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Retraction

Retracted: Application of Internet of Things Based on Wireless Sensor in Tunnel Construction Monitoring

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This article has been retracted by Hindawi, as publisher, following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of systematic manipulation of the publication and peer-review process. We cannot, therefore, vouch for the reliability or integrity of this article.

Please note that this notice is intended solely to alert readers that the peer-review process of this article has been compromised.

Wiley and Hindawi regret that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

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[1] J. Cao, R. Zhao, L. Hu, Q. Liang, and Z. Tang, "Application of Internet of Things Based on Wireless Sensor in Tunnel Construction Monitoring," *Journal of Sensors*, vol. 2022, Article ID 5302754, 8 pages, 2022.

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Research Article

Application of Internet of Things Based on Wireless Sensor in Tunnel Construction Monitoring

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In order to solve the problems of insufficient frequency, time-consuming, and labor-consuming of monitoring and measurement in the process of tunnel construction, a tunnel construction monitoring and measurement technology based on Internet of Things is proposed in this paper. This method adopts the basic theory and technology of Internet of Things, analyzes the fit relationship between Internet of Things technology and tunnel construction, uses the comprehensive perception, reliable transmission, and intelligent auxiliary technology possessed by the existing Internet of Things technology system, and has been successfully applied to tunnel engineering. The experimental results show that the contact pressure between the surrounding rock and the initial support on the monitoring and measurement section in the tunnel is zero after the initial support shotcrete is applied. The contact pressure between the surrounding rock and the shotcrete layer at the right arch waist of the left tunnel is the smallest, and the stress in the whole change process is less than 10 kPa. The contact pressure between surrounding rock and shotcrete layer after excavation is divided into three stages. *Conclusion*. the tunnel construction monitoring and measurement technology based on Internet of Things technology fully realizes the intellectualization and informatization of the construction process, plays a scientific and effective monitoring and early warning role, and reduces the project cost of the whole project, which has a certain engineering value.

1. Introduction

At present, in the aspect of tunnel construction, dynamic construction monitoring has become an urgently needed supporting technology. With the progress of technology, the construction technology for tunnel construction is also improving. Automatic mechanical equipment is mostly used in the process of tunnel excavation. The geological conditions of the tunnel are related to the selection of construction methods. Therefore, it is very important to obtain and reasonably deal with geological information in the process of construction. With the continuous improvement of the collection automation of various multisource information, the wireless data transmission, the safety early warning, and the relevant technical methods of the construction management system, the construction monitoring system can basically realize the detection of relevant environmental parameters (including vulnerable harmful gases) and the tracking and positioning of construction personnel. Moreover, in case of safety accidents during tunnel construction, the system can give corresponding safety warnings and relevant reminder information according to the monitoring data and wireless communication, so as to facilitate the construction management personnel to start early warning and corresponding emergency plan, which plays a good guiding role in the evacuation and rescue of construction personnel, and ensure the safety of tunnel construction and the property safety of units and individuals [1]. These have important practical significance for the normal progress of tunnel construction, efficient dispatching management on the construction site, and ensuring safe construction [2].

2. Literature Review

Kirpichenkova and others used a Jikang static leveling system, Campbell data acquisition system, wireless transmission module, and automatic acquisition software to form an automatic real-time monitoring system and applied the automatic real-time monitoring technology to the crossing project of a rail transit line. The system can realize data acquisition and transmission once a minute, process and analyze data in real time, realize data alarm and chart analysis, enable the construction party to adjust the speed and direction of shield propulsion in time during crossing construction, and facilitate analysis and summary after construction [3]. Ootani and others combined the static level and displacement meter to establish an omnidirectional displacement (deformation) real-time monitoring system. The remote real-time monitoring system of dangerous road displacement (deformation) based on sensor is mainly composed of on-site monitoring and data acquisition system, main control computer system, and application terminal system. Through the remote real-time monitoring system, we can timely and accurately grasp the changes of the geometric shape and position of the subway dangerous road structure and judge the safety of the subway dangerous road structure in time [4]. Liu and others applied the automatic real-time monitoring system to the Yanda section of the east extension section of Shenzhen Metro Line 2 crossing the Dake section of Metro Line 1, carried out the dynamic monitoring of the subway, implemented the information construction, continuously optimized the design, improved the construction technology, effectively prevented or reduced the occurrence of various accidents, and promoted the smooth progress of the project [5]. Marco and others developed a set of "information management system during tunnel construction" based on the geographic information system (GIS). The system uses electronic total station to conduct noncontact monitoring and data processing on the three-dimensional convergence deformation of the surrounding rock surface of the tunnel. It realizes the functions of real-time data acquisition and real-time transmission, analysis and processing, query, and visual output of monitoring data [6].

Limited by geological conditions and technical factors, at present, the application scope of Internet of Things in China is more applied in intelligent transportation than in engineering monitoring. The application of Internet of Things in tunnel engineering focuses on personnel positioning and intelligent management, and its application in the field of tunnel construction monitoring still needs to be developed. According to the basic principle and structure of Internet of Things technology, this paper analyzes the fit between Internet of Things technology and tunnel construction monitoring and measurement, puts forward the tunnel construction monitoring and measurement system based on Internet of Things technology, applies it in practical engineering, and evaluates the guidance and feedback function of the tunnel construction monitoring system based on Internet of Things. The results show that the tunnel construction monitoring and measurement system based on the Internet of Things can provide real-time and accurate information for the design and construction parties in the actual project, so as to ensure the requirements of project progress and safety.

3. Research Methods

3.1. Technical Composition of Tunnel Internet of Things

3.1.1. Constituent Elements of Internet of Things Technology. Internet of Things technology is a new network technology that connects various entities with various networks such as the Internet and widely obtains all kinds of information through strip QR code, radio frequency identification technology (RFID), sensor technology equipment, global positioning system, and wireless transmission technology, so as to realize comprehensive intelligence such as positioning, tracking, and monitoring and realize good communication between people and things [7, 8].

Structurally, it can be divided into three layers: perception layer, transmission layer, and intelligent processing layer, as shown in Figure 1.

The sensing layer is the bottom layer of Internet of Things technology, including radio frequency identification (RFID), telemetry and remote sensing (RS), sensors, and sensor networks. The transmission layer includes Internet technology, wireless transmission technology, and satellite communication technology. Intelligent processing layer refers to the data processing and application technology in the Internet of Things, including cloud computing, data processing and fusion technology, computer vision technology, and communication technology [9, 10].

3.1.2. Key Technologies of Tunnel Internet of Things

(1) Key Technologies of Perception Layer. In the sensing layer of the Internet of Things, sensor technology and RFID technology play a key role: generally speaking, sensors are devices that convert other physical information (such as pressure, speed, humidity, displacement, and deformation) into electrical signals or other required forms of information according to certain laws and output, process, store, display, and control data. Radio frequency identification (RFID) is a noncontact automatic identification technology. It can automatically identify objects to obtain relevant data through RF signals without manual intervention. It is a wireless version of bar code [11, 12].

(2) Key Technologies of Transport Layer. Electromagnetic wave signals can propagate freely in space without the help of media. The transmission mode of information reception or transmission using this characteristic is wireless transmission. It mainly includes the following: Wi Fi technology, ZigBee technology, and the third generation mobile communication technology (3G Technology).

(3) Computer Vision Technology. Computer vision technology is the key technology of the Internet of Things in the intelligent processing layer. Instead of the visual processing of the brain, the three-dimensional image processing is used to complete the corresponding image processing by the computer instead of the visual processing of the brain. Computer vision technology includes image processing technology, pattern recognition technology, and image understanding technology.

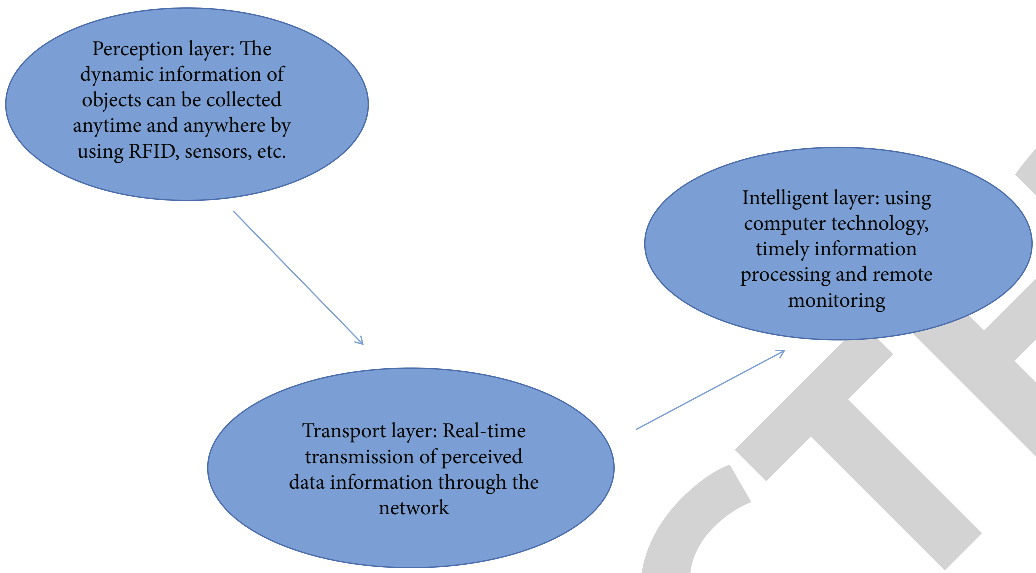

Figure 1: Schematic diagram of technical structure of Internet of Things.

3.2. Technical Scheme Design of Tunnel Internet of Things

3.2.1. Design of Tunnel Monitoring System. In the traditional tunnel monitoring system, the observation and data measurement of measurement items rely on manual measurement and paper records. It needs to spend a lot of human and material resources for real-time measurement during the construction period and operation period, and the economy and safety are low. The use of Internet of Things system for construction monitoring overcomes the shortcomings of insufficient manual measurement frequency and time-consuming in the past, provides accurate and timely changes of enclosure structure, so as to better modify construction parameters and construction technology, and provides technical support for dynamic construction [13, 14]. At the same time, the monitoring results provide information for judging the stability of surrounding rock and the reliability of primary support and secondary lining and provide basis for adjusting the grade of surrounding rock, modifying the design of support system, providing reasonable construction time of secondary lining, and changing the construction method during construction.

3.2.2. Hardware Design of Monitoring System. According to the definitions of perception layer, network layer, and application layer in the basic theory of the Internet of Things, the equipment required for monitoring and measurement can correspond to these three structural levels of the Internet of Things in function [15, 16]. Taking the monitoring and measurement system based on the Internet of Things of dugong expressway tunnel as an example, the equipment required by the monitoring and measurement system mainly includes the following: sensors, data collectors, transmission networks, terminal equipment, and software. According to the definitions of perception layer, network layer, and application layer in the basic theory of the Internet of Things, the equipment required for monitoring and measurement corresponds to the three structural levels of the Internet of Things.

(1) Sensors: sensor is an important component and basic equipment of the sensing layer of the Internet of Things, and it is the basis of the monitoring system. In terms of the structural system of the Internet of Things, the corresponding equipment belonging to the sensing layer of the Internet of things plays the function of sensing the changes of the physical and mechanical properties of the measured object and recording the change data in the whole monitoring system. The sensors used in this study mainly include vibrating wire reinforcement stress gauge, vibrating wire surface strain gauge, vibrating wire concrete strain gauge, and vibrating wire earth pressure gauge

(2) Collector: the collector in the tunnel monitoring system plays the task of collecting, saving, processing, and transmitting the data collected by the sensor. From the structural system of the Internet of Things, it belongs to the corresponding equipment including the sensing layer and the transmission layer in the Internet of Things

The preprocessing methods of monitoring data include the following: data interpolation, averaging and extension. Data smoothing is to adjust the unreasonable amount of data in the monitoring data section. When the monitoring data is greatly affected by accidental factors and fluctuates irregularly, this group of data can be smoothed by simple moving average (or moving average), exponential smoothing, and wavelet denoising to eliminate the influence of accidental factors. Exponential smoothing refers to the weighted exponential decreasing smoothing of all past data over time. According to this definition, a simple recursive expression of exponential smoothing can be deduced as follows (1):

$$\overline{A_t} = aA_t + (1 - a)\overline{A_{t-1}}, \tag{1}$$

Table 1: Main technical indexes of MCU-32 distributed modular automatic measurement unit.

Model	MCU-32
Overall dimension	400 mm × 300 mm × 185 mm
Working power supply	220 V AC or 16.5 V solar power
Transmission distance	About 1000 m (485 transmission), other transmission modes are determined by external transmission equipment
Working temperature and humidity	Temperature: -30~70°C, relative humidity 90%
Stored data	About 7000 × 32
Data retention time	>10 a
Access sensor	32/set
Networking quantity	64 sets
Design life	>10 a

where $\overline{A_{t-1}}$ represents the data after smoothing the weighted index of each previous time period, A_t indicates that there is no monitoring data for leveling, and a is the weighted exponential smoothing coefficient, taking 0.2 ~ 0.3 according to the calculation accuracy.

According to the research requirements, MCU-32 distributed modular automatic measurement unit is selected to automatically collect the data of various sensors. This type of collector can automatically collect the data of each sensor, with high measurement accuracy, reliable system stability, and flexible data collection mode; good adaptability to the site, waterproof; lightning protection; and anti-interference. It has a variety of data transmission modes and supports wired and wireless data transmission, which comprehensively considers the ability of information collection, transmission diversity, and anti-interference.

Each MCU-32 distributed modular automatic measurement unit includes four modules: measurement module, main control and communication module, power supply module, and wiring port module. These four modules can work together, see Table 1 for its main technical indicators.

MCU-32 distributed modular automatic measurement unit has the following basic characteristics: open structure, high measurement accuracy, and strong system stability. Each MCU-32 is a modular combination, which is convenient for repair and maintenance; MCU-32 does not need additional lightning arrester and has perfect lightning protection function and complete system self-inspection function; there are many data transmission modes: RS485 transmission, TCP/IP network transmission, optical cable transmission, GPRS/CDMA transmission, etc. The stored data can be transmitted through the serial port or copied to the computer with USB flash disk, and the data transfer is flexible.

(3) Transmission network: the transmission network of tunnel construction monitoring system needs to summarize the data and transmit the data to the database and data processing system. From the structural system of the Internet of Things, it belongs to the corresponding equipment in the transmission layer of the Internet of Things [17, 18]

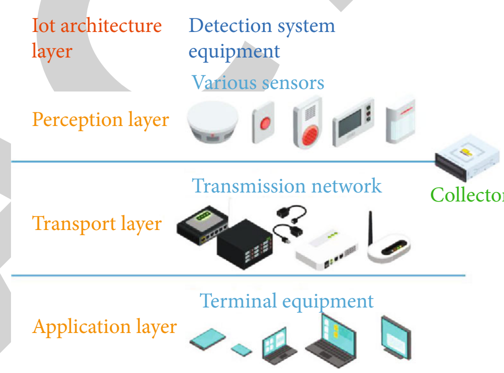

Figure 2: Corresponding relationship between tunnel construction monitoring system equipment and IOT structure layer.

Table 2: Pressure test frequency.

Excavation time	Frequency
1 ~ 15 d	1 ~ 2times/d
16~30 d	1/2 d
1 ~ 3 m	1 ~ 2 times/w
>3 m	1 ~ 3 times/m

The transmission network needs to support more flexible data transmission and transfer modes, which can be completed with the help of MCU-32 main control and communication module and wiring port. The wired transmission modes of the collector include RS485 transmission, TCP/IP network transmission, and optical cable transmission, and the wireless transmission modes include wireless data transmission, radio transmission, and GPRS/CDMA transmission. In terms of data transfer mode, it can be transmitted through serial port or copied by USB flash disk.

(4) Terminal equipment: terminal equipment is the equipment for the operation of database and data

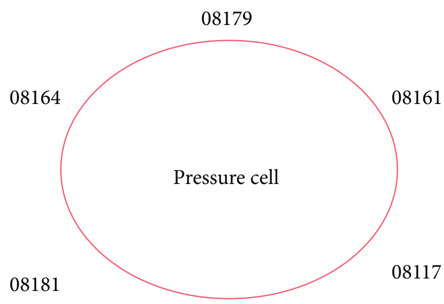

Figure 3: Layout of section measuring points.

analysis and processing software. It mainly completes the reception, storage, analysis, and processing of the data transmitted by the collector. From the structural system of the Internet of Things, it belongs to the corresponding equipment in the application layer of the Internet of Things. The corresponding relationship between tunnel construction monitoring system and IOT structure layer can be used as shown in Figure 2

3.2.3. Software Scheme of Monitoring System. The software scheme of the monitoring system can be divided into two parts.

(1) The collector control program can manage the data transmission of each monitoring section and the data collection of each sensor

(2) The monitoring and analysis program can connect with the control software of the collector, analyze and process the monitoring and measurement data collected by the collector, draw the displacement time curve according to the data, form the data chart and analysis report, and more intuitively display the changes of tunnel structure

3.3. Application of Tunnel IOT Monitoring System

3.3.1. Monitoring Scheme. Taking the contact pressure between surrounding rock and initial support as an example, this paper illustrates the specific application of Internet of Things technology in tunnel monitoring and measurement. The monitoring method is to embed various pressure boxes and other sensors between surrounding rock and support, combined with MCU 32 collector. The monitoring frequency is shown in Table 2. The main technical points are as follows.

(1) Five measuring points are arranged on each section, as shown in Figure 3. The number on the side of the pressure box is the number of the pressure box

(2) The sensor is arranged at the interface between surrounding rock and primary lining for surrounding rock pressure measurement

(3) Before embedding, the initial frequency of the pressure box sensor shall be recorded, the sensor shall be numbered, and the corresponding connector shall be marked. Pay attention to the conductor protection during embedding

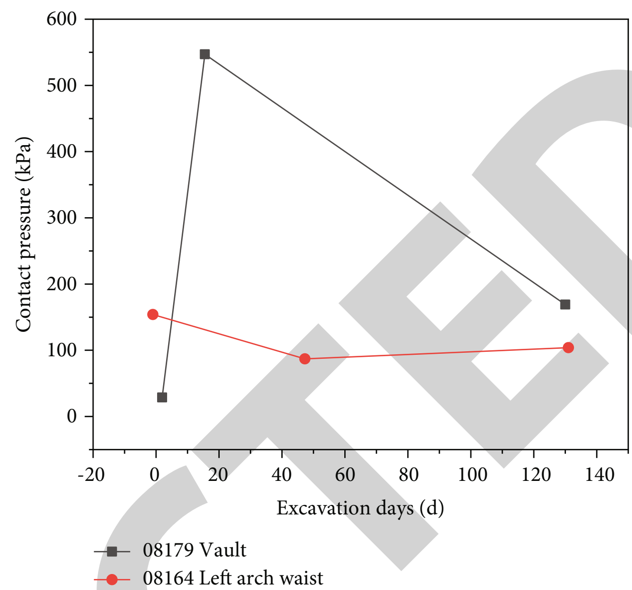

Figure 4: Contact pressure time curve of left tunnel K47+487.

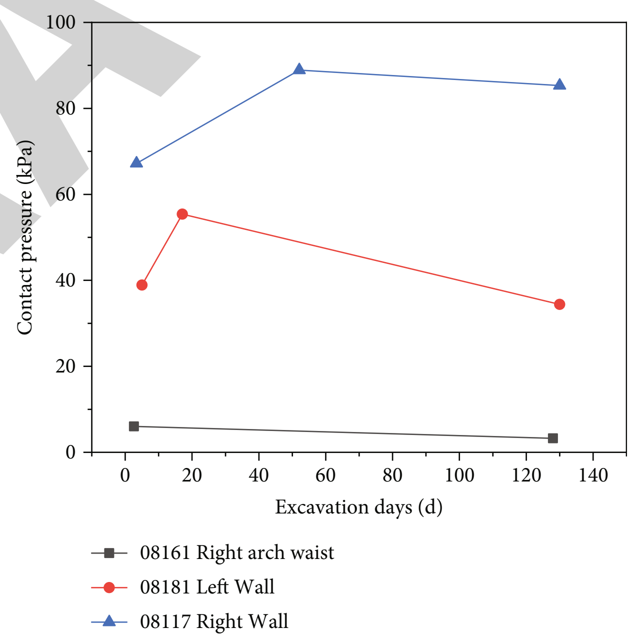

Figure 5: Contact pressure time curve of left tunnel K47+487.

(4) Connect the pressure box to the MCU 32 collector and convert the frequency into the corresponding contact stress according to the calibration coefficient

4. Result Analysis

4.1. Measurement Data and Results of Monitoring System. At K47+487 of the tunnel left tunnel face, in order to dynamically grasp the change of surrounding rock pressure and provide effective data and information for the smooth

Table 3: Stress changes at monitoring points of tunnel monitoring section.

Deformation stage	Deformation parameters	Location of monitoring section				
		Vault	Left arched waist	Right arch waist	Left wall	Right wall
Phase I	Duration/d	16	6	2	16	10
	Contact stress growth/(kPa d-1)	34.03	24.82	3.15	3.44	6.98
Phase II	Duration/d	84	24	4	64	45
	Contact stress growth/(kPa d-1)	-4.48	-2.08	-1.18	-0.23	0.42
Phase III	Duration/d	30	100	124	50	75
	Contact stress growth/(kPa d-1)	-0.43	-0.11	0.02	-0.11	0.05
Whole deformation process	Peak stress/kPa	544.6	148.9	6.3	55.0	88.8
	Pressure range after stabilization/kPa	100~200	40~100	0 ~ 10	30~40	80~90
	Time required for stabilization/d	100	30	6	80	55

progress of construction, the pressure box is installed in time after the excavation of the face, the contact pressure is monitored and measured, the data of surrounding rock pressure changing with time is obtained, and the data curve is preliminarily analyzed [8, 19]. The monitoring and measurement frequency shall be implemented according to Table 2 above. The variation curve of surrounding rock pressure along time is shown in Figures 4 and 5.

4.2. Analysis of Monitoring Measurement Results

(1) It can be seen from Figures 4 and 5 that after the construction of the initial support shotcrete, the shotcrete layer can adapt to the deformation of the surrounding rock and deform accordingly because the concrete has not been consolidated. Therefore, the contact pressure between the surrounding rock and the initial support on the monitoring and measurement section in the tunnel is zero. When the shotcrete layer is consolidated to form effective strength, the shotcrete layer will prevent the further deformation of the surrounding rock, which is still in the stress release stage, resulting in stress between the shotcrete layer and the surrounding rock. With the passage of time, the stress of the shotcrete layer at each monitoring point gradually increases, and then the deformation tends to be stable [20, 21]

(2) According to the statistics, the contact stress between the left and right sections of the tunnel is less than 10 kPa. According to the statistics, the contact stress between the left and right sections of the tunnel is the smallest, and the contact stress between the left and right sections of the tunnel is less than 10 kPa. The contact pressure between the surrounding rock of the left arch waist and the shotcrete layer increased rapidly in the first 6 days and began to drop after reaching the peak stress of 148.9 kPa in the sixth day and stabilized between 80~90 kPa. At the initial stage of excavation, the contact pressure of the left wall rises rapidly, and the rising speed decreases after the 7th day of excavation. After the 16th day of excavation, the peak pressure reaches 55 kPa, and then at the 16th day (about 2 weeks), the contact pressure begins to decline and tends to be stable. The change of the right wall is similar to that of the left wall. The contact pressure increases rapidly with time within one week of excavation and then increases slowly. It does not increase at the 55th day (about 2 months) but decreases slightly and tends to be stable. The contact pressure between the surrounding rock of the arch crown and the shotcrete layer is the largest, and the stress is the largest. The peak stress reaches 544.6 kPa when excavating for 16 days (about 2 weeks), then the contact pressure begins to decrease, but the value is still large, and the deformation tends to be stable for a long time. It gradually tends to be stable after excavating for 90 days (3 months) [22, 23]

(3) According to the results reflected in the contact pressure time statistical diagram, the contact pressure between surrounding rock and shotcrete layer after excavation can be roughly divided into three stages: the first stage is from just excavation (0 d) to 1 ~ 2 weeks after excavation, the stress is released rapidly in this stage, and the contact pressure between surrounding rock and shotcrete layer rises rapidly. The second stage is from 1 ~ 2 weeks after excavation to 1 month after excavation. In this stage, the contact pressure between surrounding rock and shotcrete layer is still in the rising stage, but the rising speed is significantly lower than that in the first stage. There is no significant change in the contact pressure between surrounding rock and shotcrete layer at some measuring points, and it is in the slow growth or stable stage. The third stage is one month after excavation. At this time, the contact pressure between surrounding rock and shotcrete begins to stabilize without great change. It can be considered that the surrounding rock is in a stable state. The deformation of each monitoring point of the tunnel is summarized in Table 3

4.3. Guiding Role for Construction

(1) According to the results reflected in the contact pressure time statistical diagram, the contact pressure at the vault of the left tunnel of Dabaoshan tunnel is significantly higher than that at the rest of the tunnel face. Moreover, there is a tensile stress zone in the vault, which is easy to produce local damage such as relaxation, falling blocks, and falling stones. In addition, during the construction of the shotcrete layer at the arch crown, the thickness of the shotcrete layer is often insufficient due to the construction process and construction period, or the shotcrete layer is not in close contact with the surrounding rock, resulting in a large cavity after the shotcrete layer, which will affect the construction progress and endanger the safety of construction personnel. Therefore, during construction, due to paying special attention to the thickness and compactness of the shotcrete layer at the arch crown, grouting treatment shall be carried out in time at the poor surrounding rock to prevent local damage

(2) One to two weeks after tunnel excavation is a period of rapid growth of contact pressure and deformation. In this stage, the construction principle of NATM shall be strictly followed, monitoring and measurement shall be strengthened, shotcrete shall be applied as soon as possible, surrounding rock shall be closed, and bearing ring shall be formed. At the same time, grouting shall be carried out in time for the parts with cavities between the shotcrete layer and the surrounding rock to fill the cracks in the surrounding rock and improve the self-supporting capacity of the surrounding rock

5. Conclusion

(1) Through the core technology of Internet of Things, this paper provides technical support for the tunnel construction monitoring system, which makes the construction more efficient and ensures the safe and efficient progress of tunnel engineering. It provides technical support for intelligent and information construction

(2) The internal construction environment of the tunnel is bad, and a variety of technologies and equipment are affected by the tunnel construction environment, which cannot ensure the normal application of technologies and equipment. Therefore, corresponding data sensing and acquisition modules and wireless communication modules are required to maintain good operation status in poor environment

(3) Reducing the cost of the application of Internet of Things technology can not only reduce the project cost but also reduce the exclusion of owners and construction parties from the Internet of Things monitoring platform. To solve this problem, the key lies in the maturity of technology application. Mature technology can ensure the rapid and large-scale development of the Internet of Things and promote the virtuous cycle of Internet of things related industries, so as to reduce the cost of each link

(4) There are a large number of wireless transmission networks in the Internet of Things environment. The network signals in public places are not encrypted; so, the network is easy to be invaded, and data information is easy to be stolen. This not only affects the safety of tunnel engineering data but also affects the normal operation of the emergency command system. Therefore, it is necessary to strengthen the security of the underlying sensor network and ensure the normal operation of the equipment through technical means

(5) Nowadays, the application of Internet of Things technology in various fields has its own system, which makes the application of Internet of Things technology in the field of tunnel engineering personnel detection and emergency command have obstacles. Therefore, cooperation in various fields is needed to establish a standardized standard system to truly realize the unity of tunnel engineering safety monitoring and intelligent emergency command

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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