and data collaboration technology; DTW virtual-real bidirectional mapping technology; Workshop big data technology, etc

(4) DTW operation technology. It mainly includes: DTW virtual-real real-time interaction technology; Multi-source data collaborative control technology; Self-organizing adaptive dynamic scheduling technology; Production factor management, production planning, production process and other iterative operation and optimization technology; DTW operating standards, protocols and technical specifications.

(5) Intelligent production and precise service technology based on DTW. It mainly includes: workshop equipment health management technology and service; Product quality real-time control and analysis technology and services; Workshop energy consumption optimization and forecasting technology and services; Intelligent material tracking and rationing technology; Collaborative production process analysis technology; Intelligent production operation optimization technology and service; Workshop precision control technology and services.

4. APPLICATION OF DIGITAL TWINNING WORKSHOP

1. Fault prediction and maintenance of workshop equipment

The initial application of digital twin is fault prediction of aircraft. Fault prediction and safety operation and maintenance are very important for large equipment and infrastructure such as aircraft and ships. It is also an important research direction of digital twin to manage the whole life cycle of products through high-fidelity and real-time updated virtual models. Failure prediction and health management of large equipment is a very complicated work, which is due to the extremely complex structure of the equipment and the close correlation between the internal components, and the lack of real-time data. Fault prediction and equipment maintenance based on digital twinning can quickly capture faults based on dynamic real-time data, accurately locate fault causes, and evaluate equipment status for predictive maintenance. For the fault prediction and maintenance of equipment based on digital twinning, the electronic and mechanical three-dimensional models should be established first. Then, according to the analysis of external field data, the typical high-frequency failure modes should be sorted out, and the typical failure modes and cause classification database of products should be established. After comprehensive consideration of the multi-physical structure of mechanical and electronic products in the products, the simulation model under multi-physical and multi-stress of system level should be established. And according to various test results, the key characteristic parameters, stress and mechanism model of the equipment are modified, and finally the digital twin reference model is formed. 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. Meanwhile, through the update of

the use data, failure data and maintenance data of the physical entity, the loss is calculated, the remaining life of the equipment is predicted, and the maintenance decision is guided.

2. Workshop production scheduling optimization

Production scheduling is the nerve center of decision-making optimization, process control and performance improvement of production workshop, and it is the operation pillar of orderly, stable, balanced, economic, agile and efficient production workshop. The scheduling mode driven by digital twinism is supported by digital twinism system and forms a new scheduling mechanism of virtual and real response, virtual and real interaction, virtual control and iterative optimization through virtual and real mapping and interactive integration of all factors, all data, all models and all Spaces, so as to realize cooperative matching and continuous optimization of scheduling elements of "work-piece -- machine -- constraint -- target". In the digital twin-driven scheduling mode, scheduling elements map to each other in physical shop and virtual shop, forming a synergistic optimization network of virtual and real symbiosis. The physical shop actively perceives the production state, while the virtual shop conducts scheduling state analysis, scheduling scheme adjustment and scheduling decision evaluation by means of self-organization, self-learning and self-simulation, so as to quickly determine the scope of anomalies, respond quickly and make intelligent decisions, with better adaptability to change, disturbance response and anomaly resolution.

The digital twin-driven scheduling mode makes scheduling optimization and process control present a new transformation, that is, the driving mode changes from energy driven to data driven, the scheduling elements change from entity interconnection to virtual and real mapping, the response mode changes from passive response to active response, the process control changes from extensive control to precise control, and the management form changes from hierarchical structure to flat structure. The research on digital twin-driven scheduling technology needs to make breakthroughs in the following difficult issues: (1) In terms of the virtual-real interaction mechanism, the virtual-real interaction behavior is systematically studied to reveal the virtual-real interaction mechanism under the self-organization, self-learning and self-optimization mechanism, so as to realize the optimal matching and efficient operation of scheduling elements; (2) In the aspect of dynamic iterative optimization, a new scheduling optimization method is studied, which can carry out "task-resource" autonomous decision-making, dynamic iterative and continuous optimization.

3. Planning of production process

Technological procedures are the technical documents of product manufacturing process and operation methods. They are the disciplinary documents that all relevant production personnel should strictly implement and conscientiously carry out. They are the basis for product production preparation, production scheduling, worker operation and quality inspection. Digital twin-driven process planning refers to the realization of process design and continuous optimization oriented to production site through the establishment of virtual simulation models of products, resources and process flow with ultra-high degree of simulation, as well as virtual-real mapping and interactive integration of all elements and processes. In the process design mode driven by digital twinning, the simulation model of virtual space maps to the entity of physical space, forming an iterative collaborative optimization mechanism of virtual and real

symbiosis. The process design mode driven by digital twinning is shown in Figure 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.

The process design method driven by digital twinning needs to make breakthroughs in the following difficult problems: (1) Digital twinning process model construction studies the theory and method of physical entity digital twinning model construction based on the integration of geometric quantity and multiple physical quantity, as well as the process modeling and simulation technology based on digital twinning 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, as well as process problem prediction, parameter dynamic adjustment, process iterative optimization and decision making, evaluation and evaluation based on real-time data theory and method.

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. 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 the help of digital twin technology, the control system can be accurate, the algorithm is efficient, the operation is reliable and the cost is economical. The advantages of control based on digital twinning are as follows: (1) In the equipment design stage, the control system is designed and matched based on virtual and real synchronization of digital twinning, 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 stage, to further promote the comprehensive matching of control system and equipment, improve the design defects, reduce the design redundancy; (3) In the running

stage, the control feedback information is no longer a relatively independent parameter, but a physical real-time state presented by the digital twin, which can provide objective and effective data support for the algorithm's independent decision-making. To explore the control based on digital twinning and study the new design, debugging and operation mode of the control system under digital twinning, it is urgent to make breakthroughs in the following aspects: (1) Interface interaction needs to solve the problem of driving interaction and state feedback between the model and the control system, so as to achieve seamless interaction between the digital twinning and the control system. (2) Control simulation is based on physical properties and dynamic characteristics. It realizes behavior simulation of digital twin model driven by control data, which is a real description of physical equipment. (3) Autonomous decision-making is based on a large number of timely and multi-dimensional data of the digital twin model, which breaks through the local optimal limitation of the traditional training set relying on common data, and resolves the effectiveness and accuracy of autonomous decision-making from the data source.



Fig. 2: Process design mode driven by digital twinning

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

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.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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