Application Research of Digital Twin and Deep Learning Technology in Intelligent Manufacturing of Machining Equipment

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Abstract. This study constructs a digital twin model of manufacturing and processing equipment, integrates large-scale production data, conducts in-depth analysis of production behavior, and carries out deep learning and production parameter optimization training. It utilizes the dynamic updating ability of artificial neural networks to accurately determine the production situation of the processing equipment in the time period. Theoretical processing and data application modules are deeply integrated to achieve accurate simulation and predictive analysis of physical equipment. The system has the ability to perceive equipment status and predict functionality, optimize the manufacturing process on the production line, improve manufacturing efficiency and product quality, and promote the intelligent transformation of traditional manufacturing industries.

Keywords: Digital Twin · deep learning · intelligence · predictive maintenance

1 Introduction

In recent years, digital twin technology has rapidly developed and been widely applied in fields such as manufacturing, construction, and healthcare, providing strong support for achieving intelligent, digital, and sustainable development in traditional industries. In the field of manufacturing and processing equipment, applying digital twin technology for intelligent transformation of production processes has strong foresight. Compared with traditional equipment management methods such as post-event detection and dynamic testing, intelligent production processes have successfully improved the problem of lagging response to faults and increased the accuracy and efficiency of equipment management. In addition, intelligent production processes also provide early fault prediction before the occurrence of faults and perform fault elimination to reduce the incidence of faults. Through scientific equipment management, intelligent production processes promote the orderly development of proactive fault detection technology application in enterprises. Therefore, in the predictive maintenance system, it is necessary to strengthen the analysis of digital twin technology and carry out reasonable fault data training and deep learning to further improve the reliability and application effects of intelligent production processes.

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2 Overall Design of Intelligent Equipment Management System

2.1 Intelligent System Functional Scheme

During the system construction process, an intelligent manufacturing system for processing and manufacturing was built based on the information layer and oriented by digital twin technology. The digital twin program can dynamically provide feedback on the real manufacturing process of physical space equipment, with the production data of the physical layer serving as the key basis for model construction. To achieve the goal of creating the physical layer, the following functional solutions were designed: firstly, the digital twin program needs to have the ability to dynamically provide feedback on manufacturing equipment data; secondly, to ensure that the data stored in the physical space and information structure are in sync to achieve effective integration of physical and virtual information; thirdly, to effectively obtain manufacturing production data from the equipment to provide valuable decision-making solutions for intelligent manufacturing. [1].

2.2 Application of Digital Twin Technology in Physical Space, Information Storage, and Data-Driven Decision-Making

Digital Twin Technology is a technology and tool for practicing intelligent manufacturing concepts, which is currently officially applied to the Predix platform for global industrial production. Through a series of verification, deployment, and simulation experiments, it realizes the simulation integration of industrial assets and the overall system throughout the industrial platform. Digital twin technology effectively enhances the data interaction ability between the physical space and the information storage unit, and has successfully formed an application system for data feedback, data synchronization, and data decision-making. The system consists of three components: physical space, information storage unit, and data decision-making module.

The physical space mainly includes the physical objects of the manufacturing and processing equipment and the physical parameter sensing system. The physical parameter sensing system can effectively connect the sensors installed in various links of the manufacturing and processing equipment to collect the equipment operating conditions during the processing period, such as the equipment status and operation parameters. Due to the influence of multiple factors such as signals and noise in the information collection program and information transmission process, the collected information needs to be effectively processed and the interfering factors reduced in the information storage unit which integrates various physical information foundations. After the effective processing of the real appearance parameters of the manufacturing and processing equipment, the signal data is transmitted to the information transmission unit through the mapping unit. The interface used for information transmission has functions such as information integrity preservation and effective transmission of complex data, which can achieve data communication between platforms, various types of data, and multiple interfaces.

2.3 High-Dimensional Digital Correlation-Information Layer Construction

In the field of industrial production, the information layer that was previously applied referred to the collection and processing of data manually by humans to form processing and production parameters. However, the data generated by this method has a certain degree of delay and poor flow, and is prone to information "island effects," making it unsuitable as a manufacturing technology that develops self-perception and self-decision-making functions. With the deep development of digital technology, the intelligent interconnection of manufacturing and processing equipment has brought better solutions to the flow and delay of data. By accurately detecting the operating status of the equipment, relevant technicians can collect all simulation and modeling data related to the physical information of the equipment in real-time.

The information storage unit is a three-dimensional digital model built around the equipment manufacturing and processing process, integrating various production parameters in various processing stages. In physical space, after mapping the production materials using a data mapping dictionary, a three-dimensional digital model matching the structure will be generated. After effectively integrating various processing data, this model forms a digital twin structure of the manufacturing equipment production system. The formed digital twin structure can dynamically and realistically reflect the specific situation of manufacturing and processing production data, covering the data situation throughout the entire life cycle of the equipment's actual manufacturing and processing.

In addition, the data decision-making module can provide functions such as dynamic simulation, simulation production, and decision-making solution verification to verify the feasibility of decision-making solutions. In short, the application of the information layer refers to monitoring all parameters that may affect production efficiency or quality through the intelligent operation of the equipment, extracting them all, and building a database that supports product production. Finally, by combining the digital high-dimensional correlation features extracted by deep learning technology, all unstable factors in the equipment's operation process can be controlled to a minimum.

2.4 Physical and Virtual Data - Cloud Decision Optimization

The application of digital twin technology in industrial manufacturing, especially in the digital twin of equipment, can reflect the physical operating conditions of devices or equipment in real-time. By closely observing the digital twin, the fusion of physical layer data and virtual layer data can be more clearly understood. Digital twin technology also plays an important role in the design of the data decision module, mainly to improve the module's information perception, equipment fault prediction, and decision-making feasibility. In order to optimize the neural network data scheme, data training is first performed using processing methods, and then the trained neural network is used to detect equipment status from the perspective of physical space manufacturing equipment. This can determine the equipment's functional condition, predict possible faults in equipment operation, and evaluate the remaining operating time of the equipment.

3 The Application of Digital Twin Technology in the Intelligent Transformation of Production Equipment

3.1 Setting of Physical Scenes

To construct a three-dimensional production model of processing equipment, multi-category objective resource integration is carried out, and the physical characteristics of the environment where the manufacturing and processing equipment is located are effectively considered, and the types of sensors to be installed are determined to ensure the comprehensiveness and effectiveness of data collection. During actual production, the manufacturing and processing equipment are mainly CNC-based, including lathes, milling machines, and machining tables. The physical space used during practical processing is mainly of four types: motion, temperature, vibration, and positional changes. At the same time, various physical spaces are in a highly coupled state and have certain correlation effects with each other. To effectively collect the operation status of the processing equipment, various sensors are used to monitor the equipment status and ensure the completeness of information collection. [2].

3.2 Building a Digital Twin Production System

The digital twin structure for machining equipment needs to accurately reflect the operational status of the real equipment in the physical space from multiple aspects, such as geometric appearance, physical space, behavioral prediction, and production standards. The specific process for building the production system is shown in Fig. 1.

3.3 Creating a Deep Learning Analysis Platform

In intelligent learning models, the reasonable integration of deep learning technology effectively alleviates the pressure of collecting manual feature information, especially in the collection of image, voice and other files, where the “convolution” and “recurrent” neural data extraction demonstrate strong learning advantages. By using artificial neural networks to analyze potential equipment failures during operation, corresponding maintenance solutions are provided, equipment status detection is strengthened, and dynamic error analysis is performed, thus transforming the management control mode and enhancing proactive management prediction.

By integrating, classifying, and storing data generated during processing, a powerful data resource library is formed, which effectively drives the operation of the artificial neural network, enabling it to efficiently complete data training. After data training in multiple fields, the optimization of physical data is improved, while various predictive models are preserved. By utilizing the equipment digital twin system and sensors installed on the equipment, process data is effectively monitored to accurately determine the equipment’s status and position. During equipment prediction, by combining historical operating data, effective testing and judgment of the measured data is performed to provide optimization solutions for equipment performance, gradually enhancing equipment management intelligence [3].

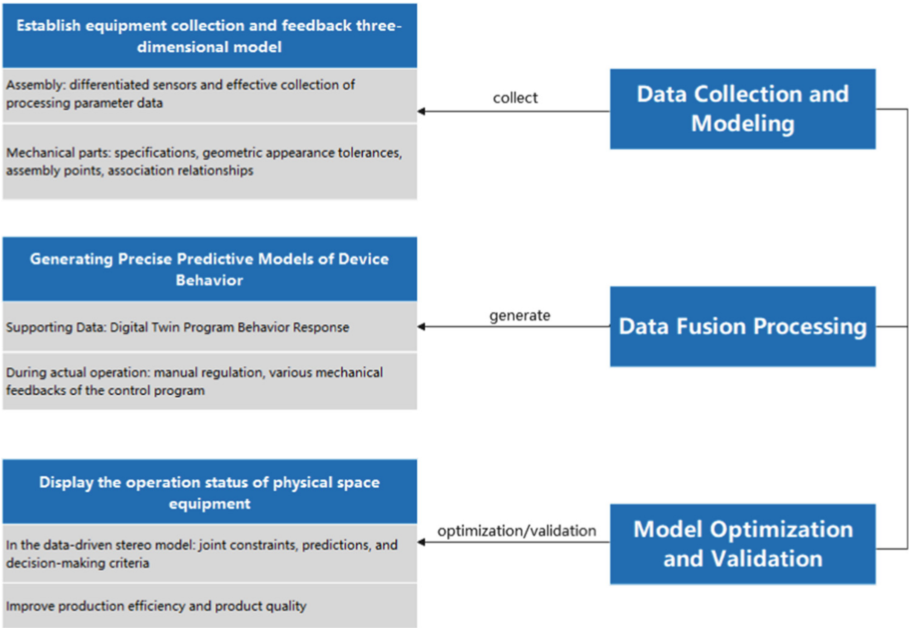

Fig. 1. Construction process diagram of digital twin manufacturing production line.

4 System Development Example

A certain university cooperates with enterprises to use digital twins as the intelligent system operating environment, and integrates deep learning technology. Taking multi-perspective data collection as the direction, it comprehensively supervises and regulates the processing equipment.

4.1 System Building Ideas

The overall concept and design of the system architecture is shown in Fig. 2.

4.2 Data Collection Process

In the design scheme adopted in this project, the equipment to be improved is mainly used for extrusion production. Therefore, it mainly exchanges data with lower-level network protocols such as OPCUA and more sensitive TSN through protocols such as the Internet of Things (IoT) LOT that can be applied to the site management layer. The method of data exchange is further filtered and analyzed according to different signal types and properties to obtain different data processing results, which are then transmitted to the virtual factory in the cloud for non-real-time prediction and optimization. This makes digital twin technology a reliable data tool for collaborative design, simulation design, and optimized design.

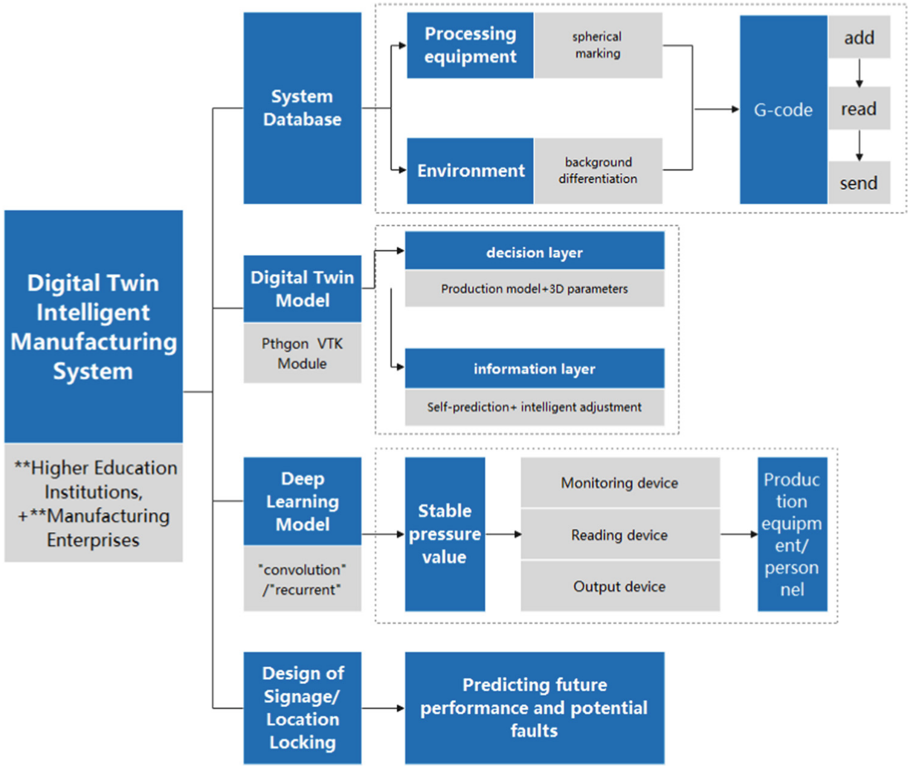

Fig. 2. System architecture diagram

The key to data collection lies in image position locking, and the acquisition of radius and coordinate information [4].

n = number of cameras, n > 2;

"g" represents the physical space position of the target measurement processing equipment, g(x, y); obtain the edge image coordinates G(x, y);

a = x + rcos(theta) b = y + rsin(theta), where theta is any value between 0 and 360;

g'(x) = lim(h- > 0) [g(x + h) - g(x)] / h g'(y) = lim(h- > 0) [g(y + h) - g(y)] / h.

"h"is a positive real number approaching zero limit, representing a small displacement on both sides of x.

Process the coordinates of g(x,y) data to convert it into a grayscale image, perform three-part segmentation and obtain corresponding frequency values, and take matching circular parameters including the coordinates of the center and the radius of the circle.

4.3 Create a Deep Learning Program to Improve the Training Effectiveness of Data Materials

Based on the theoretical foundation of deep learning, the coordinate parameters, radius, and other parameters of the cameras installed in the physical environment of the processing equipment are collected, and deep training is carried out on the data materials to ensure that the algorithm program has strong position locking ability for the target object to be tested.

Sample data acquisition. Use intelligent machinery to collect information on various nodes of the processing equipment. Combining the center parameter obtained from the marker, this is used as input data to construct the two-dimensional coordinates of the equipment.

Deep learning program. The input and output programs are provided when the system is designed, and the two programs are packaged in the neural network structure. The calculation result of the input layer corresponding to the node parameters is equivalent to the product of the number of cameras and the number of input parameters. In actual system development, the number of input parameters is 3 sets. The fixed parameters packaged in the neural network structure are set to 50 during system development.

4.4 System Benefit Analysis

During the development of this system, digital twin technology was effectively integrated, and dynamic data on the location, operating posture, and operating parameters of the processing equipment were effectively collected using visual observation methods. At the same time, the information visual acquisition method was effectively optimized, artificial identification technology was added, and the accuracy of target object position locking was effectively improved. With the general image processing method, specific point information can be effectively identified to provide the best image processing and obtain more streamlined data results [5] In the deep learning algorithm program, it has more efficient data training ability, can effectively deal with the acquisition position of the marker information, and reasonably eliminate various problems such as image interference, deformation, and position deviation. At the same time, the design of the camera installation position and layout can obtain training results in the coincidence of the view.

5 Conclusion

In summary, combining digital twin production simulation technology with deep learning methods provides a new intelligent management program for equipment with forward-looking predictive functions. [6] This system design method effectively alleviates the problem of insufficient data flow in equipment manufacturing and processing working conditions, improves the early detection and elimination of faults, and effectively reduces the frequency of equipment failures. During the system construction, dynamic collection of information was effectively analyzed, the operating status of the equipment was reasonably analyzed, and corresponding prediction results were provided to promote the development of equipment management intelligence.

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