Research on Adaptive Control and Precision Optimization Technology of Industrial Robot for Intelligent Manufacturing

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Abstract: Under the background of intelligent manufacturing, the adaptive control and precision optimization of industrial robots are very important to enhance the competitiveness of manufacturing industry. This article aims to deeply study the related technologies of industrial robots for intelligent manufacturing, systematically analyze the theoretical basis and precision optimization theory of industrial robots, explore the application of adaptive control technology in robot trajectory tracking, coping with load changes and improving dynamic performance, and further analyze the feasibility and advantages of the integration of adaptive control and precision optimization technology. Adaptive control technology can improve the performance of industrial robots in complex working conditions, and precision optimization technology can significantly reduce the motion error of robots. The integration of the two technologies can improve the comprehensive efficiency of robots in all directions. This fusion technology provides solid theoretical support and technical guidance for the wide application of industrial robots in the field of intelligent manufacturing, and is of great significance to promoting the development of intelligent manufacturing industry.

1. Introduction

As the core driving force of the development of modern manufacturing industry, intelligent manufacturing is leading the profound change of industrial production mode. In this wave of change, industrial robot has become the key equipment to realize intelligent manufacturing with its high automation, accuracy and flexibility [1]. The complexity of industrial production environment and the diversity of tasks put forward strict requirements for the control performance and accuracy of industrial robots [2]. The traditional fixed parameter control method can't meet the high performance requirements of industrial robots under complex and changeable working conditions, so adaptive control technology and precision optimization technology have become the key to improve the efficiency of industrial robots [3].

From a global perspective, scientific research institutions and enterprises all over the world attach great importance to the research and development of adaptive control and precision optimization technology for industrial robots [4]. In the aspect of adaptive control, many international researches are devoted to developing more intelligent and efficient adaptive algorithms to improve the adaptability of robots to complex environments. In the field of precision optimization, advanced error compensation strategies and high-precision sensor technology are constantly emerging [5]. Although the related research in China started a little late, it developed rapidly, and many universities and research institutes actively participated in it, and achieved a series of valuable research results.

However, the current research still faces many challenges. The real-time and stability of adaptive control algorithm in practical application need to be further improved, and the robustness of precision optimization technology in complex working conditions is insufficient [6]. In-depth research on adaptive control and precision optimization technology of industrial robots oriented to intelligent manufacturing is of great practical significance for enhancing the core competitiveness of

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China manufacturing industry and promoting the development of intelligent manufacturing industry. The purpose of this article is to systematically study the adaptive control and precision optimization technology of industrial robots, deeply analyze their theoretical basis and application methods, and explore the effective integration path of them.

2. Industrial robot adaptive control theory

The dynamic model of industrial robot is the cornerstone of adaptive control. Researchers usually use Lagrange equation or Newton-Euler equation to construct its dynamic model, which accurately describes the relationship between the force, torque and motion of each joint of the robot [7]. Adaptive control has a unique concept and classification in the field of industrial robots. Conceptually, it can automatically adjust the control parameters according to the system operation to adapt to environmental changes and uncertainties. There are various classification methods. Taking model reference adaptive control as an example, it can adjust the controller parameters in real time by comparing the system output with the reference model output [8]. This control method enables the robot to maintain good control performance in the face of changes in load, friction and other factors. Self-tuning adaptive control is also widely used. It estimates the model parameters online based on the input and output data of the system, and then adjusts the controller to optimize the robot performance. These adaptive control theories have laid a solid theoretical foundation for the stable and efficient operation of industrial robots under complex and changeable working conditions.

3. Application of adaptive control technology in industrial robots

In the actual operation of industrial robots, adaptive control technology plays a vital role, which significantly improves the robot's ability to cope with complex working conditions [9]. Adaptive control technology plays a key role in trajectory tracking control. When industrial robots perform tasks, they need to accurately track the preset trajectory to ensure the accuracy of operation. Traditional fixed parameter control methods are often difficult to achieve high-precision trajectory tracking in the face of external interference or changes in robot parameters. Adaptive control technology can automatically adjust control parameters according to real-time feedback information, so that the robot can track the target trajectory more accurately. For example, in the welding operation of automobile parts, robots need to weld parts with different shapes and positions, and adaptive control technology can adjust the motion parameters of robots in real time to ensure the accuracy of welding trajectory.

Table 1 Comparison of Operational Parameters for Robots under Different Control Methods When Load Changes

Load (kg)	Control Method	Joint Angular Velocity (rad/s)	Joint Torque (N·m)
10	Traditional Fixed-Parameter Control	5.2	20.5
10	Adaptive Control	5.1	20.2
30	Traditional Fixed-Parameter Control	4.5 (with significant fluctuations)	35.6 (with significant fluctuations)
30	Adaptive Control	4.9	34.8
50	Traditional Fixed-Parameter Control	3.8 (with severe fluctuations)	50.1 (with severe fluctuations)
50	Adaptive Control	4.7	48.6

Adaptive control technology is excellent in dealing with the load change of robot. During the working process of industrial robots, their load may change significantly, such as when carrying objects with different weights. If fixed parameter control is adopted, when the load changes, the motion performance of the robot will be seriously affected and may even lead to operational errors. Adaptive control technology can automatically adjust the control strategy according to the real-time change of load, so as to ensure that the robot can run stably and efficiently under different load conditions. See Table 1 for the comparison of operating parameters of the robot under different control modes when the load changes.

In the experiment, the initial load of the robot was set at 10kg, and then gradually increased to 50kg. The operating parameters such as joint angular velocity and joint torque of the robot under the traditional fixed parameter control and adaptive control were compared. As can be seen from the data in the table, when the adaptive control technology is used, the angular velocity of the joint of the robot fluctuates slightly during the load change, and it is always kept in a relatively stable range, and the joint torque can also be adjusted reasonably according to the load, thus ensuring the stability and accuracy of the robot operation. Under the traditional fixed parameter control mode, with the increase of load, the fluctuation of joint angular velocity increases obviously, and the joint torque also changes unreasonably, which seriously affects the running performance of the robot.

In the working scene of fast movement or frequent start-stop, the robot needs to have good dynamic response ability. Adaptive control technology can sense the change of robot's motion state in real time, and adjust the control parameters quickly, so that the robot can respond quickly and smoothly in the dynamic process, reduce vibration and impact, and improve production efficiency and product quality. For example, in the high-speed picking and placing of electronic chips, adaptive control technology can ensure that the robot can still accurately locate and operate at high speed.

4. Precision optimization of industrial robots

As a key index to measure the quality of work, the accuracy of industrial robots covers many dimensions such as positioning accuracy and repetitive positioning accuracy. It is influenced by many factors, which can be mainly attributed to mechanical structure error, thermal deformation error and control algorithm error. The mechanical structure error comes from the manufacturing and assembly process of robot parts. For example, the machining accuracy of the bar is limited, which will lead to the deviation between the actual size and the design size, accumulate errors when the robot moves, and affect the positioning accuracy of the end effector. The assembly clearance of each joint can not be ignored, too large clearance will make the robot shake when moving, which will reduce the accuracy of repeated positioning.

The thermal deformation error can not be underestimated. When industrial robots work continuously for a long time, the components such as motors and reducers will generate heat due to friction, which will lead to structural thermal expansion. Thermal expansion changes the relative position of parts, resulting in additional errors. For example, in the high-speed machining task, thermal deformation may cause the positioning deviation of the robot end to increase gradually, which seriously affects the machining accuracy. The error of control algorithm is mainly reflected in interpolation algorithm and compensation algorithm. Although the simple interpolation algorithm has a small amount of calculation, there is a deviation between the generated trajectory and the ideal trajectory, which affects the motion accuracy of the robot. However, if the compensation algorithm is designed irrationally, it can not accurately estimate and compensate all kinds of errors, and it is difficult to achieve high-precision control.

In order to optimize the accuracy of industrial robots, we need to start from many aspects. In terms of mechanical structure, the manufacturing accuracy of parts is improved, and high-precision machining technology and advanced assembly technology are adopted to reduce the assembly gap. For the thermal deformation error, a temperature sensor can be installed to monitor the temperature change in real time, and the thermal error model can be combined to make real-time compensation. In the control algorithm, a more accurate interpolation algorithm, such as spline curve interpolation, is selected, and at the same time, the compensation algorithm is optimized, and the error compensation accuracy is improved by using advanced sensor data, so as to improve the accuracy of industrial robots in an all-round way and meet the increasingly stringent industrial production requirements.

5. Integration of adaptive control and precision optimization technology

In the development process of intelligent manufacturing, industrial robots are facing more and more complex and diverse task requirements, and it is difficult to meet the requirements of improving their overall performance by single adaptive control or precision optimization technology. The integration of adaptive control and precision optimization technology has become the key path to improve the comprehensive efficiency of industrial robots. Adaptive control technology focuses on enabling the robot to adjust control parameters in real time according to environmental changes to maintain good dynamic performance. Precision optimization technology is mainly aimed at reducing the error of robot in the process of movement and improving the accuracy of positioning and operation. The integration of the two can make the robot not only run stably under complex working conditions, but also ensure high-precision operation.

Taking the car body welding process in automobile manufacturing as an example, the welding task requires the robot to move accurately between parts with different shapes and materials and complete the welding operation. In this process, the robot will face the load change caused by the difference of component materials and the thermal deformation caused by long-term work. At this time, the advantages of the integration of adaptive control and precision optimization technology are highlighted. The adaptive control algorithm can monitor the load change in real time, dynamically adjust the driving torque of robot joints, and ensure the stability of robot movement. Through the real-time perception of thermal deformation, the control parameters are adaptively changed to compensate the errors caused by heat. Precision optimization technology further improves the positioning accuracy of the robot from the aspects of mechanical structure and control algorithm.

Table 2 Comparison of Welding Quality before and After the Integration of Adaptive Control and Precision Optimization Technology

Quality Indicator	Before Integration of Fusion Technology	After Integration of Fusion Technology
Weld Spot Position Deviation (mm)	Average: 0.5, Maximum: 0.8	Average: 0.08, Maximum: 0.1
Weld Bead Width Uniformity (mm)	Fluctuation Range: 0.2-0.4	Fluctuation Range: 0.05-0.1

See Table 2 for the comparison of welding quality before and after the integration of adaptive control and precision optimization technology. In the experiment, the same welding task is set, and the key quality indexes such as the position deviation of welding point and the uniformity of weld width are compared before and after the application of fusion technology. As can be seen from the data in the table, before the application of fusion technology, due to the influence of load change and thermal deformation, the position deviation of welding points was large, reaching 0.5mm on average, and the uniformity of weld width was unstable, with a fluctuation range of 0.2-0.4 mm. After applying the fusion scheme of adaptive control and precision optimization technology, the position deviation of welding point is significantly reduced to less than 0.1mm, and the fluctuation range of weld width uniformity is reduced to 0.05-0.1mm, which greatly improves the welding quality.

6. Conclusions

In this article, the adaptive control and precision optimization technology of industrial robots oriented to intelligent manufacturing are deeply studied, and valuable results are obtained. In the aspect of adaptive control technology, its important application in trajectory tracking control, load change response and dynamic performance improvement of industrial robots is clarified. Through the actual case and comparative data, it can be seen that this technology can make the robot automatically adjust the control parameters according to the real-time working conditions, effectively cope with external interference and the change of its own parameters, and ensure the stable and efficient operation of the robot. For example, adaptive control technology plays a key role in the welding of automobile parts and the picking and placing of electronic chips, which improves the working ability of robots.

For the precision optimization technology, this article analyzes in detail the mechanical structure, thermal deformation and control algorithm that affect the accuracy of industrial robots, and puts forward corresponding optimization strategies. By improving the manufacturing accuracy of parts, adopting real-time thermal error compensation and optimizing control algorithm, the positioning accuracy and repetitive positioning accuracy of the robot can be significantly improved, and the demand for high accuracy in industrial production can be met. More importantly, this article demonstrates the feasibility and significant advantages of the integration of adaptive control and precision optimization technology. Taking the automobile body welding process as an example, the fusion technology can not only deal with the load change and thermal deformation in real time, but also further improve the accuracy and welding quality from the aspects of mechanical structure and control algorithm. By comparing the experimental data, it is clear that after the application of fusion technology, the indexes such as welding point position deviation and weld width uniformity have been greatly improved.

To sum up, adaptive control and precision optimization technology and their integration have an important role in promoting the application of industrial robots in the field of intelligent manufacturing. In the future, we should continue to study relevant technologies in depth to further improve the performance of industrial robots, so as to better meet the needs of the continuous development of the intelligent manufacturing industry and help the manufacturing industry to a higher level.

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