

The Application of Intelligent Robot Numerical Control Technology in Medical Equipment Manufacturing

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Abstract: The traditional manufacturing methods of medical devices have gradually revealed some significant drawbacks under the rapid development of modern technologies and the constantly evolving societal needs. These issues are particularly evident in the heavy reliance on manual labor during the manufacturing process, which introduces certain errors and instability. Human mistakes can easily lead to product quality defects and resource wastage. Furthermore, due to constraints related to labor quantity and skill levels, the production efficiency of medical devices is low, and the precision of the equipment is insufficient, which severely limits the improvement of healthcare standards. In response to these challenges, the application of intelligent robotic CNC technology in medical device manufacturing has become a growing trend. This paper explores the value of this technology, analyzes the current state of the industry, and aims to promote the healthy and sustainable development of the medical device manufacturing sector.

Keywords: Intelligent Robots; CNC Technology; Medical Devices; Applications.

1. Introduction

Traditional manufacturing methods for medical devices have gradually revealed some significant drawbacks under the rapid development of modern technologies and the continuously changing societal demands. Intelligent robotic CNC technology provides a new solution with considerable significance for medical device manufacturing, better meeting today's healthcare needs. With the rapid advancement of science and technology, the application of intelligent robotic CNC technology enables highly precise production and processing, reducing the impact of human factors on product quality. It aligns with the industry's trend toward smart, automated, and precise manufacturing and can effectively enhance production efficiency and product quality.

2. Intelligent Robotic CNC Technology

2.1. Characteristics of Intelligent Robotic CNC Technology

CNC technology, combined with digital control systems, is applied in advanced manufacturing fields and primarily used to control the movement and operation of industrial machinery. It is a new type of technology that integrates multiple disciplines, including computer technology [1], automatic control technology, and mechanical manufacturing technology. The technology controls the relative movement between tools and workpieces in the form of digital signals, thus achieving high precision and high-efficiency processing and manufacturing.

It consists of two main parts: the CNC system and the CNC machine tool. The CNC system is the core of CNC technology and is composed of embedded computers and related software. It is responsible for receiving program instructions input by the operator, monitoring and managing the processing procedure, and controlling the movement and operation of the CNC machine tool. The CNC machine tool processes and manufactures workpieces according to system instructions through servo motors, drive devices, and tools.

To further replace tedious manual operations, intelligent robotic CNC technology has emerged and is widely applied in various mechanical manufacturing fields such as automated assembly, precision intelligent processing, and CNC milling machines. This leads to the automation and intelligent upgrading of the traditional medical device manufacturing process. Its main characteristics include:

(1) Automation: With the introduction of intelligent robots, the degree of automation in equipment manufacturing is further enhanced. This is reflected in the replacement of basic manual tasks, with robots being capable of handling prolonged and tedious processing operations while maintaining high efficiency. Over time, as robots replace manual labor, they significantly reduce labor costs for manufacturing enterprises. Furthermore, compared to traditional manual labor, intelligent robots follow predefined programs rigorously, thereby avoiding human errors that may arise from long hours of repetitive tasks. As a result, the quality standards and delivery requirements show minimal variation, leading to an increase in product yield rates [2].

(2) Integration: After the application of intelligent robotic CNC technology, the operation system undergoes intelligent transformation. Using integrated technology, the system combines various manufacturing-related modules into a unified operating platform. This is demonstrated by the integration of different mechanical structures, actuators, and sensors into a highly integrated hardware system. Intelligent robotic CNC technology uses software programming to control and guide the robot. The components can acquire task objectives, analyze environmental information, make decisions, and perform corresponding actions. Different software modules can be integrated into a single control system, enabling automated robotic operations. The system collects and processes data generated during robot operations in real time, and through integration with other systems (such as the factory ERP system and supply chain system), seamless connectivity with other devices and systems is achieved, thereby enhancing the automation level and efficiency of production.

(3) Precision: With the increasing demand for higher product quality standards, the requirements for manufacturing precision in mechanical production have also risen. Intelligent robotic CNC technology achieves precise machining by setting the corresponding parameters for the desired product and executing relevant operations. In precision processing fields, it can even achieve nanoscale accuracy.

2.2. Advantages and Current Status

Format and save your graphic images using a suitable graphics processing program that will allow you to create the images as PostScript (PS), Encapsulated PostScript (EPS), or Tagged Image File Format (TIFF), sizes them, and adjusts the resolution settings. If you created your source files in one of the following you will be able to submit the graphics without converting to a PS, EPS, or TIFF file: Microsoft Word, Microsoft PowerPoint, Microsoft Excel, or Portable Document Format (PDF).

The advantages of combining intelligent robots with CNC technology lie in improving product quality and production efficiency, as well as diversifying product types. Compared to the traditional labor-intensive manufacturing model, these advantages are becoming increasingly apparent and better align with the current needs in the equipment production field. The advantages are: first, optimizing product quality. Intelligent robots, assisted by CNC systems, set machining parameters and perform precise measurements, inspections, and feedback during the process, reducing quality fluctuations caused by human factors[3]. Additionally, the CNC system supervises the entire process and proactively prevents potential production issues, improving product consistency and stability. Second, enabling precision manufacturing. Intelligent robots simulate the production of possible samples before actual production, which is particularly significant for high-risk machining operations. Furthermore, robots can flexibly adjust their working modes and machining parameters as needed, adapting to different work requirements and changes, thus enhancing the flexibility and adaptability of the production line. Third, increasing efficiency. In comparison to the traditional manufacturing model that requires large amounts of labor and physical resources for each part, this production model can tailor different production processes based on the characteristics of the components, greatly simplifying the overall process and eliminating unnecessary steps. It better meets the current needs for automation and intelligent transformation in equipment production.

3. Current Status of the Medical Device Manufacturing Industry

In 2022, the market size of China's medical device industry reached 958.2 billion RMB, with a compound annual growth rate of approximately 17.5% over the past seven years. The industry has formed a large-scale, well-structured, and technologically advanced system. From a market size perspective, China has become the second-largest medical device market in the world, after the United States.

Although the supply chain in China is relatively complete with clear divisions of labor, certain high-end medical devices, such as medical imaging equipment, pacemakers, and artificial joints, are still heavily reliant on imports from large foreign companies due to technological monopolies. These devices involve considerable complexity and precision,

requiring an entire production line, as well as the collaboration of intelligent robots and CNC systems, which presents a challenge for domestic manufacturers. Domestic medical device manufacturers mainly supply mid- to low-end products, such as ultrasound devices, electronic endoscopes, and hemodialysis equipment. However, most companies still use conventional machine tools for production, resulting in low levels of automation and intelligence. This often leads to dimensional deviations in parts, and after assembly, the overall quality of the devices may be difficult to ensure, which in turn lowers product performance, service life, and even affects therapeutic efficacy [4].

In recent years, multiple government departments in China have encouraged and prioritized the transformation and upgrading of medical device manufacturing enterprises. The "14th Five-Year Plan for the Development of the Pharmaceutical Industry" outlines the overall goal of enhancing innovation-driven growth by 2025, significantly improving the modernization level of the industrial chain, strengthening the medical and pharmaceutical supply guarantee system, and advancing internationally towards high-end sectors. The plan also emphasizes the development of new medical imaging, in vitro diagnostics, and disease rehabilitation devices, while accelerating the application of artificial intelligence and other information technologies in medical equipment. Furthermore, the plan highlights the focus on developing engineering technologies to enhance product stability and reliability, as well as digital technologies for medical devices.

The integration of intelligent robotic CNC technology with medical device manufacturing can effectively address the shortcomings of traditional manufacturing methods, aligning with the goals outlined in the "14th Five-Year Plan" for the pharmaceutical industry. At the same time, the transformation of production lines towards smarter, more automated, and systematized operations actively supports the national push for intelligent manufacturing.

4. Application of Intelligent Robot CNC Technology in the Medical Device Manufacturing Industry

4.1. Medical Imaging

The integration of intelligent robot CNC technology with medical imaging enables the storage of large amounts of medical imaging data in specific network resources. Using DSA (Digital Subtraction Angiography) and sensors, real-time contour data of the patient's affected area can be captured, aligned, and fused. Simultaneously, by analyzing the patient's contour and posture information, the imaging device parameters can be automatically adjusted. For example, the system can automatically optimize the positions, angles, and exposure parameters of the radiation source and detector based on the patient's height, weight, and body type. It can also identify and track changes in the patient's posture, correcting the posture during the image acquisition process to achieve better image quality. Finally, irrelevant areas are removed, and the image is enhanced, assisting physicians in diagnosing the patient's condition and reducing the rate of misdiagnosis.

4.2. Robot Arm

With the development of technology, the application of intelligent robotic arms in medical equipment manufacturing

has become increasingly widespread, with the CNC system serving as the core of the entire process. The robotic arm mimics most of the operations performed by the human hand, utilizing various communication technologies, and is characterized by flexibility and high precision.

4.3. Control of Medical Equipment

Modern medical equipment typically features complex designs and functionalities, involving the coordination of multiple components and software systems, and requires connection to the internet and other systems. This complexity can lead to potential vulnerabilities and defects, making the equipment more susceptible to attacks or failures. The manufacturing process involves multiple links in the supply chain, which may include components and software from different suppliers, making it impossible to guarantee the security of every step. Various factors often create security risks in some medical devices. Therefore, the application of intelligent CNC technology to the safety mechanisms of medical equipment—integrating advanced artificial intelligence and automation technologies—can enhance the safety, reduce failure rates, and improve the efficiency of use, while ensuring the safety of both patients and healthcare personnel through real-time monitoring, automatic judgment, and handling of abnormal situations[5].

The specific manifestations are as follows:

(1) Real-time Monitoring: Intelligent CNC technology employs various sensors to monitor the operational status and environmental parameters of medical equipment in real-time. For example, surgical robots use cameras and other sensors to monitor the surgical area and the patient's condition, while monitoring devices track physiological parameters such as heart rate and respiration rate. Real-time monitoring allows the system to quickly detect anomalies.

(2) Automatic Judgment: The intelligent CNC system analyzes and processes real-time monitoring data using advanced algorithms and models. By comparing the current data with predefined safety standards or reference data, the system automatically judges whether an anomaly exists. For instance, a surgical robot may automatically detect unexpected surgical interference, while a monitoring device automatically evaluates whether the patient's physiological parameters exceed safe limits.

(3) Handling Abnormal Situations: When the system detects anomalies, intelligent CNC technology autonomously decides to take automatic or semi-automatic actions to address the issue. This may include automatically stopping the equipment, triggering alarms, or providing warning information to healthcare personnel through human-machine interfaces. In some emergency situations, corrective measures may be automatically taken to restore the equipment to a safe state.

(4) Self-learning Capability: The intelligent CNC system has the ability to continuously learn and update its algorithm models to adapt to new equipment characteristics and complex medical scenarios. This improves the system's adaptability and accuracy, helping to better address various safety challenges.

(5) Data Recording and Analysis: The system records and analyzes the data from the equipment's operational process for post-event analysis. This helps identify potential issues and improve the device's performance. Additionally, the data can be used to formulate better safety strategies and guide future device design and improvements.

4.4. Production of Medical Device Accessories

With the widespread adoption of intelligent robotic CNC technology in mechanical manufacturing, its use of computer control systems to achieve automated control of robots allows for efficient production of medical device accessories while improving precision and quality.

Intelligent robots, based on pre-set programs, automatically complete various processes such as machining, cutting, and polishing, reducing the need for manual labor and significantly improving production efficiency. Moreover, they offer higher consistency and accuracy. Compared to traditional manufacturing methods, intelligent robotic CNC systems have lower maintenance costs, longer service lives, and can reduce the reliance on manual operations, leading to labor cost savings. In a shorter amount of time, they can complete large-scale production tasks, minimizing production time and resource waste.

In terms of intelligence, intelligent robotic CNC technology possesses advanced features and flexibility. Through intelligent interconnection with other devices and systems, it enables data sharing and real-time monitoring. It provides production management and control functions, allowing for flexible adjustments and customized production based on different requirements, thus meeting the diverse needs of customers.

5. Future Vision

Currently, China has gradually applied intelligent robotic CNC technology in the mechanical manufacturing sector. However, in the field of medical device manufacturing, the application is still predominantly focused on low- and mid-end medical devices. High-end products require advanced CNC technology and the integration and coordination of various production lines and equipment, which means research is still in its early stages.

In the future, medical device manufacturing companies should increase investment in the research and application of intelligent robotic CNC technology. They need to actively participate in domestic and international technological cooperation and transformation, striving for more research funding and professional talent support. Strengthening the internal technical research and development teams, recruiting and training talent with backgrounds in intelligent robotic CNC technology, will be essential. It is also crucial for companies to closely monitor the domestic and international market demands for medical devices and technological development trends, adjusting corporate strategies and product structures in a timely manner to ensure that they meet market needs and enhance competitiveness.

For the entire industry, intelligent robotic CNC technology is an inevitable trend in medical device manufacturing. By utilizing advanced technology to reduce reliance on manual labor for basic and tedious tasks, this approach will minimize errors and risks caused by human factors. It will encourage the medical device manufacturing industry to collaborate with multiple related disciplines, continuously break through challenges in frontier fields, achieve innovative results, improve the quality and performance of medical devices, and provide more advanced medical solutions.

6. Conclusion

In summary, the application of intelligent robotic CNC technology in medical device manufacturing has brought

revolutionary changes and profound impacts to the industry. By integrating intelligent robots and CNC technology, medical device manufacturers can achieve more efficient, precise, and reliable production processes.

Firstly, intelligent robots are capable of performing complex, precise, and repetitive tasks such as component manufacturing, assembly, and testing, thus improving production efficiency and reducing labor costs. Secondly, intelligent robots offer high precision and reliability, ensuring consistency in product quality and performance. Additionally, they provide a safer working environment, reducing the risk of human operators working in hazardous environments.

Moreover, with the introduction of digital control systems, manufacturers can achieve precise motion control and process management, ensuring product accuracy and stability. CNC technology also enhances automation, reducing manual intervention and errors, thereby improving product quality and work efficiency. However, challenges and limitations still exist in medical device manufacturing, particularly in terms of technical complexity and maintenance difficulty, as well as employee acceptance and adaptation to technological changes.

To achieve broader application, it is essential for manufacturers and industry stakeholders to collaborate, overcoming technical and managerial challenges, and establishing comprehensive policies and standards to promote the continuous innovation and development of intelligent

robotic CNC technology in medical device manufacturing.

References

- [1] Jiao B. A review of research into the intelligent development of the discipline of mechanical and electrical engineering[J]. *Journal of Electrotechnology, Electrical Engineering and Management*, 2022, 5(1): 27-34..
- [2] Bian Renpeng, Jia Zhixin, He Ketai. Reliability Prediction and Verification of the CNC Punching Machine Loading and Unloading Gantry Robot [J/OL]. *Journal of Harbin Engineering University*: 1-10 [2023-08-03]. <http://kns.cnki.net/kcms/detail/23.1390.U.20230526.1328.002.html>.
- [3] Zhu Kunfu. Analysis and Thoughts on Medical Equipment Manufacturing Based on Intelligent Robot Numerical Control Technology [J]. *Shanghai Light Industry*, 2023(01): 138-140.
- [4] Zheng Dongmei, Wang Qingxi. Reliability Study of Industrial Robots in CNC Machine Tool Processing of Medical Devices [C] // *Hong Kong Kangjian Pharmaceutical Co., Ltd. Proceedings of the 2017 Boao Medical Forum*. [Publisher Unknown], 2017: 246.
- [5] Wen Shanshan. Research on Robot and CNC Control Technology for Intelligent Manufacturing [C] // *Tianjin Electronic Publishing House Co., Ltd. Compilation of Academic Achievements in Education for the New Era of Education*. [Publisher Unknown], 2019: 291+285. DOI: 10.26914/c.cnkihy.2019.020915.