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Research on problems and countermeasures in the application of substation intelligent inspection system

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Abstract. Substation plays an important role in the power system as the pivot of the power grid. With the continuous expansion of the power grid, the intelligent inspection system based on robots is widely used in the substation industry. However, the existing inspection robot has some drawbacks, such as low battery capacity, weak obstacle performance, slow movement speed, and blind areas during the inspection. This paper proposed some measurements aimed at these drawbacks, such as optimizing the robot performance, adding the image acquisition PTZ (Pan, Tilt, and Zoom camera) in fixed point, using the AR (Augmented Reality) glasses assistance. These approaches improve the efficiency and quality of the existing intelligent inspection system in the substation.

1. Introduction

The power grid occupies a prominent position in the energy system. As the pivot of the power grid, the substation is a significant power facility that could transform voltage, control power flow, receive and distribute electric energy. The scale of the power grid expands gradually with the continuous increase of the energy production and electricity demand, which adds to the management difficulty of the power grid. As a result, the substation inspection system requires a higher management level and technical reliability.

At first, the intelligent inspection system was widely used in the chemical industry, energy, transportation, and other industrial fields in developed countries. Based on the PDA (Personal Digital Assistant) and RFID (Radio Frequency Identification) positioning technology, the intelligent inspection system used handheld mobile terminal to collect the operation status, defects and other data of the equipment, and then transmit them to the system background [1]. By analyzing and organizing those data, reference information and management suggestions could be given to help the equipment maintenance work. With the proposal and development of the IOT (Internet of things) technology, the inspection robot system based on IOT was proposed.

The Luneng Group successfully developed an intelligent substation inspection robot in 2013, and gradually changed the technology of autonomous movement, intelligent detection, analysis and early warning of robots. All-weather monitoring, data acquisition, video monitoring, temperature and humidity measurement, and air pressure monitoring of substation equipment are carried out. In abnormal emergency situations, the intelligent detection robot can be used as a mobile monitoring platform to replace manual labor to identify equipment failures in time and reduce personnel safety risks [2].

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At this stage, the research of inspection robots focuses on four key technologies: one is positioning and navigation technology based on laser and vision fusion, and recognition and positioning technology in complex environments; the other is centralized control of inspections and automatic data collection of miniaturized drones. As well as the mining and analysis of massive inspection result data; the third is the research of mobile obstacle crossing technology, robots with point operation technology, and transmission line detection technology; the fourth is the platform design of orbital robots, indoor remote communication and precise navigation [3]. Robot technology will be the most innovative and revolutionary technological innovation in the power industry under the background of "Made in China 2025", providing important technical support for the safe operation of the power grid. Nowadays the intelligent inspection robot is widely used in the substation to assist the manual inspection.

However, the existing inspection robot cannot realize the maximum value for its low battery life, slow crawling velocity, weak obstacle performance, etc. In this paper, the drawbacks of the existing inspection robot are analyzed in detail and the corresponding suggestions are proposed to improve the performance of the inspection robot.

In this paper, the system composition of the intelligent inspection system in the substation is introduced. The advantages and the drawbacks of the inspection robot are analyzed in detail. And the corresponding optimization measurements to the drawbacks are proposed. Finally, the conclusions are presented.

2. Basics of the intelligent inspection system

2.1. System composition

Currently, the intelligent inspection system for the substation consists of user layer, business layer, gateway layer and data layer. The user layer includes the front-end based on the inspection robot and the management display platform, which could help the operation and maintenance personnel manage the inspection system conveniently. The inspection robot integrates the robot technology, the non-touch detection technology of power equipment, the multi-sensor fusion technology, the pattern recognition technology, the navigation and positioning technology and the IOT technology. It could realize the all-weather, all-round and autonomous inspection of the substation. Furthermore, it could reduce the human labor and the maintenance cost effectively, and then improve the automatic and intelligent level of the substation inspection system.

The existing inspection robot usually adopts wheel structure to walk freely on hard ground. By setting the inspection route and cycle in advance, the robot can collect the visible and infrared spectrum of the established inspection points when performing the inspection task. And then, the collected spectrum would be analyzed by the built-in image analysis service to generate a professional inspection report, which is convenient for the operation and maintenance personnel to review the historical data of the corresponding equipment. In addition, the management display platform provides the automatic alarm and history inquiry for the values exceeding the given threshold, which could improve the efficiency of the substation inspection.

2.2. Advantages of the inspection robot

The intelligent inspection robot can accurately inspect specific equipment according to the setting time and point. Compared with the manual inspection, the inspection robot is less restricted by the climate, time and etc. When there is a defect in the equipment, the operation and maintenance personnel can set the defect tracking task. And then the inspection robot can continuously perform the task, so as to monitor the defect position all time. Once the defect deteriorates, the inspection robot would alarm immediately and remind the operation and maintenance personnel to deal with it.

In addition, the inspection robot can work in the places unsuitable for manual inspection, such as the GIS equipment with SF6 Electrical insulation. The leakage of SF6 does harm to the human health but the inspection robot. At this time, the robot can enter the leakage area to take photos of SF6 meters

and upload them, so as to assist relevant staff to grasp the real-time conditions and take the corresponding measures.

3. Drawbacks of the existing inspection robot

3.1. Low battery capacity

The LER3000C intelligent robot is widely used in the State Grid at present. Its battery capacity is 1500W·h, which means that its working time is 6h under full power condition and its charging time is 4h. For the 500kV and 1000kV substations, all the station equipment has to be inspected once every three days. Specifically, if there is a defect that needs long-term tracking and monitoring, the battery life of the inspection robot would be too low to complete the 24-hour inspection task.

3.2. Weak obstacle performance

The front end of the intelligent inspection robot is equipped with an ultrasonic obstacle avoidance module, which could automatically plan the path to avoid the small obstacle. However, there are always some maintenance or reconstruction projects in the substation. When the robot encounters the obstacles of large construction vehicles or maintenance materials, the ultrasonic obstacle avoidance module cannot work in this situation. Consequently, the robot would stop the inspection task and return.

3.3. Slow movement

During the movement, the inspection robot has to scan the surrounding environment through the laser positioning module at all times to prevent itself from deviating from the inspection route. Due to the limitation of calculation ability and safety factors, the current speed of the robot is set at 0.5m/s. It takes the robot 7 minutes to enter the equipment area from the charging room, which means the robot cannot arrive at the fault equipment area immediately.

3.4. Blind areas in the inspection

The intelligent inspection robot is 1030cm high and 574cm wide, as shown in Figure 1. Limited by its own specifications, electrical safety distance and equipment space layout, the robot cannot enter some narrow and low channels. Consequently, it cannot inspect the equipment inside those channels. In addition, some equipment also exists the mutual occlusion and high position problems, which makes it difficult for the robot to collect a complete spectrum for the equipment.

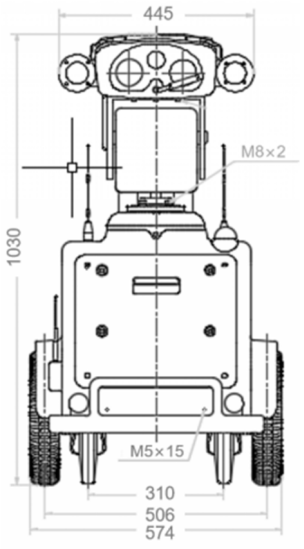


Figure 1. Specifications of the inspection robot.

4. Proposed optimization method

4.1. Optimization of robot performance

Aimed at the low battery capacity of the robot, a high-capacity battery supporting DC fast charging can be used to improve the charging speed and prolong the movement time.

Aimed at the slow movement of the robot, the frequency of environment recognition in the uniform linear motion segment can be reduced, which could effectively improve the inspection speed of the robot. In addition, the robot movement mode is adjusted to the fast movement mode in the case of emergence handling. The fast movement mode means that the motor drive speed is raised to make the robot move quickly. Thus, the inspection robot could arrive at the accident area as soon as possible, so as to respond rapidly to inspect the fault equipment.

4.2. Disposition of image acquisition PTZ

Aimed at the weak obstacle performance and blind areas of the inspection robot, the image acquisition PTZ with fixed position, which is integrated with the visible light and infrared image acquisition function, would be arranged around the equipment inspected inconveniently, as shown in Figure 2. The reasonable disposition of the image acquisition PTZ could inspect as much equipments as possible in the blind areas. The focal length and angle of PTZ can be adjusted when setting the inspection task, so that the PTZ can inspect the equipment with different spatial distribution in turn and collect their visible and infrared images.

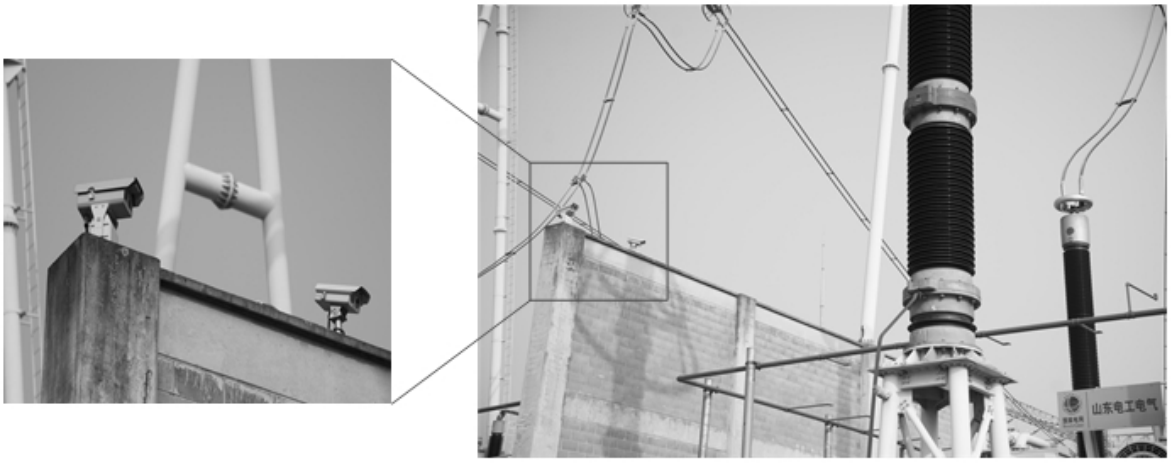


Figure 2. PTZ deployment diagram.

The disposition of image acquisition PTZ with fixed position can solve the most problems caused by the low inspection coverage during the maintenance periods. However, when the vehicles and equipment on the maintenance site accidentally block the inspection horizon of fixed-point PTZ, some equipment inspection failures still exist. In this condition, the operation and maintenance personnel could transport the mobile PTZ to the site for installation. After that, the mobile PTZ would be connected to the management system, so as to acquire the monitoring screen of the mobile PTZ. The camera of the mobile PTZ can be controlled remotely to align with the monitoring dial, and then the recognition parameters (including meter type, corresponding equipment, etc.). And then the recognition task could be triggered in time, and the defect image could be acquired and submitted to the management system for alarm analysis. If there is an alarm, the data will be recorded and submitted to the management display platform. And then the operation and maintenance personnel would click the alarm information to display the alarm video and analyze the defects. Therefore, the mobile PTZ can not only meet the needs of intelligent inspection during maintenance, but also be applied to defect tracking and monitoring. It is useful for its characteristics of flexible deployment and uneasily affected by the environment.

4.3. Assistance of AR inspection

The AR inspection can effectively combine the flexibility of the manual inspection and the digital advantages of intelligent inspection. On the one hand, it could inspect the uncovered caused by the low battery capacity, the weak obstacle performance, blind areas, etc. On the other hand, it could provide the warning prompt, the remote assistance and other inspection assistances during the manual inspection, which could effectively improve the state perception ability, the defect detection ability, the equipment management ability, the active alarm ability and the emergency response ability.

4.3.1. Meter identification, verification, upload and storage. As shown in Figure 3, the AR glasses can intelligently identify all kinds of meters that need to be copied during the inspection process. When the AR glasses identify the meter, the deep convolution neural network would be operated to identify the data of the meter. The operation and maintenance personnel only have to check the identified data. The checked data would be submitted to the business layer in real time to generate an inspection report. Meter identification can effectively reduce the occurrence of missing and wrong data, and promote the efficient development of inspection task.



Figure 3. Meter identification, verification, upload and storage.

4.3.2. Early alarm of the significant component. The AR glasses integrate 3D environment understanding and object recognition technology. By three-dimensional reconstruction and positioning, it could complete the understanding of the equipment and its components, as long as its surrounding environment. The recognition information includes the type of components, the position and connection relationship between components. At first, the AR glasses automatically identify the setting equipment or important components, and then display the virtual three-dimensional model and information of the equipment in the real space. According to the model, the operation and maintenance personnel can directly acquire the maintenance history the next maintenance cycle of the important

components. If the operation and maintenance personnel think there is a possible defect, the AR glasses could take photos and videos of the possible defect and then report it conveniently.

4.3.3. Remote collaboration. Once encountering defects, the operation and maintenance personnel can initiate the remote cooperative call to the remote expert online through the AR glasses. During the call, the image presented on AR glasses, as shown in Figure 4, would be will be shared with the remote experts in real time. The experts could analyze the given image and do some important marks on the images. The marking information will be rendered by the AR glasses and presented in three-dimensional space. In this way, the remote experts could guide the operation and maintenance personnel to deal with the defects, which could effectively avoid their misoperation. The guidance process could be recorded in time for analysis and teaching as well. In conclusion, the remote collaboration makes it possible for the interaction between operation and maintenance personnel and remote experts in space.



Figure 4. Experts remotely assist the staff on duty.

5. Conclusions

With the development of power equipment monitoring technology, the intelligent inspection system in the substation can meet the basic requirements of daily inspection tasks. However, it still has some drawbacks, such as low battery capacity, weak obstacle performance, slow movement speed and blind areas during the inspection. Aimed at these drawbacks, this paper proposed some measurements, such as optimizing the robot performance, adding the image acquisition PTZ in fixed point, using the AR glasses as assistance. These approaches effectively compensate for the lack of the existing inspection system. Furthermore, these measurements could promote the implementation of some new technologies in the substation maintenance, such as the automatic collection of equipment information, the remote automatic inspection, the efficient processing of massive data and the intelligent transmission of the defect information.

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