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Explore the Application of Machine Vision Technology in the Automation of Machinery Manufacturing

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Abstract: The continuous acceleration of China's industrialization process has made automation and intelligent technologies increasingly dominant. Implementing these technologies can enhance machining and production efficiency, free up manpower, automate machinery manufacturing processes, and yield greater economic benefits. Thus, this paper outlines the key applications of machine vision technology in modern machinery manufacturing automation. It discusses how machine vision can contribute to core functions such as workpiece measurement, detection, and robot welding, facilitating automation, intelligence, and sustainable development. The aim is for the findings of this paper to offer valuable insights into relevant professions and production processes, thereby catalyzing the pace of mechanical manufacturing automation.

Keywords: Machine vision technology; Machinery manufacturing automation; Importance; Application

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1. Introduction

With the deep integration of information technology and advanced manufacturing, machine vision technology has emerged as a pivotal component in mechanical manufacturing automation. It mimics human visual perception by employing image processing techniques and pattern recognition algorithms to acquire image data and subsequently control production processes. In today's global manufacturing landscape, efficiency, precision, and environmental sustainability are paramount goals, and automation in machinery manufacturing has become indispensable for improving product quality, cost reduction, and enhancing competitiveness. This research delves into the intricate applications of machine vision technology in tasks such as workpiece size measurement, defect detection, and precision welding operations, while also exploring its role in advancing the eco-friendly and intelligent evolution of the manufacturing industry.

2. Overview of machine vision technology

Machine vision technology integrates multiple disciplines, including optics, image processing, pattern recognition, computer science, and artificial intelligence. It aims to equip machines with the ability to "see" and "understand," enabling them to perform various functions such as target detection, recognition, measurement, positioning, and defect detection through the acquisition of image information. In practical applications, machine vision systems typically incorporate key components such as light source illumination, lens imaging, image acquisition cards or embedded image processors, image preprocessing, feature extraction and matching, and deep learning model inference. These components simulate the human visual perception process, demonstrating objectivity, high accuracy, fast speed, and continuous operation [1]. In industrial production lines, machine vision technology is extensively used for product quality control. Additionally, its applications in logistics sorting, automatic driving, drone navigation, medical image diagnosis, agricultural automation, and other fields are significant and contribute to the intelligent upgrading of related industries. This technology lays a solid foundation for the future development of an intelligent society.

3. The importance analysis of mechanical manufacturing automation

Machinery manufacturing automation stands as the cornerstone of modern industrial production, significantly reducing human involvement and dependency on human resources. This, in turn, lowers labor costs and intensity, enabling uninterrupted 24-hour production. Through precise and efficient automated assembly lines and intelligent robot operations, it effectively shortens product manufacturing cycles and enhances order delivery speed, customer satisfaction, production capacity, and overall enterprise competitiveness. Simultaneously, as relevant technologies continually advance, automation systems ensure product quality consistency and stability via precise control and real-time monitoring. This helps reduce product defects caused by human factors, aiding enterprises in meeting stringent quality requirements.

Furthermore, the liberation of labor allows for a better production environment, reducing labor intensity and shifting focus towards higher-level technology research and development, quality management, and production optimization. This, in turn, promotes industrial upgrading and talent structure transformation [2]. The author believes this aligns well with current societal emphasis on "green" and "conservation," fostering green and sustainable mechanical production, expanding economic benefits, and ensuring ecological balance.

Through intelligent control systems and precise monitoring equipment, automated production achieves accurate monitoring and management of energy consumption, maximizing energy utilization and savings. Additionally, automated production lines effectively reduce waste and pollutant generation and emission, facilitating green production and sustainable development. This meets crucial societal demands for environmental protection and sustainable development.

From an economic and national development standpoint, the widespread adoption and development of machinery manufacturing automation hold strategic significance in enhancing national manufacturing industry competitiveness. Amidst fierce global competition, enterprises equipped with advanced automated production lines can reduce costs and improve efficiency, swiftly responding to market demand changes, personalized customization, and large-scale flexible production. Consequently, they expand market share, making this sector a key battleground for global development and investment competition among nations.

4. Application of machine vision technology in mechanical manufacturing automation

4.1. Job measurement

Workpiece measurement stands as a pivotal step in ensuring product quality, accuracy, and consistency. Traditional contact measurement methods, however, may face limitations in terms of speed, accuracy, and adaptability to complex geometries. In the realm of mechanical manufacturing automation, machine vision technology offers significant advantages in workpiece measurement. Specifically, a dedicated machine vision system is integrated into the automated production line, equipped with hardware facilities like high-resolution industrial cameras, precision optical lenses, and suitable light sources to capture clear, distortion-free workpiece images [3]. Advanced image processing algorithms such as edge detection, template matching, or deep learning-based feature recognition technology are then employed to precisely extract key geometric feature information from the images.

For instance, when detecting the length, width, diameter, or angle of a part, machine vision software can analyze boundary pixels in the image to locate the workpiece outline and calculate corresponding geometric parameters. In the case of more intricate 3D workpieces, multi-view imaging or multi-sensor fusion technology may be combined to acquire comprehensive and accurate spatial data for three-dimensional dimensional measurement. Additionally, machine vision technology can monitor real-time position and attitude changes of the workpiece on the production line, providing accurate guidance for subsequent processing and assembly, thereby effectively reducing scrap rates and repair costs.

Evidently, this highly automated measurement method significantly enhances the controllability and flexibility of the production process, thereby promoting the high-quality development of the machinery manufacturing industry [4]. The application of machine vision technology in workpiece measurement not only enhances production efficiency and product quality but also fosters more innovation and development opportunities for the manufacturing industry. With the continuous maturation of artificial intelligence and big data technology, the prospects for machine vision systems have become broader. In the future, as intelligent manufacturing advances, machine vision technology will play an even more significant role. For instance, combined with the Internet of Things (IoT) technology, it can achieve remote monitoring and intelligent management, making the production process more intelligent and automated. Moreover, with the ongoing development of deep learning and other technologies, the machine vision system's ability to identify and measure complex workpieces will be further enhanced, meeting higher accuracy requirements.

4.2. Job detection

Similarly, in the application of machine vision technology in workpiece inspection, advanced machine vision systems are configured with high-resolution cameras, customized light sources to ensure imaging quality, and specially designed optical lenses to accommodate various sizes and shapes of workpieces. A suitable detection point is established on the production line to capture real-time image information of the workpiece, which is then transmitted to the backend computer for processing. The software should be equipped with image analysis algorithms to deeply analyze the acquired image data, swiftly identifying small defects such as cracks, scratches, dents, color differences, shape deviations, and other surface imperfections on the workpiece.

Moreover, the integration of deep learning and artificial intelligence technology enables self-optimization and enhances detection accuracy, allowing for precise judgment even with complex and diverse products. By incorporating machine vision technology into the workpiece inspection process of mechanical manufacturing automation, not only can 24/7 uninterrupted high-speed online detection be achieved, significantly elevating the level of product quality control, but it can also substantially reduce labor costs and minimize the occurrence of defective products caused by human error, thereby ensuring the stability and continuity of the entire production process [5].

Furthermore, machine vision technology can expand its functionalities and applications in workpiece inspection. For instance, through three-dimensional scanning and measurement of the workpiece surface, accurate analysis of the shape, size, and profile of the workpiece can be achieved, further enhancing product quality and accuracy. Additionally, the machine vision system can be integrated with robotics to achieve automatic grasping and assembly, thereby improving the efficiency and flexibility of the production line [7].

4.3. Robot welding

Machine vision technology achieves highly intelligent control of the welding process by integrating a high-precision optical imaging system and advanced image processing algorithms. During the pre-processing phase of the workpiece, the machine vision system accurately identifies the position, shape, and size information of the weld. Through real-time images captured by the camera, the software algorithm swiftly analyzes and calculates the welding path and parameters, ensuring precise robot positioning. This is particularly advantageous for complex geometric shapes or irregular welds.

In the actual welding process, machine vision technology can monitor welding quality in real time. By observing the shape of the weld pool, spatter, and the appearance of the welded joint, the system quickly provides feedback on the welding effect, automatically adjusting welding current, voltage, speed, and other process parameters according to preset standards to achieve accurate welding and reduce defective product generation. Furthermore, machine vision technology combined with the robot motion control system can achieve dynamic tracking welding. Even with minor thermal deformation or assembly errors of the workpiece during welding, the vision system can promptly detect these changes and guide the robot to make corresponding compensatory actions, ensuring precise execution of the welding trajectory [7].

The application of machine vision technology in robot welding extends beyond workpiece pretreatment and welding quality monitoring. It enables more intelligent control and optimization of the welding process. On one hand, the machine vision system can monitor and analyze thermal deformation and assembly errors occurring during welding in real time, adjusting welding parameters and attitude to achieve accurate welding path control. This enhances welding efficiency and quality while preventing welding defects caused by workpiece deformation. On the other hand, machine vision technology, in conjunction with other sensors and control systems, can handle more complex welding tasks. For instance, in an automated welding production line, the machine vision system can collaborate with devices such as force sensors and laser rangefinders to control welding force and weld spacing. By monitoring mechanical characteristics and dimensional deviations during welding, the machine vision system can adjust welding parameters promptly to ensure welding quality meets requirements.

Additionally, machine vision technology can combine machine learning and artificial intelligence algorithms to achieve intelligent optimization and fault diagnosis of the welding process [8]. By analyzing extensive welding process data, the machine vision system continuously optimizes welding parameters and attitudes to enhance welding quality and efficiency. It can also automatically identify welding defects, predict potential welding failures, and take preemptive measures to correct and prevent them. As artificial intelligence technology and machine vision algorithms continue to advance, the field of robot welding will witness further innovation and breakthroughs. Future machine vision systems may enable higher precision welding path planning and real-time control, more accurate welding quality assessment and defect detection, and more intelligent fault diagnosis and prediction capabilities.

Clearly, the application of machine vision technology in robot welding not only enhances product quality and production efficiency but also aligns with the high-quality requirements of modern industry. It is an indispensable key technology for future smart factories, further enhancing the automation level and production efficiency of robot welding, and promoting industrial manufacturing towards a more intelligent, efficient, and sustainable direction [9-11].

4.4. Green development

With the continuous improvement of industrial production requirements for environmental protection, energy saving, and sustainability, the importance of machine vision systems is becoming increasingly prominent. With their significant advantages of reducing resource consumption, optimizing process flow, and reducing environmental pollution, they have also become key technologies for research, development, and optimization processes in the industry.

Firstly, machine vision systems play a crucial role in identifying and positioning raw materials to ensure the precise operation of pre-treatment stages such as cutting and stamping, thereby reducing unnecessary material loss and waste generation, saving resources, and reducing the cost of solid waste treatment. For instance, in plate processing, high-precision visual measurement enables on-demand cutting, thus avoiding excessive cutting and edge waste in large areas. Surface defect detection and dimensional accuracy inspection allow problematic products to be removed before entering the next process, thereby avoiding subsequent energy consumption and potential environmental pollution. This improves overall production efficiency and reduces rework and scrap rates [12-14]. Another example is the real-time feedback of weld position, molten pool status, and welding effect in robot welding, ensuring product quality and effectively reducing energy consumption increase and harmful smoke emission caused by excessive heat input. Intelligent maintenance and predictive maintenance functions can detect equipment failure risks in advance, arrange maintenance promptly, and prevent energy waste and accidental emissions of pollutants caused by sudden downtime, further promoting energy conservation and emission reduction goals.

As machine vision systems are widely applied in industrial production, their role in environmental protection, energy saving, and sustainability becomes increasingly prominent. Apart from raw material identification and processing applications, machine vision systems also play crucial roles in product assembly, quality inspection, logistics management, and other aspects. In the product assembly stage, they enable automatic alignment and assembly of parts, enhancing assembly efficiency and accuracy, while avoiding incorrect assembly and resource waste due to human error. Real-time monitoring of assembly process issues allows timely adjustments, improves assembly quality, reduces the rate of defective products, and minimizes resource consumption and waste generation.

In terms of quality inspection, machine vision systems replace manual visual inspection to achieve faster and more accurate product quality assessment. Through high-precision image analysis technology, they detect surface defects and dimensional deviations, ensuring products meet standard requirements, enhancing customer satisfaction, and reducing resource waste caused by after-sales service and return processing. In logistics management, machine vision systems enable intelligent warehouse management and cargo tracking, facilitating real-time monitoring and management of logistics information. By identifying cargo barcodes and packaging status, they enhance warehousing efficiency, reduce erroneous shipments and logistics congestion, cut energy consumption and transportation costs, and steer the logistics industry toward a more intelligent and efficient direction.

These applications serve as crucial foundations for the green and low-carbon modern machinery manufacturing industry, warranting further in-depth research and practical exploration [15].

5. Conclusion

In summary, the extensive utilization of machine vision technology in machinery manufacturing automation has significantly propelled the transformation of the manufacturing industry to a higher echelon. From precise workpiece measurement to high-precision quality inspection, from flexible and efficient robotic welding operations to sustainable green manufacturing practices, machine vision technology continuously enhances the efficiency and quality of mechanical manufacturing with its unique advantages. Looking ahead, with the ongoing optimization of machine vision algorithms, the technology will unleash even greater potential in machinery manufacturing automation, providing robust technical support and driving innovation for the transformation and upgrading of China's and even the global manufacturing industry. Concurrently, bolstering research and development in machine vision technology will aid in constructing a more intelligent and environmentally friendly new manufacturing system, warranting in-depth exploration and practical implementation.

Disclosure statement

The author declares no conflict of interest.

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