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Research Article

Vibration and Displacement Monitoring of Surface and Rock Strata in Geological Hazards Based on Mixed Technologies

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With the rapid development through the advancement of technology, China geological hazard monitoring system has made great progress in engineering application. Advanced geological technology on hazardous geological monitoring is emerging, Internet of Things (IOTs), Geographic Information System (GIS), and Remote Sensing (RS), for example. However, there are still many problems existing subjected to monitoring system, such as sensor power storage, stability, compatibility, and weak analysis ability, which hinders the further development and popularization of the automatic monitoring system on geological hazards. In this paper, a new buried rock sensor and a fixed inclinometer are adopted, combined with the IOTs and the Beidou navigation system, to build an automatic monitoring system for geological disasters; it not only improves the accuracy and timeliness of monitoring data of surface and rock strata vibration and displacement of geological disasters but also provides guidance for future system design and development, especially in remote areas with steep terrain.

1. Introduction

Geological disaster refers to the disaster events that cause the change of geological environment and geological body due to natural or man-made reasons and cause harm to human and society. China is one of the countries with the most serious geological disasters in the world, where lives Wenchuan and related geological disaster-prone regions. Since the first half of 2020, 1351 geological disasters have occurred all over the country. In particular, after May, regional heavy rainfall has caused a large number of geological disasters in Jiangxi, Guangdong, Guangxi, Guizhou, and other places. Faced with the severe situation of geological disaster prevention and control, China has gradually established a set of geological disaster prevention, risk assessment, and early warning system with Chinese characteristics. From July 17th to 23rd, 2021, Henan Province encountered a rare heavy rainstorm in history. The average process rainfall in the province was 223 mm, and 285 stations exceeded 500 mm. The daily precipitation of 20 national-level meteorological stations exceeded the historical extreme value since the establishment of the station. Among them, Zhengzhou, Xinmi, and Songshan stations all exceeded their historical daily extremes by more than 1 time, and the maximum hourly rainfall of Zhengzhou Meteorological Observation Station (16-17:00 on the 20th, 201.9 mm) exceeded the historical record of hourly rainfall in mainland my country. Many rivers have flooded above the warning level, and Zhengzhou, Xinxiang, Hebi, and other places have suffered from heavy rainstorms and floods. On May 22, 2021, an earthquake of magnitude 7.4 occurred in Maduo County (34.59°N latitude, 98.34°E longitude), Guoluo Prefecture, Qinghai, with a focal depth of 17 kilometers. Some roads, bridges, and other infrastructure were damaged, resulting in a direct economic loss of 4.1 billion yuan. At 17:00 on June 1, 2022, an earthquake of magnitude 6.1 occurred in Lushan County, Ya'an City, Sichuan, with a focal depth of 17 kilometers; at 17:03 that day, an earthquake of magnitude 4.5 occurred in Baoxing County, Ya'an City, with a focal depth of 18 kilometers. The earthquake caused damage to some towns and houses in Lushan County and Baoxing County. In a word, natural disasters never stop.

Actually, in October 2018, General Secretary Xi Jinping presided over the third meeting of the Financial and Economic Commission of the CPC Central Committee; he pointed out that strengthening the prevention and control of natural disasters is of vital importance to the national economy and people's livelihood and that an efficient and scientific natural disaster prevention and control system should be established to improve the whole society's ability to prevent and control natural disasters. In November 2019 [1], at the 19th collective study session of the Political Bureau of the CPC Central Committee, General Secretary Xi Jinping stressed the need to improve the comprehensive monitoring of multiple disasters and disaster chains, early risk identification, forecast, and early warning capabilities, strengthen the management of emergency plans, and improve the emergency plan system [2]. In June 2020, the State Council issued the notice on carrying out the First National Comprehensive Risk Survey of Natural Disasters, with the aim of ascertaining the number of hidden risks of natural disasters nationwide, ascertaining the ability of key areas to resist disasters, and improving the ability to prevent and control various disasters. Meanwhile, quantitative models are mathematical expressions based on the relationship between the factors affecting the disaster point and the geological disasters that have occurred.

The key limitations related to vibration and displacement monitoring in China are that remote controlling and monitoring is a valid and convenient detection way for monitoring slope status and for mastering slope engineering, but a single science and technology cannot completely solve all the geological disasters encountered. It is also urgent that researchers can combine various modern technologies and apply them to various aspects of geological disasters, especially in remote mountainous areas and wilderness areas [3].

2. Geological Disaster Monitoring and Predictive Warning

In recent years, with the development of the new generation of information and communication technology, especially the development and application of modern sensors, wireless IoTs [4], RS [5–7], GIS [8, 9], big data, and other technologies, early identification and automatic monitoring and warning of geological hazards have become the mainstream technical means. In particular, the combination of the IoTs and GIS technology makes the detection of geological disasters advanced dramatically. The new monitoring method makes the monitoring content richer and more detailed, makes the results more reliable through the analysis of big data, and greatly improves the success rate of monitoring and early warning. In recent years, China has invested a large amount of funds in the implementation of geological disaster monitoring and early warning engineering so that the geological disaster monitoring and early warning industry is extremely popular, and many enterprises are pouring into this field. But the field of geological disaster monitoring and early warning is a systematic engineering, involving a very rich and complex content; some practitioners have many misunderstandings and even wrong understanding of geological disaster monitoring and early warning. In this paper, it combines the scientific research and engineering practice of geological disaster monitoring and early warning system and technology in recent years and discusses the thinking and understanding of related issues and technologies.

3. Current Technology Application Development

Scholars at home and abroad have carried out a lot of work for the scientific research of geological disaster monitoring and early warning and achieved fruitful results. The United States, Japan, France, and other countries have established corresponding sensor monitoring networks and have advanced levels in remote monitoring control transmission and automatic monitoring. For example, the Menlo Park Geological Survey Bureau in California of the United States took the lead in applying GIS technology to the geological disaster research in California [10], the LSS-01 landslide automatic monitoring system developed by Japan, and the landslide monitoring system using sensors developed by Canada have all realized the remote collection and processing of geological disaster data.

In recent years, our country through a large number of basic research and engineering practice, geological disaster monitoring, and early warning part of the research results have been in the forefront of the world. China has carried out the construction of a real-time monitoring system for geological hazards based on wireless communication technology for landslides and slopes in Hong Kong SAR and summarized such applications. China Mobile IoTs Co., Ltd., Chongqing Former Land Resources and Housing Administration, and other units combined sensor technology, IoT technology, GIS technology, etc., to build a set of automatic geological disaster online monitoring and early warning and intelligent visualization command and dispatch system, which plays an important role in geological disaster prevention and control.

4. Vibration and Displacement Monitoring Sensor

During the formation process and after the formation, the earth's surface layer and rock layer will be affected by various geological forces [11]. Some of them remain in the original state when they are formed, while some of them are deformed and lead to various geological disasters. Vibration and displacement are the main causes of geological disasters [11, 12]. In this paper, new vibration and displacement monitoring equipment is adopted, and the monitoring data is sent back to the data centre for analysis through wireless IoTs technology and then sent to the command centre and relevant personnel.

4.1. Buried Rock Sensor Equipment. Vibration monitoring is to understand the internal dynamic characteristics of the

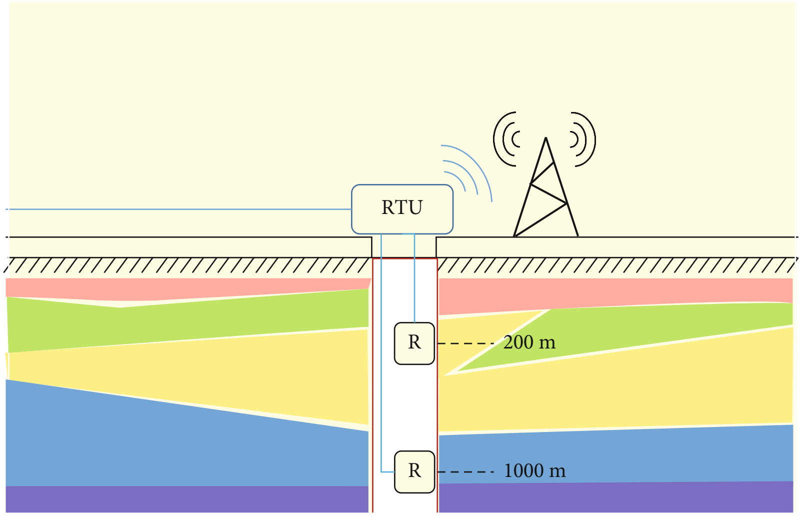

Figure 1: Buried rock sensor.

structure by monitoring the vibration of the structure under external excitation, so as to conduct damage analysis and safety assessment of the structure. Vibration monitoring generally adopts acceleration sensor measurement; the main indicators include sensitivity, long-term reliability, signal transmission distance, and environmental adaptability. In this paper, by embedding the buried rock sensor equipment into the rock 50 cm, 200 m, or more than 1000 m to monitor the surrounding geological changes and at the same time share the monitoring data with the seismic network, to improve the monitoring and warning capacity of rock stratum vibration, the accuracy of which can reach more than 1 mm. Figure 1 shows the buried rock sensor equipment 50 cm, 200 m, or more than 1000 m below.

4.2. Fixed Inclinometer. Displacement monitoring is mainly used to monitor the surface displacement change of slope body and carry out trigger dynamic monitoring. Whether the slope is stable or not has an extremely important impact on the overall safety of the mountain. By installing fixed inclination meters and other equipment to monitor the slope in real time, such as abnormal changes in the slope, the alarm information will be sent to the earthquake, traffic, emergency, bridge, and other relevant departments in time, so as to avoid similar T179 train derailment events happening again. In this paper, a fixed inclinometer is selected, which can be used for automatic monitoring of displacement. It has the characteristics of high precision, good stability, and strong anti-interference ability. Figure 2 shows the design, which works stably even in the harsh environment such as damp and landslide and is suitable for displacement measurement laid in various places for a long time.

5. Design of Geological Hazard Monitoring System

5.1. System Architecture. At present, in the process of geological disaster prevention and control, the combination of Internet of Things technology, sensor technology, automation technology [13–16], and other means to respond has become an important part of geological disaster monitoring and prevention work. In order to realize the remote automatic monitoring of geological disasters on the surface and rock strata, a set of automatic monitoring system was built, which mainly consists of sensors, wireless transmission, data processing, monitoring, and alarm. The application of the sensor system can obtain the geological disaster information comprehensively and accurately. Figures 3 and 4 depict the overall architecture. The monitoring data will be transmitted to the data centre through NB-IoT, 4/5G, Beidou navigation satellite, and other wireless communication networks for comprehensive data analysis, and the damage level of geological disaster points will be determined and sent to relevant personnel. Actually, a number of researchers focus on application through the use of self-developed navigation system combined with Remote Sensing and other advanced technologies.

5.2. The Main Task

5.2.1. Establish an Intelligent Monitoring System. In combination with geological characteristics, hydrology and water conservancy factors of the target region, integrated settlement monitoring, crack monitoring, rainfall monitoring, video monitoring, and other integrated and all-round monitoring, build a set of "Beidou + Internet of Things" intelligent monitoring program, improving the geological disaster prevention and control capability.

5.2.2. Establish an Intelligent Early Warning System. According to the site geological environment and historical monitoring data, a comprehensive early warning and forecast model applicable to the local area is established to make early warning and forecast for different disaster monitoring points in time and quickly, so as to provide decision-making basis for the government departments to prevent, control, command, and dispatch geological disasters on the site.

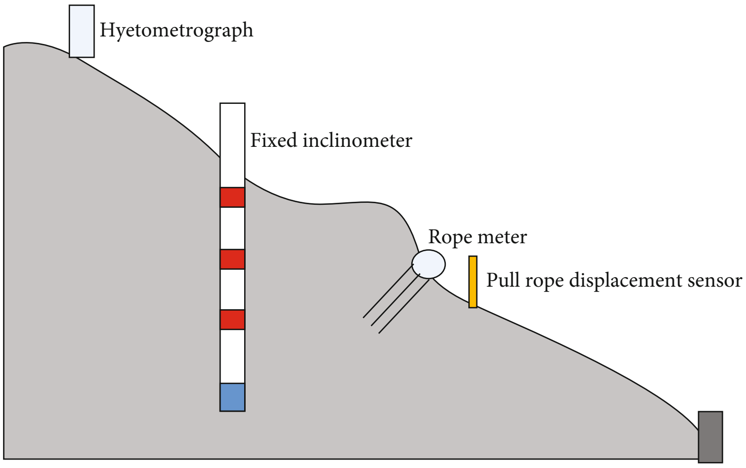

Figure 2: Fixed inclinometer.

Figure 3: Architecture design upper part.

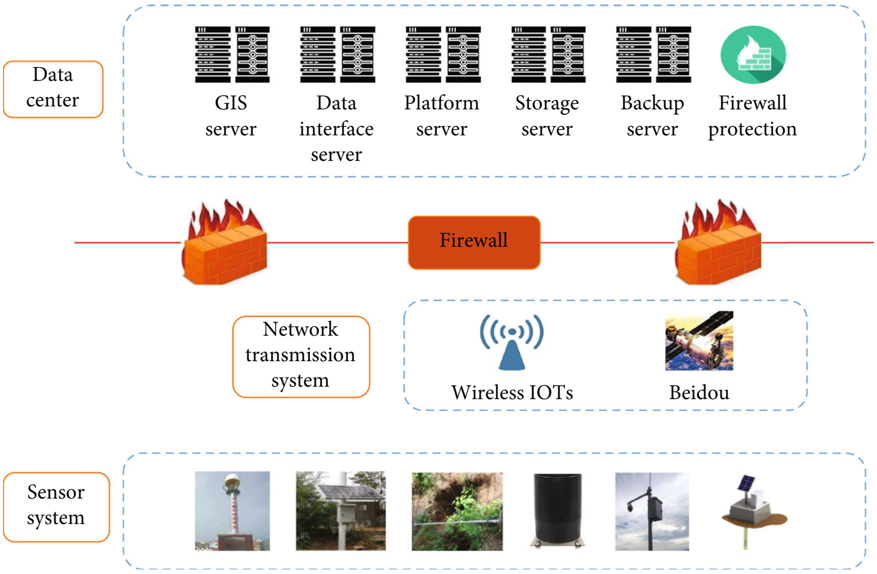

Figure 4: Architecture design lower part.

5.2.3. Establish an Intelligent Application System. Based on the existing basis and combined with the actual needs, the intelligent application system is established to provide support for the field investigation personnel, background monitoring personnel, decision-making and commanding personnel, system management personnel, etc., so as to realize the disaster prevention and control work management information, information transmission network, disaster warning scientific, and disaster information service.

5.3. Monitoring Content. Real-time monitoring of geological hazards is the main function of this system [17, 18]. As the target areas are mostly in remote areas, wireless Internet of Things communication means with low power consumption, low delay, and large capacity are needed. Combined with geological status and historical monitoring data, the following four contents are mainly designed.

5.3.1. Ground Subsidence Monitoring. Ground subsidence monitoring refers to the continuous measurement of the micro movement or deformation of the monitored target with certain measurement means, and the three-dimensional change and trend analysis are obtained. From the perspective of spatial position, ground subsidence monitoring includes plane displacement monitoring and vertical displacement monitoring [19–21]. The purpose of land subsidence monitoring is to prevent, control, and slow down the occurrence and development of land subsidence. By laying a fixed inclinometer on the deformable body to monitor the displacement, the data of the horizontal and vertical displacement of the deformable body are obtained in time, so as to predict the deformation analysis. Groundwater activity is also one of the key factors leading to geological subsidence, so the water level sensor can be installed underground to observe the water level data, so as to provide more reliable data for subsidence monitoring.

5.3.2. Crack Deformation Monitoring. Crack monitoring is an intuitive and reliable necessary means to monitor the relative opening, closing, dislocation, subsidence movement, and rate changes on both sides of the slope crack [22]. The buried rock sensor is used to monitor the slope vibration quantity, and the actual accuracy can reach 1 mm. For the cracks that need to be observed, 1-2 groups of monitoring points can be set, respectively, at the widest and the end of the cracks, depending on the site conditions.

5.3.3. Rainfall Monitoring. Rainfall is an important inducer of geological disasters. In mountainous areas with long rain and heavy rain, landslides and debris flows are closely related to rainfall. Rainfall monitoring mainly adopts automatic rainfall gauge to monitor the hydrological data such as rainfall in the target area and combined with historical hydrological data and meteorological data to make prediction and analysis, so as to provide support for geological disaster analysis.

5.3.4. Real-Time Video Monitoring. The video surveillance can be remotely controlled by cooperating with the high-definition (HD) camera and professional monitoring equipment so that the monitoring personnel can visually observe the state of hidden points and various terrain changes without visiting the site, realizing unattended and improving timeliness. At the same time, through the face recognition function, the person in the target area will be alerted, and the corresponding emergency measures will be taken in combination with the scene situation.

5.4. System Construction. To further dig out information of geological disasters, disaster monitoring automation data acquisition, wireless transmission, real-time storage, rapid analysis and processing, build a set of weather, high precision, advanced intelligence, rapid response of geological hazard monitoring and early warning system, mainly provide monitoring, early warning, analysis, sharing, mobile applications, the comprehensive decision-making functions, such as access to urban wisdom brain at the same time, to realize the information management of geological disaster prevention and control, scientific monitoring, and early warning of geological disasters, and to provide visual decision support for government departments.

5.4.1. Monitoring and Early Warning System. On the one hand, through the management, inquiry, and display of the disaster site and monitoring equipment, the basic situation of the geological disaster area can be clearly understood and grasped. At the same time, the electronic fence antitheft module of the equipment is integrated. After the equipment leaves the monitoring point, the background can receive real-time alarm information and GIS track map [22, 23]. On the other hand, the disaster warning threshold is set, and for the disaster monitoring points and equipment that reach the threshold value, the corresponding methods are selected to disseminate the warning information according to the standard of geological disaster forecast and warning level of the former Ministry of Land and Resources. At the same time, issued after the review of the early warning information, people can get the early warning information through telephone/web prompts, SMS/mobile phone APP push, and other methods and, at the same time, push emergency response measures, shelter, and contact information.

5.4.2. Disaster Analysis System. By selecting arbitrarily, monitoring equipment, monitoring period, such as data analysis, visual display, has been made at the same time can be combined with the historical data of ground subsidence, crack changes, monitoring, ground water level, rainfall monitoring equipment comparison and trend analysis, and comprehensive decision analysis, provide the basis for subsequent evolution and emergency command.

5.4.3. Data Sharing System. Geological disaster monitoring data includes basic geographic information database, disaster database, monitoring database, and system operation and maintenance database, which relates to national production and life security and national information security and has extremely important political and economic significance [24–26]. Therefore, the whole monitoring system needs advanced data management technology; at the same time, it should have a clear system architecture, clear authority

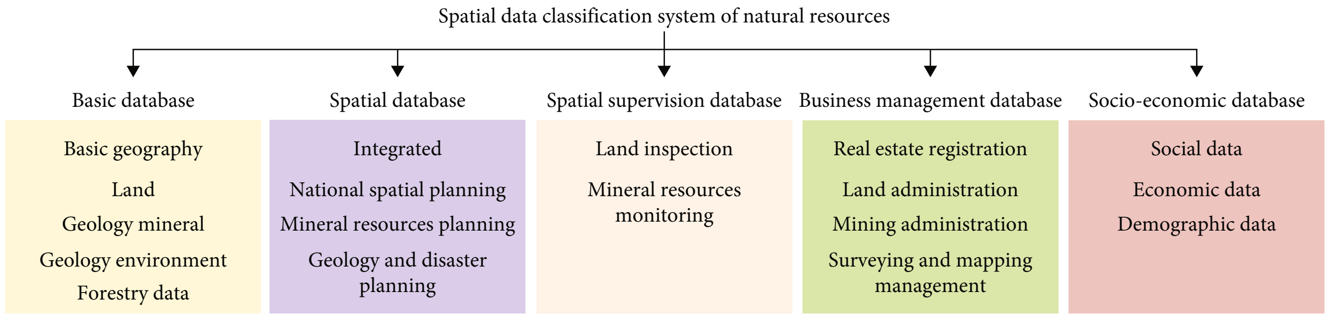

Figure 5: Spatial data classification system of natural resources.

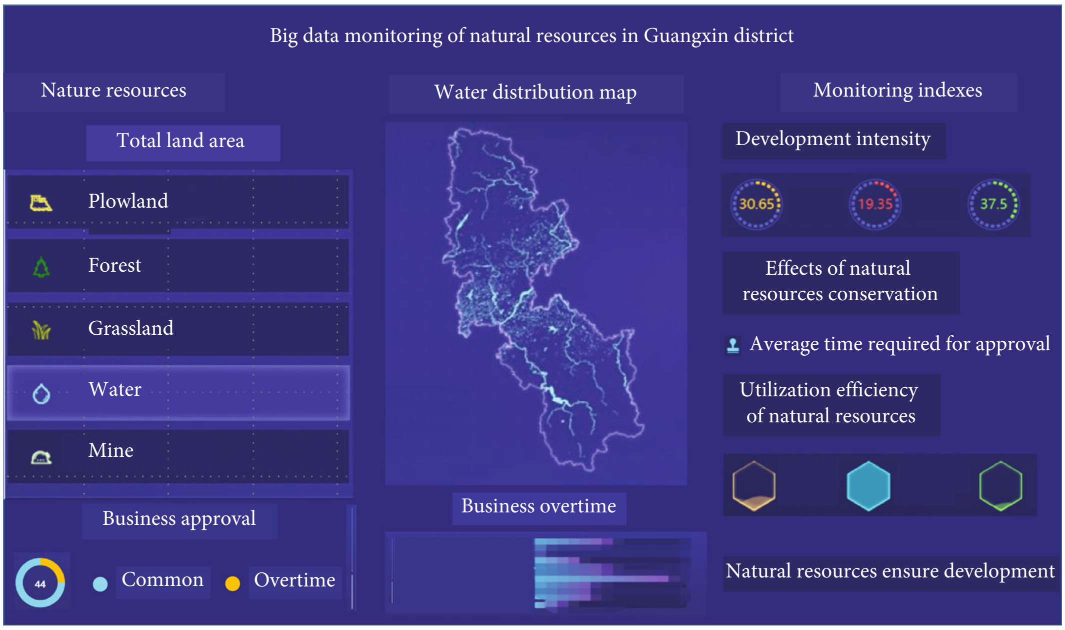

Figure 6: Element classification system of geological hazards.

system, extensible system interface, unified standards, and specifications, so as to realize the scientific and effective management of geological disaster information.

5.4.4. Smart Mobile Terminal. Professionals can view the dynamics of the authorized observation site, including the latest offset, relevant information of the site, historical data, and video surveillance, through the mobile phone anytime and anywhere. It also has the functions of the module such as warning and analysis on the Web [27]. At the same time, the local site environment can be uploaded to the remote end through the tap module, and the historical situation, geological condition, and disaster prevention publicity of the geological disaster area can be quickly understood through the intelligent customer service.

5.4.5. Platform System Management. The system administrator sets all kinds of parameters allowed by the platform, including threshold parameters and monitoring parameters, and at the same time the system function and system user classification management authorization. Common users can modify some personal data, including the username, profile picture, email address, password, and other basic personal data.

6. Experiment

Firstly, after using mixed technology, geological resources integration information platform database of Guangxin District includes all kinds of structured and unstructured data, spatial data, and nonspatial data. Geared to the needs of the new era of geological resource management work demand, adhering to the existing technical regulations, standards, based on natural resources in the space information data resources for unified planning, the formation of horizontal foundation data, spatial planning, business management data, such as multitype data, content, standard authority, complete dynamic fresh data directory system, it mainly includes basic database, planning database, operational database, spatial monitoring database, and socioeconomic database. Figure 5 shows spatial data classification system of natural resources in order to further employ implementation.

Secondly, a series of automatic total stations have been introduced into Guangxin district, which is showed in Figure 6, and an automatic monitoring system for surface displacement of stope slope has been established. It can automatically complete the measurement cycle, real-time evaluation of measurement results, deformation trend, and other intelligent functions and continuously monitor the monitoring target for 24 hours. In order to obtain the deformation characteristics of dangerous slope rock mass before and after blasting, several sets of surface displacement monitoring systems were established on the surface of dangerous slope.

Finally, the existing technology can meet the requirements of monitoring and early warning; it still has some limitations. For example, although some geological disaster monitoring technologies can solve the problems of monitoring cost and monitoring accuracy, they cannot consider the needs of monitoring automation and real-time monitoring. Combined with the models, it can cope with those issues. Both the collected datasets and mixed technology are essential for vibration and displacement monitoring of surface and rock strata.

7. Conclusions

The automatic monitoring and early warning system can provide vibration, displacement, and other state information continuously in real time, so as to reflect the change of surface layer and strata environment of geological disasters in real time, so as to better protect people's life and property safety. Based on the subsidence deformation factors, such as construction, rainfall, intelligent monitoring system, and utilization of historical data and long-term monitoring data of deep analysis, so as to build intelligent early warning system, adopt a new generation of information technology; at the same time, with the implementation of all-weather, automatic, whole life cycle of data acquisition, transmission, and analysis, effectively ensure the technical personnel's life safety. It can be foreseen that automatic monitoring will be a key development direction in the field of geological hazard monitoring engineering. At present, combined with a new generation of information technology in the automatic monitoring and early warning system for data acquisition, analysis, processing, and the lack of unified standards and specifications, the transverse joint and longitudinal joint barriers, in the next study, will be combined with more in-depth excavation monitoring of large data and the model is perfect so that the geological disaster in automatic monitoring data analysis methods tends to be unified and standardized.

8. Future Work

Vibration and displacement monitoring system provides a wide range of benefits, in addition to those already present in this paper. More efficient maintenance procedures, more early warning for impending problems, more extended using life, and more advanced productivity, vibration, and displacement sensors and monitoring equipment play an essential role in safeguarding assets. In future work, we will pay more attention to improve the maintenance efficiency combined with mixed technology, which usually influences the time cost and emergency rescue.

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 there is no conflict of interest regarding the publication of this paper.

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