

# Review of research and application on digital twin technology

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**Abstract:** Digital twin is a new technical means to realize the interactive integration of the physical world and the information world. It has been widely used in many business fields and has received more and more attention. Based on the analysis of the connotation and architecture system of digital twin, this paper discusses its key technologies in model construction, data collection and analysis, virtual-reality interaction and visualization, summarizes the research progress of digital twin technology in hot fields such as intelligent manufacturing, smart cities, mining, power monitoring and water conservancy projects, summarizes the existing deficiencies and future development trends, in order to provide reference and inspiration for the development of digital twin technology.

**Keywords:** digital twin, intelligent manufacturing, smart city, smart mine, 3D modeling.

## 1. Introduction

In recent years, the term digital twin has quickly become popular and has become a hot concept. Gartner Group, a global authoritative information technology research and consulting company, has listed digital twin as one of the top ten strategic technology development trends for three consecutive years<sup>[1]</sup>. Lockheed Martin Space Systems Company, the largest weapons manufacturer of the world, has listed digital twin as the top of the six top technologies for the future defense and aerospace industries. The Intelligent Manufacturing Alliance of CAST Member Societies listed digital twin as one of the top ten technological advances in the world's intelligent manufacturing at the World Intelligent Manufacturing Conference<sup>[2]</sup>.

Digital twin technology concepts are being promoted and applied in aerospace, architectural design, intelligent manufacturing, smart cities, energy and electricity, and other fields, playing an increasingly important role in promoting digital transformation and intelligent upgrading in various industries. This article summarizes the concept, key technologies and main application areas of digital twin technology, and analyzes its future development trends, aiming to provide a comprehensive and in-depth understanding and reference for researchers, practitioners and decision makers in related fields.

## 2. Definition and Connotation of Digital Twin

### 2.1 Definition of Digital Twin

The concept of digital twin was first proposed by Professor Michael Grieves of the University of Michigan in 2002 for product life-cycle management. It was originally named “Mirrored Space Model”. Later, John Vickers of NASA named it “Digital Twin”<sup>[3]</sup>, and the concept of digital twin gradually entered the public eye.

In 2015, Siemens defined digital twin as the process of building virtual models of physical entities through digital means. Tao<sup>[4]</sup> defined digital twin as a technology that digitally builds dynamic virtual models of physical entities with multiple dimensions, multiple spatial scales, multiple disciplines, and multiple physical quantities, and characterizes and simulates the properties and rules of physical entities .

Zhang<sup>[5]</sup> believes that digital twin is digital models of physical objects. The model can evolve in real time by receiving data from the physical object, so that it remains consistent with the physical object throughout its life cycle. Based on digital twin, analysis, prediction, diagnosis, training, etc.

can be performed, and the simulation results can be fed back to the physical object to help optimize and make decisions about the physical object.

The International Organization for Standardization defines digital twin as “digital representations of observable manufacturing equipment that enable the manufacturing equipment to converge at the same speed as its digital model.”

At present, although there are still differences in the description of the concept of digital twin in academia and industry, they are tending to agree that digital twin is digital expressions of real objects in the physical world for specific purposes. Digital twin technology has also received increasing attention from enterprises and governments, becoming one of the key strategic technology trends recognized by all walks of life around the world.

## 2.2 Digital Twin Architecture

The digital twin architecture was first proposed by Grieves et al., which consists of physical entities, virtual entities, and the connection between them<sup>[5]</sup>. On this basis, Tao Fei et al. expanded and added two new dimensions, twin data and services, and proposed a five-dimensional model of digital twin. The five dimensions of this model are physical entities , virtual entities , services , twin data , and connections. Connections can be established between any two parts to ensure the rationality and stability of the system during operation<sup>[4]</sup>. Its architecture is shown in Figure 1.

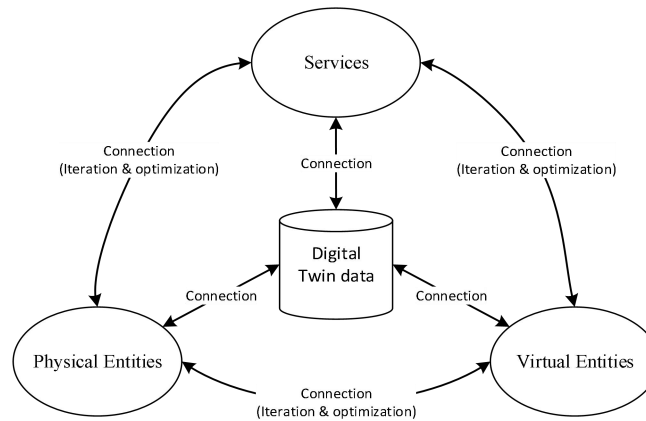


Fig. 1 Five-dimensional model of digital twin

Physical entities is the basis of the five-dimensional model of digital twin. Accurate analysis and effective maintenance of physical entities are the prerequisites for establishing digital twin models. virtual entities consists of geometric model, physical model, behavioral model and rule model .These models describe and characterize physical entities from multiple time scales and multiple spatial scales. Services refer to the service encapsulation of various types of data, models, algorithms, simulations, and results required in the application process of digital twin, and provides functional services and business services.

Twin data is the driver of digital twin, mainly including physical entity data, virtual entity data, service data, knowledge data and fusion derived data.Connection realizes the interconnection and interoperability of various components of the model, and supports real-time interconnection and fusion of virtual and real.

## 3. Key Technologies of Digital Twin

### 3.1 Multi-domain and Multi-scale Model Building Technology

The digital twin model is a digital representation of a real physical entity or system. It is used to understand, predict, optimize and control physical entities or systems, and is the basis for realizing model-driven. Multi-domain modeling refers to the cross-domain fusion modeling of physical entities and systems from different domain perspectives under normal and abnormal working

conditions. Multi-scale modeling can connect physical processes at different time scales to simulate a wide range of scientific problems. Multi-scale models can represent basic processes at different time lengths and scales and connect different models by uniformly adjusting physical parameters. These computational models have higher accuracy.

There are many ways to model the model. These include manually editing and modeling using 3D software such as Solid Works and 3DMax based on information such as the size of the physical entity<sup>[7]</sup>. Drone oblique photography technology collects regional geographic information and building data to generate a real-life 3D model. Laser point cloud technology is used to generate a complete terrain model through a 3D laser scanner and massive data processing software<sup>[8]</sup>. In the process of building large digital twin, multiple modeling technologies are often integrated to achieve the construction of complex twins.

### **3.2 2.2 All-factor Multi-source Heterogeneous Data Collection and Transmission Technology**

Comprehensive perception of the physical world is an important foundation and prerequisite for realizing digital twin. The collection of data from various types of IoT sensors provides technical support for the overall perception of the physical world. It is of great significance to build a fast and reliable information transmission network to transmit system status information to the host application system securely and in real time, and to drive the status, posture, and position of the virtual model in real time<sup>[9]</sup>.

At present, with the rapid development of informatization and intelligence, information systems related to the physical world are often heterogeneous digital systems built by different manufacturers, using different technologies, for different businesses, and at different times. This has caused great difficulties in the efficient collection and integration and analysis of massive heterogeneous data. High-precision IoT sensors and high-bandwidth Internet transmission channels are important technical guarantees for the efficient collection and transmission of all-factor, multi-source, heterogeneous data in the future.

### **3.3 Virtual Reality Interactive Display Technology**

Three-dimensional and virtual reality visualization and interaction technologies can present the operation and maintenance status of real physical systems in a hyper-realistic form. They can perform multi-scale real-time status monitoring and operation status evaluation on key subsystems, and attach the monitoring and analysis results to the corresponding subsystems and equipment and facility components. The system superimposes the analysis results on the created three-dimensional model system in a virtual-real mapping manner, perfectly reproducing the real physical system<sup>[10]</sup>. With the help of other electronic devices, users can provide immersive virtual reality experience from multiple aspects such as vision, hearing and touch, achieving the goal of high-quality human-computer interaction.

## **4. Main Application Areas of Digital Twin Technology**

### **4.1 Digital Twin and Intelligent Manufacturing**

At present, digital twin technology is most widely used in the manufacturing industry. In terms of product design, prototype data and user data are collected in a virtual space to generate a virtual model. Through technologies such as augmented reality and virtual reality, designers and users can see, touch or use the virtual model to experience the design effect before the actual production of the product, reduce the possibility of product quality defects, and speed up product delivery efficiency.

In the vehicle industry, digital twin technology is used to build complex test platforms, conduct virtual prototyping and verification, represent, analyze and test real vehicles, and reduce the development and production time of new cars. In the aviation industry, Boeing uses digital twin technology to provide virtual replication of physical aircraft components, simulate their

performance during the fuselage life cycle, and verify performance in the early stages of aircraft design. In CNC equipment, a digital twin system structure model for CNC machine tools is constructed to achieve the transmission and management of multi-source heterogeneous data and digital twin-driven milling cutter status monitoring. In addition, digital twin technology is also used in error prediction, wear reproduction, and service life prediction of CNC equipment<sup>[11]</sup>.

#### **4.2 Digital Twin and Smart City**

Digital twin have become an important technical path for the transformation and development of smart cities. Both China and foreign countries have issued relevant policies to guide urban planning and construction based on digital twin technology. The realization of digital twin cities requires the support of surveying and mapping geographic information, three-dimensional modeling, IoT identification perception, visualization rendering, as well as cloud computing, artificial intelligence, big data and other technologies. Digital twin-related technologies are used to construct a one-to-one correspondence between the main entities in the physical world of the city and the virtual space of the network, achieving mutual mapping and collaborative interaction between the two, and ultimately realizing the digitization and virtualization of all elements of the city, providing decision-making support for urban management<sup>[12]</sup>.

Typical application scenarios of digital twin cities include urban planning and management, digital park operation and maintenance management, and intelligent management of natural resources. In the actual construction of digital twin city cases, there are twin systems for specific directions such as urban disaster warning, rail transit planning, geographic information update, urban water resource management and protection, and ancient building complex management, which have promoted the development of urban intelligence.

#### **4.3 Digital Twin and Smart Mine**

The informatization and intelligence of mines is an inevitable trend of current development. It is of great significance to use digital twin technology to realize transparent mining in mines, reduce the number of personnel in dangerous working areas, and improve the safety index of the working environment.

At present, the research and application of smart mines based on digital twin is mainly in the field of coal mining. Ge<sup>[13]</sup> proposed the Mine Digital Twin Modeling construction method for mine scenarios, built a fully mechanized intelligent twin digital body, and realized intelligent control, fault prediction and three-dimensional human-computer interaction of mine equipment. Ruan<sup>[14]</sup> proposed a multi-dimensional and multi-scale digital twin rapid modeling method: using three-dimensional laser scanning technology and point cloud processing algorithm to build a large-scale geometric model of the coal mine hoisting system; using the underground 10G ring network and PLC/OPC standard specification protocol to establish a system behavior model under massive data; combining database technology and domain expert knowledge base to build a system fault knowledge model; finally, using Unity3D software to achieve deep integration of the model, improving the safety and intelligence of the mine hoisting system.

#### **4.4 Application of Digital Twin in Other Fields**

Digital twin has also been studied and applied in the three-dimensional modeling and safety warning of water conservancy projects, fault analysis and life prediction of water conservancy equipment and facilities<sup>[15]</sup>. In the power system, digital twin is mainly used in power generation system fault identification and prediction, power grid simulation, power supply system monitoring and load analysis<sup>[16]</sup>. In the steel industry, digital twin is mainly used in sintering, iron-making, steel-making, continuous casting and steel rolling. Through three-dimensional modeling tools and real-time data collection, digital twin can realize functions such as simulation monitoring of production processes, process parameter design optimization, product quality management,

equipment operation and maintenance, and safety management, which has improved the level of intelligence to a certain extent.

## 5. Conclusion

With the rapid development of technologies such as the Internet of Things, cloud computing, big data, 3D modeling, and artificial intelligence, digital twin technology has shown good development prospects in many fields such as intelligent manufacturing, smart cities, intelligent mining, water conservancy projects, and power systems. However, digital twin is also an interdisciplinary subject. There is a huge gap between the beautiful scenes it depicts and the actual application effects. It lacks more perfect theoretical guidance and more complete basic technical support. Most of the existing applications are still limited to 3D visualization. There is still a lack of typical application cases in virtual-real mapping, collaborative interaction, etc. There is still a large gap between its investment cost and actual benefits.

Therefore, the future development of digital twin will still rely on rich theoretical support, convenient model building methods, efficient data acquisition and processing capabilities, and more friendly human-computer interaction interfaces, so that digital twin technology can be better implemented and applied, and the level of intelligence in the industry can be improved.

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