Journal of Electronic Research and Application, 2025, Volume 9, Issue 2
http://ojs.bbwpublisher.com/index.php/JERA
ISSN Online: 2208-3510
ISSN Print: 2208-3502

Research and Design of Intelligent Inspection System for Thermal Power Plants

Wei Zhang*, Tingfeng Zhang

College of Electrical Engineering, Liaoning University of Technology, Jinzhou 121001, China

***Corresponding author:** Wei Zhang, 1326001933@163.com

Abstract: To meet the demand for intelligent and unmanned development in thermal power plants, an intelligent inspection system has been designed. This system efficiently performs inspection tasks and monitors the operational parameters of key equipment in real-time. The collected data is uploaded to the monitoring center, allowing operation and maintenance personnel to access equipment information promptly. Data analysis is used to provide fault warning and diagnosis for critical equipment. The system employs the Pure Pursuit algorithm, which effectively avoids obstacles and ensures path continuity and stability. Simulation results show that the Pure Pursuit algorithm significantly improves the navigation accuracy and task efficiency of the inspection robot, ensuring the reliability of thermal power plant inspections.

Keywords: Thermal power plants; Intelligent inspection; Parameter acquisition; Path planning

Online publication: March 28, 2025

1. Introduction

Currently, the reliability of primary equipment in thermal power plants is relatively low. It cannot fully meet the requirements for unmanned operations. When issues such as equipment failure, gas leaks, or fires occur, they cannot be detected and addressed in time. This poses serious risks to both personnel and equipment safety and may even result in casualties [1]. Traditional inspection methods rely on manual operations. Personnel must regularly visit each inspection point with handheld instruments to check electrical equipment and collect a large amount of operational data. This approach is physically demanding, inefficient, and unreliable. Additionally, the complex working environment increases the risk of accidents and injuries during inspections [2].To address the need for intelligent and unmanned operations in thermal power plants, it is necessary to develop and implement intelligent inspection systems. These systems can collect and monitor equipment data in real time, detect safety hazards promptly, and eliminate them before they escalate [3].

The research and application of intelligent inspection systems are gaining increasing attention in industrial production. These systems significantly enhance the predictability of equipment performance and provide valuable references for equipment condition monitoring and evaluation [4–8]. Moreover, intelligent inspection systems can replace manual inspections. They reduce labor costs, improve inspection efficiency, minimize safety risks, and enhance overall productivity [9–15]. This paper introduces the design of an intelligent inspection system for thermal power plants. The system efficiently performs inspection tasks, monitors key equipment parameters in real time, and uploads the data to a central monitoring system. It enables operators and maintenance personnel to access up-to-date equipment information and, through data analysis, achieve fault prediction and diagnosis for critical equipment. The system uses the Pure Pursuit algorithm, which effectively avoids obstacles and ensures path continuity and stability.

2. Design of the intelligent inspection system for thermal power plants

The intelligent inspection system is built on a mecanum wheel chassis, with the STM32 microcontroller as the MCU (Microcontroller Unit). The system integrates multiple functional modules, including a temperature detection module, gas detection module, navigation module, video detection and image processing module, OLED display module (for real-time display of data such as temperature, harmful or flammable gas presence, and smoke concentration), motor drive module, audio-visual alarm module, and communication module. The overall design of the system is shown in **Figure 1**.

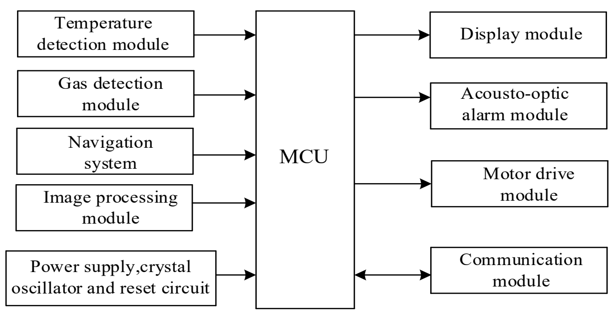

Figure 1. Overall system design

3. Design of key functional modules in the intelligent inspection system

3.1. Positioning and navigation

The intelligent inspection system uses laser navigation technology. It determines the robot's position in the global coordinate system through a laser sensor. The system adopts artificial landmarks for positioning. By using a rotating laser sensor to detect the landmarks in the environment, the position and orientation of the sensor in the global coordinate system are calculated using trigonometric geometry.

3.2. Gas detection and infrared temperature measurement

The gas detection module in the system uses an MQ-2 smoke and gas sensor module. The MQ-2 sensor is suitable for detecting various non-combustible smoke, natural gas, and liquefied petroleum gas. It has high sensitivity, especially for detecting non-combustible smoke containing carbon dioxide or hydrogen gas, and offers strong anti-interference performance. The temperature detection module uses infrared thermal imaging technology for online monitoring. It performs real-time temperature measurement of key components such as pipelines, valves, and other related equipment in the power plant.

3.3. Image processing module

The image processing module is designed to recognize parameters displayed on analog or digital meters in the thermal power plant, such as thermometers and liquid level gauges. The process of on-site instrument parameter recognition is shown in **Figure 2**. These parameters are converted into digital signals and uploaded to the monitoring center in real time. The module uses the Open MV image processing module. Open MV is a fully independent and programmable vision processing module with strong extensibility. It is designed for video and machine vision processing in embedded systems. The module is reprogrammed using C language, enabling advanced data structures to quickly handle complex video images and textual outputs. This makes it a highly efficient vision sensor for embedded applications.

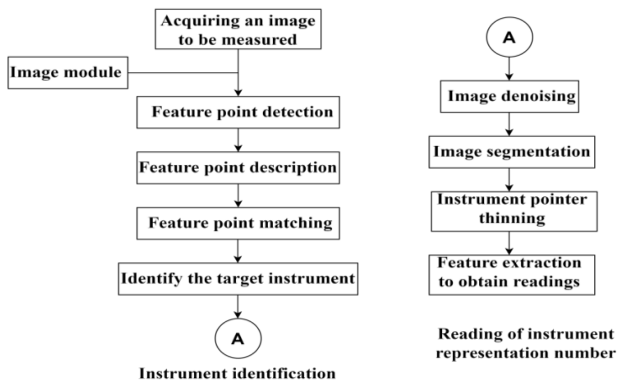

Figure 2. Flowchart of on-site instrument parameter recognition.

3.4. Vibration and audio signal analysis and collection

The vibration and audio signal collection module is designed to collect real-time vibration and audio signals from on-site equipment such as motors, fans, and generators. It analyzes the collected data to monitor whether the equipment's vibration and noise levels are normal. Using fault diagnosis algorithms, the system can detect abnormalities in real time. It provides early warnings of potential issues, allowing preventive measures to be taken in advance and avoiding operational accidents.

4. Path tracking algorithm of the intelligent inspection system

4.1. Grid map construction

Grid maps are commonly used in autonomous navigation for inspection robots. These maps are typically created using a combination of Radar sensors and SLAM algorithms, particularly in indoor environments with unknown conditions. However, during the actual map-building process, Radar sensors are affected by noise and motion distortion. This can result in significant discrepancies between the generated grid map and the real environment, which hinders effective path planning for the inspection robot. To address this issue, this paper combines manual measurements with the grid map generation algorithm in MATLAB to create a 2D grid map. The specific steps are as follows:

(1)Manual measurements are used to determine the overall dimensions of the pump room, the exact size of drainage equipment and the locations of the equipment within the pump room. Based on this information, a 2D floor plan of the pump room is drawn, as shown in **Figure 3**.

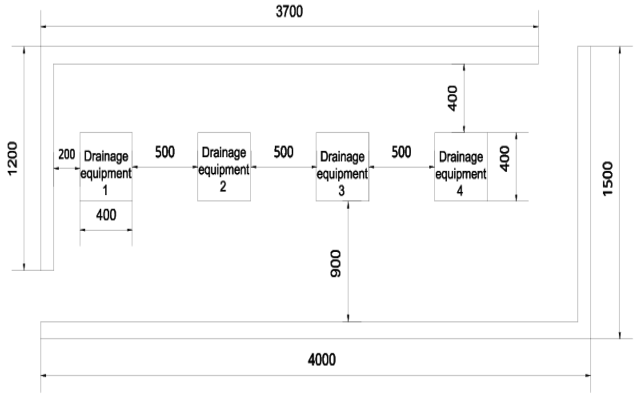

Figure 3. Geographical layout of the pump room

(2) Based on the 2D floor plan of the pump room, the obstacles and navigable areas are digitized into a 15 × 40 matrix. In this matrix, the value “0” represents navigable areas, while “1” represents obstacle areas. The digitized 2D layout is shown in **Figure 4**.

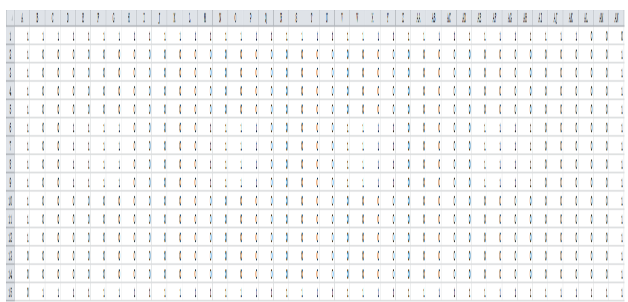

Figure 4. Digitized 2D layout

(3) The positions of the equipment in the pump room are known and not changed frequently. Therefore, combining manual measurements with MATLAB’s grid map generation algorithm is a feasible approach to build the 2D grid map of the pump room. The resulting 2D grid map is shown in **Figure 5**.

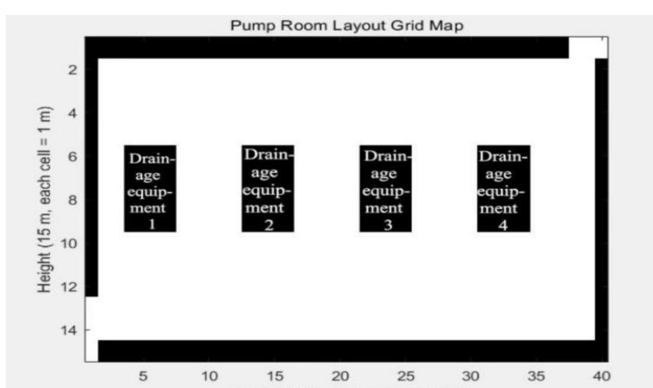

Figure 5. Equipment grid map

4.2. Path planning based on the Pure Pursuit algorithm

4.2.1. Principle of the Pure Pursuit algorithm

The Pure Pursuit algorithm is used to implement path planning for the intelligent inspection system. It ensures that the inspection system moves smoothly along the planned path. **Figure 6** shows the principle of the Pure Pursuit algorithm.

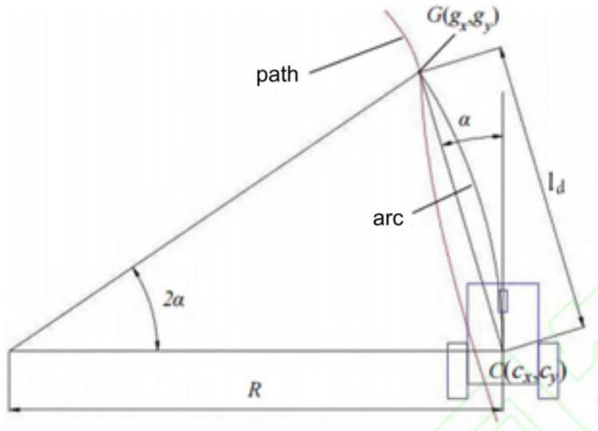

Figure 6. Principle of the Pure Pursuit algorithm

In **Figure 6**, $G(g_x, g_y)$ represents the next target point to be tracked. This point lies on the planned global path. The current position of the reference point C is given as (c_x, cy). The distance from the current position of the inspection system to the target point is denoted as l_d(m). The angle α(°) represents the angle between the vehicle's heading and the direction of the target point. Using the distance formula between two points, ldl_d can be calculated as follows:

$$l_d = \sqrt{(g_x - c_x)^2 + (g_y - c_y)^2} \tag{1}$$

$$v(t) = \frac{V_R + V_L}{2} = k_v l_d \tag{2}$$

In Equation 2, k_v represents the relationship between v_t (the velocity) and l_d (the distance to the target point). Using the law of sines, the following equation can be derived:

$$\frac{l_d}{sin(2\alpha)} = \frac{R}{sin\left(\frac{\pi}{2} - \alpha\right)} \tag{3}$$

$$\frac{l_d}{2\,sin(\alpha)\,cos(\alpha)} = \frac{R}{cos(\alpha)}$$

$$\frac{l_d}{sin(\alpha)} = 2R$$

Thus, the required turning angle for the inspection system can be calculated as:

$$\alpha = arcsin\left(\frac{l_d}{2R}\right) \tag{4}$$

4.2.2. Application of the Pure Pursuit algorithm

Figure 7 shows the path planning results for the pump room using the Pure Pursuit algorithm. The algorithm calculates the distance and angle between the reference point and the target point in real time. It dynamically adjusts the robot's direction to ensure smooth path progression. Combined with the laser navigation module, the Pure Pursuit algorithm effectively avoids static obstacles and maintains path continuity and stability. Simulation results show that the Pure Pursuit algorithm significantly improves the navigation accuracy and task efficiency of the inspection robot, ensuring the reliability of thermal power plant inspections.

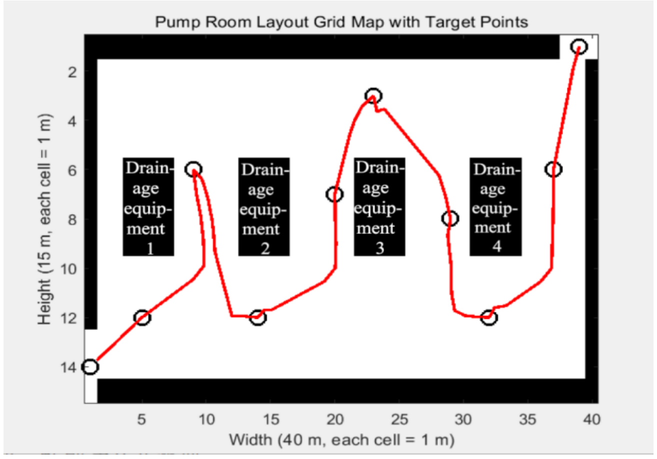

Figure 7. Path planning with the Pure Pursuit algorithm

5. Conclusion

The intelligent inspection system designed in this paper has autonomous path planning and navigation capabilities. It can collect and monitor thermal power plant equipment information in real time, accurately detecting the operational parameters of key equipment. The data is uploaded to the monitoring center, ensuring that operation and maintenance personnel are promptly informed of the equipment status. Through data analysis, the system achieves fault warning and diagnosis, effectively identifying and eliminating safety risks. The system uses the Pure Pursuit algorithm, which effectively avoids obstacles and ensures path continuity and stability. Simulation results show that the Pure Pursuit algorithm significantly improves the navigation accuracy and task efficiency of the inspection robot, ensuring the reliability of thermal power plant inspections. Additionally, the application of the intelligent inspection system reduces production costs, minimizes safety hazards, and increases production efficiency. It meets the demand for intelligent and unmanned development in thermal power plants.

Disclosure statement

The authors declare no conflict of interest.

References

[1] Zhou L, Zhang Y, Sun Y, et al., 2011, Research and Application of Intelligent Substation Inspection Robots. Automation of Electric Power Systems, 35(19): 85–88 + 96.

[2] Delobel L, Aufrere R, Debain C, et al, 2019, A Real-Time Map Refinement Method Using a Multi-Sensor

Localization Framework. IEEE Transactions on Intelligent Transportation Systems, 20(5): 1644–1658.
[3] Keqiang J, Zhizhou S, Yongcheng L, et al, 2017, Development and Application of the Rail-Type Inspection Robot Used in Substation Rooms. MATEC Web of Conferences, 139(5): 00210.
[4] Wu X, Li D, Liu T, et al, 2020, Research on Anti-Fall Algorithms of Substation Intelligent Inspection Robots. Advances in Intelligent Systems and Interactive Applications.
[5] Wang C, Yin L, Zhao Q, et al, 2020, An Intelligent Robot for Indoor Substation Inspection. Industrial Robot, 47(5): 705–712.
[6] Chen X, Ren G, 2020, Key Technologies and Development Trends of Intelligent Manufacturing and Robot Application. IOP Conference Series: Earth and Environmental Science, 461(1): 012049.
[7] Xiao P, Zhang C, Feng H, et al., 2010, Research on GPS Navigation of Substation Inspection Robots. Sensors and Microsystems, 29(08): 23–25+28.
[8] Ren A, Sun Y, Ma T, 2009, Research on DGPS/DR Combined Navigation Technology for Mobile Robots. Machinery and Electronics, 2009(03): 58–61.
[9] Wei P, Zhang Z, Zhang C, et al., 2009, Research on Navigation System of Unattended Substation Inspection Robots. Automation and Instrumentation, 24(12): 5–8+25.
[10] Zhao J, Feng S, Sun T, et al, 2020, Functional Design and Application of Intelligent Robot Technology in Coal-Fired Smart Power Plants. Energy Technology, 2020(4): 35–42.
[11] Hu X, Wang F, 2021, Research on Path Planning and Optimization Technology of Intelligent Robots. Robot Technology and Applications, 43(2): 15–22.
[12] Delobel L, Aufrere R, Debain C, et al, 2019, A Real-Time Map Refinement Method Using a Multi-Sensor Localization Framework. IEEE Transactions on Intelligent Transportation Systems, 20(5): 1644–1658.
[13] Lin H, Xiang D, Ouyang J, et al, 2021, Research Review on Path Planning Algorithms for Mobile Robots. Computer Engineering and Applications, 57(18): 38–48.
[14] Patle B, Babu L, Pandey A, et al, 2019, A Review: On Path Planning Strategies for Navigation of Mobile Robots. Defence Technology, 15(4): 582–606.
[15] Song X, Chen C, Fan Q, et al, 2019, Application Research on New Inspection Robots Based on Intelligent Sensors. Henan Science and Technology, (10): 19–21.