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Research on a Comprehensive Monitoring System for Tunnel Operation based on the Internet of Things and Artificial Intelligence Identification Technology

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Abstract: This article proposes a comprehensive monitoring system for tunnel operation to address the risks associated with tunnel operations. These risks include safety control risks, increased traffic flow, extreme weather events, and movement of tectonic plates. The proposed system is based on the Internet of Things and artificial intelligence identification technology. The monitoring system will cover various aspects of tunnel operations, such as the slope of the entrance, the structural safety of the cave body, toxic and harmful gases that may appear during operation, excessively high and low-temperature humidity, poor illumination, water leakage or road water accumulation caused by extreme weather, combustion and smoke caused by fires, and more. The system will enable comprehensive monitoring and early warning of fire protection systems, accident vehicles, and overheating vehicles. This will effectively improve safety during tunnel operation.

Keywords: Internet of Things; Artificial intelligence; Operation tunnel; Monitoring

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1. Introduction

With the advancement of urbanization in China, the large-scale construction of highways has increased the number of tunnels in recent years. The advancement of construction projects has led to various tunnels being built, such as extra-long tunnels, extra-large cross-section tunnels, shallow-buried tunnels, small-distance close-access tunnels, tunnels with complex geological conditions, and so on, which has also brought huge challenges to the operational safety of the tunnels.

In recent years, technological achievements have been made in the structural monitoring of tunnel operations. The existing monitoring technology has guaranteed the structural operation safety of tunnels [1]. However, there is an increasing risk in safety management and control due to the increase in the number of tunnels, the increase in traffic flow caused by social development, extreme weather caused by climate change, and the occurrence of ground vibrations caused by frequent movements of tectonic plates. This also greatly increases the operational risks of tunnels, especially municipal tunnels. Existing monitoring technology can no longer fully meet the demand of tunnel safety operations so further monitoring technology upgrades are urgently needed to ensure operational safety. With the commissioning of the independently developed Beidou satellite navigation system in China, the large-scale commissioning of 5G base stations, and the rapid development of artificial intelligence (AI) technology, technical support has been provided for operational tunnel monitoring based on the Internet of Things and artificial intelligence identification technology.

This article will conduct research on a comprehensive monitoring system for tunnel operations by analyzing various safety risk monitoring technologies to ensure safe tunnel operations.

The system will be constructed using the principles of advanced technology, complete functions, stable performance, and cost savings. This system will be an information system that aligns with the applications of highways and highway industries. Maintenance and operation factors are also comprehensively considered to leave room for expansion for future development, expansion, renovation, and other factors. When designing the system, the five factors below are considered.

(1) Adhere to the principle of practicality first.

(2) The design of the system solution strictly follows the design guidelines of system engineering and strikes a balance between the rationality of the system and the advancement of technology.

(3) System design should adopt standardized and modular design as much as possible and strictly comply with international, domestic, and industry standards of relevant technologies to ensure openness and transparency between systems and interconnection between systems.

(4) The entire system adopts an overall design with high reliability, in which the selected equipment itself should have high safety and reliability, and key equipment or components should have a backup system.

(5) The system should be easy to manage and maintain, and information infrastructure design, such as computer networks, should adopt a simple and easy-to-use architecture to reduce system operation and maintenance costs.

2. Tunnel entrance side slope stability monitoring

An automatic observation point has been set up on the slope of the tunnel entrance to ensure the safety of the tunnel operations as shown in **Figure 1**. This is because the tunnel entrance is prone to landslides, displacements, and other related conditions that can affect the safe operation of the tunnel. The observation point uses various tools such as a pull-wire displacement meter, Beidou monitoring system, intelligent crack monitor, inclination displacement meter, fixed inclinometer gauges, rain gauges, and panoramic cameras. These tools comprehensively monitor parameters like surface displacement, cracks, surface tilt displacement, deep displacement, and environment. The data collected from these tools helps identify risks promptly and take necessary actions to eliminate them.

Figure 1. Beidou monitoring point site layout map

3. Tunnel body deformation monitoring

Based on the analysis of the geological conditions of the existing tunnel operations, it is crucial to monitor the deformation of the tunnel structure in specific key areas. These areas include shallow buried sections, adjacent sections, V-level, upper surrounding rock sections, and fault fracture zones. The primary focus of the monitoring is to keep an eye on vault settlement and peripheral convergence. A laser rangefinder is used to monitor peripheral convergence, while a magnetostrictive static level is used for vault settlement monitoring as shown in **Figure 2**. Through relevant monitoring, it is possible to provide immediate feedback on structural deformation in key areas, provide timely warnings, eliminate risks, and ensure the safety of structural operations [2].

Figure 2. Field test diagram of magnetostrictive static level

4. Comprehensive monitoring of tunnel operation environment

During tunnel operation, various safety risks can arise, such as toxic and harmful gases, extreme temperature and humidity, poor illumination, water leakage or road water accumulation due to extreme weather, combustion and smoke caused by fires, and so on. Therefore, it is crucial to ensure the safety of tunnel operations by conducting comprehensive monitoring of the operating environment as shown in **Figure 3**. This includes monitoring gases, temperature and humidity levels, tunnel lighting, road water accumulation, smoke, open flames, and other potential hazards [3].

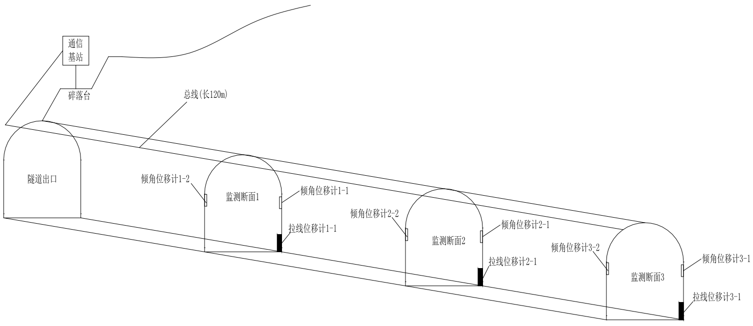

Figure 3. Schematic diagram of comprehensive monitoring of the operating environment

A comprehensive monitoring system is being used to address water accumulation on the tunnel road. It utilizes artificial intelligence infrared monitoring, a water level meter, and an AI intelligent recognition camera based on the Internet of Things. These technologies work together to provide timely early warning of water accumulation on tunnel roads during heavy rain conditions. The system combines video surveillance technology, infrared water detection technology, and water level measurement to improve the effectiveness and timeliness of monitoring to reduce safety hazards and improve operational safety [4].

5. Fire protection facility monitoring

The primary purpose of monitoring fire protection facilities is to keep track of the water level in the fire protection system and ensure water pressure in each pipe network is balanced. Any abnormal situations are swiftly handled through monitoring to ensure the smooth operation of fire protection facilities. The current intelligent fire protection system is comprised of an intelligent fire hydrant monitoring system and a fire water pressure monitoring system. It combines the monitoring of fire protection facilities, main pipelines, and water storage into a single, comprehensive monitoring system as shown in **Figure 4**.

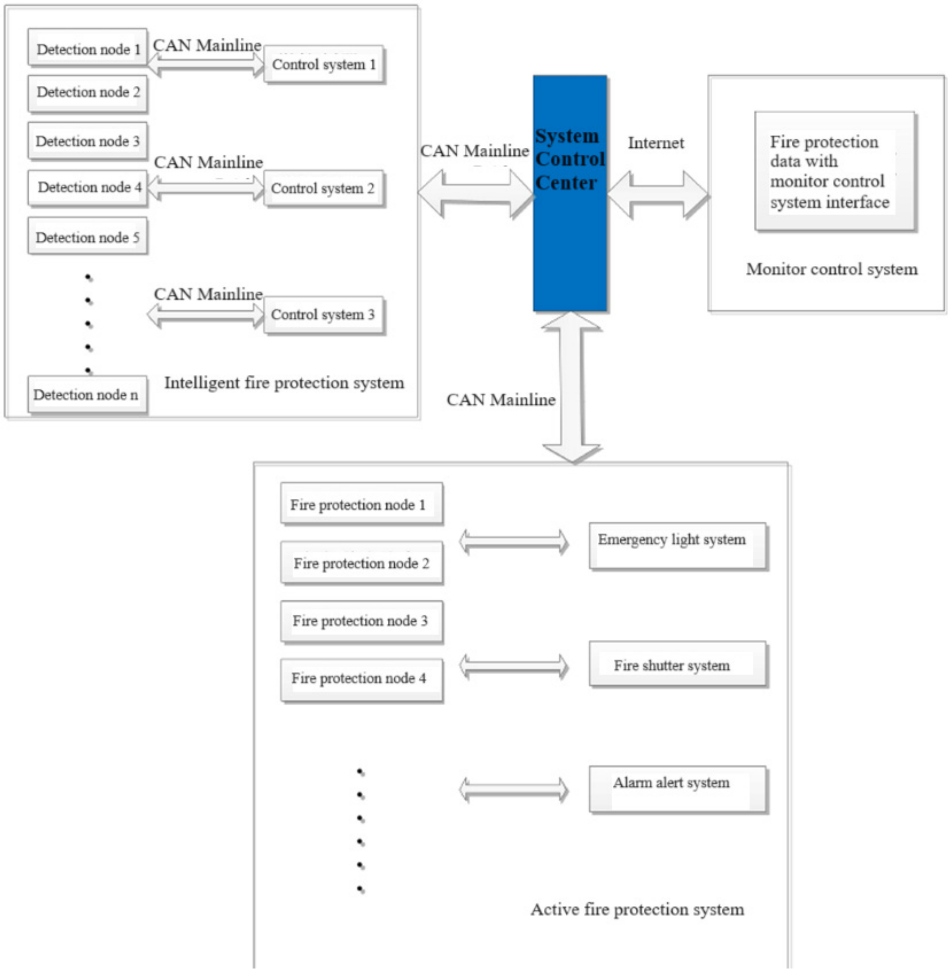

Figure 4. Overall design of intelligent fire protection system

6. Comprehensive monitoring of traffic status

The system combines real-time traffic flow monitoring, vehicle types, accidents, fires, and other information into a complete traffic status intelligent monitoring system, then divides the data into two categories, which are the data obtained through intelligent device sensing and the data entered by on-site accident-related personnel [5]. The fire monitoring system uses infrared automatic monitoring equipment as the main part and a manual alarm system as a supplement. The comprehensive monitoring system structure is shown in **Figure 5** [6].

Beidou real-time positioning has technical difficulty when monitoring vehicle trajectory in tunnels, so a Leishi traffic sequencing all-in-one machine is used to obtain vehicle trajectory information continuously, achieving continuous position tracking of the vehicle in tunnel. The platform can map the vehicle position into the coordinate system of the high-precision map and display the real-time traffic status and traffic event information of the selected tunnels in the road network on the virtual map. The Leishi traffic sequencing all-in-one machine for vehicle trajectory acquisition as shown in **Figure 6** is mainly used in traffic sequencing systems to track real-time vehicle trajectories [7].

The system also tracks the temperature of vehicles to reduce the occurrence of fire accidents to ensure tunnel safety. The overheating of the vehicle in the tunnel can be detected by combining data such as the characteristic and license plate information extracted through the detection unit set up at the tunnel front end, the vehicle trajectory information obtained by the Rayvision sequencing all-in-one machine, the vehicle temperature information obtained by the thermal imaging temperature detection unit, and real-time trajectory tracking [8]. The tunnel front-end vehicle overheating detection and warning system is shown in **Figure 7**.

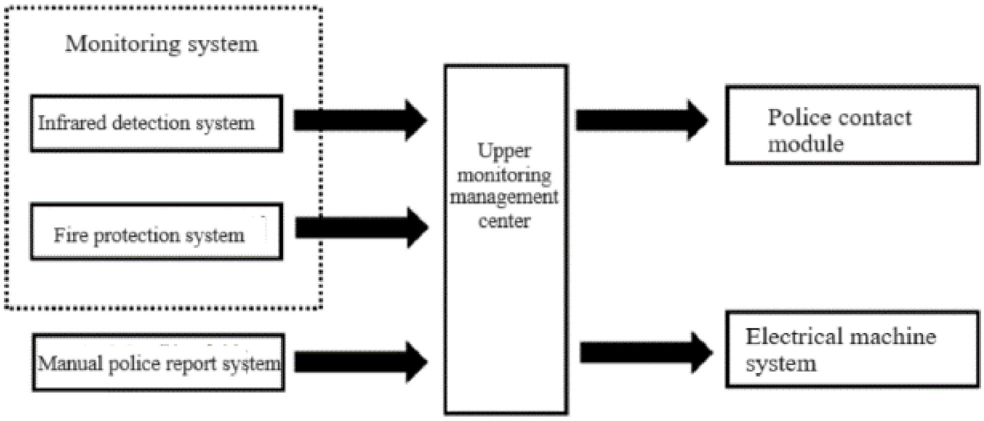

Figure 5. Fire system monitoring structure diagram

Figure 6. Photo of the Leishi traffic sequencing all-in-one machine

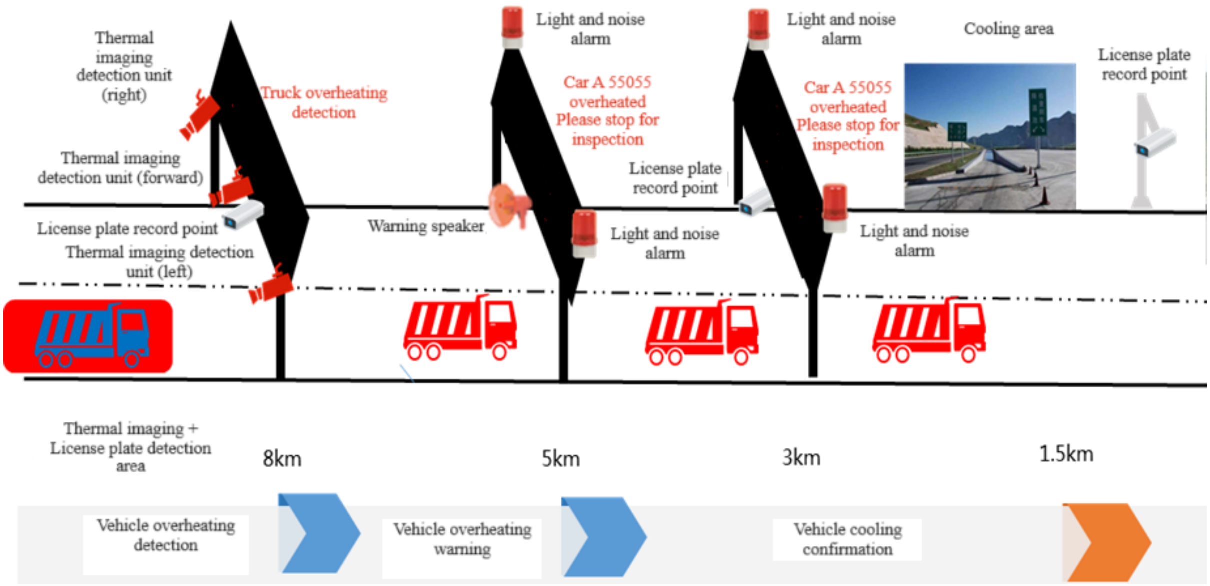

Figure 7. Tunnel front-end vehicle overheating detection and warning system

7. Conclusion

By adopting a comprehensive tunnel monitoring system based on the Internet of Things, real-time monitoring and timely warning of tunnel structural safety and operational risks can be carried out, further improving the safe operation of tunnels as listed below [9,10].

(1) Real-time monitoring of tunnel structure safety can effectively improve tunnel operational safety and detect the stress state of the tunnel structure in real time.
(2) Comprehensive monitoring of the real-time operating environment of tunnel can ensure early warning of abnormalities in the tunnel for prompt elimination of operational safety hazards.
(3) The safety risk of spontaneous combustion of vehicles can be reduced by monitoring overheating vehicles to avoid bringing safety hazards into tunnels.
(4) The operational safety of tunnels can be improved through comprehensive monitoring of tunnel operations to establish a strong transportation system in the country.

Disclosure statement

The authors declare no conflict of interest.

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