Intelligent Inspection Technology of Ring Network Cabinet Holographic Sensing Based on Multi-Sensor Fusion

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Abstract: As the key equipment of urban power supply network, the ring network cabinet has a complex internal environment, and the traditional inspection method is facing difficulties. In this article, the holographic sensing intelligent inspection technology of ring network cabinet based on multi-sensor fusion is studied. By integrating multi-sensor technology, multi-sensor fusion technology and three-axis navigation and positioning technology, this article designs an intelligent inspection robot. This article studies and analyzes the relevant technical basis, including the principle of multi-sensor technology, the connotation of multi-sensor fusion technology and the key points of three-axis navigation and positioning technology, and completes the hardware architecture, sensor layout and functional module design of the robot. This article explores the technical innovation, and the research results provide a new way to improve the efficiency and accuracy of the inspection of ring network cabinets, and promote the intelligent development of the inspection technology of urban power supply network.

1. Introduction

As the core hub of urban power supply network, the stable operation of ring network cabinet plays a key role in ensuring the reliability and sustainability of urban power supply [1]. Due to the complex internal structure, dense electrical equipment, various electromagnetic interference, temperature and humidity changes and other factors, it constitutes an extremely complex internal environment [2]. Traditional inspection methods, whether manual regular inspection or simple automatic inspection, are facing many insurmountable difficulties. Manual inspection is not only inefficient, but also limited by people's subjective factors and physiological limits, so it is difficult to comprehensively and accurately detect the potential faults in the ring network cabinet [3]. Simple automatic detection can't comprehensively analyze various parameters in complex environment because of single technology, which leads to one-sidedness and limitation of detection results.

Under the above background, it is of great practical significance to study and promote the application of multi-state sensing intelligent inspection device for ring network cabinets [4]. From the economic point of view, accurate and efficient inspection can find and solve the faults of ring network cabinets in time, which can avoid huge economic losses caused by power failure accidents and ensure the normal order of power consumption in industrial production and residents' lives [5]. From the social level, reliable power supply is the foundation of stable social development, and advanced inspection technology is helpful to improve the quality of power supply service and enhance the public's satisfaction and trust in power supply.

Many scholars and scientific research teams have carried out a lot of research work on the inspection technology of ring network cabinets. Some developed countries have made some achievements with advanced sensor technology and automation control concept in the early stage, but there are still some problems such as high equipment cost and poor adaptability [6]. China related research has developed rapidly in recent years. However, the existing technology still has obvious shortcomings in multi-parameter fusion analysis, precise positioning and navigation in complex environment and so on.

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Based on multi-sensor fusion technology, this study aims to integrate multi-sensor technology, multi-sensor fusion technology and three-axis navigation and positioning technology, and design an intelligent inspection robot with comprehensive and accurate ability to perceive the internal environment of the ring network cabinet. This research not only has a solid theoretical foundation, but also has significant practical significance. It is committed to breaking through the bottleneck of traditional inspection methods, improving the intelligent level of inspection of ring network cabinets, and providing a strong guarantee for the safe and stable operation of urban power supply networks.

2. Theoretical cornerstone of intelligent inspection technology

Multi-sensor technology provides a rich source of information for intelligent inspection. Different types of sensors, such as temperature sensor, humidity sensor, partial discharge sensor, etc., respectively monitor different physical parameters inside the ring network cabinet [7]. Based on the thermal effect principle, the temperature sensor can accurately measure the temperature change of the key parts of the ring network cabinet, and provide a basis for judging whether the equipment is overheated due to overload and other reasons. The humidity sensor monitors the internal humidity in real time based on the influence of water molecules on the electrical properties of specific materials to prevent the insulation performance from decreasing due to excessive humidity.

Multi-sensor fusion technology is to comprehensively process the information obtained by various sensors. This technology organically fuses the information collected by different sensors through specific algorithms, such as weighted average method and Kalman filter method. In this way, the one-sidedness and uncertainty of single sensor information can be effectively overcome, and the accuracy and reliability of judging the running state of the ring network cabinet can be improved.

Three-axis navigation and positioning technology provides accurate navigation and positioning support for the intelligent inspection robot to move in the complex space inside the ring network cabinet [8]. Through three-axis accelerometers, gyroscopes and other equipment, the robot can perceive its own posture and position changes in real time, and realize autonomous and accurate movement in combination with the preset inspection path planning, so as to ensure comprehensive inspection of all key parts inside the ring network cabinet.

3. Design of holographic sensing intelligent inspection robot for ring network cabinet

The design of intelligent inspection robot with holographic perception for ring network cabinet aims to break through the limitations of traditional inspection methods and realize comprehensive and accurate perception of the internal environment of ring network cabinet by integrating various advanced technologies. This design covers many key aspects such as hardware architecture, sensor layout and functional module planning.

(1) Hardware architecture design

The hardware architecture of the robot is the basic support for its efficient inspection. The overall architecture adopts modular design concept to facilitate maintenance and upgrading. It is mainly composed of a main frame, a driving system, a sensor integration module, a data processing unit and an energy supply module (see Table 1). The main frame is made of light and high-strength alloy materials, which can reduce the robot's own weight and improve its movement flexibility while ensuring the stability of the structure. The driving system adopts four-wheel independent driving mode, which can realize various motion postures such as forward, backward, steering and in-situ rotation, so as to adapt to the complex spatial layout inside the ring network cabinet.

Table 1 Hardware Architecture Composition of the Holographic Sensing Intelligent Inspection Robot for Ring Main Units

Hardware Component	Function Description
Main Frame	Made of lightweight and high-strength alloy materials, providing a stable supporting structure
Drive System	Four-wheel independent drive, enabling various motion postures to adapt to complex spaces
Sensor Integration Module	Integrates various sensors to collect internal environmental parameters of the ring main unit
Data Processing Unit	Processes and analyzes sensor data to make decisions and judgments
Energy Supply Module	Provides stable power to ensure continuous operation of the robot

(2) Sensor layout design

The sensor layout is directly related to the comprehensiveness and accuracy of the robot's acquisition of the internal environmental information of the ring network cabinet. At the front end of the robot, a high-definition camera and an infrared thermal imager are installed to monitor the physical state and temperature distribution on the surface of the equipment in real time. Partial discharge sensors and temperature sensors are arranged at the key electrical connection parts inside the ring network cabinet to capture partial discharge signals and temperature changes in real time and find potential electrical faults in time (see Table 2). Temperature and humidity sensors are distributed around the robot to obtain the overall temperature and humidity environment information inside the ring network cabinet.

Table 2 Sensor Layout and Monitoring Parameters of the Holographic Sensing Intelligent Inspection Robot for Ring Main Units

Sensor Location	Sensor Type	Monitoring Parameter
Front End	High-Definition Camera	Physical state of equipment surfaces
	Infrared Thermal Imager	Temperature distribution
Key Electrical Connection Points	Partial Discharge Sensor	Partial discharge signals
	Temperature Sensor	Temperature changes
Around the Robot	Temperature and Humidity Sensor	Temperature and humidity environmental information

(3) Functional module planning

The functional module planning of the robot revolves around three core links: data acquisition, data analysis and processing and fault early warning. The data acquisition module is responsible for coordinating all sensors and collecting all kinds of environmental parameters and equipment operation data inside the ring network cabinet according to the preset time interval and sampling frequency. The data analysis and processing module uses multi-sensor fusion technology to deeply analyze the collected data and dig out the potential correlation and fault characteristics behind the data. According to the data analysis results, the fault early warning module sends out an early warning signal in time when abnormal data is detected, and transmits the fault information to the monitoring center through the wireless communication module, so that the operation and maintenance personnel can take corresponding measures quickly to ensure the safe and stable operation of the ring network cabinet. Through this series of closely coordinated functional modules, the intelligent inspection robot with holographic perception of ring network cabinet can complete the inspection task of ring network cabinet efficiently and intelligently.

4. Research on technological innovation

The holographic sensing intelligent inspection technology of ring network cabinet shows remarkable innovation characteristics in many dimensions. These innovations not only improve the efficiency and accuracy of inspection, but also bring new breakthroughs in the field of monitoring

the operation status of ring network cabinet.

(1) Inspection robot aiming at the internal environment of ring network cabinet

As an inspection robot specialized for the internal environment of ring network cabinet in the industry, its design and function are unique and innovative. Traditional inspection equipment is mostly universal, so it is difficult to optimize the complex and special environment inside the ring network cabinet. The structure and algorithm of this robot are tailored around the internal environment of the ring network cabinet.

The shape design of the robot fully considers the narrow and irregular spatial layout inside the ring network cabinet, and adopts a compact and flexible structure, which can freely shuttle in a limited space and reach corners that are difficult for traditional equipment to reach. In terms of perception, it integrates a variety of high-precision, miniaturized sensors, which can work stably under severe conditions such as strong electromagnetic interference inside the ring network cabinet after special adjustment, and accurately obtain all kinds of key data.

(2) Three-axis orbit micro-control system

Three-axis track micro-control system is one of the core innovative technologies for intelligent inspection robot to realize accurate positioning and efficient inspection. By accurately controlling the robot's trajectory in 3D space, the system enables the robot to conduct a comprehensive inspection of the interior of the ring network cabinet according to the preset optimal path.

In the three-axis track micro-control system, the X, Y and Z axes respectively correspond to different spatial dimensions inside the ring network cabinet (see Figure 1 for details). The X-axis is mainly responsible for the linear movement of the robot in the horizontal direction, and it can quickly scan along the length direction of the ring network cabinet to realize the comprehensive monitoring of the side equipment of the cabinet. The Y axis controls the robot to move in the direction perpendicular to the side of the cabinet, so that the robot can flexibly adjust the distance from the detected equipment to ensure clear and accurate detection data. When detecting the electrical connection points deep inside the cabinet, the accurate control of Y axis can make the sensor in the best detection position. The Z-axis is responsible for the vertical lifting movement of the robot, which adapts to the inspection requirements of equipment with different heights in the ring network cabinet. Whether it is the grounding device at the bottom or the bus bar at the top, the robot can realize accurate detection through the adjustment of the Z-axis.

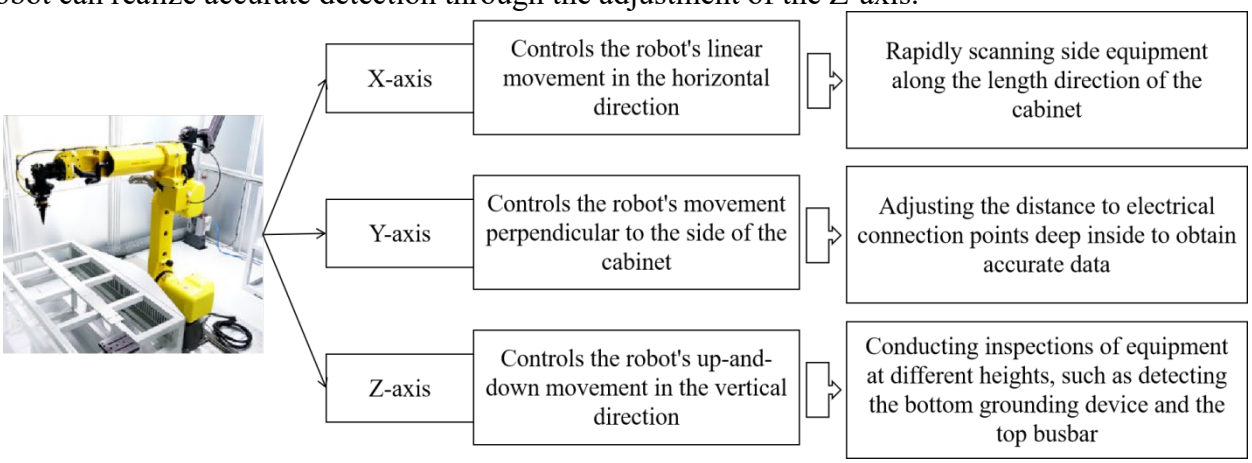

Figure 1 Functions and application scenarios of each axis of three-axis track micro-control system

This three-axis coordinated micro-control system, combined with advanced positioning algorithm, makes the positioning accuracy of the robot reach millimeter level, which greatly improves the accuracy and reliability of inspection. Compared with the traditional inspection method, it greatly reduces the blind spot of inspection and ensures that every key part in the ring network cabinet can be effectively detected.

(3) Multi-sensor fusion and intelligent data analysis algorithm

This technology innovatively adopts advanced multi-sensor fusion algorithm to deeply fuse and analyze data from different types of sensors. In the traditional inspection process, all kinds of sensor

data are often processed independently, which can not fully explore the potential relationship between data. Through intelligent algorithm, the system comprehensively analyzes various data such as temperature, humidity, partial discharge and image, and constructs a multi-dimensional model of the running state of the ring network cabinet. When the temperature sensor detects an abnormal temperature rise in a certain area, the algorithm will automatically correlate the partial discharge data and equipment image information in the same area. If the partial discharge signal is enhanced and the appearance of the equipment shows abnormal signs at the same time, the system can judge the potential fault in this area more accurately and give an early warning in time.

5. Conclusions

In this article, the holographic sensing intelligent inspection technology of ring network cabinets based on multi-sensor fusion is deeply studied, aiming at solving the dilemma of traditional inspection methods of ring network cabinets and improving the efficiency and accuracy of inspection. By integrating a variety of key technologies, an intelligent inspection robot suitable for the complex environment inside the ring network cabinet is successfully designed.

In the research process, the theoretical cornerstone of intelligent inspection technology is analyzed in detail. Multi-sensor technology provides rich environmental information for robots, multi-sensor fusion technology improves the accuracy and reliability of information processing, and three-axis navigation and positioning technology ensures the precise movement and positioning of robots in the ring network cabinet. Based on these theoretical foundations, the design of intelligent inspection robot is completed. From the hardware architecture, modular design makes it easy to maintain and upgrade; The sensor layout has been carefully planned to ensure comprehensive access to the internal information of the ring network cabinet; The functional modules closely cooperate around data collection, analysis and processing and fault early warning to realize efficient inspection.

Technological innovation is a highlight of this study. The inspection robot designed for the internal environment of the ring network cabinet fully adapts to the special needs of the ring network cabinet in structure and function, and overcomes the shortcomings of traditional inspection equipment. The three-axis orbit micro-control system realizes millimeter-level positioning accuracy by precisely controlling the movement of the robot in 3D space, and greatly reduces the blind spot of inspection. Multi-sensor fusion and intelligent data analysis algorithm deeply explore the potential relationship of data, which significantly improves the accuracy and timeliness of fault diagnosis. To sum up, the research results provide a brand-new and effective technical scheme for the inspection of ring network cabinets, which is of great significance to ensure the safe and stable operation of urban power supply network.

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