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Design and Application of Tunnel Service Safety Monitoring and Early Warning System Based on Multi-Sensor

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Abstract. Considering the service life and operation safety of the tunnel structure, it is necessary to carry out research on the development of tunnel service safety monitoring and early warning system, explore the actual working state of the tunnel in real time, effectively monitor the disease of the tunnel structure and warn in time.In this paper, the design of tunnel service safety monitoring and early warning system is discussed and studied based on the comprehensive consideration of how to obtain the disease characteristics, spatial location, mechanical properties and related dynamic changes of the key parts of the tunnel in real time, aiming at the diseases such as water leakage and deformation in the regular detection of the tunnel during the operation period. A tunnel service safety monitoring and early warning system based on multi-sensor is recommended, which can provide a favorable technical reference for the applicability and rationality design of tunnel service safety monitoring and early warning system.

Keywords. Multi-Sensor; Tunnel service safety; Periodic inspection; Monitoring and early warning.

1. Introduction

At present, China 's tunnel construction has become the world 's largest in terms of scale and mileage.Compared with other non-underground projects, the probability of tunnel safety accidents and quality accidents is higher, and the consequences are more serious[1]. Although the construction technology and quality level of tunnel structure have been improved year by year, tunnel engineering, as an underground structure, has a complex and changeable working environment. Due to the influence and restriction of various factors for a long time, there are various potential safety hazards. During its operation and service, there may be structural cracks, water leakage, deformation and

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other diseases [2].Therefore, the use function of the tunnel is greatly reduced, which has a great impact on society and traffic, and even threatens the safety of life and property.

Many scholars at home and abroad have studied the early warning and prediction of tunnel engineering. Such as Zhang Junrul [3] developed a tunnel health monitoring and intelligent information management evaluation system, and looked forward to the new trend of the development of tunnel intelligent monitoring technology and information management system. Based on Java programming language and Access system, Fang Yu [4] developed a tunnel construction monitoring data analysis and management system. Based on the data-driven principle, Li [5] reconstructed the business logic, developed a new tunnel geological information system TGIS, and constructed a tunnel support evaluation system based on holographic deformation monitoring by introducing three-dimensional laser scanning. G et al. [6], K et al.[7], H et al.[8] have carried out tunnel monitoring technology research.

In view of the current situation and demand, considering the characteristics of tunnel diseases and the changes of mechanical properties during the operation period, and considering the economic cost input, tunnel technical conditions and service life, etc.In this paper, a tunnel service safety monitoring and early warning system based on multi-sensor is proposed for the diseases such as water leakage and deformation in the regular detection of tunnel structure.The system monitors and analyzes the spatial location, mechanical properties, diseases and other related dynamic changes of key parts of the tunnel, intelligently perceives the service status of the tunnel structure, timely and dynamically grasps the technical status and disease development and evolution of the tunnel structure, improves the service quality and service life of the tunnel, and provides data support for the scientific management and maintenance decision-making of the tunnel, thus promoting the progress and development of tunnel structure and material design technology.

2. Project Overview

The bedrock of some sections of a tunnel is exposed, and most of the sections are covered by Quaternary residual slope deposits, which are alluvial boulder soil and gravel silty clay in residual slope deposits. The bedrock is shale, carbonaceous shale and banded shale with fine sandstone. The tunnel lining adopts a composite lining structure, and the pavement adopts a cement concrete structure. The full section of the tunnel is sprayed with a special fire retardant coating for the tunnel, and electromechanical facilities such as lighting and mechanical ventilation are installed. According to the engineering geological mapping, there is a small amount of runoff in the valley of the tunnel area, and the surface water volume is greatly affected by the amount of atmospheric rainfall. The tunnel layout is shown in figure 1, and the distribution of tunnel surrounding rock grade (construction pile number) is shown in table 1.

Figure 1. Layout of a tunnel

Table 1. Distribution of tunnel surrounding rock grade (construction pile number)

serial number	Pile number paragraph	surrounding rock grade	length
1	K4+280~K4+580	V	300
2	K4+580~K4+760	IV	180
3	K4+760~K6+410	III	1650
4	K6+410~K6+670	IV	260

3. Research on the Technical Status of the Project

3.1. Civil Structure and Other Engineering Facilities Inspection

In order to grasp the technical status of the tunnel structure, this project is based on the ' Technical Specification for Highway Tunnel Maintenance' (JTG H12-2015) to inspect and evaluate the entrance, door, lining, pavement, maintenance road, traffic signs and lines, contour marks, etc. The inspection results are summarized as shown in table 2, and the inspection conditions of entrance, lining and pavement are shown in figures 2-7.

Table 2. Summary table of inspection results of civil engineering structure

Tunnel name	scope of examination		result	technical condition
a tunnel	civil structure	tunnel face	The slope on the right side of the main tunnel outlet is water seepage, and the slope on the left side of the auxiliary tunnel outlet is developed.	Main tunnel civil structure score JGCI = 69.5, classified as category 3.
		tunnel portal	Part of the ceramic tiles near the left haunch of the main tunnel entrance portal fall off.	Auxiliary tunnel civil structure score JGCI = 85.25, rated as Category 1.
		tunnel lining	Local lining cracking damage, water seepage signs. Among	

		them, there are 36 cracks in the main tunnel lining and 22 water seepage. There are 13 cracks in the auxiliary hole and 5 water seepage.	
	pavement	There are two damaged pits on the tunnel pavement, and the main tunnel pavement is wet and slippery.	
	overhaul road	Individual maintenance road cover plate cracking, damage.	
	drainage system	No obvious damage was found.	
	Ceiling and various embedded parts	No obvious damage was found.	
	inner decoration	Ten diseases were found in the main tunnel decoration, and the scale value was 1. Six diseases were found in the interior decoration of the auxiliary cave, and the scale value was 1.	
	Logo Line outline	All kinds of logos are relatively perfect. Local contour mark damage ; the elevation mark setting at the entrance and exit of the tunnel is not standardized ; there is no tunnel speed limit sign at the entrance of the tunnel.	
Other Engineering Facilities		There is mainly local seepage in the equipment cavern.	QTCI = 90.91, classified as category 1.

Figure 2. Seepage on the right side slope of the hole

Figure 3. Water seepage on the right side wall of lining

Figure 4. Oblique cracks on the right haunch of lining

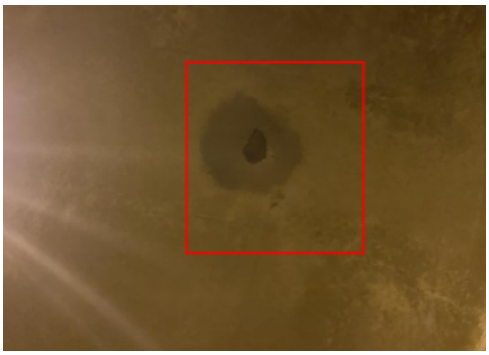

Figure 5. Auxiliary tunnel vault seepage water

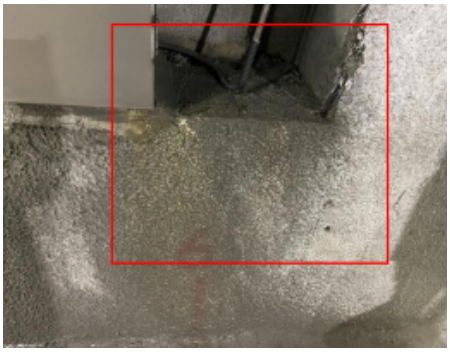

Figure 6. The right side wall equipment cavern seepage

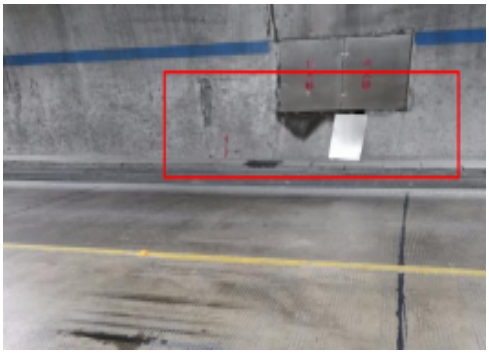

Figure 7. Water seepage in equipment cavern

3.2. Technical Condition Assessment of Tunnel

(1) Technical condition assessment of civil structure : Based on the appearance inspection results of civil structure, according to the ' Technical Specification for Maintenance of Highway Tunnels ' (JTG H12-2015), the technical condition assessment results of the civil structure of the tunnel are as follows : the technical condition of the civil structure of the tunnel (main hole) is classified as 3 categories, and the technical condition of the civil structure of the tunnel (auxiliary hole) is classified as 1 category.

(2) Evaluation of technical conditions of other engineering facilities : According to the " Technical Specification for Maintenance of Highway Tunnels " (JTG H12-2015), the technical conditions of other engineering facilities of the tunnel are evaluated as follows : the technical conditions of other engineering facilities of the tunnel are evaluated as Class 1.

Combined with the situation that the electromechanical technical condition grade is 2, the overall technical condition grade of the tunnel is evaluated as 3.

4. System Design and Application Research

Based on the investigation of the technical condition of the tunnel and the evaluation results of the technical condition, a tunnel service safety monitoring and early warning system based on GNSS displacement monitoring system, crack meter, strain gauge and other multi-sensors is designed. It focuses on the real-time monitoring of the cracks, seepage and deformation of the tunnel structure, and efficiently obtains the disease characteristics, spatial location, mechanical properties and related dynamic changes of the key parts of the tunnel in real time. The tunnel service safety monitoring and early warning system based on multi-sensor is composed of sensor subsystem, data acquisition and transmission subsystem, data analysis and management subsystem, early warning and monitoring management subsystem. The data transmission of the typical section monitoring layout of the tunnel, the monitoring layout of the tunnel portal slope and the tunnel portal end wall, and the tunnel service safety intelligent monitoring and early warning system is shown in figures 8-9.

Aiming at the cracks and water seepage diseases of tunnel structure, multi-sensors such as Beidou displacement monitoring system, laser convergence meter, inclinometer, strain gauge, rain gauge, temperature, humidity and light gas integrated monitor are arranged at the entrance and exit slope of tunnel, end wall and cracks of tunnel portal and typical section to monitor the development and change of cracks and water seepage of tunnel structure in real time. The tunnel point cloud model is shown in figure 10. The data management platform interface of tunnel service safety monitoring and early warning system based on multi-sensor is shown in figure 11, and the system monitoring data curve is shown in figure 12.

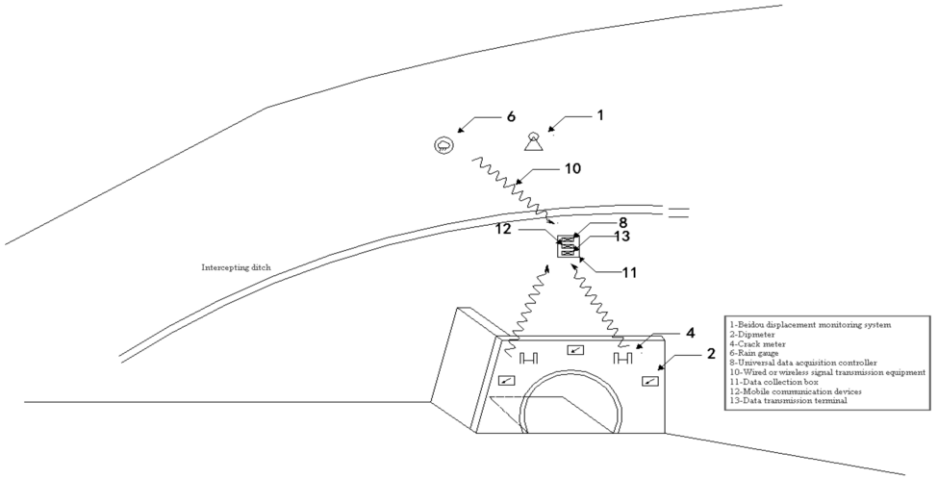

Figure 8. Typical section monitoring layout diagram of tunnel portal

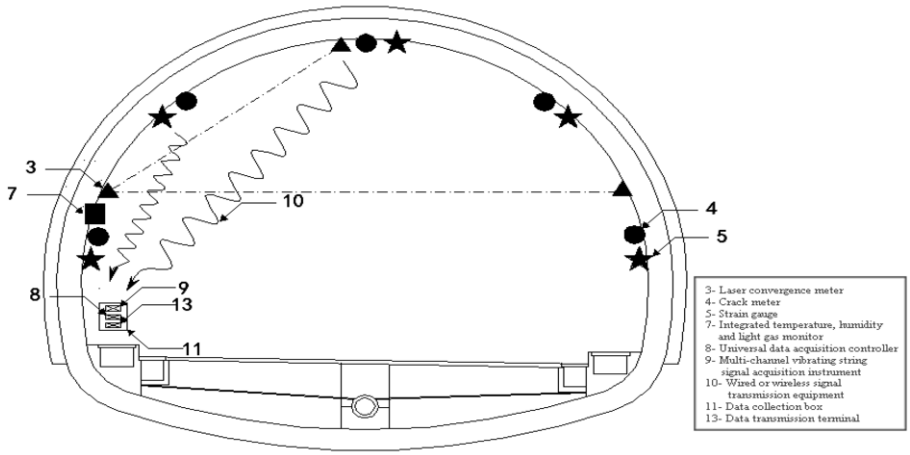

Figure 9. Monitoring layout diagram of typical section of tunnel

Figure 10. Tunnel point cloud model diagram

The sensor subsystem transmits the monitoring data obtained by the multi-sensor to the outside of the hole by wired or wireless means through the data acquisition box, and then transmits the data to the data transmission subsystem by means of mobile communication. The data analysis management subsystem performs polling judgment, processing and analysis on the monitoring data received in real time by the data transmission subsystem, and generates electronic reports such as daily reports, weekly reports, and monthly reports for unified management and unified storage. The early warning and monitoring management subsystem will automatically organize the early warning and alarm information into early warning reports to perform early warning operations when the measured point data reaches the early warning value and alarm value, and can log in, query, browse, and manage the collected monitoring data in real time. Monitoring daily, weekly, monthly reports, early warning reports, etc.

Figure 11. System data management platform interface

Figure 12. System monitoring data curve diagram

5. Conclusion and Suggestion

In this paper, the tunnel service safety monitoring and early warning system is designed and applied to solve the problems of how to obtain the disease characteristics, spatial location, mechanical properties and related dynamic changes of the key parts of the tunnel in real time, such as water leakage, deformation and other diseases in the regular detection of the tunnel during the operation period. Compared with the traditional monitoring technology, it saves a lot of manpower and material resources, ensures the timeliness of data transmission, greatly improves the authenticity and reliability of the data, and can realize the full automatic on-line monitoring of the deformation and stress of the tunnel structure. Real-time perception of the service status of the tunnel structure, timely and dynamic grasp of the technical status of the

tunnel structure and the development and evolution of the disease. It makes the early warning of tunnel structural abnormalities more timely and accurate, improves the service quality and service life of the tunnel, grasps the working status of the tunnel operation in real time, predicts and evaluates the safety performance of the tunnel operation period, and provides data support for the scientific management and maintenance decision of the tunnel, so as to promote the progress and development of tunnel structure and material design technology.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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