Proceedings of the 3rd International Conference on Signal Processing and Machine Learning
DOI: 10.54254/2755-2721/6/20230769

# Research on inspection of machine room by mobile robot

**Shuhao Yang**

Arizona State University (Polytechnic), 5885 S Twining St, Mesa, AZ 85212

shuhaoyang23@gmail.com

**Abstract.** The machine room inspection robot, as a special robot, can locate and navigate in the machine room independently, and carry sensors to detect equipment faults and record instrument data instead of the machine room staff. In this paper, the relevant standards and existing inspection robots at home and abroad were investigated and the overall scheme was determined based on the actual machine room environment. The monitoring background employs B/S architecture, allowing staff to deliver inspection tasks and manage robots from any computer. The motion map is created using the GMapping algorithm, and the topology map for inspection is created based on the inspection task and feasible path. For raster map localization, the adaptive Monte Carlo localization algorithm is used. The functional layer software for the robot is designed based on the inspection function to be performed by the robot and the man-machine interaction with the monitoring background. The findings of this paper's research indicate that the inspection robot system can meet the requirements of computer room autonomous inspection.

**Keywords:** Inspection system, Positioning, Navigation, The robot.

## 1. The introduction

With the development of information technology in the world, the routine inspection method has gradually changed from manual inspection to robot inspection, and manual inspection has strong dependence on qualitative judgment of personal senses [1]. The responsibility and mental state of inspection personnel are required to be high, and the relative work efficiency is low. Therefore, the machine room inspection adopts the intelligent mobile robot.

The research on robot inspection in the field of equipment room first appeared in Japan at the end of 1980s [2]. In the early stage, most robots inspected power lines and nuclear power plants by remote control operation.

In 1991, in order to reduce the special equipment room assignments in the number of staff and improve the accuracy of inspection equipment, the Tokyo electric power company has designed a kind of work on the 66 kv transmission line of mobile robot, mechanical arm used to cross with arc in the power transmission tower, and the function of fault detection and data records, inspection of mobile robot, A special multi-car connection structure and a bionic mobility strategy are designed to cross irregular points on the cable, such as insulators and cable branches.

Inspection robot for domestic research started later than Japan and other countries, however, due to the practical demand of domestic substation inspection and related technology of whole and relevant national policy support, since the 21st century, domestic substation inspection robot research has experienced a process of rapid development, especially the past 10 years. The vast majority of equipment room inspection robots are from China.

according to the actual environment of the machine room, the relevant standards and existing inspection robots at home and abroad were investigated and the overall scheme was determined. The monitoring background adopts B/S architecture, so that the staff can use any computer for inspection task delivery and robot management [3].

The motion map based on GMapping algorithm, and then the topology map for inspection is established according to the inspection task and feasible path. Adaptive Monte Carlo localization algorithm is used for localization based on raster map. An optimal path is planned according to the assigned inspection task points on the topological map, and a navigation algorithm is designed to guide the robot to complete point-to-point navigation.

In this paper, according to the inspection function to be realized by the robot and the man-machine interaction with the monitoring background, the functional layer software is designed for the robot [4]. In order to avoid potential command conflicts between modules, the work of the robot is divided into five working modes: drawing, deployment, inspection, automatic charging, manual operation and one idle mode. Then, modular software design is carried out to complete all functions. It hopes to provide some insightful suggestions for further study in this field.

## 2. The key technology

When the robot is operating normally, there are many function modules, and there may be potential command conflicts between the modules, such as the navigation module and the movement command of the robot via the handle or remote operation, or automatic charging and task scheduling module will call the path planning module to get the navigation path, to call the navigation module. As a result, it configures different working modes for the robot, while the robot can only work in one mode to avoid command conflict. Each working mode has corresponding function modules, as well as operation interfaces that allow a series of tasks to be assigned and operated.

The inspection robot system is made up of various components such as robot ontology, local background monitoring, deployment terminal, robot charging room, Ethernet, and so on. Related technology includes the design of the robot's structure as well as its perception and control, which includes environmental modeling and localization, path planning, motion control, testing and avoiding obstacles, fault diagnosis and fault-tolerant control, and so on, as well as specific detection and monitoring tasks related to video and audio processing, anomaly detection equipment, mission planning, and so on.

### *2.1. Structure of inspection robot*

The structure of the inspection robot varies according to the specific inspection contents and checking equipment room scene, such as sensor to carry four rotor aircraft which has been widely applied in mines, power plants, and other patrol, climbing robot with vacuum suction cup, carry a camera sensor, can be used for Bridges, buildings, and other places to carry on the inspection, Micro robots are widely used for inspection in some small Spaces in some f Outdoor transformers, switches, arresters, and other equipment are the most important targets of inspection in a substation environment, and the road used for inspection is relatively smooth, wheeled mobile robot is efficient, and simple structure, used in the inspection room is also a good choice at the moment.

With the advancement of science and technology, the requirements for mobile mechanisms are increasing, which is primarily reflected in the quality of lightweight, easy to operate, and energy saving.

*2.1.1. Lightweight.* In general, the weight of the robot is influenced by its shell, mechanism materials, carrying the battery, head, and other equipment. As a result, we should try to select scientific materials with high performance, density, and light quality. Furthermore, a well-designed structure can significantly reduce the weight of the robot.

*2.1.2. Convenient operation.* This is most noticeable in the control system aspect. When designing the control system, we should simplify the instructions, accelerate transmission, and account for some special cases to increase the mobile robot's efficiency.

*2.1.3. Energy conservation.* At the moment, energy waste is an important area of social research. Energy-saving measures include selecting low-energy consumption control devices and working components, a more labor-saving mobile structure, and cleaner power energy. It can also extend the robot's working time.

### *2.2. Environment modeling and localization of inspection robot*

Modeling the environment and localizing mobile robots are inextricably linked, especially in the unknown environment, where an accurate map facilitates precise positioning and precise positioning facilitates a more comprehensive map model. Raster models, geometric models, topology models, 3D models, etc. all fall under the umbrella of environmental modeling. This type of modeling is better suited for laser and sonar sensors to build graph, is simple and intuitive, and has a larger weakness in that maps require more space than other alternatives [5]. The robot's exploration of its environment yields abstract geometric features, which are then used to create a map, or geometric model. The intricacy of extracting geometric features from environmental data and comparing them to those actually observed is a major drawback.

Using a graph representation, the topology model depicts the environment as a set of interconnected nodes that each represent a different set of environmental characteristics. The main source of difficulty is in learning how to set up nodes and how to pair them with existing ones. When a multi-line lidar sensor or stereo camera is used, it is common practice to create a 3D model for analysis. Most existing 3D artworks are raster models that have been expanded to fill all three dimensions. The probability-based modeling approach has also become the standard for reducing the memory consumption brought on by the raster model.

Mobile robots typically use dead reckoning, signway-based localization, beacon-based localization, and probabilistic map-based localization for their localization needs. Dead reckoning is a technique for determining a robot's current position based on its previous position and the robot's accumulated mileage as determined by its sensors. The big error is one of its drawbacks.

### *2.3. Path planning and navigation of inspection robot*

The environment must be significantly modified for guideway-based positioning to work, which entails manually setting some landmarks in the environment that the robot can accurately locate according to. To enhance the hardware performance of the inspection robot and ensure its long-term stability during outdoor inspections, a beaconing-based localization approach can be used. This involves placing an active beacon in the area of interest and then locating it using geometric principles. The robot's environment modeling and positioning could be more accurate, for example. A more reasonable path planning method and motion control strategy could be developed.

The wireless communication technology is the primary medium for signal transmission and data transmission between the host computer and the slave computer. With the help of the host computer, the worker can issue a series of commands (such as "walking instructions," "image acquisition," "photo taking," and "temperature measuring") to the robot, and the latter will then obtain real-time images, the infrared heat map of the circuit, and the robot's current location, all of which are then sent back to the host computer. Selecting a communication module with a high bandwidth, strong anti-interference ability, and long transmission distance will guarantee trouble-free communication between the host computer and the robot.

The data from sensors and equipment temperature detected by infrared imager can be obtained, processed, recorded, stored, and displayed with the help of information acquisition and processing technology. Images and sensor data are the two primary categories of information gathered. The robot's Infrared Imager takes readings and sends them to a computer, where they are processed and

DOI: 10.54254/2755-2721/6/20230769

used to create an image that includes the equipment's temperature. Information processing technology's primary role is to collect data from the inspection robot, process it afterward, and transmit the results to the higher-ups. The system's data not only reduces collection time, but also enhances the comprehensiveness of the data and provides data support for additional data and equipment modeling.

## 3. Demand analysis of inspection robot system

### *3.1. Functional design*

The specific inspection requirements are determined by first researching the substation's surrounding area to learn about the roads, obstacles, magnetic field distribution, items that need to be tested during the inspection, and so on. From there, we refer to relevant inspection standards and look into other domestic inspection robot products to learn more about how they perform these tests. Here is a rundown of the most important criteria:

It is indeed important to start with the inspection robot's chassis, a background monitoring system, a charging station, and a network hub.

Second, the robot can transmit video and audio to the monitoring background in real time via high-definition, visible cameras, thermal imaging cameras, and sound acquisition equipment for inspection in the substation.

Third, the complex magnetic field conditions in the environment and the degraded performance of magnetometers, GPS, and other equipment make it difficult to work normally [6]. This is because transformers and other equipment in substations can interfere with the surrounding geomagnetic field.

In the fourth place, the robot has a long working time after charging and an automatic charging function.

To guarantee the robot's communication is always reliable, the fifth feature is its ability to interact with a monitoring system in the background. The robot also needs to be resistant to the effects of rain and wind. It can also detect the state of the equipment and read data from the instruments. Finally, it has a one-button reverse navigation function and can perform manual and autonomous inspections.

### *3.2. Performance design*

*3.2.1. Inspecting the motion mode of the robot.* The use of a wheeled mobile robot, such as the ones mentioned above, is recommended in a substation setting. Wheeled mobile robots typically fall into one of two categories: the car mobile robot, which mimics human-driven vehicles in its movement mode by using a set of directional wheels and a set of drive wheels. Also available are differential mobile robots, which use the angular difference between their left and right wheels to steer. This makes for easier operation, making differential mobile robots particularly well-suited for in-room patrol.

*3.2.2. Selection of location navigation mode.* Magnetic stripe, fixed track, laser sensor, vision, and other similar methods are commonly used for navigation in the equipment room [7]. While magnetic stripe and fixed-track navigation methods perform reliably and accurately in the field, they also demand extensive modifications to the natural environment and are therefore expensive. Once in operation, making adjustments to the navigation trajectory is a time-consuming and laborious process that offers very little flexibility.

*3.2.3. Monitoring the architecture of the back-end software.* Client/server mode and browser/server mode are the two most common approaches to monitoring the underlying software architecture. However, there will be compatibility issues between different system versions, and updating the client function will be a hassle. All processing for B/S mode software happens on the server. The service can be accessed directly in a web browser, and the user experience is excellent due to the service's attractive interface.

## 4. Research on inspection of mobile robot

### *4.1. Functional requirements for mobile robots*

The robot's first requirement is a superstructure and chassis that can bend and twist. The robot should also have a manual mode in which the operator can take charge. Third, the robot chassis should be able to turn in any direction with zero obstruction, and it should be able to decide whether to translate or rotate in place in order to navigate tight spaces.

Fourth, the robot's chassis needs vibration filtering capabilities so it can respond to variations in terrain. Fifth, the robot's wheels should be of a certain wear-resistant thickness to guarantee the service life. Sixth, while in motion, the robot must be able to actively avoid obstacles, and it must also have a passive protection device in case of emergency.

Furthermore, magnetometers, GPS, and other equipment are affected by the complex magnetic field conditions in the environment, as transformers and other equipment in substations can disrupt the natural geomagnetic field. The robot's top layer hardware should also include a high-definition camera, thermal imager, and sound collector for use during inspections.

In addition, there are features like a low battery alarm and an automatic return to charge that allow the robot to work for extended periods of time. As a final point, the robot's top-most inspection gear should be able to observe from a variety of angles to guarantee inspection coverage.

The inspection robot's control system serves as its "brain," or its central processing unit. Microcontrollers, Programmable Logic Controllers (PLC), and Embedded Systems are some of the most widely used control systems. CPU, RAM, ROM, timers, and counters are just some of the many components of a computer that can all be housed on a single chip. Single-chip microcomputers have the benefits of being compact, having their own unique program code, requiring little in the way of setup, and being inexpensive; however, their limited control precision, slow running speed, poor anti-interference ability, and lengthy development program time are all drawbacks. a PLC, or a programmable logic controller. Is a computer system with electronic components optimized for use in manufacturing settings. The PLC controller has been used in real-world settings for decades. It costs more than a single-chip microcomputer, but it has superior anti-interference capabilities, a low failure rate, simple equipment expansion, low maintenance requirements, and a fast development cycle. Using programmable logic controllers, or PLCs, is commonplace in manufacturing. Embedded systems are computer systems that are purpose-built to function as a part of another device. Embedded systems are distinct from single-chip microcomputers in that they run on their own operating system; this allows them to process more complex data and represents an improvement over single-chip microcomputer control; however, this also means that they have a higher writing threshold and are typically written in the programming language C. In conclusion, an efficient and compact embedded control system is used as the primary control system of the inspection robot, as dictated by the specifications of the robot's design.

### *4.2. The movement of a mobile robot*

Consequently, the inspection robot's tasks can be broken down into the following categories. The inspection robot has the ability to navigate indoor spaces either independently or under remote control. The first step is to arrive at the predetermined spot without incident. Second, make sure the machine is operating at the correct temperature and has a decent sound level; photograph the important gauges and instruments, label the photos, and record the readings. Next, conduct an on-site circular inspection or return the test data wirelessly to the control room management system.

Both the ground control system and the robot's primary control system contribute significantly to the inspection robot's overall control system. The inspection work in the substation can be done without the help of the better assistant operation personnel because the control system relies heavily on wireless remote control. These are some of the primary roles that the primary control system plays: In order to guarantee the precision of the robot's detection abilities, the motion control module finalizes the PWM (Pulse Width Modulation) control of the drive motor, enhances the robot's running stability, and regulates the pan-head rudder [8]. Navigation and positioning module, image acquisition module uploads infrared image and high-definition image to the upper computer for inspection personnel to observe and judge; wireless data transmission module ensures reliability of connection between the inspection drone and the upper computer; sensor detection module, complete the data detection of the substation inspection environment, and each sensor information collection, timely upload, ensure the accuracy and diversity of data.

### *4.3. Mobile Robot Motion Performance Test*

The system's primary features are autonomous localization and path planning with obstacle avoidance, the ability to take photos or perform other tasks, and the ability to upload data to a server in real time. From the perspective of software and hardware integration, the hierarchy should be broken down into three distinct tiers: the top-level management system, the middle-level business processing system, and the bottom-level motion control system.

When the battery is low during a patrol or when the patrol ends and the module returns to the charging room, the auto-charging function is activated by the patrol module. However, the auto-charging function also functions as a standalone mode and can be directly called by the monitoring background to return to the charging room. As soon as the program detected that it had been given a key for the return function, it set to work selecting the appropriate route back to the charging room and calling the navigation module to the door in stages. In order to charge, the robot's information processing board must first unlock the charging room door (or, in the worst case scenario, the monitoring background must unlock the door for the robot). Once inside, the robot must then activate the charging room's positioning function, use reverse linear navigation to reach the charging pile, and begin charging. If the charging is successful, the process ends; otherwise, the robot is allowed to navigate to the outside charging room and try again until it succeeds [9].

The robot's location data can be received by the deployment terminal while in deployment mode, allowing the terminal to mark out the patrol topology and verify the deployment route. The location, manual, and navigation components are all activated [10] when deployment mode is selected. To begin, a member of staff will drive the robot to the location in the substation where the inspection is needed or to the beginning and ending points of a predetermined inspection path. The robot will then be calibrated by pressing the corresponding button on the deployment terminal, which will then record the robot's position and attitude. If the robot is at the task point of the patrol, the deployment terminal will also need to record the cloud platform's angle at that location. When you're ready to finish deploying points, hit the terminal's "end deployment" button. This will cause the robot's interface to be updated with the patrol topology. Additionally, the robot's topology diagram can be accessed via the user interface. After a patrol topology has been deployed, the robot can verify that all paths on the topology are operational by navigating through them using the navigation module. Build in the ability to perform test runs.

IV.IV Mobile robot human-machine interactive control interface application

Man-machine interaction system is mainly composed of the following parts: (1) Motor speed display. It is mainly used to observe the speed of DC motor in the process of robot walking to prevent the speed instability of DC motor. (2) GPS coordinates. Its main display robot current coordinates, because the GPS must receive satellite signals, it can not be used indoors. (3) Position and pose module display. Display the real-time pitch angle, yaw angle, roll angle and its own coordinates x, y, z Axis positions. (4) Infrared Ranging. The infrared ranging display will measure 10cm-80cm obstacle distance, a total of six infrared ranging modules, mainly on the inspection robot around the obstacles and measuring the front and back gullies. (5) Electricity display. When the power is lower than a set value (self-set), the robot will be alarm to prevent its power is too low to cause work interruptions. (6) Motor Control and speed adjustment. The main function of the low-speed climbing or obstacle-

DOI: 10.54254/2755-2721/6/20230769

surmounting robot is remote control. (7) Steering gear control. It is mainly on the head of the rotation and pitch control, observation of the surrounding situation.

## 5. Conclusion

Equipment room inspection robots are no exception; they will be moving in the direction of autonomous inspection action development, not only able to move and detect alarms, but also able to use manipulator or other tools to solve problems on site, as software and hardware technology for robots advances in tandem with their increasing use across a wide range of industries. The advent of the 5G network has led to an increasingly unattended smart grid [11]. Intelligent inspection robots that can access all levels of buildings and outdoor spaces will be necessary then. Robot ontology by ontology structure unit, control unit, detection unit, inspection robot is widely used in a wide range of industries in recent years, or even appear frequently in a line of public view, and its development is swift. If you compare it to a manual inspection, you will quickly discover that it is a far superior method.

In order to address these issues, this paper proposes the development of an inspection robot equipped with an omnidirectional mobile chassis. Although experiments show that the robot can achieve climbing, surmounting obstacles, and other simple travel actions, such as tension in laboratory equipment, the inspection robot of this paper is still in the early design stage, and the robot design process begins with the overall architecture, in the mechanical structure design of an omni-directional mobile chassis. After that, full design and assembly are carried out, and the various mobile schemes are compared and analyzed.

## References

[1] Takeda M. Applications of MEMS to industrial inspection[C]// The, IEEE International Conference on MICRO Electro Mechanical Systems. IEEE, 2001:182-191.
[2] Briones L, Bustamante P, Serna M A. Wall-climbing robot for inspection in nuclear power plants[C]// IEEE International Conference on Robotics and Automation, 1994. Proceedings. IEEE, 1994:1409-1414 vol.2.
[3] Deremetz M, Lenain R, Couvent A, et al. Path tracking of a four-wheel steering mobile robot: A robust off-road parallel steering strategy[C]// The European Conference on Mobile Robotics. 2017.
[4] Naveed K, Khan Z H. Adaptive path tracking control design for a wheeled mobile robot[C]// IEEE International Conference on Control Science and Systems Engineering. IEEE, 2017:194-199.
[5] Yan B, Chen H, Huang W. Study on the method of switch state detection based on image recognition in substation sequence control[C]// International Conference on Power System Technology. IEEE, 2014:2504-2510.
[6] Gomes T, Marques S, Martins L, et al. Protected shortest path visiting specified nodes[C]// International Workshop on Reliable Networks Design and Modeling. IEEE, 2015:120-127.
[7] Cui X, Fang H, Yang G, et al. A new method of digital number recognition for substation inspection robot[C]// International Conference on Applied Robotics for the Power Industry. IEEE, 2016:1-4.
[8] Gao J W, Xie H T, Zuo L, et al. A robust pointer meter reading recognition method for substation inspection robot[C]// International Conference on Robotics and Automation Sciences. IEEE, 2017:43-47.
[9] Deremetz M, Lenain R, Couvent A, et al. Path tracking of a four-wheel steering mobile robot: A robust off-road parallel steering strategy[C]// The European Conference on Mobile Robotics. 2017.
[10] Lu S, Zhang Y, Su J. Mobile robot for power substation inspection: a survey[J]. IEEE/CAA Journal of Automatica Sinica, 2017, PP(99):1-18.

DOI: 10.54254/2755-2721/6/20230769

[11] Seung-Nam Yu,Jae-Ho Jang,Chang-Soo Han.Auto inspection system using a mobile robot for detecting concrete cracks in a tunnel[J]. Auto-mation in Construction.2007,16:255-261.