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Generation and Application Evaluation of Intelligent Numerical Control Programming Strategy for Domestic CAM System Integrated with AI Technology

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Abstract: Domestic CAM systems integrated with AI technology have made significant progress in the generation and application evaluation of intelligent CNC programming strategies. Machine learning and knowledge graphs assist in strategy generation, including process parameter optimization. System development requires designing architectures and building knowledge bases. Comparative analysis is used to verify its efficiency and quality. Although facing constraints such as standards and talent, they have brought about changes in intelligent manufacturing. In the future, cooperation between industry, academia, and research, as well as talent cultivation, should be strengthened.

Keywords: Domestic CAM system; Intelligent CNC programming strategy; Technology ecosystem construction

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1. Introduction

In 2021, the "14th Five-Year Plan for Intelligent Manufacturing Development" was promulgated, aiming to promote the digital transformation of the manufacturing industry and enhance the level of intelligent manufacturing. Against this backdrop, the research and application of intelligent numerical control programming strategies for domestic CAM systems integrating AI technology are of great significance. AI technologies such as machine learning and knowledge graphs play a key role in the generation of numerical control programming strategies, promoting the generation and application of intelligent numerical control programming strategies in various aspects, including process parameter optimization, tool path planning, and system architecture design. However, the system faces issues such as imperfect technical standards and certification systems, as well as insufficient talent capability adaptability in its industrialization promotion. Therefore, in-depth research and improvement of related content are of great significance for promoting the development of domestic CAM systems and realizing intelligent manufacturing.

2. Technical framework and theoretical basis of AI-integrated CAM system

2.1. Key application areas of AI technology in CAM systems

In domestically produced CAM systems integrating AI technology, AI technologies such as machine learning and knowledge graphs play a pivotal role in generating numerical control (NC) programming strategies. Machine learning, by learning from a vast amount of historical programming data, uncovers patterns and rules within it, enabling the prediction and generation of reasonable programming strategies. Its underlying logic lies in constructing models using algorithms and training them based on data to continuously optimize the accuracy of predictions. For instance, by learning from data of successful machining cases, it provides similar effective strategies for programming new parts. Knowledge graphs, on the other hand, integrate knowledge in the field of NC programming in a structured manner, clearly presenting the connections between various types of knowledge and enhancing the efficiency of knowledge retrieval and application. It can organize programming rules, process knowledge, etc. in an orderly manner, enabling the system to quickly and accurately call upon relevant knowledge when generating programming strategies. The two complement each other, demonstrating good applicability in the generation of NC programming strategies and aiding CAM systems in achieving intelligent programming strategy generation [1].

2.2. Generation mechanism of intelligent numerical control programming strategy

The key to the intelligent numerical control programming strategy generation mechanism of domestic CAM systems integrated with AI technology lies in the core algorithm for AI-based process parameter optimization and automatic tool path planning. In terms of process parameter optimization, the algorithm utilizes machine learning technology to construct a prediction model based on multi-source data such as processing material characteristics and part accuracy requirements, exploring the optimal combination of cutting speed, feed rate, and other parameters, aiming to improve processing efficiency and quality [2]. Automatic tool path planning, on the other hand, utilizes computer vision and intelligent search algorithms to identify and analyze features of the part’s 3D model, considering factors such as tool shape and machining allowance. Through intelligent search, it selects the shortest and smoothest tool path among numerous possible paths, ensuring the efficiency and stability of the processing process and providing solid strategic support for intelligent numerical control programming.

3. Development and practice of domestic AI-CAM system

3.1. System architecture design and technical implementation path

In the development of domestic AI-CAM systems, the system analysis and processing of numerical control programming data, such as learning from machining architecture design should focus on the whole, constructing an architecture that integrates artificial intelligence modules with traditional CAM functions. AI technology should be deeply embedded to achieve intelligent process data through deep learning algorithms to refine programming strategies. In terms of technical implementation, on the one hand, hardware equipment performance should be optimized to provide efficient computing power support for AI algorithm operations; on the other hand, suitable software modules should be developed, including a data preprocessing module to standardize the input machining information, and an intelligent decision-making module to generate programming strategies based on AI models.

At the same time, based on relevant research, advanced data interaction interface design should be utilized to ensure smooth data transfer and efficient collaboration among various modules, achieving the comprehensive implementation of domestic AI-CAM systems from architecture to functionality, and promoting the generation and application of intelligent numerical control programming strategies [3].

3.2. Construction of process knowledge base and expert system

In the development and practice of domestic AI-CAM systems, the construction of process knowledge bases and expert systems is a crucial step. By achieving autonomous evolution and knowledge accumulation of machining processes through deep learning, the process knowledge base can be continuously enriched. On one hand, deep mining and analysis of a large amount of historical machining data are conducted to extract effective process parameters, machining methods, and other knowledge, which are then stored in the process knowledge base. On the other hand, deep learning algorithms are utilized to enable the system to adaptively optimize and adjust processes during the continuous processing of new machining tasks, transforming new successful experiences into knowledge and adding them to the base. Based on this process knowledge base, an expert system is constructed. The expert system simulates human expert thinking, and generates intelligent CNC programming strategies quickly and accurately based on the knowledge in the knowledge base and combined with the requirements of the current machining task. This construction method not only improves programming efficiency but also enhances the scientificity and rationality of the strategies [4].

4. Multi-dimensional application performance evaluation system

4.1. Processing efficiency and quality evaluation indicators

4.1.1. Comparative analysis of intelligent programming efficiency

In domestic CAM systems integrating AI technology, comparative analysis of intelligent programming efficiency is crucial. Establishing a quantitative comparison model for man-hour consumption between traditional programming and AI programming is an important way to measure the efficiency of intelligent programming. Traditional programming relies on manual input of instructions and path planning by programmers, which is time-consuming and laborious, with relatively low efficiency. AI programming, on the other hand, utilizes machine learning algorithms to automatically analyze part features, optimize processing parameters, and quickly generate machining programs [5]. By precisely quantifying and comparing the man-hour consumption of the two methods in completing the same tasks, the advantage of AI programming in efficiency improvement can be clearly understood. For example, for programming complex curved surface parts, traditional programming may take hours or even days, while AI programming may only take tens of minutes. This not only saves time but also enables enterprises to quickly respond to market demands, enhance competitiveness, and provides a strong basis for evaluating the application effectiveness of intelligent programming strategies in domestic CAM systems.

4.1.2. Verification method for processing quality stability

The verification method for processing quality stability aims to ensure that the numerical control programming strategies generated by domestic CAM systems integrating AI technology can consistently maintain a high level of processing quality. By repeatedly executing the same programming strategy to process the same workpiece multiple times, collecting accuracy and surface roughness data from different batches of processing, and using statistical methods such as calculating standard deviation and coefficient of variation to evaluate the dispersion of data, the fluctuation of processing quality can be measured. The smaller the standard deviation or coefficient of variation, the higher the stability [6]. Conversely, with the help of control chart technology, key quality characteristic values such as processing accuracy and surface roughness are plotted into control charts to monitor in real-time whether the processing process is in a stable and controlled state. If data points exceed the control limits or exhibit abnormal distribution patterns, it indicates that there is a problem with the processing quality stability, and the numerical control programming strategy needs to be adjusted and optimized to ensure the stability and reliability of processing quality.

4.2. Research on adaptability to application scenarios

4.2.1. Case study on complex surface machining

In the case study of complex surface machining, taking typical parts such as aeroengine blades as the object, their complex surface shapes require extremely high machining accuracy and surface quality. The domestically produced CAM system integrated with AI technology generates intelligent CNC programming strategies in the machining of such parts, achieving efficient and precise machining. During the actual machining process, the system can quickly plan tool paths based on the geometric characteristics of the complex surface of the blade, avoiding interference and optimizing cutting parameters. Through testing the machined blades, it was found that the dimensional accuracy meets the design requirements, and the surface roughness is also controlled within the ideal range. This case fully verifies the effectiveness and adaptability of the system in complex surface machining scenarios, providing strong support for the further application of domestically produced CAM systems in high-precision manufacturing fields such as aerospace [7].

4.2.2. Process adaptability of new composite materials

In the generation and application evaluation of intelligent numerical control programming strategies for domestically produced CAM systems integrating AI technology, the adaptability to new composite material processing is a crucial aspect. For new materials such as carbon fiber, it is necessary to focus on the system's strategy generation capabilities. The system must be able to accurately identify the characteristics of carbon fiber materials, such as high specific strength and anisotropy, and generate corresponding numerical control programming strategies, like optimizing tool paths to reduce damage to the fibers during processing and avoid defects such as delamination and fracture [8]. At the same time, reasonable selection of processing parameters, such as cutting speed and feed rate, should be considered to ensure a balance between processing efficiency and quality. The stability of the evaluation system for processing new composite materials in different processing environments, including its adaptability to temperature and humidity changes, should be evaluated to ensure that the CAM system can reliably generate effective intelligent numerical control programming strategies for new composite material processing in actual production, achieving high-quality and high-efficiency processing.

5. Industrialization application and technological innovation landing

5.1. The feasible path of localization substitution

5.1.1. Pain point solutions for industry applications

In the fields of mold manufacturing, aerospace, etc., domestically produced CAM systems integrating AI technology have practical and feasible solutions for industry application pain points. Mold manufacturing often faces the challenge of complex surface machining programming. Domestic CAM systems utilize AI intelligent algorithms to automatically identify surface features, quickly generate optimized CNC programming strategies, greatly improve programming efficiency and machining accuracy, and meet the requirements of precision mold manufacturing [9]. The aerospace industry has extremely high requirements for the reliability and efficiency of component manufacturing. Domestic CAM systems use AI to analyze machining process data, predict potential problems, and adjust programming strategies in real time to ensure stable machining processes and effectively solve the balance between quality and efficiency in aerospace component manufacturing. These solutions not only meet the current needs of the industry, but also lay the foundation for domestic CAM systems to achieve localization substitution and occupy a dominant position in industrial applications.

5.1.2. Strategy for building a technological ecosystem

In terms of building a technological ecosystem strategy, it is necessary to work together from multiple parties. Software developers should strengthen cooperation with AI technology research institutions to jointly optimize the algorithms and models integrated with AI technology in domestic CAM systems, and improve the accuracy and efficiency of intelligent CNC programming strategies. Alternatively, hardware manufacturers need to closely cooperate with software suppliers to ensure that hardware performance can fully support the efficient operation of AI algorithms and achieve deep integration of software and hardware. Similarly, industry associations should play an active role in building communication platforms, promoting information sharing and cooperation among domestic CAM system enterprises, upstream and downstream suppliers, research institutions, and users, and accelerating the transformation and application of technological achievements. In addition, by establishing unified technical standards and specifications, ensuring compatibility and interoperability between different systems and equipment, building a healthy, orderly, and competitive domestic CAM technology ecosystem, laying a solid foundation for domestic substitution, and promoting the wider application of AI integrated domestic CAM systems in the field of intelligent numerical control programming [10].

5.2. Innovative cases of new process methods

5.2.1. Application of adaptive machining strategy

The application of adaptive machining strategy is of great significance in domestic CAM systems integrating AI technology. This strategy utilizes AI technology to flexibly adjust processing parameters and paths based on real-time monitoring data. For example, in the processing of complex curved parts, the system can obtain real-time information such as tool wear and workpiece deformation through sensors, and AI algorithms can quickly analyze and process it, adaptively optimizing parameters such as feed rate and cutting depth. This effectively improves machining accuracy, reduces errors caused by fixed parameters, and makes the machining quality of complex parts more stable. Otherwise, it avoids situations of excessive or insufficient cutting, improves material utilization, and reduces production costs. The application of this adaptive machining strategy fully demonstrates the advantages of domestic CAM systems integrated with AI technology in meeting diverse and high-precision machining needs, effectively promoting the implementation of intelligent CNC programming strategies in practical production.

5.2.2. Integration of mixed manufacturing processes

In domestic CAM systems integrating AI technology, there are many innovative cases of mixed manufacturing process integration. For example, in the field of aviation component manufacturing, the material stacking advantage of additive manufacturing is combined with the high-precision forming advantage of subtractive manufacturing. Using AI technology to analyze the complex structure of parts, planning to quickly construct rough shapes through additive manufacturing. At this point, AI can optimize the deposition path and parameters of materials, improve material utilization and molding speed. Then, with the help of subtractive manufacturing for precision machining, AI intelligently generates tool paths for subtractive machining based on the state of the parts after additive manufacturing, ensuring dimensional accuracy and surface quality. This hybrid manufacturing process integration not only overcomes the limitations of a single process, but also significantly shortens the manufacturing cycle, reduces costs, and achieves efficient connection from design to manufacturing through AI empowerment, promoting the practical application of intelligent CNC programming strategies in industrialization.

5.3. Restrictive factors for industrialization promotion

5.3.1. Technical standards and certification system

In the process of generating and promoting intelligent CNC programming strategies for domestic CAM systems integrated with AI technology, the imperfect technical standards and certification system are a major limiting factor. The lack of unified and clear technical standards in the industry results in differences in functional settings, data interfaces, programming specifications, and other aspects among different domestic CAM systems. This leads to many difficulties for enterprises in selecting and applying them, making it difficult to make effective comparisons and evaluations. At the same time, due to the lack of an authoritative certification system, users have doubts about the actual performance, reliability, and stability of integrating AI technology into domestic CAM systems, and dare not easily adopt it. The lack of industry standards and incomplete certification system greatly hinders the promotion and application of intelligent CNC programming strategies for domestically produced CAM systems integrating AI technology in the industry. It is urgent to establish a scientific, standardized, and unified technical standard and certification system to safeguard its industrialization landing.

5.3.2. Research on the adaptability of talent abilities

In the industrial promotion of intelligent CNC programming strategies for domestic CAM systems integrating AI technology, the adaptability of talent capabilities is a key limiting factor. Operators need to have a foundation in traditional CNC programming, be familiar with machine tool operation, process parameter settings, etc. After integrating AI technology, they are required to master the basic principles of machine learning and data processing methods to understand the logic of intelligent programming strategy generation. Currently, talents often lack the ability in this area. Additionally, technical R&D personnel not only need to be proficient in AI algorithms, but also need to have a deep understanding of CNC machining processes in order to optimize intelligent programming strategies. However, the reality is that there is a scarcity of composite talents who understand both AI and CNC machining. Furthermore, the curriculum design of universities and vocational colleges has not kept up with technological development in a timely manner, and the talent training system is disconnected from the actual needs of the industry, further exacerbating the mismatch between talent capabilities and industrialization promotion needs. It is urgent to improve the adaptability of talent capabilities through adjusting courses, strengthening practice, and other means.

6. Conclusion

The generation and application evaluation of intelligent numerical control programming strategies for domestic CAM systems integrated with AI technology have brought significant changes to intelligent manufacturing. Its technological innovation value is reflected in multiple aspects such as improving programming efficiency and optimizing processing paths, effectively driving the digital transformation of the manufacturing industry. However, in the current process of research and development and industrialization, key bottlenecks such as insufficient depth of technological integration and talent shortage still persist. Looking ahead, with the rise of emerging technologies such as digital twins and cloud intelligent manufacturing, domestic CAM systems are expected to achieve more intelligent and collaborative development. To build an intelligent manufacturing technology ecosystem, it is necessary to strengthen industry-university-research cooperation, break through core technologies; increase talent cultivation efforts, enhance the overall level of the industry; promote upstream and downstream collaboration in the industrial chain, form a complete ecosystem, and help domestic CAM systems

Disclosure statement

The author declares no conflict of interest.

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