Electric Power Intelligent Inspection Robot: a Review

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Abstract. The electric power intelligent inspection robot is equipped with high-definition visible light camera, infrared thermal imager, sound-collecting equipment and other intelligent detection devices and intelligent analysis algorithm software to complete the control loop from rapid acquisition of all-weather data, real-time information transmission, intelligent analysis and early warning to fast decision feedback. Therefore, instead of manual inspection, the automatic detection and intelligent analysis of the state of the power equipment are realized, and the reliability of the operation of the power grid and the power equipment is improved. The use of electric power intelligent inspection robots is an important means to realize the intelligentization of power grids, and is an important direction for the future development of smart grids. Given the current research status and deficiencies at home and abroad, this paper discusses the electric power intelligent inspection robots from aspects of main technologies, cutting-edge technology, functional positioning and standard system, and discusses the research status of electric intelligent inspection robots. On this basis, future research and development direction are put forward. This paper has a guiding role and reference value for the research of electric power intelligent inspection robot.

1. Introduction
The intelligent inspection robot is based on intelligent technology and has programmability [1-3]. With the development of technology, the functions of the intelligent inspection robot are gradually improved, making it simulate manual operation in the application process and replace the traditional manual inspection. This kind of inspection method is more flexible and less affected by external climate, environment and other factors, and is suitable for all kinds of inspection work. The intelligent inspection robot itself carries related equipment such as infrared thermal imaging cameras, which can identify and control the environmental factors of the automatic and manual inspection, fire warning, and fire protection during the inspection process [4-7]. In short, its functions are gradually improving, which has greater advantages than traditional manual inspections and has broad application prospects.

1.1. Research status of intelligent inspection robot
Intelligent inspection robots originated in the 1980s. Countries such as the United States and Canada took the lead in applying line inspection robots in the power industry. By the end of the 1980s, the United States gradually used autonomous line patrol robots on this basis, which could autonomously detect and deal with line faults, etc., to achieve inspection results (Fig.1). At the beginning of the 21st century, Canada gradually used a brand-new inspection robot with live wires. This robot can effectively
overcome obstacles in the line, and can also detect visible light and infrared video, and can complete live work such as crimping tube resistance measurement task. In 2008, the United States gradually designed a brand new inspection robot system. The robot adopts a wheel-arm composite structure with two arms symmetrically arranged front and rear. The main innovation lies in the structural design and adaptive structural design of the wheel claws. This structure enables the robot to cross multiple obstacles during the inspection process and realize obstacle detection.

Figure 1. American electric power inspection robot

Figure 2. Intelligent inspection robot

Domestic research on inspection robots first began in the 1990s. After years of research, intelligent inspection robots have gradually achieved certain development results, especially the application of intelligent inspection robots in power industry substations, replacing traditional manual inspections to ensure the smooth development of inspection work. With the advancement of intelligent inspection robot technology in recent years, research in this area has gradually increased to meet the needs of all aspects of economic and social development (Fig.2). For example, the "AApe" series of electric power
detection and operation robot systems, the robot mechanism under 500kV ultra-high voltage environment, autonomous control, data and image transmission, electromagnetic compatibility, and other key technology applications have promoted the overall development level of the power industry and made intelligent inspection robots are gradually being used in many aspects of the development of the power industry.

2. Overview of Intelligent Inspection Robot
There are various types of intelligent inspection robots, such as switch room inspection robots [8-9], substation inspection robots [10-11], and corridor inspection robots. Taking the corridor inspection robot as an example, various functions in the field of pipe gallery monitoring can be integrated into practical applications. This robot is suitable for areas with high real-time requirements for the integrated pipe gallery monitoring area. In the design, it has the overall structure of the modular design. In practical applications, the functional module can be expanded according to the user's needs. The robot's monitoring module also has voice structure, short message interface, alarm management and remote control modules, which can meet the needs of users in many aspects.

The power transmission lines of China have the characteristics of wide areas, complex terrain, harsh natural environment, and long-term exposure to the field such as power lines and towers. As a result, transmission lines are often affected by factors such as mechanical tension, electrical flashover, and material aging. Wear and corrosion. Therefore, in this case, it is necessary to conduct regular patrols and inspections of the transmission line to understand and grasp the various problems of the transmission line in time and replace the line if necessary. Intelligent inspection robots can play an important role in the management and inspection of power transmission lines. Through automatic line inspections, intelligent robots can timely grasp the operation and use of transmission lines, understand changes in the surrounding environment, etc., which is beneficial to eliminate hidden dangers in line operation. Intelligent robots in power transmission lines use mechatronics systems, including the fusion of mechanical systems, automatic control, communications, and sensors. Mechanical systems are the core technology of intelligent inspection robots. From the current application of intelligent inspection robots in my country, the mechanical system of intelligent inspection robots in power transmission lines has the following strict requirements.

(1) From the kinematics point of view, the mechanical system and structure should be able to roll, crawl, cross, and avoid obstacles on the transmission line during use, and be able to make flexible adjustments to the spatial position during use.

(2) The mechanical structure needs to have a certain load capacity so that it can install related instruments and equipment according to the needs during the application process.

(3) The mechanical structure needs to be light and compact, making it easy to carry and easy to operate.

3. Key technologies of intelligent inspection robots

3.1. Inspection robot organization
The intelligent inspection robot contains many key technologies, and the mobile robot mechanism is an important content. There are many applications of biomimetic mechanisms in inspection robots, which contain more joints, have a complex structure, are larger, and have poor adaptability and load capacity. Based on the characteristics of its more joints, the difficulty coefficient of its motion control is relatively large, and it is necessary to pay attention to the precision control in the control process. Due to the large difference between the dynamic characteristics of robots and humans, it is restricted by this characteristic in the actual application process. Therefore, the intelligent inspection robot needs to be compact and flexible to ensure that it can flexibly perform online and offline operations in the application. However, as far as the current situation is concerned, it cannot fully meet the actual needs of its application. Although many researchers use lightweight materials for the design of intelligent
robots, which reduces the weight of the machine itself, it also greatly reduces the driving capability of the machine itself and increases its load.

3.2. Intelligent control system
Intelligent inspection robots are often used in more complex and harsh environmental conditions, so they have extremely high requirements for the control system. The overall design of the intelligent inspection robot, the robot autonomously traverses obstacles on the transmission line is an important content in the intelligent system. When traversing obstacles, the two arms are respectively suspended on the line and go online after off-line crossing. During the online process, it is necessary to combine the positioning of the power line position and perform the online operation according to the result of the positioning. The robot suspended on the wire will be affected by wind force, self-adjustment, etc., so that it will more or less shift its center of gravity and swing. In this case, it is necessary to adjust and convert the positioning method to make the robot can complete the obstacle crossing. In the application of intelligent inspection robots, due to the diversity of obstacle types, it requires scientific motion planning to ensure the accuracy of its operation.

3.3. The online power supply system
The application of intelligent inspection robots, due to the lack of online replenishment devices, makes many instruments on high-voltage transmission lines and live working instruments adopt battery power supply. The battery-powered capacity is limited, its working time is short, and it needs frequent replacement, which seriously affects the reliable operation of these instruments and equipment. Therefore, the improvement of the online power supply system is necessary and practical. With the advancement of technology, many companies have gradually adopted the power supply mode of small gasoline generators. Gasoline generators carry fuel tanks, which are affected by environmental factors during use, making their operation stability poor. Therefore, to ensure the stability of the power supply system, it is best to obtain power resources directly from the power line to achieve a coupled power supply. However, this method is still in the stage of theoretical research, and the practical application technology is not yet mature. The output power of the induction power supply is small and the equipment is large, which cannot fully meet the needs of industrial development. Therefore, it is necessary to develop and use some induction power-taking devices with smaller equipment and higher efficiency.

3.4. Navigation and positioning technology
Intelligent inspection robots are often used in the field environment. In this case, the robot system itself will be affected by the strong electric and magnetic fields around the high-voltage transmission lines. Therefore, the intelligent inspection robot system has extremely high technical requirements for automatic navigation sensors. In terms of the current development conditions of intelligent inspection robots, the application of visual navigation technology is more common. In the actual application process, it has a high spatial and gray resolution, wide detection range, high precision, and can accurately and quickly get relevant information. If an electromagnetic sensor is used in the design to make it navigate along the phase line of the high-voltage transmission line, in this design mode, its navigation will not be interfered by strong electric fields and strong magnetic fields. Besides, the sensor itself has the advantages of compactness, flexibility, and lightweight. The software processing and calculation have high efficiency and accuracy, which can meet the needs of production and life. Therefore, the use of this sensor has a broad application space.

3.5. Online inspection method and operation technology of inspection robot
In the application process of the intelligent inspection robot, the offline monitoring method is generally adopted for the monitoring of the transmission line fault. Specifically, because the robot is equipped with a related camera and the remote inspection line is faulty, in this case, the robot control system itself cannot realize the real-time monitoring function. Therefore, in the research of intelligent
inspection robots, real-time monitoring technology needs to be the research focus. According to the actual needs of the development of intelligent inspection robots, it is necessary to develop a more reliable online monitoring method for transmission line damage and broken stock failures. It can cope with various environments where robots work. Due to the complex working environment of the intelligent inspection robot, the technical requirements for the monitoring system are relatively high, and the related equipment must have the characteristics of lightweight and high monitoring accuracy. In the monitoring process, the external interference factors are small, so that it can provide important technical support for the development of inspection work and ensure the quality of inspection work. The intelligent inspection robot can also use a variety of sensors to scan lines, etc. to realize fault monitoring. The application of intelligent inspection robots will also be affected by the needs of transmission line inspection and operation tasks, which makes the robot itself must have better line maintenance capabilities. In this case, the robot must be equipped with relevant modular work, so that it can handle and maintain line faults in time during operation and use so that the transmission line can be maintained in a stable and safe operating state.

4. Development trend

4.1. Transmission line inspection robot based on multi-sensor fusion
With the gradual development of intelligent inspection robot technology, autonomous inspection robot technology and line fault detection methods are gradually becoming mature. Intelligent inspection robots will gradually integrate multiple sensors in future applications, and run multiple sensor fusion methods to cross obstacles, navigate and locate, etc., so that the robot can quickly realize fault judgment and positioning, and ensure that the line can be restored in a short time Normal operating state.

4.2. Inspection robot based on combined operation mode
In the actual application process of the intelligent inspection robot, if it has the processing function of multiple tasks, it has a larger volume, a heavier weight, and poor flexibility. In this case, the promotion and application of robots are more difficult. The line inspection task has particularity and complexity, which makes it possible to realize the integration of several operation methods in future applications, such as the combination of robot inspection and online monitoring, to improve the inspection operation and realize the information sharing of various systems.

4.3. Transmission line inspection robot based on smart grid
In the future development of intelligent inspection robots, it is necessary to gradually improve its functions based on smart grid technology, give full play to the technical advantages of intelligent inspections, and ensure smooth and efficient inspections.

5. Conclusion
With the development of technology and the gradual development of intelligent inspection technology, intelligent inspection robots are used in many industries, especially in the power industry. They are widely utilized, giving full play to their technical advantages and improving the efficiency and quality of intelligent robot inspections. The intelligent inspection robot gradually replaced the traditional manual operation and promoted the development of the entire industry.

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