ISSN 2706-655X Vol.5, Issue 7: 24-29, DOI: 10.25236/IJFET.2023.050704

Research on Issues Related to Digital Twin Modeling

Yuxizi Zheng[1], Xuemei Wang[1], Zhe Xu[1,a,*], Yuanping Dong[1], Mengting Hou[1], Shuo Guo[1]

[1]*Xi'an Research Inst. of Hi-Tech, Xi'an, China*
[a]*zyxz2316@163.com*
[*]*Corresponding author*

Abstract: *The establishment of digital twin model is at the core of the whole digital twin system. This paper analyzes the key technologies involved in the establishment of digital twin system, including complex system modeling, sensing and monitoring, Big data, dynamic data driving, and intelligent optimization and decision-making. On this basis, it is summarized that digital twin technology has the characteristics of transitioning from serial design to collaborative design, from post production validation to early validation, and from fixed models to dynamic models; And there are still problems in the application process of the digital twin system, such as the lack of unified standards, the establishment of modeling precision, the construction of real-time transmission channels, and the establishment and management of databases; Finally, prospects for its development were presented.*

Keywords: *Digital twin system; Modeling and Analysis; Intelligent optimization and decision-making; Big Data Analysis*

1. Introduction

In recent years, simulation technology has developed in the direction of digitization, virtualization, networking, intelligence, universality, and collaboration. With the deep integration of cloud computing, Internet of Things, Big data, artificial intelligence and other new generation information technology with modeling and simulation technology, digital twin technology has emerged. Due to its interoperability, scalability, real-time, fidelity, closed-loop and other characteristics, it has received extensive attention in the national economy, national defense construction and other fields.

Made in China 2025 clearly points out that the deep integration of informatization and industrialization is the core task to promote the innovative development of manufacturing industry. The dynamic collaborative linkage and decision-making optimization of distributed and heterogeneous manufacturing resources and manufacturing services through data interconnection has become a trend in the development of the manufacturing industry. The digital twin system can combine product manufacturing, product design, product services, product quality, and digital technology to achieve real-time feedback of virtual product data on real product production processes, thereby improving the comprehensive competitiveness of products.

2. Analysis of Key Technologies for Establishing a Digital Twin System

Digital twins need to rely on methods including simulation, measurement, and data analysis to perceive, diagnose, and predict the state of physical entities, thereby optimizing physical entities and evolving their own digital models. Simulation technology, as the core technology for creating and running digital twins, is the foundation for digital twins to achieve data exchange and fusion. On this basis, digital twins must rely on and integrate other new technologies, and work together with sensors online to ensure their authenticity, real-time performance, and closed-loop performance. It mainly involves complex system modeling, sensing and monitoring, Big data, dynamic data driving, intelligent optimization and decision-making[1].

2.1. Modeling Techniques for Complex Systems

Models are the key to the operation of digital twin systems, and accurately constructing models is the foundation for maximizing the functionality of digital twin systems. Tao Fei[2] proposed the digital twin

ISSN 2706-655X Vol.5, Issue 7: 24-29, DOI: 10.25236/IJFET.2023.050704

five dimensional model and explored its applications in ten major fields. In order to provide evidence for the construction process of digital twin models, a set of construction criteria for "four transformations, four possibilities, and eight uses" of digital twin models has been proposed, which has certain guiding significance for the construction of digital twin models. Jiang Haifan[3] further proposed the concept of the Digital Twin Evolution Model (DTEM). By connecting digital models, digital projections, and digital twins through the timeline, they are associated with specific application scenarios, enabling technologies, and tools in the context of intelligent manufacturing, giving them new connotations in dimensions such as space, time, and application, forming the three evolution stages of digital twins.

The digital twin model mainly includes visual models and mathematical models. By studying the structural composition and assembly relationships of physical entities, 3D modeling tools such as 3D MAX, SolidWorks, and CATIA can be used to establish models corresponding to each part. After verification, the models of each part are synthesized to obtain a visual model that reflects the overall appearance, structure, size, and other information of the physical object, making the model more realistic[4]. The digital models of complex systems have the characteristics of multiple disciplines, different forms, multiple types, and large quantities, and can be constructed according to the product composition relationships of subsystems[5]. By analyzing the connections and motion patterns between various subsystems of the physical object, corresponding mathematical models are abstracted using mechanism modeling or parameter estimation methods. Simulation studies are conducted under different conditions using simulation tools such as MATLAB/Simulink and Modelica[6]. A connection relationship needs to be established between the mathematical model and the visual model, and the two models need to be combined to run together to observe the motion changes of the model more directly.

Due to the different operating states of the physical object in different environments, the interference received is also different, and the output monitoring results obtained may also have certain differences. Therefore, it is necessary to consider the possible operating environment of all physical objects and establish an environmental model, so as to better analyze the operating status of digital twin models in various environments and make the digital twin system more close to the actual Physical system[7]. Environmental models mainly include temperature and humidity, wind field, atmospheric model, etc.

2.2. Sensing and monitoring technology

Perception is the underlying foundation of the digital twin architecture. In a complete digital twin system, obtaining the operational environment and the state data of the components of the digital twin is an important part of achieving precise mapping and real-time interaction between physical objects and their digital twin systems, including all elements, all businesses, and all processes. Therefore, the digital twin system puts forward higher requirements for perception technology. In order to establish a global and all-time IoT perception system and achieve multi-dimensional and multi-level accurate monitoring of the operational situation of physical objects, perception technology not only requires more accurate and reliable physical measurement technology, but also considers collaborative interaction between perception data, clarifies the spatial position and unique identification of objects in the entire domain, and ensures the credibility and controllability of devices[1]. In physical space, distributed sensor networks installed on the surface or embedded within the system structure are used to obtain information on structural status and load changes, operations, and environmental changes, and to monitor the production, manufacturing, service, and maintenance processes of the system in real-time[8]. Select appropriate communication protocol, establish two-way communication between physical model and digital twin model, and transmit the collected data to digital twin model. The continuously acquired sensing data can not only be used to monitor the current state of the system, but also be used to predict the future state of the system with Big data, dynamic data driven analysis and decision-making and other technologies[9].

2.3. Big data technology

For a large and complex system, its basic geometric structure parameters and component assembly have included massive data, and different types of new data will continue to be generated in the process of design and use, which requires the use of digital mainline technology for unified management of all data[10]. At the same time, with the help of Big data analysis technology, data can be stored, filtered, processed, etc. in real time Mining value from constantly changing data. Starting from data, enhance the understanding of the system, explore the underlying correlation between multi-source heterogeneous data, and better achieve diagnosis, prediction, and decision-making guidance for the system[11].

ISSN 2706-655X Vol.5, Issue 7: 24-29, DOI: 10.25236/IJFET.2023.050704

2.4. Dynamic data-driven technology

Real time interaction and dynamic evolution are two important characteristics of digital twins. Dynamic Data Driven Application Systems (DDDAS), a new simulation application mode, can organically combine models with Physical system[12]. On the one hand, for some complex, multi parameter, nonlinear systems, it can improve the simulation accuracy, thereby improving the simulation analysis and prediction ability; On the other hand, it can be used for real-time control and decision-making, improving the timeliness of the system. In the actual application process, the model is dynamically updated using real-time monitoring data. The updated model can obtain many data that cannot be directly measured, thereby more accurately analyzing and predicting the system status, and more effectively guiding users to dynamically control the system[13].

2.5. Intelligent Optimization and Decision Technology

Traditionally, modeling is based on mechanisms, and the parameters in the model are often determined based on a large amount of test data analysis, mostly fixed models. In actual operation, due to the presence of random factors and the interaction between different subsystems, the model will have errors, its accuracy will be reduced, and its fit and adaptability will also be affected.

In the context of the development of artificial intelligence, introducing intelligent algorithms into the process of establishing digital twin models is an effective measure to improve modeling accuracy[14]. Train the model using real-time transmission data and pre processing data, provide the optimal model parameters and order in the current state, and achieve the transition from a fixed model to a model with dynamic optimization function[15]. By continuously optimizing the model, on the one hand, it can better fit the actual object and more accurately reflect the operating mechanism of the object; On the other hand, it is possible to make more accurate predictions of the operational trends of physical objects, providing reference opinions for expert decision-making[16].

In the digital twin system, based on sensor technology, a comprehensive perception of the massive data involved in the physical operation status is carried out. Through data processing and modeling analysis, a bottom-up information flow and a top-down decision flow are formed, jointly forming a closed-loop system optimization. The use of intelligent decision-making technology can intervene in the operation and development of physical objects[17].

In the troubleshooting and prediction stage, when the digital twin system provides possible causes of faults that have occurred and potential faults that may occur during future operation based on algorithms, intelligent decision-making technology is used to determine whether intervention is needed in the operational status of the physical object to avoid the occurrence of faults and reduce damage to the physical object and other losses[18].

In the optimization process of the model, the system provides the combination of the best parameters and orders at the current moment. The decision-making system needs to comprehensively consider the effectiveness and efficiency of the model under this parameter combination based on indicators, and compare it with the original model to decide whether to accept the changes to the model[19].

3. Characteristics and unresolved issues of digital twin technology

3.1. Characteristics of digital twin technology

3.1.1. From Serial Design to Collaborative Design

The development of industrial products mostly requires a series of processes such as argumentation, analysis, and design. During this period, collaborative work across multiple disciplines and fields is required, often taking a long time from project proposal to design completion, resulting in a decrease in development efficiency[20]. On the one hand, for different indicators, design based on their own professional field, and each profession independently conducts simulation verification, resulting in the coupling relationship between different elements affecting each other after the integration of various parts; On the other hand, the current traditional design is mainly carried out in a serial manner. After the designer completes the model design in this stage according to the indicators, the simulation and calculation results are transmitted to the designers in the next stage. The designers in the next stage continue to complete the design based on this, which will extend the development cycle.

ISSN 2706-655X Vol.5, Issue 7: 24-29, DOI: 10.25236/IJFET.2023.050704

The introduction of a digital twin system will improve the aforementioned issues. Centered around the digital twin system, professional designers can simultaneously design and modify models within the digital twin space, strengthening connections between different disciplines and fields, and reducing the impact of multi factor coupling after model fusion. Different designers can check the design progress of the model at any time as needed, achieving information interconnection and exchange. Applying collaborative methods to the product development process and changing traditional design patterns can help shorten the development cycle and accelerate the design process.

In addition, with the development of virtual reality technology, AR and VR have successively entered our lives. In the digital twin system, virtual reality technology is introduced to allow multiple designers to modify the model at the same time. Each designer enters the digital space through their own terminals, allowing them to have a more intuitive understanding of the details of the model and better assist them in modifying the model.

3.1.2. From post production validation to early validation

After the product design is completed, testing and verification are required. According to traditional verification methods, physical objects need to be manufactured and tested based on them. During the testing process, key indicator information is recorded, and after processing and analysis, the design is optimized, followed by physical manufacturing according to the modified design. This cycle repeats until all indicators are met after a certain number of times before finalization. Repeated testing incurs significant time and labor costs, and repeated iterations can also result in a waste of resources to a certain extent. Moreover, it is difficult to achieve full coverage of various situations in the required field environment for testing, which has a certain impact on the optimization efficiency of the design.

Because digital twins can simulate products comprehensively in structure, function, performance, behavior and other aspects, some Test effort in the design process can be carried out in the digital twin system. By setting different parameters in the digital twin system, simulating the operating status of the product under different conditions, comparing the differences in product performance and development cycle caused by different parameter conditions, analyzing the impact of various factors on the product, and continuously improving the design. The digital twin system can be reused, and through the combination of virtual and real research on the best application methods, the comprehensive utilization efficiency can be improved, which can save manufacturing costs, avoid significant losses, and improve the efficiency of business processes.

3.1.3. From post production validation to early validation

In the traditional mode, the analysis of product performance requires the establishment of accurate models based on historical data, or segmented modeling for different times and states, and analysis and research based on fixed models. Using a fixed model is relatively simple in the analysis, use, and maintenance process of the model, but its adaptability and fit are poor. In the process of using the physical system, under the influence of external interference and random factors, there will be significant deviations in the simulation of the physical system, making it difficult to truly simulate the operating status.

In the digital twin system, a fixed model driven by historical data is evolved into an adaptive model driven by dynamic data. Utilizing real-time data transmission between digital twin models and physical models, and utilizing real-time data to modify and update the model, the model can more accurately reflect the current state of the physical object and reduce the impact of uncertainty during use.

3.2. Problems to be solved in digital twin technology

3.2.1. Lack of unified standards

At present, there is a lack of authoritative and unified standards for the application of digital twin technology, which to some extent hinders the development of this technology[21]. In terms of theory, there are currently many definitions for digital twin technology, mostly describing and explaining it from different aspects and characteristics, but lacking a comprehensive and accurate definition; In terms of application, currently in the process of establishing digital twin models, different disciplines have different research focuses, different software is used according to needs, and a unified modeling platform is lacking, which poses certain difficulties for model fusion and expansion; In terms of model evaluation, there is no unified standard for evaluating the model scientifically based on which indicators during the delivery and use process after the model is established.

ISSN 2706-655X Vol.5, Issue 7: 24-29, DOI: 10.25236/IJFET.2023.050704

3.2.2. Precision of modeling

In the traditional mode, the analysis of product performance requires the establishment of accurate models based on historical data, or segmented modeling for different times and states, and analysis and research based on fixed models. Using a fixed model is relatively simple in the analysis, use, and maintenance process of the model, but its adaptability and fit are poor. In the process of physical operation, under the influence of external interference and random factors, there will be significant deviations in the simulation of the physical system, making it difficult to truly simulate the operating state.

In the digital twin system, a fixed model driven by historical data is evolved into an adaptive model driven by dynamic data. Real time transmission between the digital twin model and the physical model, utilizing real-time data to modify and update the model, enables the model to more accurately reflect the current state of the physical object and reduce the impact of uncertainty during use.

The establishment of a digital twin virtual model requires being as close to the physical object as possible, ensuring accurate reflection of the operational rules of the physical object, and accurately reproducing a series of actions during the physical operation process, achieving the effect of virtual and real synchronization. Therefore, the establishment of the digital twin model is based on the consideration of the rapid calculation process and good real-time performance, as well as the reduction of the Granularity of the model and the comprehensive consideration of the fidelity of the model.

3.2.3. Construction of real-time transmission channels

A key aspect of the application of digital twin technology is the transfer of data between digital twin models and physical entities. Due to the fact that the adjustment of model parameters by intelligent optimization systems relies on real-time measurement data from sensors, it is important to emphasize the real-time nature of data from physical entities to digital twin models, while ensuring transmission integrity. The digital twin model predicts the operation process of the physical object, determines whether to intervene in the operation status of the physical object based on the decision results, and controls the transmission of instructions from the digital twin model to the entity, which also requires rapid response. The data exchange channel between the two should ensure both its capacity and transmission speed.

3.2.4. Establishment and management of databases

The digital twin system has a wider coverage and more comprehensive elements, involving massive amounts of data. During operation, the digital twin system needs to receive real-time data transmitted from the physical object, which is processed and stored. Compared with the traditional model, the digital twin model includes not only the modeling of the physical object, but also the modeling of the operating environment and Confounding. The model contains more parameters and more complex types. It can intelligently optimize the parameters of the model according to the received real-time data to achieve the adjustment and change of parameters. In addition, the established digital twin model should be uniformly stored in the model library to facilitate model invocation and management, achieve model sharing, and improve the efficiency of product development. With the application of digital twin system in many fields, the model base will be more and more perfect. During the operation of the entire digital twin system, a large amount of data information will be involved. Therefore, it is necessary to establish an orderly and efficient database to facilitate the storage and management of data.

4. Summary

With the acceleration of the digital process, digital twin technology has gradually become a focus of attention for domestic and foreign research institutions due to its characteristics of virtual real mapping, real-time synchronization, and symbiotic evolution. Scholars in related fields have conducted extensive research on its practical application. This article summarizes the development process of digital twin technology, analyzes the key technologies in the application of digital twin systems, and elaborates on their development trends. Digital twin technology plays an important role in product design, use, and maintenance. By utilizing digital twin technology, the development cycle of products can be shortened, the cost of operation and maintenance can be reduced, and the lifespan of products can be predicted. At present, the application of digital twin technology is still in the development stage, and there are still many problems that need to be broken through and solved. How to better and faster achieve the practical application of this technology is also the focus of the next step of research.

ISSN 2706-655X Vol.5, Issue 7: 24-29, DOI: 10.25236/IJFET.2023.050704

References

[1] Liu Yang, Zhao Xu. Research on the Industrial Digital Twin Technology System and Key Technologies [J]. Information and Communication Technology and Policy, 2021, 47 (1): 8-13.
[2] Tao Fei, Liu Weiran, Zhang Meng, et al. Digital Twin Five Dimensional Model and Its Applications in Ten Major Fields [J/OL] Computer Integrated Manufacturing System, 2019, 25 (1): 1-18.
[3] Jiang Haifan, Ding Guofu, Xiao Tong, et al. Digital Twin Evolution Model and Its Application in Intelligent Manufacturing [J]. Journal of Southwest Jiaotong University, 2022, 57(6): 1-9.
[4] Li Hao, Tao Fei, Wang Haoqi, et al. Integrated Development Framework and Key Technologies for Complex Product Design and Manufacturing Based on Digital Twins [J/OL] Computer Integrated Manufacturing System, 2019, 25 (6): 1320-1336.
[5] Nie Rongmei, Zhou Xiaoya, Xiao Jin, et al. Overview, Analysis, and Development Prospects of Digital Twin Technology [J]. Aerospace General Technology, 2022, 6 (1): 1-6.
[6] Ji Guang, Hao Jianguo, Zhang Zhongjie, et al. Twin simulation research on the flight process of a four rotor unmanned aerial vehicle [J]. Computer engineering and Application, 2022, 58 (12): 66-73.
[7] Laukotka F, Hanna M, Krause D. Digital twins of product families in aviation based on an MBSE-assisted approach[J/OL]. Procedia CIRP, 2021, 100: 684-689.
[8] Yang Linyao, Chen Siyuan, Wang Xiao, et al. Digital Twins and Parallel Systems: Development Status, Comparison, and Prospects [J/OL] Journal of Automation, 2019, 45 (11): 2001-2031.
[9] Zhang Zhen. Research on Control Circuit Status Monitoring Based on Digital Twins [D/OL] North China Electric Power University (Beijing), 2021.
[10] Fan Rui, Liu Qingchuan, Gao Jian. Intelligent production line system data monitoring technology based on digital twins [J/OL] Integrated Circuit Applications, 2021, 38 (11): 120-121.
[11] Yin Haijun, Xiao Tangwei, Li Xin. Production Line Digital Twin Workshop Control Technical Framework [J/OL] Modern Manufacturing Technology and Equipment, 2021, 57 (10): 1-6.
[12] Ge Yong, Zhao Guangyi. Research on the Application of Intelligent Manufacturing Technology Based on Digital Twins [J/OL] Modern Manufacturing Technology and Equipment, 2021, 57 (7): 189-191+207.
[13] Guo Liang, Zhang Yu. A Review of the Application Progress of Digital Twins in Manufacturing [J/OL] Mechanical Science and Technology, 2020, 39 (4): 590-598.
[14] Wang Yufei, Liu Xiaojia, Liu Huan, et al. Application of twin neural networks in electrical performance testing of aerospace products [J]. Journal of Aeronautics,2022,43(S1): 1-8.
[15] Reed S, Löfstrand M, Andrews J. Modelling stochastic behaviour in simulation digital twins through neural nets [J/OL]. Journal of Simulation, 2022, 16(5): 512-525.
[16] Ding Hua, Yang Liangliang, Yang Zhaojian, et al. Predicting the health status of coal mining machines driven by the integration of digital twins and deep learning [J]. China Mechanical Engineering, 2020, 31 (7): 815-823.
[17] Feng Shenghua. The integration and application of digital twins and AI technology [J/OL] Artificial Intelligence, 2021 (2): 29-37.
[18] Liu S, Lu Y, Li J, et al. Multi-scale evolution mechanism and knowledge construction of a digital twin mimic model [J/OL]. Robotics and Computer-Integrated Manufacturing, 2021, 71: 102123.
[19] Li Qiang. Analysis of urban flood disaster assessment and early warning system based on digital twin technology [J]. Journal of Beijing University of Technology, 2022, 48 (5): 476-485.
[20] Feng Haotian. Digital twin model construction of flexible Assembly line for thin-walled parts [D/OL] Beijing Information Science&Technology University, 2021.
[21] Jia Shiqi, Han Li, Qin Chao, et al. Research on the Application and Standardization Requirements of Digital Twins [J]. Information Technology and Standardization, 2021 (11): 18-22+30.