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Research on Automatic Patrol Inspection Technology Scheme for Safe Operation of Super Long and Long Span Highway Tunnel

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Abstract: Firstly, this paper conducts systematic research on tunnel fire and traffic incident detection technologies, and develops a high-precision monitoring and detection implementation plan for ultra-long and large-span tunnels; Secondly, in terms of tunnel fire detection, video thermal imaging technology is used as the main detection method, combined with dual wavelength flame detectors, to achieve fire open fire monitoring and pure smoke detection, making up for the blind spots of traditional fire detection, and improving the accuracy, timeliness, and reliability of monitoring. In terms of traffic incident detection, based on traditional traffic incident detection technology and advanced technical means, the system mainly focuses on lightning visual integration detection, combined with artificial video monitoring, to comprehensively judge the status of tunnel traffic incidents, thereby reducing the false alarm rate of incident detection. Finally, based on the technical research scheme, an intelligent automatic patrol robot was developed using the mobile automatic patrol mode. Using this as a carrier, various sensor modules and emergency equipment were built to replace manual 24-hour uninterrupted full coverage patrols, achieving automatic patrol, automatic reporting, analysis, early warning, and emergency response for ultra-long tunnels, reducing the cost of manual patrols and improving the efficiency of patrols, Enhanced emergency response capabilities of operating units.

Keywords: Ultra long and large span tunnels, High-precision monitoring, Fire detection, Traffic incident identification, Automatic patrol inspection, Safe operation.

1. Introduction

With the continuous increase in the total mileage of expressways in China and the gradual improvement of network topology, expressways have gradually developed from the infrastructure stage to intelligent operation. As an important component of expressways, tunnels shorten the mileage while also reducing the travel time between the two places. However, the tunnel is a semi enclosed tubular structure[1], and once a traffic accident occurs, it will lead to serious consequences, even causing casualties. Tunnel traffic accidents are mainly manifested in two categories, one is traffic accidents caused by fire, and the other is secondary accidents triggered by tunnel traffic events (including traffic accidents, vehicle failures, cargo spillage, temporary road maintenance, etc. [2]). Taking fire as an example, fire accidents are the most important type of accidents faced by highway tunnels. Highway tunnels, especially Tongzi Tunnel, are relatively closed in space, with limited escape conditions in the tunnel, fewer hot smoke outlets, and once a fire occurs, the heating speed is fast, the duration is long, and it is difficult for firefighters to enter. This increases the risk of driving. At the same time, due to the large number of vehicles in the tunnel, high speed, high wind speed, high risk, and difficulty in fighting, the design of the tunnel fire alarm system should aim to prevent accidents, detect them as soon as possible, and put out the fire as soon as possible.

Currently, a lot of research has been done on tunnel safety issues, especially tunnel fires and traffic accidents, at home and abroad, and certain results have been achieved. However, there are still a lot of defects and shortcomings, mainly manifested in the following two aspects:

1) Large detection error of tunnel fire and traffic accident monitoring equipment

The detection of incidents affecting the safe operation of tunnels at home and abroad has a single type and large error, with shortcomings such as missing reports, high false alarm rates, and timely extension. For example, the equipment commonly used to monitor fire accidents in tunnels relies solely on a single fire detector. Due to various physical phenomena associated with the occurrence of tunnel fires, and due to the limitations of the equipment's own detection performance, relying solely on a single detection device is easily affected by the external environment, resulting in inaccurate detection, high latency, missed detection, or false detection issues.

2) The construction of the linkage mechanism between various electromechanical equipment in the tunnel is not perfect

The survey found that the construction of the linkage mechanism between various electromechanical devices in tunnels in China is extremely imperfect, and there is a lack of effective communication between detection equipment and alarm and treatment equipment, making detection equipment unable to perform a good alarm, guidance, and treatment function on the premise of detecting tunnel safety accidents, leading to the unlimited development of various traffic events in tunnels, resulting in serious losses.

The occurrence of traffic accidents or fire accidents in tunnels is the two most important factors that affect the safe operation and management of tunnels, and there may be chain reactions between them. Based on this, this article takes Tongzi Tunnel as the foundation, and aims to achieve high-

precision monitoring and prediction of fire and traffic events in tunnels as the research goal, to fill the design blind spots, optimize and supplement the detection performance of traditional equipment, and achieve all-round coverage of detection in tunnels, It is of great significance to establish a corresponding incident early warning system for improving the safe operation of ultra long and large span tunnels.

Tongzi Tunnel is located in the Chongqing Zunyi Section (Guizhou Province) Expansion Project of Lanzhou Haikou National Expressway. It is a control project of the Chongzun Expansion Project, with a total length of 10497 meters, and is currently the longest tunnel in Guizhou Province's expressway project.

2. Research on Fire Detection Technology for Super Long and Long Span Tunnel

Based on the research of fire detection schemes in ultra long and large span tunnels, this paper intends to start with both open and non open flames, using video thermal imaging technology to achieve dual detection of open and non open flames in tunnels, introducing smoke detectors to achieve non open fire smoke detection, and assisting traditional dual wavelength flame detectors and temperature sensors in tunnels to achieve rapid identification of fire accident information in tunnels.

2.1. Fire Identification

In the infrared general testing mode, an infrared thermal imaging map is collected from the equipment for the set area according to the set distance and parameters, and the highest point within the field of vision is detected in real time. Comparative analysis is conducted with the set threshold value. When abnormalities are found, they are transmitted to the management personnel through audible and visual alarms and information alarms. The operation and maintenance personnel conduct manual remote control mode review based on the alarm information or trigger special patrol tasks to accurately measure temperature, Further obtain detailed temperature defect information on the parts and take appropriate countermeasures in a timely manner.

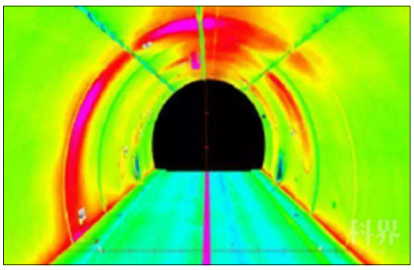

Figure 1. Fire Accident Detection Based on Infrared Thermal Imaging Technology

In highway tunnels, temperature anomalies such as vehicle collisions, spontaneous combustion, and equipment combustion are mainly reflected in heat generation. However, the tunnel environment is more complex than the road outfield conditions, and the determination requirements for fire accidents are higher. It is difficult to detect thermal defects in equipment by using ordinary thermal imaging technology to detect the highest temperature. Based on this, through targeted development of accurate temperature measurement functions, and based on high-resolution thermal imaging equipment, high-quality infrared thermal map data of patrol objects are obtained, and temperature data collection for different characteristic points of the equipment is achieved.

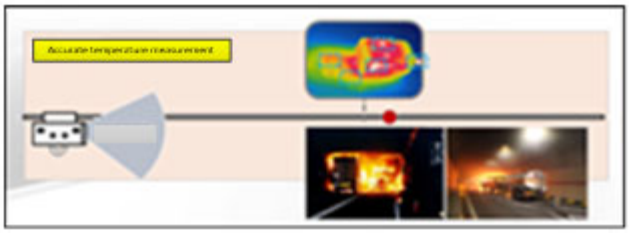

Figure 2. Schematic diagram of infrared fine measurement function

2.2. Tunnel environmental monitoring

Monitor environmental information such as CO, CH4, temperature, humidity, and smoke in the tunnel, collect environmental information in real time, and transmit it to the control center in a timely manner. This provides on-site environmental information for the operation and management personnel to facilitate their decision-making. When harmful gases are detected to exceed the standard, the system will give an alarm to prompt the operation and maintenance personnel to handle them in a timely manner, assisting in the monitoring of tunnel fire accidents.

3. Implementation Scheme of Fire Detection and Early Warning System for Super Long and Long Span Tunnel

The realization of early detection and identification of fire in tunnels is an important embodiment of the best fire detector. However, based on the widespread fire detection problems at home and abroad, detection technology always fails to achieve the effect of early warning and prediction, especially in the case of fire accidents in ultra long and large span tunnels.

Based on this, an audible and visual alarm system with a linkage mechanism, a voice prompt system, and an emergency response plan are established. In the event of a fire, relevant information can be transmitted to the fire department or control center through the alarm system. The control center determines several emergency plans that can be applied by investigating the robot's detection results about the fire accident, And manually or automatically select the scheme to conduct vehicle evacuation and fire fighting work. The specific preliminary plan for fire monitoring and early warning is as follows:

(1) Tunnel construction is based on video thermal imaging technology to continuously monitor the fire in Tongzi Tunnel for 24 hours, realizing dual monitoring of open and non open fire fires in the tunnel;

(2) Introducing smoke detectors to achieve non open fire monitoring in the early stages of tunnel fires;

(3) Using multi-source data fusion technology, process and fuse the data collected by fire detection equipment such as temperature detectors, dual wavelength fire detectors, smoke detectors, and fire video capture equipment based on deep learning algorithms to determine whether a fire accident occurs under the monitoring of the tunnel inspection robot;

(4) Establish a positioning system in the tunnel to accurately locate the fire accident point in the ultra-long

tunnel;

(5) Establish an early warning and interception system at the tunnel entrance; Build a signal transmission module, alarm system, and voice prompt system; Configure and coordinate emergency guidance facilities, alarm facilities, and fire fighting facilities in the tunnel; Achieve rapid identification, timely transmission, effective linkage, and rapid treatment of fire accidents in ultra-long tunnels, achieving the purpose of effective early warning and treatment of fire accidents.

The implementation plan for fire detection and early warning is shown in Figure 3 below:

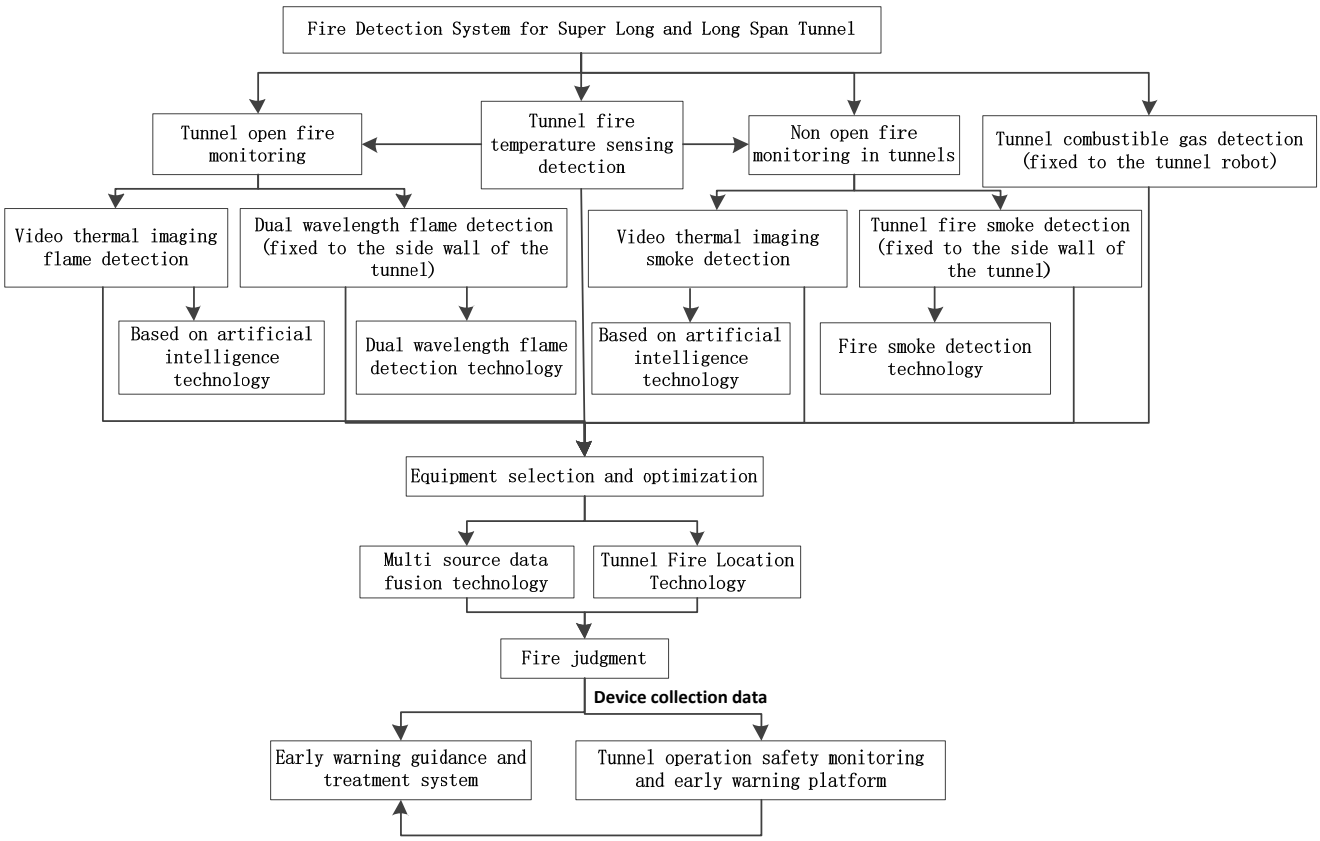

Figure 3. Implementation Plan for Fire Detection and Early Warning

4. Research on Traffic Incident Detection Technology for Super Long and Long Span Tunnels

4.1. Traffic Incident Detection Technology Based on Video Image Processing

The technology of automatic traffic incident detection based on video images is one of the hot spots and focuses in the field of intelligent transportation systems. It uses advanced video analysis, pattern recognition, data mining, and other technologies to achieve video based traffic incident detection.

The expressway tunnel traffic incident detection and early warning system consists of tunnel cameras and PTZ, video incident analysis server, incident management server, relevant monitoring software, and warning equipment. The video event analysis server is the core equipment of the entire system, consisting of a video processing unit, image processing software, video signal digitization system, communication card, and corresponding analysis software. The video event analysis server is an intelligent analysis embedded product based on vehicle behavior, using cutting-edge intelligent video analysis algorithms to automatically identify, analyze, and judge people, vehicles, and other objects. Its functions include: acquiring digital and analog video signals; Image analysis and processing using traffic incident detection image analysis algorithms; Store alarms, analysis results, and images; Communicate with the event management server. The functions of the event management server include: communicating with the video event analysis server and retrieving event videos uploaded by the analysis server; Centralized alarm, communication with traffic monitoring system equipment and monitoring computers, and joint operation of events and traffic control measures; Perform unified management, configuration, and maintenance of the entire system. Figure 4 shows the system architecture diagram.

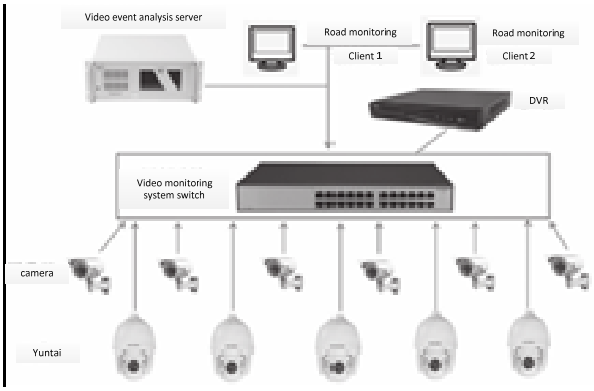

Figure 4. System architecture diagram

4.2. Implementation Plan for Rapid Identification of Traffic Accidents in Super Long and Long Span Tunnels

Tongzi Tunnel is a super long and large span tunnel, with higher traffic safety risks than short and medium long tunnels. If only using traffic incident detection technology based on video image processing, it is difficult to meet the traffic incident detection requirements. Therefore, this article proposes to establish the following scheme for the traffic incident detection part of Tongzi Super Long Tunnel:

(1) Analyze and determine the area with the highest security risk in the ultra-long tunnel, and build a video event detection system within the area. The core component of the detection system, the traffic event detection algorithm, is based on in-depth learning theory, and cooperates with various auxiliary algorithms, analysis and calculation storage servers, signal transmission technology, and corresponding software platforms to achieve traffic event detection in Tongzi Tunnel based on video image processing;

(2) An omnidirectional radar detection system is installed at a considerable height on the tunnel sidewall corresponding to the detection area in the Tongzi Tunnel to achieve accurate and omnidirectional detection of traffic events in ultra-long and large-span tunnels;

(3) Set up corresponding traffic electromechanical guidance facilities and link them with the monitoring center to achieve fully automatic response under traffic events;

(4) Develop corresponding emergency response plans to minimize the hazards and losses of a single incident based on the prevention and control of secondary incidents;

(5) Design and develop a tunnel operation safety monitoring and early warning platform to achieve monitoring and early warning of Tongzi tunnel fires and other traffic incidents.

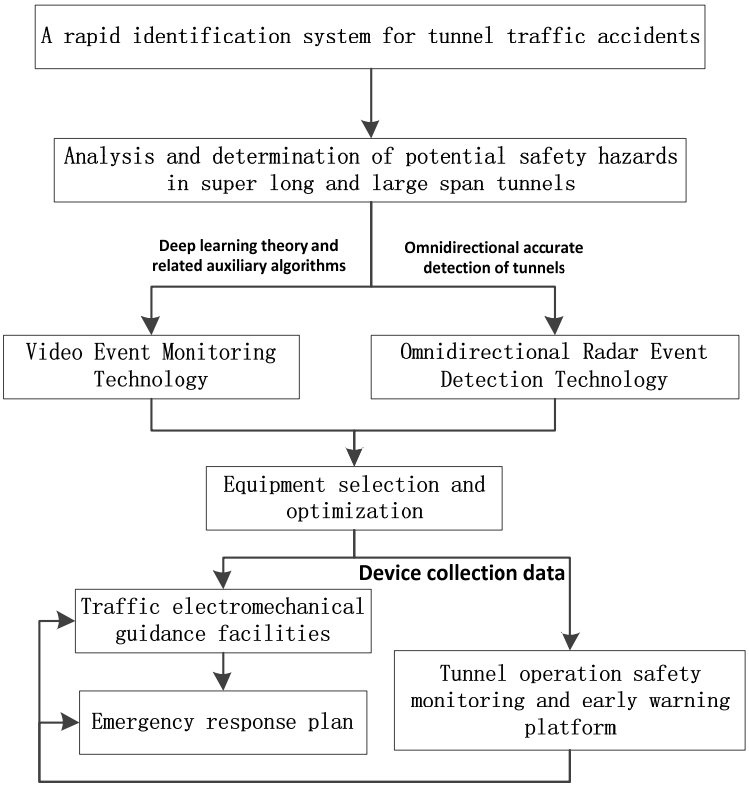

Figure 5. Implementation Scheme for Rapid Identification Technology of Tunnel Traffic Accidents

5. Research on Intelligent Supervision and Inspection System Based on Inspection Robot

5.1. Overall structure framework of intelligent inspection robot

This paper introduces an intelligent inspection robot platform for tunnels, and builds various monitoring devices to detect fire accidents and traffic incidents in tunnels. The function of the intelligent patrol robot is that it can complete the patrol work of the patrol section according to the preset settings in the automatic state, and can switch to the remote control state at any time. The intelligent patrol robot maintains contact with the road section center at any time, and can upload environmental parameters and video data in the tunnel to the control center in real-time.

The intelligent inspection robot is designed based on a modular approach, including a main control module, a power supply module, a motion control module, a communication module, and a data acquisition module, to achieve automatic inspection of fire and traffic accidents in Tongzi super long and large span tunnel. As shown in Figure 6:

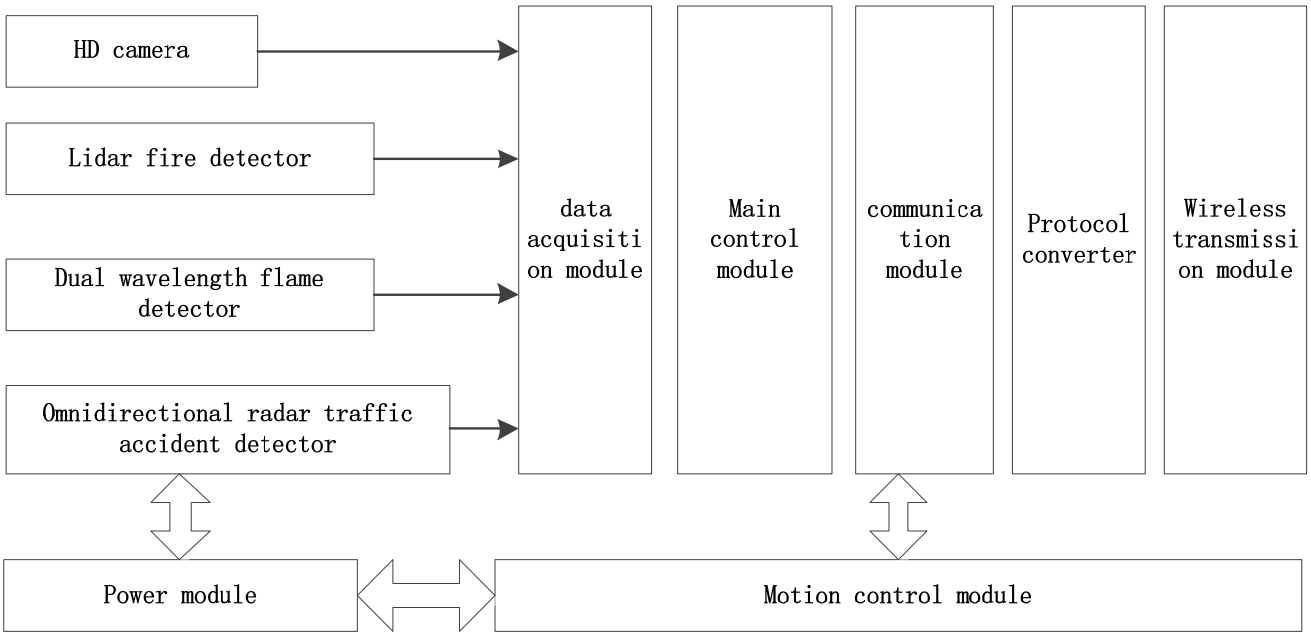

Figure 6. Overall structure framework of intelligent inspection robot

The intelligent inspection robot has the following characteristics:

1) It can operate around the clock without fatigue; Greater adaptability to harsh environments; Even if there is a danger, there is no need to worry about personal injury accidents;

2) Forward, backward, and stop, and achieve speed regulation;

3) When stopped, it has braking ability.

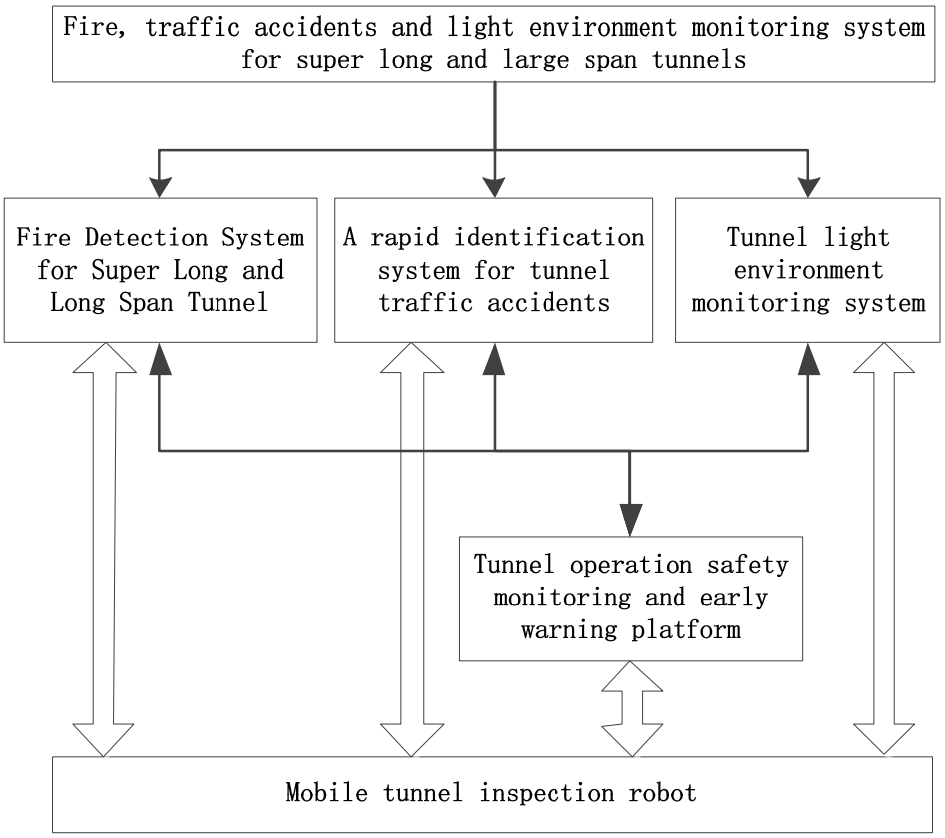

Figure 7. Overall Plan

5.2. Function building of tunnel inspection robot

According to the tunnel safety operation monitoring content and overall system plan, the functional construction of this intelligent patrol robot should meet the requirements of fire accidents and traffic accidents in the tunnel, and it should be made as intelligent as possible on the basis of meeting the basic functions and auxiliary configurations.

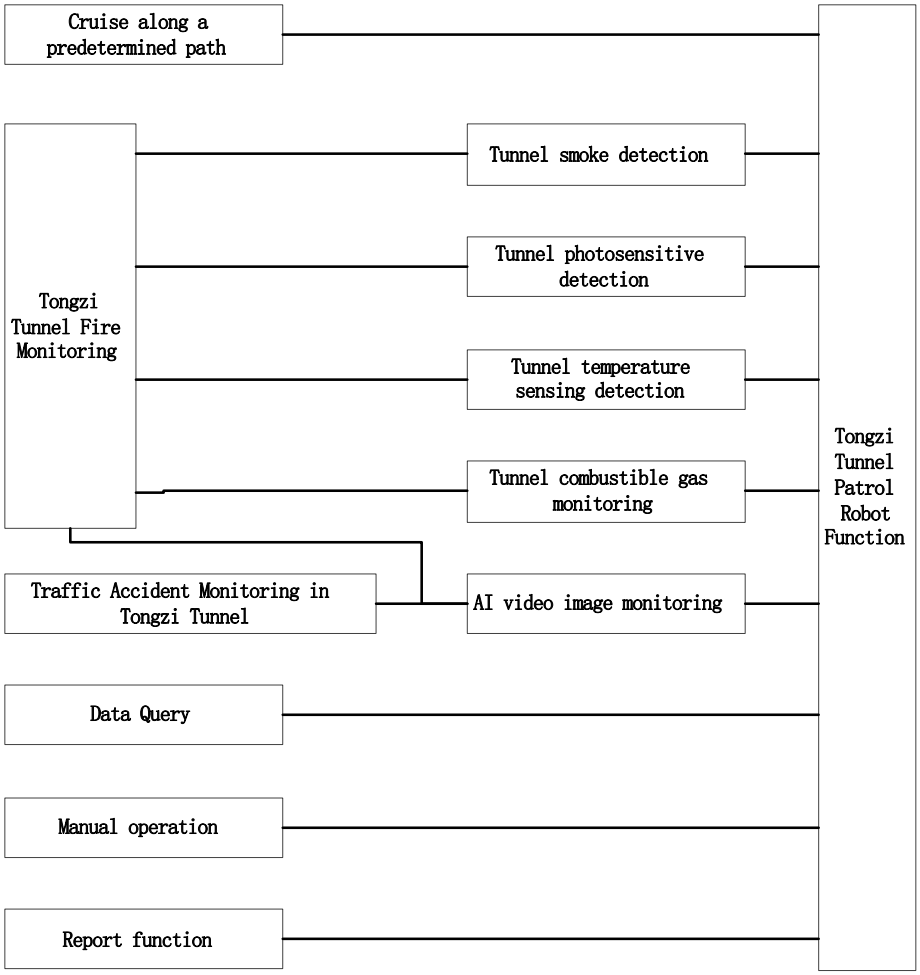

Figure 8. System Functions

The intelligent patrol robot detects relevant information in real time and processes it in the background. The database records all information transmitted by each robot, generates data charts in real time, and reports exceptions; Realize functions such as information sharing and device cascading through wireless bridges.

The intelligent inspection robot is installed with multiple sensors to achieve comprehensive detection of the tunnel traffic operating environment. Using its own mobile function, the robot inspection scheme is set up in the background for detection. During the inspection process, there are no dead corners in the patrol inspection. After each patrol inspection is completed, the patrol report can be automatically generated and the tunnel operation status can be fed back in a timely manner, which can effectively reduce the workload of operation and maintenance personnel and ensure the safe and stable operation of the tunnel.

5.3. System architecture

The intelligent inspection system is mainly composed of automatic inspection robots, carrier rail systems, power supply systems, communication systems, system management platforms, and other auxiliary systems.

(1) Patrol robot

The inspection robot is the core of an intelligent inspection system, which can use its own front-end acquisition devices such as visible light cameras and infrared thermal imagers to complete preset inspection tasks in a fully autonomous or remote control manner. The appearance of the intelligent inspection robot is as follows:

Figure 9. Schematic Diagram of Intelligent Patrol Robot

(2) Track system

The track of the intelligent inspection robot adopts a parallel double tube guide rail type track, which has a small vertical dimension and a small overall installation dimension requirement, making it convenient for engineering construction. The track material is a special high-strength aluminum alloy, and the surface is treated with oxidation and rust prevention, which can not only improve the corrosion resistance, but also improve the surface hardness and wear resistance. It has the advantages of high strength, good stability, corrosion prevention, convenient installation, and aesthetics. The track structure is shown in the following figure:

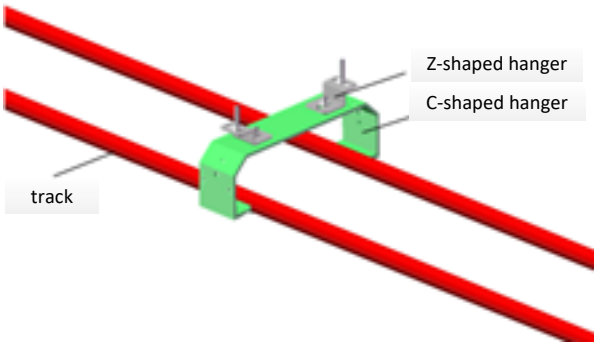

Figure 10. Track Structure Diagram

(3) Power supply system

The intelligent inspection robot uses a combination of battery power supply and distributed non-contact charging to provide power. Multiple wireless charging stations are arranged in the traffic tunnel (powered through the front-end control box). The robot is equipped with a large capacity and high-performance lithium battery, combined with a complete power management strategy of the system, to achieve long-term automatic operation.The distributed charging station is shown in the following figure:

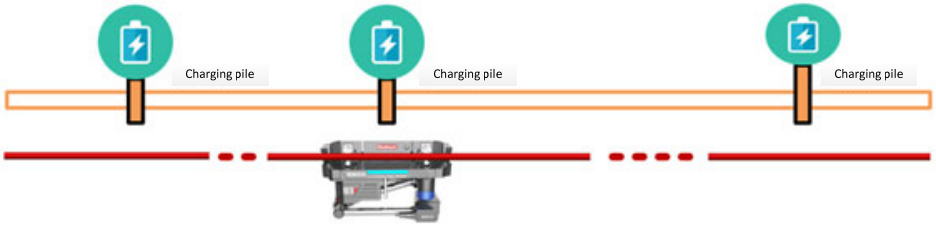

Figure 11. Schematic Diagram of Distributed Charging

(4) Communication system

The communication system is used to achieve two-way data interaction between the intelligent patrol robot and the system management platform (including various types of data such as control signals, video data, audio data, on-site sensor collection data, and alarm information). The intelligent patrol robot is connected to the control center of the traffic tunnel through a 5G communication network or private network, and then connected to the system management platform through a wired network. The system network structure is shown in the following figure:

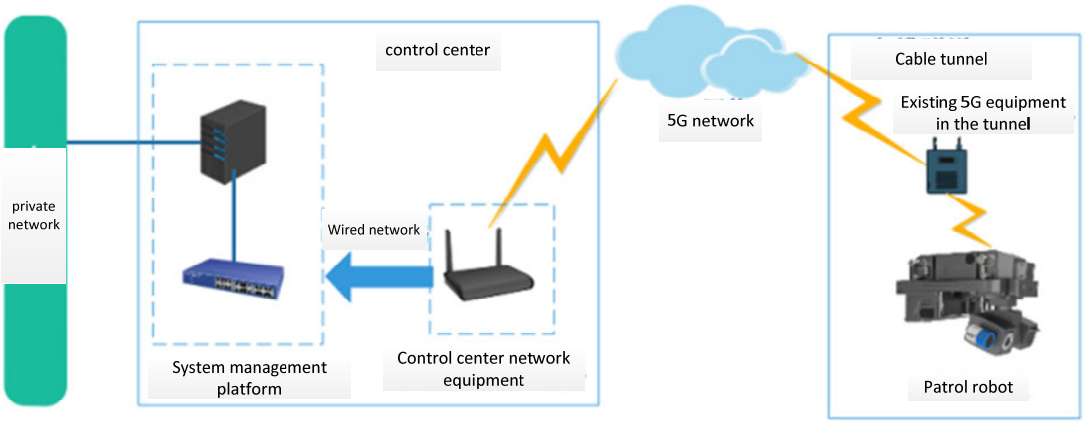

Figure 12. Communication System Network Topology Diagram

Table 1. Technical Requirements for Intelligent Automatic Patrol Robot

Serial Number	Product/Equipment Name	Remarks
1	Foundation preset position PTZ	Fully preset, digital/network type
2	Step drive terminal	Linear motion speed support protocol extended 64 level motion speed
3	Robot master CPU control board	It needs to meet the modular hot plug design. The core main control processor is designed using an ARM+DSP architecture, the collaborative transaction processing module is designed using FPGA+DSP, and the power processing module is designed using a DPA architecture; The processor performance should meet the requirements of the quad core A5 architecture 1.2G main processor unit
4	Robot communication interface control board	It is necessary to adopt a movable board design, and the chip is packaged with BGA, which is mainly responsible for the switch signal input of robot travel switches, proximity switches, band switch sensors, and other active interfaces such as relay/indicator signal output; Including serial port distributor and other interface components
5	Robot motion control module board	Responsible for the control of the main transmission AC servo motor of the robot, including the driver device module
6	Robot bus communication HUB board	Responsible for data interactive communication between robot audio and video processing, internal bus bridges, camera sensors, and other devices
7	Operation status audible and visual indication alarm	Installed above the robot for installation warning and operation status indication when the robot moves. If the robot fails, a buzzer alarm will be sent through the alarm
8	Programmable Patrol Track Control Unit	Capable of providing 1024 programmable control command sets to meet various preset position settings and linkage control requirements on site
9	Mechanical multi-dimensional dynamic mechanism assembly	Including universal bearing base, elastic telescopic steering block, driving shaft, driving bearing, driving double pulley, driven shaft, driven bearing, driven double pulley, and four sets of adjustable current collectors on both sides, to ensure the stability, signal, and power supply smoothness of the robot during movement
10	Modular final assembly control cabinet	Responsible for carrying various control boards of the robot control system (5 control board slots and 2 redundant modular power supply slots), and providing power supply and general I/O activity interfaces to each modular main board, including redundant modular power supply and industrial cooling system
11	Mechanical transmission drive and electrically controlled telescopic rod	Including transmission system, AC servo motor, incremental photoelectric encoder, elastic damping gear train, balanced and stable guide mechanism, electric telescopic rod, and other components; Including phase corrector
12	Prefabricated end of cloud platform	It can query the address, speed, controlled command, track length, real-time position of the track machine, speed information, limit switch status, preset setting parameters, etc
13	Charging pile	One charging pile and 500m supporting cable
14	Wireless AP	Three wireless APs and 500m supporting optical fiber
15	Gas detection module and software	Monitoring the content of carbon monoxide, nitrogen dioxide, and gas, specifically integrated in the robot body
16	Temperature and humidity smoke detection module and software	Temperature and humidity detection (air temperature and humidity), smoke detection (PM2.5 PM10), specifically integrated in the robot body
17	Photosensitive detection	Dual wavelength flame detection, specifically integrated into the robot body
18	Robot type	Intelligent lithium powered non elevating rail robot
19	Wireless receiving electrical box	TCP/IP network digital signal
20	Special customized parts	U-shaped rail connectors, cross shaped components, 9-hole connectors, expansion plates, 6-hole connectors, adjustable connecting rods, and terminal stability kits (quotation does not include special customized parts, which need to be customized according to the actual situation on site)
21	Main control system	Debugging software, calling software interface, database interface, basic control system platform, computer
22	Thermal imaging dual view ball machine	Visible light, thermal integrated image dual view ball machine, used for thermal imaging fire/video monitoring, mounted on the main body of the robot
24	Thunder vision integrated machine software	Expenses for access, development, integration, and debugging of Thundervision all-in-one computer software with our company
25	Alloy aluminum rail	Bearing capacity not less than 100kg (including connection and installation accessories), 3m per section, protection grade: IP65
26	Road multi-dimensional perception all-in-one machine (Thunder Vision Integrated Machine)	1. Fixed installation, frequency band 77GHZ, wavelength 4mm, speed measurement range 2km/h-250km/h; 2. All weather environment support, ICR infrared filter type, 3D digital noise reduction; 3. Forward and backward vehicle monitoring and tracking, with a maximum tracking target of 128; 4. Support the identification of new energy license plates, unlicensed vehicles, motor vehicles, non motor vehicles, and pedestrians, and support Beidou/GPS positioning; 5. Traffic accident detection and traffic flow monitoring in tunnels (vehicle density, vehicle spacing, driving speed)

(5) System management platform

The system management platform can be connected to a dedicated network, through which the staff of the superior unit can access the system management platform to achieve intelligent automatic inspection robot control, data query, task management, data export, and other operations. If there is a communication interruption or data abnormality, the robot will send out a communication alarm indication signal, and the system management platform interface will also immediately send out a communication abnormality alarm to facilitate staff to timely detect and handle the abnormality.

The intelligent automatic patrol system management platform software is designed using a B/S architecture. System data can be shared externally through the external interface of the WEB server, and can be remotely controlled, task configured, video accessed, data accessed, and integrated system management for the patrol robot through a dedicated client software/WEB client.

(4) Technical Requirements

① Autonomous charging

The intelligent automatic patrol robot body comes with a battery level detection circuit that can manually set the lower limit of the battery level alarm. Once the robot detects that the battery level is lower than the set value, it can automatically stop the current patrol task, issue an alarm, and automatically run to the charging point for charging.

② Long battery life

The battery carried by the intelligent automatic inspection robot itself is sufficient to support the robot to work continuously for 6 hours without power failure, and the charging time is not more than 3 hours, to ensure that the robot can work continuously for more than 16 hours online every day.

③ Flexible testing mechanism

The main detection unit consists of modules such as a high-definition network camera, an infrared thermal imager, and a high-precision PTZ. The PTZ can meet the continuous rotation of 0~360 °, with a large holding torque, and will not shift due to camera vibration.

5.4. Functional design

The system functions include basic capability detection, traffic incident monitoring, emergency handling, auxiliary lighting, etc.

(1) Basic detection capability

The intelligent automatic inspection robot system should be equipped with detection equipment such as visible light cameras, infrared thermal imagers, gas acquisition, and sound acquisition, and be able to upload the captured video and sound to the monitoring background.

A. Video monitoring function

The intelligent inspection robot can achieve visible light and infrared video image acquisition functions. The robot can automatically move to a designated position, control the free rotation of the pan-tilt, capture high-definition images and infrared thermal imaging of various devices in the tunnel, and transmit the collected information to the main control room in real time through a wireless LAN. The staff in the main control room can judge the tunnel operation status based on the images.

B. Infrared temperature measurement

The intelligent patrol system can achieve the infrared video image acquisition function, control the free rotation of the PTZ, take infrared thermal imaging in the smart tunnel, and transmit the collected information to the main control room in real time through the LAN. During the automatic patrol process, it automatically discovers temperature overrun nodes and areas and gives a timely warning.

C. Environmental monitoring function

The intelligent inspection robot is equipped with a gas detector, which can analyze the air environment in the tunnel at any time and obtain results, while feeding back the results to the staff in the monitoring room. It can also manually set alarm limits, including low and high temperature alarm limits, humidity alarm limits, and gas concentration alarm limits. Once the limit values are exceeded, an audible and visual alarm will be given immediately to prevent personnel from misjudging the tunnel environment, causing life hazards.

D. Bidirectional voice intercom function

When unconventional problems occur with equipment in the tunnel that cannot be solved by on-site personnel, real-time interaction between on-site personnel and remote experts can be achieved through the video and voice devices of intelligent automatic inspection robots. Experts can guide and supervise on-site personnel, achieve correct and standardized operations, and contribute to on-site problem resolution. At this point, the robot will accompany the on-site staff to work.

(2) Tunnel environmental monitoring

① Gas monitoring

Tongzi ultra long and large span tunnel frequently crosses unfavorable geology such as karst, faults, high ground stress, and coal seams, among which the gas pressure in the gas coal measures formation is 1.9Mpa. Due to the characteristics of tunnel construction in coal measures strata such as high safety hazards, low work efficiency, high difficulty in gas prediction and waterproof sealing, and the significant impact of gas content in the air after the completion of the tunnel on the overall safe operation of the tunnel, the tunnel inspection robot needs to attach gas monitoring sensors to the corresponding gas and coal measures strata for key monitoring to prevent high gas concentration from generating safety hazards.

② COVI monitoring

The tunnel inspection robot should also be equipped with a carbon monoxide (CO)/visibility (VI) integrated detection device (hereinafter referred to as COVI). The COVI detection equipment is used to conduct real-time COVI detection of different areas of the tunnel, and the detection data is used to evaluate the specific conditions of different sections of the tunnel air, in order to achieve coordinated work with ventilation equipment such as fans, so as to maintain good air conditions in the tunnel.

(3) Rapid monitoring of traffic incidents in ultra long tunnels

① Rapid Monitoring Technology of Vehicle Flow Characteristics Based on Video Images

Monitor the characteristics of traffic flow in the tunnel, such as flow, speed, and density, through video images, and generate real-time data for storage on the background platform. The inherent relationship between the frequency and characteristics of accidents can be analyzed based on vehicle flow characteristic data.

② Hazardous Vehicle Identification Technology

Based on the external feature recognition technology for hazardous, flammable, and explosive vehicles, there are several obvious differences between domestic hazardous

transportation vehicles and ordinary freight vehicles. a. Hazard signs are installed on the top of the cab; B. Special orange reflective stickers for dangerous goods will be affixed to all parts of the vehicle body; C. There are generally danger signs on the rear of the vehicle. And the vehicle type is also significantly different from ordinary freight vehicles. Writing the algorithm into the patrol robot chip can achieve the identification and detection of dangerous transportation vehicles.

③ Foreign matter detection on tunnel pavement

Through video image algorithms, foreign objects on the road are detected, analyzed based on the shape and size of the foreign objects, and judged whether they are causing obstacles to the normal passage of vehicles. Due to the fact that some throwing objects do not affect vehicle traffic, their shape and size have a certain impact on the driver, and the driver may cause tunnel accidents due to improper operation. Therefore, such foreign matters must be artificially removed. The tunnel inspection robot is equipped with communication devices and precise positioning devices, which can communicate information with operation management personnel, accurately inform the location of foreign matters on the road surface and the way to handle them. The operation management personnel can also directly and remotely view the video camera information of the inspection robot to determine the type of foreign matters on the road, thereby quickly and effectively handling foreign matters on the road.

④ Detection of vehicle parking violations in tunnels

Illegal parking of vehicles in tunnels poses a significant safety hazard, with relatively narrow visibility in the tunnel, making it difficult for drivers to distinguish the status of vehicles in front of them in a single dark environment in the tunnel, which may lead to serious traffic accidents. Therefore, the tunnel robot detects stationary vehicles in the tunnel through its onboard video monitoring system. If a violation of parking regulations is found, the patrol robot will run to the front of the vehicle and warn the violation of parking regulations through its equipped audible and visual alarm device. The tunnel robot is also equipped with a voice intercom remote broadcast system, which allows operation management personnel to notify drivers of parked vehicles through remote calls.

⑤ Traffic accident detection

Through the detection and analysis carried out by the video camera, it can quickly respond to traffic accidents in the tunnel, including traffic accidents, parking, retrograde traffic, traffic jams, pedestrians, etc.

⑥ Fire accident detection

Equipped with smoke detectors, temperature detectors, and video thermal imagers, it can quickly detect and accurately locate the occurrence of fires, and alarm through audible and visual alarms. It can be connected to the operating platform through communication equipment to send an alarm.

(3) Emergency handling function

During the daily inspection process, when an intelligent automatic inspection robot detects a traffic accident in a tunnel, it can arrive at the scene as soon as possible, issue an alarm, and upload a real-time location. Detect the concentration of smoke and harmful gases in the tunnel at the same time, and only when it is safe and controllable can rescue personnel enter the scene, greatly shortening rescue time and reducing the risk factor.

① Accurate and active fire extinguishing technology

The intelligent automatic patrol robot is equipped with temperature, smoke, and thermal imaging detection devices, and can accurately locate the fire source. For a fire that has just occurred but has not spread, the intelligent automatic patrol robot can accurately extinguish the fire through its own positioning device and fire extinguishing device.

② Assistance in rescue technology

For large fires with widespread fire, intelligent automatic inspection robots can timely alarm and notify operation management personnel, control corresponding variable information signs and traffic lights. Quickly and orderly arrange the evacuation of personnel and vehicles inside the tunnel through audible and visual alarm devices and voice systems. Real-time monitoring of fire conditions through temperature and smoke sensors moves outward as the fire expands. Upon arrival, firefighters can provide corresponding temperature data and smoke concentration, locate the nearest safe rescue distance from the fire source, and use infrared sensing equipment to locate the location of the fire source, enabling firefighters to accurately and quickly extinguish the fire during rescue operations

(4) Auxiliary lighting

The intelligent automatic inspection robot has auxiliary lighting function, which can ensure normal operation at night or under low light intensity.

5.5. Dynamic design of tunnel inspection robot

The motion module is structurally composed of a power source and a transmission device. Its main function is to provide power for the robot's inspection in the tunnel, while also serving as an executive mechanism for controlling the robot. In this paper, a servo motor is selected as the power source of the robot.

5.6. Patrol inspection method

1) Scheduled patrol inspection: patrol according to the set time.

2) Fixed point patrol: The commonly used fixed point patrol can perform automatic and constant speed patrol based on the specified path and the specified patrol target point. Simply setting the patrol path and starting the automatic patrol can enable the robot to automatically complete a patrol.

3) Scheduled patrol inspection: Conduct specific inspections according to specific tasks, such as setting up robots to perform meter reading tasks, or conducting visual defect detection tasks.

4) Prescribed route inspection: During routine inspections, the inspection route is set in advance. During the inspection process, the robot can automatically and accurately stop and detect each patrol working position. After completing the specified actions, it can automatically advance to the next patrol target point according to the path. No manual control is required. Complete the inspection operation, automatically record and save the collected data to the management platform, and generate a patrol analysis report on demand.

5) Remote control inspection: real-time remote control of robots through manual remote control inspection. This application mode is suitable for operation and maintenance personnel and management units that need to lock and monitor the status of certain types of equipment, especially when abnormal equipment and environmental conditions are detected during autonomous robot patrols and an alarm is given to the operation and maintenance personnel, the operation and maintenance personnel can quickly manipulate

the robot to reach the location of abnormal equipment in the first time, view the abnormal equipment in a timely manner, and verify the alarm information, in order to quickly formulate response strategies.

The operation and maintenance personnel have the highest operational priority for the remote control operation of the robot. After the system enters the remote control patrol mode, the robot will suspend other tasks that are being executed, and follow manual remote control instructions to achieve functions such as the robot's forward and backward movement at an adjustable speed, the elevator's up and down movement, and the omni-directional rotation of the pan and tilt table, as well as lens zoom adjustment of the dual view camera. It can ensure that the system reaches the designated location in the first time, obtain status data and visual images of the equipment and environment, and ensure the safe operation of the equipment. Autonomous patrol inspection - Operators can flexibly conduct inspections based on the patrol time, cycle, route, target, and type (infrared, visible, partial discharge, etc.)

6. Conclusion

Based on Tongzi Tunnel, this paper studies the combined detection mode based on the safe operation of ultra-long tunnels, aiming at the main safety issues in the operation process of ultra-long tunnels, based on both tunnel fire and traffic incidents, and develops a response implementation plan; Innovatively transplant mobile detection technology to highway tunnels, use intelligent patrol robots, carry various detection devices and early warning devices based on core detection technology, real-time monitor the tunnel operating environment, analyze sensor detection data, predict tunnel operating conditions in a short time in the future, and achieve safe operation of ultra-long tunnels. Based on this, the following conclusions are drawn:

(1) In this paper, video based thermal imaging technology is used to detect tunnel fire accidents, combining dual wavelength flame detection and video monitoring methods to achieve open fire and pure smoke detection when a fire occurs in a tunnel. This combined detection method can accurately identify the initial state of the fire and minimize casualties or economic losses caused by the spread of the fire.

(2) The use of traffic incident detection technology based on lightning vision integration can effectively achieve the monitoring and detection of various types of traffic incidents in tunnels, making up for the shortcomings of high false alarm rates in traditional tunnel traffic incident detection.

(3) Based on this research scheme, using intelligent patrol robots as the carrier and carrying various types of sensing equipment and emergency equipment, on the one hand, it compensates for the detection blind spot of fixed monitoring equipment, replaces manual patrol, realizes 24-hour uninterrupted full coverage monitoring of tunnel safety operations, and reduces the cost of manual patrol; On the other hand, equipped with a variety of detection equipment based on various advanced technologies to improve the accuracy, timeliness, and reliability of tunnel fire, light environment, and traffic incident detection. At the same time, equipped with emergency equipment, to a certain extent, can replace manual timely handling of some emergencies, and minimize the losses caused by accidents.

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