

Deep Integration of AI Technology for Intelligent Transformation in Mechanical Engineering

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Abstract: *With the rapid development of technology, artificial intelligence (AI) has gradually infiltrated various industries, particularly in the field of mechanical engineering, where the integration of AI technology is leading the industry towards intelligent and automated transformation. This paper discusses the inevitable trend of intelligent transformation in mechanical engineering, analyzes the innovative applications of AI technology in mechanical engineering design, manufacturing, monitoring, and maintenance, and looks forward to future development trends.*

Keywords: *Intelligent transformation in mechanical engineering; AI technology; Deep integration; Intelligent control system for excavators; Predictive maintenance for rotating machinery*

1. Introduction

As the foundation of modern industry, mechanical engineering has always been dedicated to designing, manufacturing, and maintaining various mechanical systems to meet the production and living needs of human society ^[1]. However, with the continuous advancement of technology and the increasingly diversified market demands, traditional mechanical engineering methods have gradually become inadequate in meeting the demands for high-performance, high-precision, and intelligent mechanical systems in modern society.

Currently, the mechanical engineering industry is facing unprecedented challenges and opportunities. On the one hand, global manufacturing competition is intensifying, and customer demands for personalized and customized products are growing, requiring the mechanical engineering industry to continuously improve production efficiency and product quality ^[2]. On the other hand, with the rapid development of technologies such as the Internet of Things (IoT), big data, and cloud computing, the mechanical engineering industry is embracing significant opportunities for intelligent transformation ^[3].

The rise of AI technology has brought revolutionary changes to the field of mechanical engineering ^[4]. As a technology that simulates human intelligence, the development journey of AI is full of innovation and breakthroughs. From initial expert systems and neural networks to today's deep learning and reinforcement learning, AI technology has demonstrated its powerful application potential in many fields. In the field of mechanical engineering, AI technology can optimize mechanical design, improve manufacturing efficiency, and enable intelligent monitoring and maintenance through big data analysis, machine learning, and other methods, bringing new development opportunities to the mechanical engineering industry.

Therefore, delving into the deep integration of intelligent transformation in mechanical engineering with AI technology is of great significance for promoting innovative development in the mechanical engineering industry. This paper will focus on this theme, exploring the inevitable trend of intelligent transformation in mechanical engineering, the innovative applications of AI technology in mechanical engineering, and future development trends.

2. Inevitable Trend of Intelligent Transformation in Mechanical Engineering: Driven by Market Demand, Technological Advancements, and Policy Support

(1) Market Demand Driver

With the rise of Industry 4.0 and smart manufacturing, the market demand for mechanical products

is no longer limited to basic functions and performance; instead, there is a growing emphasis on product intelligence, personalization, and customization. The introduction of AI technology enables mechanical engineering products to better adapt to market demands, enhancing product competitiveness and added value.

(2) Technological Advancement Driver

The rapid development of technologies such as artificial intelligence, big data, the Internet of Things (IoT), and cloud computing provides strong technical support for the intelligent transformation of mechanical engineering. The integrated application of these technologies enables mechanical products to achieve self-awareness, self-decision-making, and self-execution, significantly improving production efficiency and product quality.

(3) Policy Driver

Driven by both technological advancements and market demands, policy factors also play a crucial role in the intelligent transformation of mechanical engineering. Governments worldwide have identified smart manufacturing and Industry 4.0 as important directions for national development, introducing a series of relevant policies and regulations to provide strong support and guarantees for the intelligent transformation of mechanical engineering. For example, some countries encourage enterprises to increase investment and research and development in intelligent technologies by providing financial subsidies, tax incentives, and other measures. At the same time, they strengthen international cooperation and exchanges to jointly promote the process of intelligent transformation in mechanical engineering.

In practical applications, the intelligent transformation of mechanical engineering has achieved some notable success stories. For instance, a car manufacturing enterprise introduced intelligent production lines and robotic technology, achieving automated and intelligent control of the production process, significantly improving production efficiency and product quality. Simultaneously, the enterprise uses an intelligent management system to monitor and analyze production data in real-time, promptly identifying and resolving issues in the production process, thereby reducing production costs and risks. These successful practices have not only brought significant economic and social benefits to the enterprise but also set a model and benchmark for intelligent transformation in the industry.

3. Innovative Applications of AI Technology in Mechanical Engineering: Comprehensive Penetration from Design to Maintenance

(1) Engineering Design Phase

Traditional mechanical engineering design often relies on the experience and intuition of designers, requiring extensive trial and error and optimization. With the help of AI technologies, such as machine learning and deep learning algorithms, the performance of mechanical systems can be quickly predicted and optimized. For example, by learning from a large number of existing mechanical design schemes, AI systems can automatically generate new design schemes. According to a well-known mechanical manufacturer, the generation speed of new schemes has increased by 30% after adopting AI-assisted design. These AI systems typically use algorithms such as Convolutional Neural Networks (CNNs) or Generative Adversarial Networks (GANs) to efficiently search and optimize design parameters. Furthermore, they evaluate and improve designs based on set performance indicators, significantly enhancing design efficiency and quality.

In addition, AI can assist designers in complex structural analysis and multi-objective optimization. In the design of aircraft engine blades, AI algorithms not only consider traditional factors such as material strength and weight but also incorporate dimensions such as aerodynamic performance and thermodynamic efficiency. Through advanced algorithms like multi-objective genetic algorithms or particle swarm optimization, more lightweight and high-performance mechanical structures are successfully designed, improving engine efficiency by 5%.

(2) Manufacturing Phase

The application of AI technology in the manufacturing process has ushered in a new era of smart manufacturing. By installing sensors and monitoring devices on production lines to collect real-time production data, such as workpiece dimensions, processing speeds, and equipment status, and using AI algorithms to analyze and process this data, real-time monitoring and fault diagnosis of the production process can be achieved. A car manufacturing plant utilizes deep learning algorithms to monitor and predict faults in robots on the production line in real-time. By analyzing data such as robot motion

trajectories and force changes, the unplanned downtime of robots has been reduced by 20%, significantly improving production efficiency.

Simultaneously, AI can optimize production planning and scheduling. AI-driven scheduling systems can comprehensively consider multiple factors such as order demand, equipment status, and personnel arrangements, formulating optimal production plans through algorithms such as reinforcement learning or heuristic search, thereby improving production efficiency. According to McKinsey's research, such systems can improve production efficiency by up to 20%. In addition, AI algorithms can automatically adjust production parameters, such as cutting speeds and feed rates, based on historical production data and real-time demand forecasts, ensuring smooth operation of the production process and further reducing production costs.

(3) Monitoring and Maintenance Phase

Monitoring and maintenance of mechanical systems are key to ensuring their safe and reliable operation. By collecting and processing signals such as vibration, temperature, and pressure, AI systems can accurately identify potential fault hazards and issue early warnings. In a wind power generation enterprise, AI technology is applied to the monitoring and maintenance of wind turbine blades. By installing sensors on the blades to collect vibration data in real-time and using machine learning algorithms to analyze and model the data, multiple blade crack faults have been successfully predicted and addressed in advance, avoiding economic losses caused by downtime due to faults.

Furthermore, AI can optimize maintenance plans. Based on the actual operating conditions and fault history of mechanical systems, AI algorithms can formulate personalized maintenance strategies. For example, in a steel enterprise, AI technology is used for intelligent maintenance of equipment on its production line. By analyzing equipment operating data, fault records, and maintenance history, AI algorithms can predict the remaining service life and potential fault points of the equipment, thereby formulating more reasonable maintenance plans, improving maintenance efficiency, and reducing maintenance costs. According to the enterprise's statistics, after adopting AI technology, equipment maintenance costs have been reduced by 15%, and the service life of the equipment has been significantly extended.

4. Specific Case Studies

The application of AI technology in the field of mechanical engineering is becoming increasingly widespread, playing a pivotal role in various stages such as design, manufacturing, monitoring, and maintenance. The following sections will elaborate on the innovative applications of AI technology in mechanical engineering through specific case studies, supplemented by relevant technical details and success stories.

(1) AI-based Intelligent Control System for Excavators

① Case Background:

In the field of construction machinery, excavators, as essential equipment, directly impact project progress and quality through their operational efficiency and stability. Traditional control systems often rely on the operator's experience and intuition, making precise control difficult. With the continuous development of AI technology, its integration into excavator control systems has become feasible.

② Technical Implementation Details:

Taking the WS-005 excavator as an example, the system achieves precise control over the excavator's operating state by incorporating an incremental PID control algorithm and deep learning technology. The incremental PID control algorithm dynamically adjusts control parameters based on the excavator's real-time operating state, ensuring stability and operational efficiency. Deep learning technology, through the analysis and learning of vast excavation operation data, intelligently recognizes operating scenarios such as different soil types and excavation depths, and automatically adjusts control strategies according to scenario changes. The system employs Convolutional Neural Networks (CNNs) for image recognition of operating scenarios to extract feature information and utilizes Long Short-Term Memory Networks (LSTMs) for time series analysis of operational data to predict the excavator's future state.

③ System Functions:

Real-time Monitoring: The system monitors key parameters such as the power arm angle, boom angle, and bucket angle of the excavator in real-time, ensuring stability and accuracy during operation.

Intelligent Adjustment: Based on set control strategies, the system intelligently adjusts the excavator's movement speed and force to adapt to different operating scenarios and soil conditions.

Fault Diagnosis: The system also features fault diagnosis capabilities, monitoring the excavator's operating state in real-time. Upon detecting abnormalities, it promptly issues alerts and takes corresponding measures to prevent accidents.

④ Application Effects and Extended Cases:

The introduction of AI technology and the incremental PID control algorithm has significantly improved the operational efficiency and stability of the WS-005 excavator. Additionally, a certain brand of excavator has adopted a similar intelligent control system, integrating sensors, controllers, and AI algorithms to achieve real-time monitoring and intelligent control of the excavator's working state. According to data published by the brand, the adoption of this intelligent control system has improved fuel efficiency by 15% and operational efficiency by 20%. User feedback also indicates that the system automatically adapts to different geological conditions and operational requirements, significantly reducing operational difficulty and labor intensity, and enhancing operational safety and comfort.

(2) iDAQ Predictive Maintenance Solution for Rotating Machinery

① Case Background:

Rotating machinery, such as motors, fans, and pumps, is common in the industrial sector. The operational status of these devices directly affects production line efficiency and stability. Traditional maintenance methods often involve periodic inspections or post-failure repairs, making it difficult to accurately predict equipment failure times, which can lead to production disruptions and increased maintenance costs. Advantech's iDAQ predictive maintenance solution for rotating machinery, through the integration of a modular distributed measurement and control system with AI technology, enables predictive maintenance of rotating machinery.

② Technical Implementation Details:

The iDAQ predictive maintenance solution for rotating machinery adopts a modular design, allowing flexible configuration according to different equipment types and requirements. The system integrates various sensors and monitoring devices to monitor key parameters such as vibration, temperature, and pressure in real-time. Simultaneously, AI algorithms (such as Random Forest, Support Vector Machines, Neural Networks, etc.) analyze and process this data to accurately predict equipment failure times and causes. The system can also establish failure prediction models based on equipment operation history and failure modes, further improving prediction accuracy.

③ System Functions:

Real-time Monitoring: The system monitors the equipment's operational status in real-time, including key parameters like vibration, temperature, and pressure, ensuring normal equipment operation.

Failure Prediction: Through the analysis and processing of monitoring data by AI algorithms, the system accurately predicts equipment failure times and causes, providing a basis for maintenance planning.

Personalized Maintenance Suggestions: Based on the equipment's actual operation status and failure history, the system provides personalized maintenance suggestions, including maintenance timing and content.

Remote Monitoring and Management: The system supports remote monitoring and management functions, allowing users to understand equipment operational status and maintenance conditions anytime, anywhere via the internet or mobile networks.

④ Application Effects and Extended Cases:

By introducing the iDAQ predictive maintenance solution for rotating machinery, enterprises can achieve predictive maintenance of rotating machinery, significantly improving equipment reliability and service life. For example, a steel enterprise adopted the iDAQ solution to monitor and maintain its gearboxes. After a period of operation, the system successfully predicted the wear failure of the driven gear in the gearbox and issued an early warning. Based on the warning information, the enterprise promptly conducted maintenance, avoiding production disruptions and safety accidents caused by equipment failure. Additionally, the application of intelligent robotic arms in automated production lines is another successful case of AI technology in the mechanical engineering field. A certain automobile

manufacturing plant introduced multiple intelligent robotic arms into its automated production line. These robotic arms, through the integration of sensors, controllers, and AI algorithms, achieve precise grasping, assembly, and inspection of automotive parts. This not only improves production line efficiency but also reduces labor intensity and safety risks for workers.

(3) Other Typical Cases

1) Intelligent Warehousing and Logistics System:

In the warehousing and logistics sector, AI technology is also widely applied. Taking a certain intelligent warehousing and logistics system as an example, the system achieves automatic storage, retrieval, and distribution of goods by introducing AI algorithms and automation equipment. The system can automatically plan the optimal path based on order information, improving distribution efficiency. Simultaneously, through the analysis and processing of inventory data by AI algorithms, the system accurately predicts inventory demand and stockout risks, providing decision support for inventory management. According to data from the warehousing and logistics system provider, the adoption of the intelligent warehousing and logistics system has increased warehouse storage capacity by 20% and order processing speed by 30%.

2) Intelligent Manufacturing Production Line:

In the manufacturing industry, intelligent manufacturing production lines have become a future development trend. Taking a certain intelligent manufacturing production line as an example, the production line achieves intelligence and automation of the production process by introducing AI technology, Internet of Things technology, and automation equipment. The system can monitor the production line's operational status and production efficiency in real-time and make intelligent adjustments and optimizations based on set indicators. Simultaneously, through the analysis and processing of production data by AI algorithms, the system accurately predicts production demand and equipment failure risks, providing decision support for production planning and equipment maintenance. According to data from the production line provider, the adoption of the intelligent manufacturing production line has shortened the production cycle by 20% and reduced the defect rate by 30%.

Through the analysis of these specific cases, it is evident that the integration and application of AI technology in the mechanical engineering field have achieved remarkable results. Whether in intelligent control of excavators, predictive maintenance of rotating machinery, optimization of intelligent warehousing and logistics systems, or the implementation of intelligent manufacturing production lines, AI technology has demonstrated its powerful application potential and value. With continuous technological advancements and expanding application scenarios in the future, it is believed that AI will play an even more significant role in the mechanical engineering field.

5. Future Development Trends

(1) Deep Integration and Cross-Boundary Fusion

In the future, the integration of mechanical engineering and AI technology will enter a new stage. This integration will not only be limited to technological convergence but will also permeate every corner of the industry chain, value chain, and business model, achieving deep-level integration. AI technology will be more closely integrated into the entire lifecycle of mechanical engineering, including research and development, design, production and manufacturing, operation and maintenance management, driving the intelligent transformation of mechanical engineering to a higher level. For example, AI algorithms will optimize the performance of mechanical systems in real-time, enabling the operational efficiency and reliability of mechanical products to reach unprecedented heights. Simultaneously, mechanical engineering will undergo cross-boundary fusion with fields such as the Internet of Things, big data, and cloud computing, jointly constructing a more comprehensive and efficient intelligent manufacturing ecosystem. This cross-boundary fusion will promote the sharing and collaboration of information, technology, resources, and other elements, injecting new vitality into the upgrading and development of the mechanical engineering industry and driving its expansion to higher levels and broader fields.

(2) Technological Outlook

Looking ahead, the application of AI technology in the field of mechanical engineering will exhibit a more diversified and innovative trend. Emerging technologies such as deep learning and reinforcement learning will further enhance the intelligence level of mechanical systems, enabling them to more

accurately understand complex environments and make wiser decisions. In terms of new applications, AI technology will assist mechanical engineering in achieving more refined control and management. For instance, through the combination of smart sensors and AI algorithms, real-time monitoring and precise prediction of mechanical equipment status can be achieved. Furthermore, new models such as AI-based intelligent manufacturing service platforms will emerge, providing comprehensive intelligent solutions for the mechanical engineering industry and pushing the industry towards higher efficiency, lower costs, and more sustainable development.

At the same time, talent cultivation and collaboration are particularly important in the process of integrating mechanical engineering and AI technology. With the continuous development of technology, the demand for talents with interdisciplinary knowledge and skills will grow increasingly. Enterprises and institutions should strengthen cooperation with universities and research institutions to jointly cultivate compound talents who are proficient in both mechanical engineering and AI technology. Additionally, cross-industry collaboration will also become a significant force driving the integrated development of mechanical engineering and AI technology. Through exchanges and cooperation with other industries, more innovative ideas and technologies can be introduced, providing new ideas and directions for the intelligent transformation of the mechanical engineering industry.

(3) Personalized and Customized Services

With the increasing diversification of market demand, mechanical engineering will place greater emphasis on providing personalized and customized services. AI technology will play a pivotal role in this process. By deeply learning and analyzing customers' personalized needs, AI systems can provide customers with more precise, efficient, and tailored products and services. For example, in the mechanical manufacturing process, AI technology can customize the production of mechanical parts and products according to customers' unique needs and preferences, meeting the diversified demands of the market. Furthermore, AI technology can provide value-added services such as predictive maintenance and fault early warning to customers through real-time analysis of equipment operation data, further enhancing customer satisfaction and loyalty.

(4) Continuous Improvement of Intelligence Level

With the continuous advancement of technology and the expansion of application scenarios, the intelligence level of mechanical engineering will continue to improve. In the future, we will witness the emergence of more intelligent mechanical products with autonomous perception, decision-making, and execution capabilities. These products will be able to autonomously adjust working parameters and operation modes according to the actual environment and task requirements, achieving more efficient and precise operations. At the same time, with the deep integration of AI technology and mechanical engineering, intelligent mechanical products will have stronger learning and adaptation capabilities, enabling them to continuously learn and optimize their performance and behavior, bringing more convenient and efficient experiences to human society's production and life. For example, in intelligent manufacturing production lines, smart robots will be able to autonomously adjust operation processes and manipulation methods according to production plans and real-time demands, significantly improving production efficiency and product quality.

6. Conclusion

The integration of mechanical engineering with AI technology is a key trend. This paper highlights AI's role, challenges, and opportunities. Despite challenges, the potential is significant. Future efforts should focus on exploration, theoretical research, and standardization. We encourage more contributions to this promising field.

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