Current status and development prospect of artificial intelligence application in mechanical design and manufacturing field

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Abstract: *The field of mechanical design and manufacturing in the modern industrial and economic development has a key importance, the current era of big data information technology, artificial intelligence has become the focus of the times around, the need to combine artificial intelligence technology with the field of mechanical design and manufacturing focus on promoting the mechanical design and manufacturing to the intelligent, flexible and sustainable development forward. This paper begins with a theoretical overview, followed by an analysis of the current status of the application of artificial intelligence in the field of mechanical design and manufacturing from machine vision, intelligent manufacturing, intelligent control, design optimization and simulation, and further analysis of its development prospects, including the trend of green manufacturing, human-computer interaction, Internet of Things deep fusion, and finally, through the application of the case and the summary, to explain that artificial intelligence is accelerating the mechanical design and manufacturing industry to the intelligent Finally, through application cases and summarization, it explains that AI is accelerating the development of machinery design and manufacturing industry to intelligentization, and expects to provide basis for related industries and fields and promote the long-term and stable development of machinery industry.*

Keywords: *artificial intelligence; mechanical design and manufacturing; deep learning; green manufacturing; smart manufacturing*

1. Introduction

Humanity has developed from mechanization to electrification, information technology, and is now accelerating into the era of intelligence. Artificial intelligence in the era of big data has become the focus of the times, which is gradually penetrating into various fields, in which the field of mechanical design and manufacturing is particularly significant, the field of mechanical design and manufacturing will play an important role in the development of modern industry and society is the cornerstone of modern manufacturing. Promote the intelligent development of mechanical design and manufacturing field is of great significance to improve production efficiency, optimize the use of resources and promote green manufacturing. Based on the theoretical foundation, this paper provides an in-depth analysis of the current status of the application of artificial intelligence in the field of mechanical design and manufacturing, including intelligent manufacturing, design optimization simulation, machine vision, etc. Subsequently, it further analyzes the future development prospects of the combination of artificial

intelligence and the field of mechanical design and manufacturing under the era of big data, which covers the human-computer interaction, the depth of Internet of Things, the trend of green manufacturing, and predictive maintenance. Finally, through the application cases and summary, it elaborates that AI is accelerating the development of machinery design and manufacturing industry in the direction of intelligence, and discusses how to utilize AI technology to cope with the challenges faced by the traditional machinery design and manufacturing, and to promote the manufacturing industry in the direction of high efficiency, greenness and sustainability.

2. Theoretical overview

Mechanical design and manufacturing refers to the techniques and methods involved in the design and manufacturing process in the field of mechanical engineering. It includes the management and technical support of the whole process from the conceptual design and detailed design of mechanical products to the actual manufacturing and assembly. Traditional mechanical design and manufacturing techniques include manual drafting, welding, casting, grinding and drilling, laser machining, etc. for the development and production of a variety of mechanical equipment and systems, and strive to improve product quality and productivity. But often mechanical engineers in the actual manufacturing and assembly process due to the actual performance of the material error or processing technology will cause certain product defects and quality problems, and at the same time, the operation and maintenance of the equipment is also a major problem with the failure of the maintenance will result in a large number of unnecessary waste of human resources. Artificial Intelligence (Artificial Intelligence, AI), also known as machine intelligence, is an important branch of modern computer science, mainly refers to the use of human intelligence similar to the way to respond to the instructions of the intelligent machine [1]. The development of artificial intelligence makes computers able to perform human-like intelligent tasks, in the era of big data information technology in the field of mechanical design and manufacturing has long been closely integrated with artificial intelligence technology to introduce intelligence and automation into the traditional mechanical manufacturing process. Produced such as machine learning, deep learning, intelligent robotics, machine vision and other fields. Machine learning is one of the core technologies of artificial intelligence, which enables machines to automatically learn and improve performance through training data and experience without explicit programming instructions[2]. The combination of artificial intelligence and machine design and manufacturing technology brings the possibility of dramatically improving product quality and productivity while at the same time promoting the manufacturing industry in the direction of intelligence, flexibility and sustainability.

3. Application status of the combination of artificial intelligence and mechanical design and manufacturing technology

3.1 Machine vision

3.1.1 Traditional Graphics Processing Technology Disadvantages

In the traditional product design and manufacturing process, mechanical engineers are often in the actual manufacturing and assembly process of the product due to errors in the actual performance of the material or processing technology will cause certain product defects as well as quality problems, so in the mechanical processing and manufacturing process of surface defect detection is essential. Surface defect detection is an important part of engineering manufacturing, industrial production to ensure product quality and production safety, and at the same time, the surface remanufacturing and repair is of great help [3], which can greatly improve product quality and production efficiency. The traditional

image processing-based surface defect detection methods are unable to effectively detect defects in the case of complex surface details, more types of defects and larger feature dimensions, and the detection and classification speed is slow [4]. With the development of artificial intelligence (AI) has brought deep learning has greatly promoted the progress of machine vision, machine vision relative to the traditional graphics processing technology both accuracy and processing speed have been greatly improved as shown in Table 1, so that the application of this field has become more extensive and accurate.

Table 1: Comparison between traditional image processing based techniques and deep learning based machine vision defect detection methods

Compare dimensions	Traditional graphics processing method	Machine vision based on deep learning
feature extraction	Manual design, which relies on domain knowledge	Deep learning to reduce manual intervention
accuracy	The effect is good for simple defects, but the feasibility of complex scenes decreases	Orderly performance on large-scale data, especially for complex defects
robustness	Sensitive to environmental changes, such as changes in light exposure	Usually have a strong ability to adapt
Data requirements	No large amount of data is needed, only a small number of samples	Large amounts of standard data are needed to train the model
real-time efficiency	Real-time detection is possible but is limited by algorithmic complexity	Efficient real-time detection can be achieved through the optimization
Calculate resource requirements	Computational requirements are relatively low	Need for high computing resources and chip support
Complexity	The implementation is relatively simple	Need for a deep mathematical and programming background

3.1.2 Deep learning based machine vision technology

Artificial Intelligence is driving the development of machine vision from all aspects especially bringing the introduction of deep learning especially CNN, by continuously improving the models and algorithms, it makes the machine vision able to automatically extract the features from the images and classify or detect them, which dramatically optimizes the process of detecting surface defects as shown in Fig. 1. Deep learning methods can do automatic feature extraction through the network in the model, and make classification or prediction easier by mapping features from the original space to a new feature space by layer-by-layer feature transformation on the original image [5]. Deep learning is highly adaptable and can automatically learn features from big data, but it requires sufficient training data. However, with the further development of artificial intelligence giving support to big data provides massive labeled data at the same time the emergence of AI chips and integrated devices allows machine vision systems to be processed on edge devices.

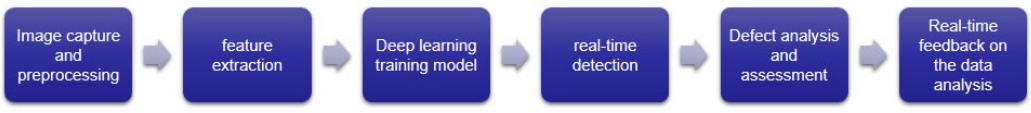

Figure 1: Surface defect detection process based on deep learning method machine vision

With the development of artificial intelligence technology, deep learning has been invoked in defect detection [6] which greatly improves the accuracy and detection speed of defect detection.

3.1.3 Current status of machine vision applications

In traditional manufacturing enterprises, the introduction of machine vision technology based on deep learning for product surface defect detection can significantly improve production efficiency and reduce production costs. For example, in the automobile manufacturing industry, it can be used to detect scratches, dents and painting defects on the car body surface. Ensure the appearance quality of the car body or detect defects or poor welding or omissions of welding parts. In the electronic product industry, machine vision is used to detect solder joint defects, short circuits and open circuits on printed circuit boards (PCBs), and check the placement quality and welding of electronic components. At the same time, in the packaging industry, it can be used to detect whether the labels on the package are correct and free of defects and the sealing quality of the package to ensure that there is no air leakage and poor sealing. Traditional manufacturing enterprises are increasingly focusing on establishing highly intelligent and automatic production lines and introducing surface defect detection technology based on machine vision to realize intelligent upgrading of production process to enhance production efficiency, reduce production costs and enhance market competitiveness.

3.2 Intelligent Manufacturing

3.2.1 Background of Intelligent Manufacturing Applications

Due to the traditional machinery manufacturing industrys production model is difficult to adapt to the rapid changes in market demand, transformation and upgrading has become an inevitable choice that the machinery manufacturing industry is currently facing. With the development of information technology and artificial intelligence, intelligent manufacturing has become an important trend in the development of manufacturing industry [7]. Smart Manufacturing (Smart Manufacturing) is a manufacturing model that applies advanced digital technology and intelligent systems to the production process to improve productivity, flexibility, quality and resource utilization efficiency. It combines information technology, the Internet of Things, artificial intelligence, big data analysis and automation technology to optimize and upgrade the manufacturing process through intelligent means. For enterprises striving for industrial transformation and upgrading, the introduction of intelligent manufacturing is a key initiative to enhance competitiveness.

3.2.2 Intelligent Manufacturing Production Line

The introduction of intelligent manufacturing production line in processing and manufacturing will greatly optimize the enterprise production scheduling, reduce labor costs, and optimize the use of resources. The production line is based on the Ethernet/IP industrial Internet, which integrates CNC machine tools, robots, intelligent sensors, information management, cloud platforms, industrial Internet, and other key technology elements of smart manufacturing [8]. As shown in Figure 2, an intelligent manufacturing line for machining manufacturing usually consists of six major parts: automation equipment, sensors and IoT, data analysis and artificial intelligence (AI), digital control system, intelligent quality control and inspection system, and finished product transportation system. Among them, automation equipment such as robots can be connected with digital technology to realize the sharing and transmission of production information, from raw material procurement to finished product shipment, forming a supply chain, production line, and the whole life cycle of the product digital control and monitoring, to realize the whole tracking and information interoperability and sharing [9].

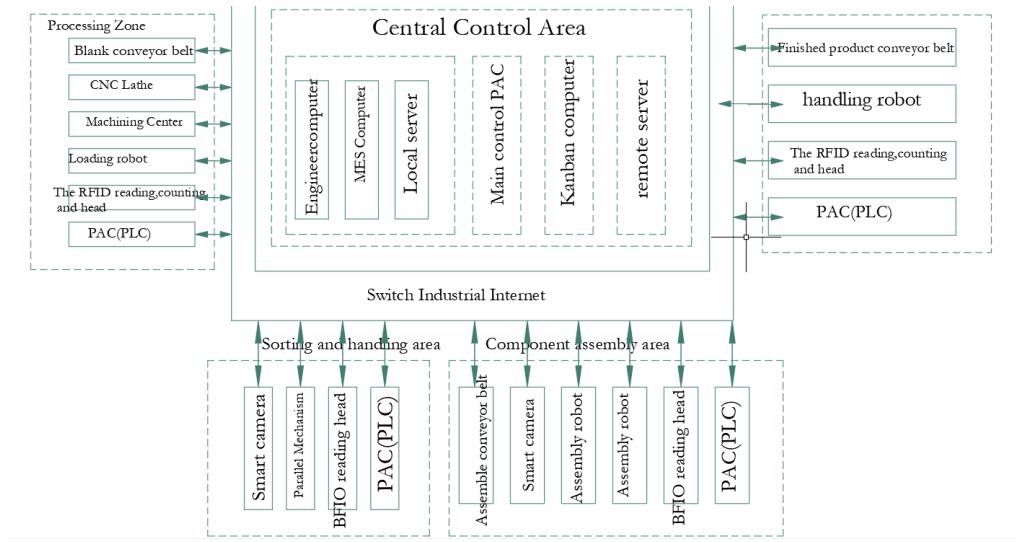

Figure 2: Schematic diagram of intelligent manufacturing industry line

Intelligent manufacturing lines are widely used in a variety of fields such as automotive manufacturing, aerospace, electrical and electronics, medical devices, machinery manufacturing and agricultural machinery. For example, in the aerospace field, automated equipment and robots can be used to process complex composite parts to improve strength and reduce weight, while intelligent quality control and inspection systems to ensure the precise assembly and quality control of complex structures to enhance the safety and performance of the aircraft. In short, the introduction of intelligent manufacturing technology not only optimizes the production process, but also helps enterprises to respond to market changes, meet individual needs and improve overall competitiveness.

3.3 Design optimization and intelligent simulation

The application of artificial intelligence (AI) technology in the field of mechanical design is becoming more and more widespread in the era of big data, and the application of artificial intelligence (AI) technology in mechanical design is gradually changing the traditional design process, and gradually showing its strong potential and application value in terms of improving the design efficiency and optimizing the quality of product design, and reducing the cost. In the product design process, machine learning algorithms and optimization techniques are used to automatically adjust product design parameters to achieve optimal performance, which can be used to improve the fuel efficiency of automobile engines, aerodynamic design of aircraft, etc. [10]. In the field of intelligent simulation and modeling on the one hand AI can accelerate the simulation process by predicting the performance of mechanical systems under different conditions through intelligent models, reducing the time of traditional simulation at the same time in data-driven modeling using machine learning techniques to construct more accurate models from actual operational data to improve the design and optimization process. the role of AI in intelligent simulation and modeling significantly improves the efficiency, accuracy, and innovation of mechanical design and innovation, providing engineers and designers with powerful tools to drive progress in mechanical design.

3.4 Intelligent control

The combined application of artificial intelligence (AI) and mechanical engineering in the field of intelligent control has made remarkable progress. With the continuous development and upgrading of computer technology, a new generation of intelligent control systems has become a symbol of modern

industrial development. Traditional mechanical manufacturing is an experience-based production method that relies on workers experience and sensory judgment to operate. Now the use of artificial intelligence technology for control, such as fuzzy control and neural network control, can improve the accuracy and stability of machine operation. The traditional mechanical engineering technology involves a cumbersome process in the application process, which, together with the large volume of production tasks, leads to the characteristic of low production efficiency [11]. Smart factories achieve comprehensive automation and intelligence of the production process by using AI technology, including automated production lines, robotic operation, real-time monitoring and adjustment and predictive maintenance to improve the service life and productivity of equipment. Using deep learning models, intelligent control systems can achieve multivariate control of complex systems, and by using AI to analyze massive production data, companies can optimize production processes, reduce costs, improve product quality, and solve complex production scheduling and resource allocation problems. Intelligent control systems can further enhance the core competitiveness of machinery manufacturing enterprises, and help manufacturing enterprises create a better corporate image and product reputation. With the further maturation and popularization of technology, intelligent control systems will play an important role in more fields.

4. Development trend and outlook

4.1. Human-computer interaction

In the field of machine design and manufacturing, Human-Machine Interaction (HMI) is developing rapidly, which greatly improves the efficiency, precision and flexibility of design and manufacturing. In the future, collaborative robots will play a key role in machine design and manufacturing. Compared with traditional robots, collaborative robots, as an emerging robot that solves the problem that humans and robots cannot work in the same space at the same time, have been developed rapidly in the field of intelligent manufacturing [12-14]. Collaborative robots can work together with human operators, through the Internet and mobile devices, remote maintenance and adjustment to complete the repetitive, dangerous or high precision requirements of the task, to improve production efficiency and safety at the same time these robots can be through the sensors and AI technology with the operator to carry out intelligent interactions, adapting to different working environments and task requirements.

4.2 Predictive maintenance

With the further development of the fourth industrial revolution traditional manufacturing industry has basically realized digitalization, automation, intelligent structure transformation and upgrading. Intelligent manufacturing makes the manufacturing system degrees of freedom highly constrained to bring management simplification at the same time, its system availability requirements will be increased [15]. At the same time the application of AI technology in predictive maintenance is revolutionizing the field of mechanical design and manufacturing such as through data analysis, automation and intelligent decision-making to improve the reliability and productivity of equipment. Figure 3 shows the predictive maintenance workflow

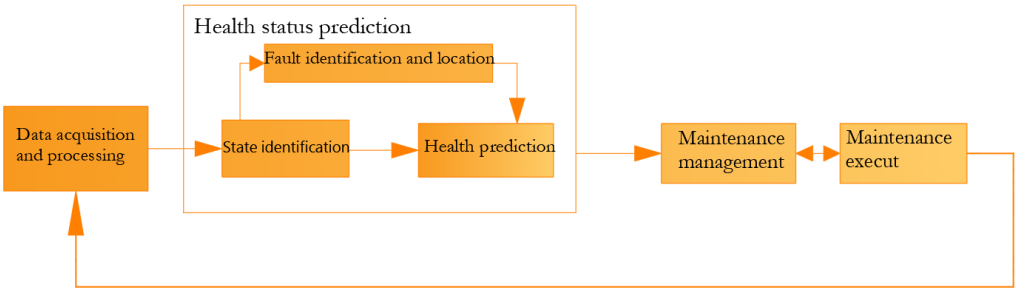

Figure 3: Predictive maintenance workflow

Artificial Intelligence (AI) technology plays a key role in predictive maintenance data analysis and pattern recognition.The AI system collects equipment operating data by integrating various sensors (e.g., vibration sensors, temperature sensors, pressure sensors, etc.) and constructs predictive models using machine learning algorithms (e.g., regression analysis, decision trees, neural networks, etc.) to analyze the historical and real-time data of the equipment to predict potential failures at the same time. Anomalous patterns in the data can be identified to detect potential problems early. For example, by analyzing vibration data or temperature data, AI can identify early signs of equipment anomalies. Adaptive algorithms can also be used to adjust predictive models to adapt to changes in equipment usage conditions and environment.

4.3 Deep integration of the Internet of Things

Commonly speaking, IoT technology is a technical architecture that combines the physicalworld with the digital world, and realizes digital sensing, intelligent analysis and autonomous decision-making of equipment, facilities and environment, etc., by means of sensors, communication technology and data processing [16]. The integration of artificial intelligence and IoT in the field of machinery manufacturing is mainly reflected in the intelligent production equipment as shown in Figure 4.

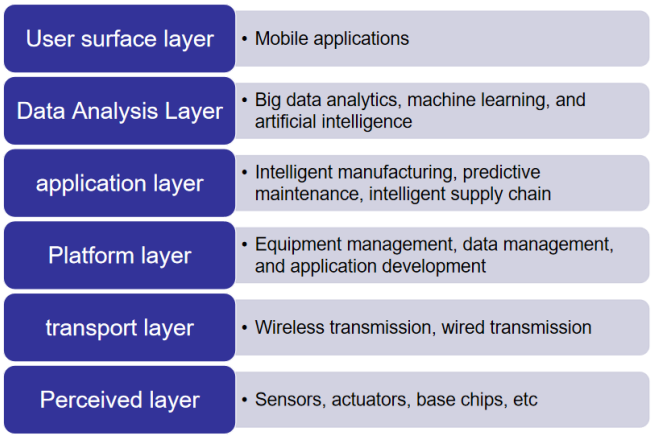

Figure 4: Composition of intelligent production equipment based on IoT technology

The combination of AI and IoT technologies has led to intelligent, automated and data-driven innovations in the field of machine design and manufacturing. At the level of smart devices and systems, the combination of AI and IoT enables real-time monitoring of equipment status, collecting data (e.g.,

temperature, pressure, vibration, etc.) through sensors and analyzing this data to predict the health of the equipment. In terms of intelligent production AI combined with IoT technology can achieve automated control of the production process, optimize the production process through intelligent algorithms, improve production efficiency and product quality and at the same time can also dynamically adjust the production parameters to adapt to different production needs and conditions.

In short the deep integration of AI and IoT promotes the development of real-time monitoring of equipment, predictive maintenance, intelligent production, quality control, personalized production and supply chain optimization. The application of these technologies not only improves production efficiency and product quality, but also provides enterprises with more intelligent decision-making support and promotes the overall transformation and upgrading of the manufacturing industry.

4.4 Green Manufacturing Trends

In the field of machinery design and manufacturing with the continuous progress of technology and environmental awareness, the green manufacturing trend has become an important development trend, especially in agricultural machinery processing, the environmental protection of green technology is reflected in the reduction of pollutant emissions, reduce the damage to the environment and so on [17]. With the further application of artificial intelligence in the field of machinery design and manufacturing, agricultural machinery through machine learning based on soil moisture and crop growth can achieve accurate seeding, fertilizer and spraying, reducing the use of pesticides and fertilizers, reducing environmental pollution and combining with sensor technology to achieve the autonomous navigation and operation of agricultural machinery, reducing the dependence on manpower and improving agricultural production efficiency. Manufacturing companies are also paying more attention to the recycling and reuse of materials when designing their products, choosing renewable, biodegradable and low-environmental impact materials, such as bio-based plastics, recycled metals and composites, to reduce the impact on the environment. The aim is to promote the development of a circular economy. The application of artificial intelligence in green manufacturing is promising. Through intelligent design, production optimization, resource conservation and additive manufacturing and other technical means, it can significantly improve the efficiency of machinery manufacturing and use, reduce resource consumption and environmental impact, and promote the field of machinery design and manufacturing towards sustainable development.

5. Conclusions

In summary, the application of artificial intelligence in the field of mechanical design and manufacturing is becoming more and more extensive, and with the continuous progress of technology and the depth of application, it shows more and more broad prospects. Based on the theoretical foundation, this paper provides an in-depth analysis of the current status of the application of artificial intelligence in the field of mechanical design and manufacturing, including intelligent manufacturing, design optimization simulation, machine vision, etc. Subsequently, it further elaborates on the future development prospects of the combination of artificial intelligence and the field of mechanical design and manufacturing under the era of big data, which covers the human-computer interaction, the depth of Internet of Things, the trend of green manufacturing, and predictive maintenance. Finally, through the application cases and summary, it elaborates that AI is accelerating the development of the machinery design and manufacturing industry in the direction of intelligence, and AI will play an increasingly important role in the field of machinery design and manufacturing in the future, which will bring far-

reaching changes and development opportunities to promote the manufacturing industry in the direction of high efficiency, greenness and sustainability.

References

[1] Qingsong Hu. Research on the application of artificial intelligence technology in modern agricultural machinery. Southern Agricultural Machinery,2023,54(06):63-65.

[2] Wentong Luo,Weiguo Li. Application of Artificial Intelligence in the Management of Yellow River Water Conservancy Projects. Hehai University, Jiangsu Water Conservancy Society, Zhejiang Water Conservancy Society, Shanghai Water Conservancy Society. Proceedings of the 2024 (12th) China Water Conservancy Informatization Technology Forum. Upstream Hydrology and Water Resources Bureau of the Yellow River Conservancy Commission;2024:8. DOI:10.26914/c.cnkihy.2024.009437.

[3] A RT A，SS B，MFN B，et al．Unsteady aero-elastic analysis of a composite wing containing an edge crack． Aerospace Science and Technology，2021，115: 1-16

[4] Zeqing YANG, Mingxuan ZHANG, CHEN Yingshu, et al. Research progress of surface defect detection method based on machine vision. Modern Manufacturing Engineering,2023, (04): 143-156.DOI:10.16731/j.cnki.1671-3133.2023.04.020.

[5] Zeqing YANG, Mingxuan ZHANG, CHEN Yingshu, et al. Research progress of surface defect detection method based on machine vision. Modern Manufacturing Engineering,2023, (04): 143-156.DOI:10.16731/j.cnki.1671-3133.2023.04.020.

[6] VILA R R，ZAPATA J，RUIZ R． An automatic system of classification of weld defects in radiographic images． NDT and E International，2009，42(5): 467-476．

[7] Zengliang Tang. Exploratory research on intelligent manufacturing to promote the transformation and upgrading of machinery industry. China equipment engineering,2024, (12):38-40.

[8] Jinjiang Cao, Jiacai Huang, Daoqing Chen. Design and realization of intelligent manufacturing line control for machining. Manufacturing Automation,2023,45(07):70-74.

[9] Zengliang Tang. Exploratory research on intelligent manufacturing to promote the transformation and upgrading of machinery industry. China Equipment Engineering,2024, (12):38-40.

[10] Chongying Yang. Research on Artificial Intelligence Technology in Mechanical Design and Manufacturing in the Information Age. Hubei Agricultural Mechanization,2020, (01):154.

[11] Jianpeng Zhou. Discussion on the application of intelligent control engineering in mechanical and electronic engineering. China equipment engineering,2024, (09):40-42.

[12] Yang LIU, Kai SUN. Research status and technology development analysis of collaborative robots. Journal of Northern Polytechnic University,2017,29(02):76-85.

[13] Yanying WAN, Qilin WU. A review of safety protection technology for industrial robots. Electromechanical Engineering Technology,2021,50(09):121-123+173.

[14] Huaqiu LIU, Lei HUANG, Yiwei CHEN. Development status and technology research of collaborative robots at home and abroad. Modern Manufacturing Technology and Equipment,2023,59(03):93-96.

[15] Yiming Zang, Mingbo Yang. Predictive maintenance strategy for intelligent maintenance under industrial internet conditions. Equipment Management and Maintenance,2017, (19): 62-63. DOI:10.16621/j.cnki.issn1001-0599.2017.12D.34.

[16] Peng Li. Exploration of instrument and equipment management mode of inspection and testing organizations based on internet of things technology. Popular Standardization, 2024,(14):175-177.

[17] Haixia Zhang. Application of green manufacturing process technology in agricultural machinery processing. Southern Agricultural Machinery,2024,55(11):196-198.