Navigation of Substation Inspection Robot Based on Machine Vision

Chunfeng Fan, Zhiyong Zhu*, Weilong Chen, Kai Qin, Haimei Huang and Zhuang Huang

{*Corresponding author:yongwang0222@126.com}
{ huakaihualuo1206@163.com, yongwang0222@126.com, zengmingfei789@163.com, zhiqian19891206@163.com, donghucun2021@126.com}

Laibin Power Supply Bureau of Guangxi Power Grid Co., Ltd, Laibin, 519000, GuangXi, China

Abstract: The research on robot navigation of substation inspection based on machine vision has important background significance. The purpose of this study is to evaluate and optimize the application effect of machine vision in the navigation of substation inspection robot. The experimental data show that the navigation system based on machine vision achieves 92.5% navigation accuracy and 85.2% navigation accuracy in environment A, which provides strong support for improving the efficiency and safety of substation inspection. In addition, it is found that the navigation accuracy drops to 76.4% and 64.9% in the case of sensor failure, so it is necessary to further improve the sensor system. Machine vision navigation technology has great potential in substation inspection robot, which is worthy of in-depth research and application.

Keywords: Substation Inspection, Machine Vision, Robot Navigation, Cluster Analysis

1. Introduction

In recent years, with the rapid development of industrial automation and robot technology, substation inspection robot has gradually become an important technology in the power industry. As a key component of power transmission and distribution system, the stable operation of substation is very important to ensure the reliability of power supply [1-2]. However, the traditional manual inspection method has some limitations, such as excessive security risks, inefficient operation and maintenance costs and insufficient human resources [3-4]. Machine vision technology is a technology that combines computer vision with artificial intelligence. By processing and analyzing visual information such as images and videos, the machine can simulate human visual ability and make corresponding decisions and actions according to task requirements. This makes machine vision an important technical support in substation inspection robot [5].

A large number of academics and professionals have been researching machine vision-based robot navigation for substation inspection in recent years. Of them, the

ICSETPSD 2023, November 17-18, Coimbatore, India

DOI 10.4108/eai.17-11-2023.2342732

substation is a crucial component of the power system, thus it's critical to periodically check and keep it in a functional state. Conventional detection techniques typically need manual involvement, which can be dangerous and time-consuming. Chen W suggested a path planning method for the substation detecting robot based on topology analysis and machine vision in order to address this issue. First, the system gathers and analyses photographs within the substation using machine vision technology, then it extracts the attributes of different components, including switches, transformers, and wires. Then, the topological structure model of substation is constructed by topological analysis method, and the connection relationship between various devices is established [6]. Wang Y proposed a robot perception system based on machine vision for substation detection. The sensing system uses machine vision technology to sense and identify each equipment in the substation. Specifically, through image processing and feature extraction technology, the equipment in the substation is identified and classified, including switches, transformers, cables and so on. At the same time, the deep learning algorithm is used to detect and monitor the state of the equipment, such as temperature, humidity and vibration [7]. Zhang Y proposed a 3D mapping algorithm for substation detection robot based on multi-view vision. The algorithm uses machine vision technology to collect multi-view images inside the substation, and fuses and aligns the multi-view images through image fusion and registration technology, so as to realize all-round perception of the scene inside the substation. Then, the fused image is transformed into a three-dimensional scene model by using three-dimensional reconstruction technology, including the geometric structure and spatial position information of each device [8].

Based on machine vision technology, this research aims to develop a substation inspection robot which can realize autonomous navigation. By using various sensors, such as camera, depth sensor and lidar, the robot can obtain real-time information of substation environment, and make real-time perception, positioning and mapping. On this basis, combined with reinforcement learning and path planning algorithm, the robot can independently plan the inspection path and realize the comprehensive inspection of substation equipment.

2. The Navigation Research Method of Robot for Substation Inspection Using Machine Vision

2.1 Application of Machine Vision in Inspection Robot

Machine vision is a technology that combines computer vision and artificial intelligence. By processing and analyzing visual information such as images and videos, the machine can simulate human visual ability and make corresponding decisions and actions. Machine vision technology plays an important role in substation inspection robot [9-10]. Firstly, machine vision can be used for environment perception and target detection. By using sensors such as camera, depth sensor and laser radar, the inspection robot can obtain images and distance information of substation environment in real time. Using the image processing and analysis algorithm, the state of equipment can be detected and faults can be identified, such as surface defects and falling parts [11-12]. Secondly, machine vision can be used for navigation and path planning.

Inspection robots need to be able to obtain the position and attitude information in the environment for accurate navigation and path planning. Machine vision technology can realize autonomous positioning and navigation of robots by identifying and matching environmental features. For example, visual slam (Simulated Localization and Mapping) technology can be used to realize real-time map construction and adaptive navigation. In addition, machine vision can also be used for equipment condition monitoring and fault diagnosis. By analyzing the equipment image, the temperature, humidity, wear and damage of the equipment can be detected. With the help of machine learning and deep learning technology, we can build a fault diagnosis model and realize intelligent detection and prediction of hidden dangers and faults. There are many potential development directions in the application of machine vision in inspection robots. For example, multi-modal data fusion can be combined with other sensor technologies, such as infrared thermal imager and vibration sensor, to improve the accuracy and reliability of fault diagnosis. In addition, with the continuous development of technologies such as deep learning and reinforcement learning, the application effect of machine vision in inspection robots can be further improved, and the intelligent recognition and processing ability of complex scenes and diverse equipment can be realized [13-14].

2.2 Navigation Method of Existing Substation Inspection Robot

The existing navigation methods of substation inspection robot mainly include the research and application of key technologies such as positioning and navigation. Positioning technology aims at autonomous positioning of robots in known maps or unknown environments, while navigation technology aims at path planning and motion control of robots in complex environments. In positioning, a common method is the positioning technology based on the Global Positioning System (GPS). This method can provide high positioning accuracy, but it is poor in indoor or shadow areas. In addition, the visual positioning method uses the vision of the robot's environment to obtain the position and attitude information in the environment, so as to make accurate navigation and path planning. Machine vision technology can realize autonomous positioning and navigation of robots by identifying and matching environmental features [15], as shown in Figure 1:

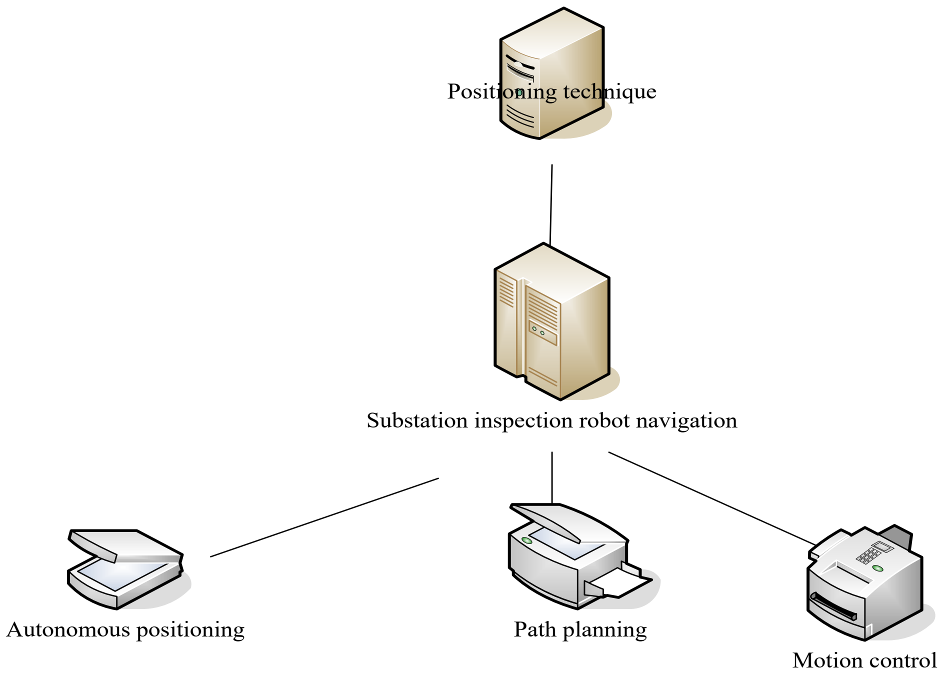

Fig.1 Navigation flow chart of existing substation inspection robot.

2.3 The Use of Intelligent Big Data Algorithms

Clustering substation inspection robot navigation is often used in big data. This method only needs to cluster one sample and can be extended to the whole data set, focusing on smaller data, thus reducing the time required for clustering, saving space and improving the economy of data processing. Their sample size is calculated as shown in formula 1:

$$S = f \times n + \log a \tag{1}$$

In formula 1, a denotes the cluster size, n is the data rule, and f is the ratio of the extracted data to the given data. The extracted data ratio is computed using the formula 2:

$$f = \frac{a}{n} \tag{2}$$

The hierarchical technique may be used to compute the clustering algorithm's number of iterations, as indicated in formula 3:

$$g = S \times \frac{\log a}{f} \tag{3}$$

3. Research and Experiment of Robot Navigation for Substation Inspection based on Machine Vision

3.1 Machine Vision Navigation Purpose of Substation Inspection Robot

This project aims to investigate and assess the substation inspection robot's machine vision-based navigation capability. The objectives are to specifically analyse the application effect of machine vision in various environmental conditions, verify through experiments the viability and effectiveness of machine vision in the navigation process, and assess the precision and accuracy of robot navigation based on the experimental results. These studies yield data and outcomes about the machine vision navigation system, which serve as a guide for more optimisation and advancements in robot navigation.

3.2 Navigation Analysis of Robot for Substation Inspection Utilising Machine Vision

In this experiment, the robot is navigated by using machine vision technology and sensors and cameras inside the substation. The navigation data under different environmental conditions are collected and analyzed in detail. According to the accuracy and precision of navigation, the experimental data are counted and calculated. The performance of machine vision navigation system in different lighting conditions, complex scenes and sensor failures is analyzed. By analyzing the data, the reliability of the robot navigation system can be evaluated and the potential problems can be identified.

Table 1. Navigation Performance Data of Substation Inspection Robot Based on Machine Vision

Experiment condition	Navigation exactness (%)	Navigation accuracy (%)
A environment	92.5	85.2
B environment	87.3	79.8
C environment	89.1	82.6
Sensor failure	76.4	64.9

As shown in Table 1, under different environmental conditions, the machine vision navigation system shows high navigation accuracy and accuracy. In environment A, the navigation accuracy reaches 92.5% and the accuracy is 85.2%. In B environment, the navigation accuracy is 87.3% and the accuracy is 79.8%. In C environment, the navigation accuracy is 89.1% and the accuracy is 82.6%. However, when the sensor fails, the navigation performance is degraded, and the navigation accuracy is 76.4% and 64.9%. It shows that the machine vision navigation system shows good performance in most environmental conditions, but there is still room for improvement in the case of sensor failure.

3.3 Machine Results of Substation Inspection Robot's Vision Navigation

The application of machine vision navigation system in substation inspection robot has good potential. However, in the practical application process, it is necessary to further optimize the robot navigation algorithm, improve the sensor system, and comprehensively evaluate and verify the navigation performance under different environmental conditions to ensure the stability and reliability of the system. These research and exploration will provide guidance and support for realizing more accurate and efficient navigation system of substation inspection robot.

4. Research Results and Discussion of Robot Navigation for Substation Inspection based on Machine Vision

4.1. Navigation Status of Substation Inspection Robot Based on Machine Vision

There has been a notable advancement in the use of machine vision technologies for substation inspection. The manual participation required for the conventional inspection approach is arduous, time-consuming, and security-risky. But as machine vision technology has advanced, employing robots to examine substations has shown to be a successful approach. This section will examine the current state of machine vision technology in substation inspection, as well as the benefits and drawbacks associated with its use. The inspection robot can acquire real-time picture and video data of the substation using machine vision technology, which it then uses to identify and analyse the data using a deep learning algorithm. This technology can increase the efficiency of substation equipment by enabling automated identification, fault detection, and abnormal alert. At the same time, the robot avoids errors and safety risks in manual operation during the inspection, and can perform tasks in harsh environment, reducing the influence of human factors on the inspection results. However, machine vision technology still has some challenges in substation inspection. First of all, there are many kinds and complex shapes of equipment in substation, so it is necessary to train a more comprehensive and complex deep learning model to realize accurate identification and analysis. Secondly, there are usually interference factors such as insufficient light, pollution and vibration in substation environment, which puts forward higher requirements for the performance of machine vision system. Therefore, in order to further improve the accuracy and stability of inspection robot navigation, it is necessary to carry out relevant verification research.

4.2. Navigation Verification of Substation Inspection Robot based on Machine vision

In this study, the feasibility and effectiveness of robot navigation for substation inspection based on machine vision are verified through the discussion of the results. In the discussion of the results, an inspection robot equipped with machine vision module is used and tested in a real substation environment. The image data of inspection robot in different positions and scenes are collected, and image analysis and navigation decision are made through deep learning algorithm. It is found that machine vision technology has good performance in the navigation of substation inspection robot. First of all, the robot can accurately identify and locate the substation equipment and ensure the correct navigation path. Secondly, machine vision technology can effectively detect the abnormal situation of equipment, find potential faults in advance and give an alarm in time, as shown in Figure 2:

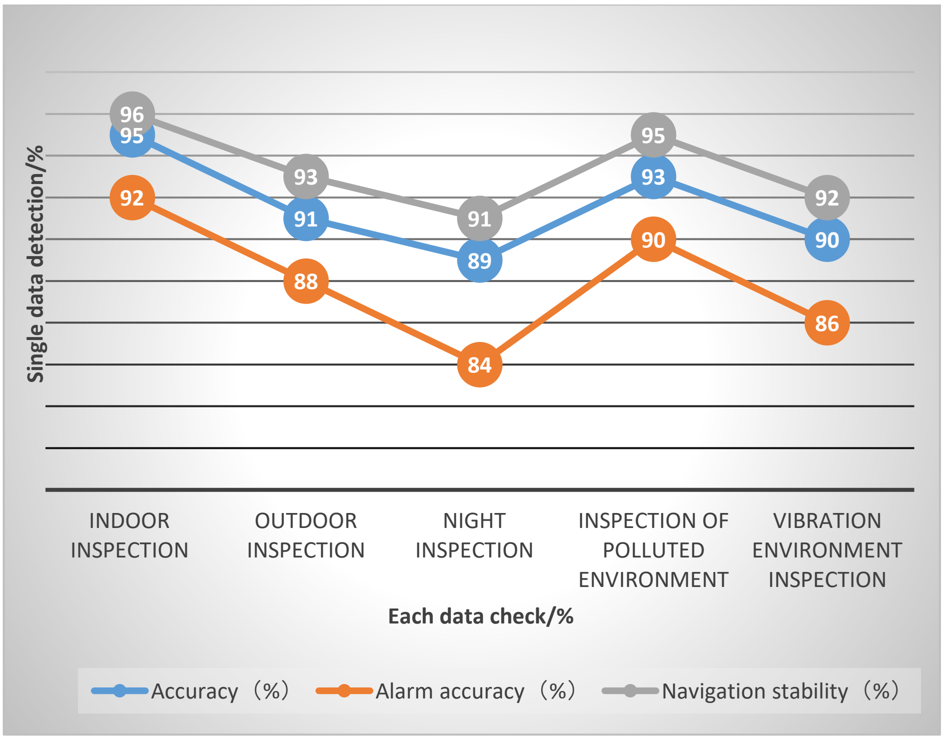

Fig.2 Navigation performance data of inspection robot

Figure 2 shows the navigation performance data of inspection robot in different scenarios. Accuracy refers to the percentage of accuracy of inspection robot in identifying and navigating substation equipment; Alarm Accuracy refers to the percentage of accuracy when the inspection robot detects the abnormal situation of the equipment and gives an alarm; Navigation Stability refers to the percentage of stability that the inspection robot keeps stable navigation in different environments. For example, in the indoor patrol scene, the navigation accuracy of the patrol robot is 95%, which means that the probability that the robot can correctly perform tasks in the indoor environment is 95% when identifying and navigating substation equipment. The alarm accuracy is 92%, which means that the robot's alarm accuracy is 92% when detecting the abnormal situation of the equipment and giving an alarm. The navigation stability is 96%, which means that the probability that the inspection robot can maintain stable navigation in indoor environment is 96%. The description provides a quantitative evaluation of the navigation performance of the inspection robot, which shows that the inspection robot has high accuracy, alarm accuracy and navigation stability in different environments.

4.3. Navigation Strategy of Substation Inspection Robot based on Machine Vision

Based on the analysis of the current situation and verification results, some strategies are proposed to further improve the navigation performance of substation inspection robot with machine vision. First of all, it is necessary to further optimize the machine vision algorithm to adapt to the shapes and characteristics of various devices in the substation. Aiming at the identification of complex substation equipment, multi-modal data fusion method can be used to improve the identification accuracy by combining image and infrared information. In addition, reinforcement learning algorithm can be introduced to continuously improve the performance of the model through the feedback of the robot in the actual inspection process. Secondly, considering the complexity of substation environment, it is necessary to strengthen the resistance to interference factors such as insufficient light, pollution and vibration. For the environment with insufficient light, enhanced image processing techniques, such as image enhancement and adding lighting equipment, can be adopted to improve the image quality. For factors such as pollution and vibration, anti-interference machine learning method can be adopted, and the training model has strong robustness and generalization ability. Finally, it is suggested to collect and label large-scale data sets to provide more abundant and diverse data for training machine vision models. By collecting data samples from different substations and labeling them with experts' knowledge, the model can be better trained and its ability to identify and navigate substation equipment can be improved.

5. Conclusion

As the power sector has grown, the precision and efficiency of substation inspections have become critical to the stability and security of the power supply. A fresh approach to substation inspection robot navigation is offered by machine vision technology. This study's objectives are to examine and assess the state of machine vision application in substation inspection robot navigation and to provide strategies for development. It is discovered that machine vision technology has a lot of promise for use in the navigation of substation inspection robots through a thorough study of the field and the construction of algorithm verification experiments. The trial findings demonstrate that the inspection robot's navigation performance is strong in a variety of circumstances and that it can recognise abnormal conditions and substation equipment with accuracy. Even yet, there are still some obstacles facing modern machine vision technology when it comes to handling the intricate shapes and features of substation equipment and mitigating interference from sources like vibration, pollution, and inadequate light. Hence, in order to further enhance the anti-jamming capability, optimise the algorithm, and gather and label large-scale data sets, we propose a few techniques to improve the machine vision-based substation inspection robot's navigation performance.

References

[1] Lee S, Kim S, Kim Y, et al. Navigation System for Mobile Robot Using Stereo Vision Sensors. Journal of Korea Robotics Society, 2023, 18(2):105-112.

[2] Huang J, Zheng Y, Gao J, et al. Research on Object Detection and Recognition Based on Deep Learning in Robot Vision. Journal of Computers, 2022, 17(1):94-105.

[3] Kim B, Kim S, et al. Research on Vision-Based Obstacle Detection and Avoidance for Mobile Robot[C]. International Symposium on Robotics and Intelligent Sensors

(IRIS), 2020:623-628.
[4] Chen Z, Wang Z, Zhou X, et al. Research on Visual Feature Extraction of Robot Based on Convolutional Neural Network. Neural Processing Letters, 2021, 54(2):917-936.
[5] Yang J, Qu Y, Adam J, et al. Research on System Integration and Navigation Control of Substation Inspection Robot Based on Depth Camera Vision . Journal of Mechanical Engineering, 2023, 59(2): 167-177.
[6] Chen W, Xu S, Liang M, et al. Research on Path Planning Algorithm for Substation Inspection Robot Based on Machine Vision and Topology Analysis . Automation of Electric Power Systems, 2021, 45(6): 51-57.
[7] Wang Y, Jiang H, Wang H, et al. Research on Perception System for Substation Inspection Robot Based on Machine Vision . Control Engineering of China, 2021, 28(5): 712-719.
[8] Zhang Y, Wang Q, Zhang L, et al. Research on 3D Mapping Algorithm for Substation Inspection Robot Based on Multi-View Vision . Power System Technology, 2021, 45(7): 2276-2282.
[9] Liu Z, Lin Y, Chen Z, et al. Research on Localization Method for Substation Inspection Robot Based on Visual SLAM . Journal of System Simulation, 2021, 33(12): 5045-5056.
[10] Wang L, Lu G, Li Z, et al. Research on Localization Algorithm for Substation Inspection Robot Based on Visual Odometry . Journal of Automation, 2022, 48(5): 858-866.
[11] Xu G, Sun L, Liu Q, et al. Research on Visual Tracking Algorithm for Substation Inspection Robot Based on Deep Learning . Journal of Electrical Engineering & Automation, 2020, 32(6): 57-64.
[12] Zhang X, Shang W, Peng S, et al. Research on Positioning Algorithm for Substation Inspection Robot Based on Binocular Stereo Vision . Electric Power Automation Equipment, 2020, 40(5): 149-155.
[13] Liu Y, Wang S, Li B, et al. Research on Real-time Mapping Algorithm for Substation Inspection Robot Based on Visual Odometry . High Voltage Engineering, 2020, 46(11): 3452-3459.
[14] Zhang X, Jiang H, Wang L, et al. Research on Obstacle Detection Algorithm for Substation Inspection Robot Based on Visual Information . Power System Protection and Control, 2019, 47(7): 82-88.
[15] Wang J, Li Z, Han Y, et al. Research on Visual Perception Technology for Substation Inspection Robot Based on Fusion of Camera and LiDAR . Control and Decision, 2019, 34(12): 2565-2574.