Evolution Path and Application Scenario of Slope Geological Disaster Monitoring--Knowledge Graph Based on Citespace

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Abstract. With the development of global climate change and infrastructure construction, slope geological hazards have become increasingly prominent. Especially for all infrastructure projects with multiple points and line lengths, slope types are complex and diverse, hazard distribution ranges are comprehensive, and influencing factors are diverse. This makes intelligent algorithms increasingly an essential means of efficient research on slope geological hazards. In this paper, Citespace knowledge graph analysis software is used to sort out the CNKI core database from 2000 to 2022. Literature data related to slope geological disaster research based on intelligent algorithms are analyzed through a spatiotemporal evolution map and keyword co-occurrence network to predict the evolution path and research trends and hot spots. The results show that the research on slope geological disasters has experienced four stages: "traditional monitoring -- digital monitoring -- model building --AI collaboration." The research theme is collected into two spatiotemporal evolution paths with numerical simulation and disaster assessment as the core. The application scenarios mainly include analysis of geological disaster cause mechanisms, geological disaster monitoring methods, and geological disaster prevention exploration. As a result, the field of slope geological hazards will develop towards multi-source data fusion monitoring, multi-disciplinary cross-fusion, and multi-scenario intelligent deduction.

Keywords: Infrastructure; geological hazards; intelligent algorithm; citespace

1 Introduction

Slope geohazard refers to the natural or artificial slope due to seismic, hydrological, meteorological, and other natural or artificial factors. It can result in slope disturbance damage, such as sliding, collapse, mudflow, landslide, and other disaster phenomena. This type of disaster has large-scale, substantial damage, and a wide range of hazards.

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Therefore, it is one of the significant problems in the construction and maintenance of infrastructure is unavoidable.

Slope geohazard, the natural or human infrastructure construction, is the cornerstone of China's economic and social development. With the increasing scale and density of infrastructure construction and urban development, from the plains to the mountainous areas, across the mountains and rivers, multiple slope geohazard threats are raised. Therefore, it is of great theoretical and practical significance to sort out and analyze the application of geological slope intelligence algorithms in studying slope geohazards. It is also crucial to explore the deeper cross-cutting scenarios in the field of slope geohazards scenarios of artificial intelligence.

2 Traditional and new approaches to slope geohazard technology

In today's era, the incidence of geological disasters on infrastructure slopes is becoming increasingly frequent and provides an essential concern in the homeland and emergency protection field. The 21st century is the trend of the times, with rapid development of intelligence derived from the research of intelligence and infrastructure slope geology.

The combination of intelligence and infrastructure slope geology research provides more effective and accurate information sources for traditional infrastructure research, continuously improving its simulation and prediction accuracy.

2.1 Traditional slope monitoring technology

Slope deformation is the primary manifestation of infrastructure slope geohazard. The reasonable utilization and implementation of its monitoring technology to prevent pre-disaster and post-disaster disposal work provide theoretical and practical primary data so that the effective measurement of slope geohazard can assist. Table 1 summarizes the main survey techniques of traditional slope deformation.

Table 1. Traditional slope monitoring techniques [1]

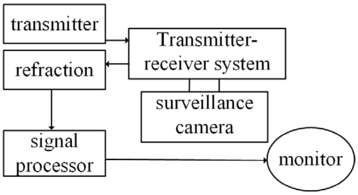
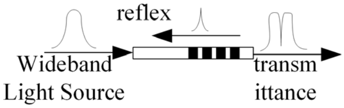
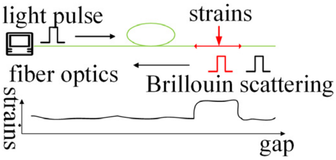
Monitoring content	Monitoring methods	Monitoring instruments	Characteristics of monitoring methods	Scope of use
Surface deformation	Geodetic method	Dumpy level, theodolite	Influenced by terrain and climate	Displacement monitoring
		Total station, electronic theodolite	Affected by terrain and climate	
	Tilt measurement method	Tiltmeters, surface inclinometer	Unable to measure displacement	Slope deformation monitoring
	Joint measurement	Tiltmeters, surface	The accuracy is low and difficult to protect	Geotechnical crack

	method	inclinometers		monitoring
Deep deformation	Inclinometer method	Drilling inclinometer, drilling	The range is small, and the cost is high.	Deep displacement monitoring
Soil stress	Compression method	Earth pressure gauge	Accuracy is generally low	Deformation Detection

2.2 Novel slope monitoring technology methods and their combined models

With the development of informatization, intelligence, and other high-tech, the monitoring means have been comprehensively upgraded and effectively enhanced through various combinations to build different slope detection technology methods. The monitoring operation efficiency is effectively improved. The new slope detection methods can be divided into contact and non-contact categories according to their characteristics. The principles of new slope monitoring technology and its application scenarios are summarized in Table 2 and Table 3.

Table 2. Contact slope deformation monitoring technology table

Technical Name	Principle	Advantages and characteristics	Application scenario
Time domain reflection method (TDR technology) [2-3]	 TDR measurement principle	High signal confidence, fast response, and low power consumption.	Geotechnical deformation, slope survey
Fiber Bragg Grating (FBG)[4]	 FBG measurement principle	Small size and high sensitivity	Engineering and ground settlement monitoring
Brillouin optical time-domain reflection technology (BOTDR [5]	 Schematic of BOTDR monitoring	Real-time, high accuracy, anti-interference	Slope deformation monitoring

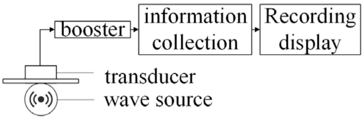
Acoustic Emission Technology (AE)[6]	 AE Schematic	Low cost, easy monitoring, and wide application.	Rock dynamic monitoring and early warning

Table 3. Non-contact slope deformation monitoring technology table

Technical Name		Principle	Advantages and characteristics	Application scenario
Measurement robot[7]		Measurement, collection, recording, organization, early warning	High accuracy, fast speed	Surface dynamic deformation monitoring
Remote sensing, global navigation satellite systems, geographic information systems (3S technology) [8]	Remote Sensing Technology (RS)	Collection, processing, imaging detection and identification	Wide range and low ground constraints	Emergency management of geological disasters Ecological dynamic monitoring
	Geographical information system (GIS)	Geospatial-based, real-time delivery of spatial and dynamic geographic information.	Higher operational stability and low failure rate	
	Satellite positioning system (GPS)	Satellite-based, accurate geographic and time information.	High precision and automation	
3D laser scanning technology[9]		Disseminate and receive signals and calculate spatial distances.	High accuracy, long scanning distance	Geological and lithology recognition
Synthetic-aperture Radar Interferometry (InSAR)[10]		Radar transmits and receives microwaves and calculates regional surface changes.	All-day measurement, all-weather, high accuracy, and low cost	Landslide hazard monitoring
Close-range photogrammetry technology[11]		Measuring and interpreting images to obtain data information.	Instant access to physical information.	geological survey

Tables 1, 2, and 3 show that the gradual development of slope geohazard monitoring means from the traditional to the intelligent direction is an inevitable choice and an important development direction.

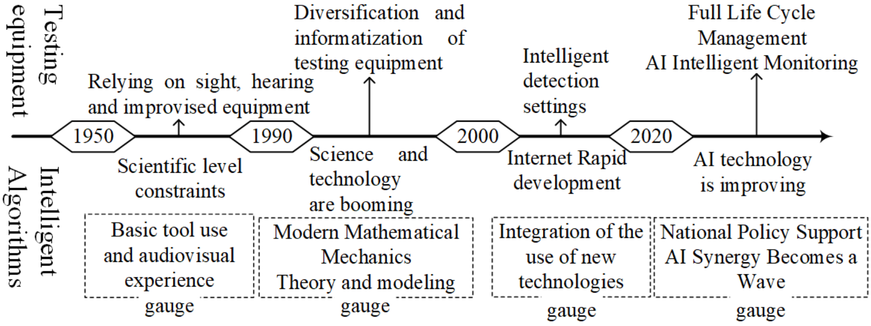


Fig. 1. Development history diagram of monitoring technology and intelligent algorithm

Fig. 1 shows the development history of slope geohazard monitoring technology, generally taking the 1950s as an opportunity for development. Breakthroughs were made in the 1990s in the informatization and diversification of monitoring equipment. Intelligent research is carried out in the 21st century, and the current trend of synergistic development is satellite + intelligent algorithms.

3 Evolutionary path analysis of research applications in the field of slope geohazards

3.1 Data sources and research methodology

In this paper, we take SCI, EI, Peking University core, AMI, CSSCI, and CSCD databases in CNKI as the data source and take the research of transportation slope geohazards as the theme. The advanced search precise theme is slope geohazards + slope hazards + geohazards. The fuzzy keywords are intelligence + computation + network + methodology + intelligence + artificial intelligence. The period is selected as 2000-2022. We obtained a total of 687 references. We conducted data mining and content analysis of Citespace bibliometrics software, the latest progress, cutting-edge issues, directions of technological development, and future development trends of slope geohazards and their intelligent algorithm applications. The aim is to provide a complete knowledge map for scientific research in this field.

3.2 Evolutionary mapping of research stages and technical approaches

The research process can be divided into three stages by clustering the keywords of research applications of intelligent algorithms in infrastructure slope geohazards. Fig. 2 shows the spatiotemporal evolution of keywords in the three research stages. The average year each keyword appeared used as the main timeline.

Traditional mathematical monitoring (before 2015).
The research on geological hazards during this stage is mainly based on actual

measurements, including the measurement of hazards and impact forces caused by landslides, collapses, underground mining, earthquakes, etc. The survey requirements for reinforcement requirements, assessment, and positioning in geological hazard treatment are also included. For example, Fei et al. conducted a field investigation along the Qinghai-Tibet Railway. They put forward risk treatment measures for different sections of mountainous sections, plateau surfaces, basins, and broad valleys [12]. Wen combined the construction and maintenance of railroads in karst areas and put forward drilling and pressurization combined reinforcement mode [13]. Tao and Hong studied Ningguo highway slope hazards and prevention countermeasures in the proposed infrastructure slope stability of the reinforcement algorithm; the study pointed out that using mathematical algorithms in monitoring slope hazards occupies a significant position [14].

Digital monitoring to modeling (2015-2020).

In this stage, slope disaster prevention and monitoring is still the main research field of scholars, and the monitoring and prevention means have changed in stages. Scholars began to use three-dimensional modeling, displacement monitoring, and coupled simulation to carry out regional forecasting and prevention work. For example, Zhang et al. established a three-dimensional landslide geological model based on CATIA software [15]. They constructed a visual scene of the synergistic dynamic changes of the construction site monitoring data and the three-dimensional geological model at the inlet end of the Songpan Highway Tunnel [15]. Zhang et al. established a high-precision displacement monitoring system for landslides based on the virtual reference station of the BeiDou satellite [16]. They verified the efficient application in Jiaxian County, Shaanxi [16]. Qin et al. studied landslide sections in Kaiyang County, Guizhou Province [17]. They proposed a geohazard susceptibility evaluation method coupled with a slope deterministic coefficient model and logistic regression model, which provides a practical reference for urban land monitoring [17].

Modeling to AI synergy (after 2020).

Accompanied by the development of artificial intelligence and the Beidou system, China's geologic disaster prevention research from the traditional point prevention advanced to become a collaborative prevention and control research in the region. This undoubtedly strengthens the monitoring means of geologic disasters. For example, Zhang et al. proposed a method of building a prevention and control system based on artificial intelligence technology to prevent and control geologic disasters [18]. They explored its application prospects and challenges [18]. Hao et al. combined 3S technology and the Beidou satellite system to establish an emergency rescue and protection system for geologic disasters [19]. Dou et al. utilized the advantages of machine learning algorithms, such as powerful nonlinear processing capability and robustness [20]. They concluded that they are more reliable and convenient than traditional monitoring and manual interpretation [20].

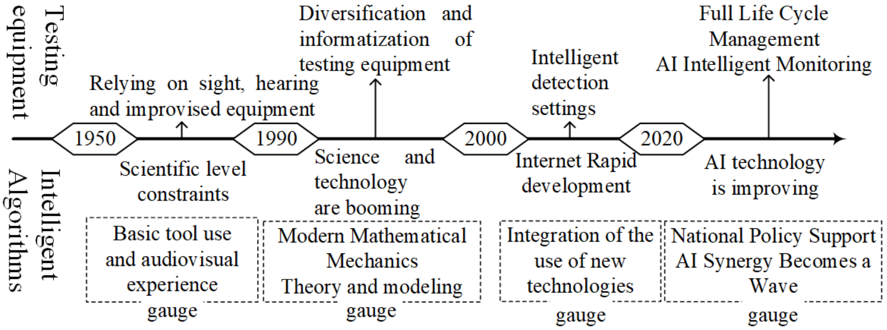


Fig. 2. Transformation and upgrading of research technology in the field of slope geological disasters

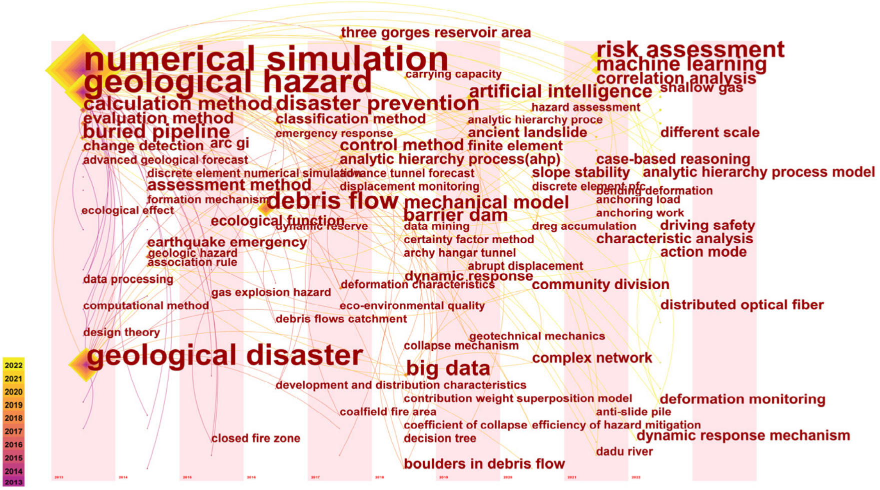


Fig. 3. Stage division and evolution path of keywords

3.3 Evolutionary path analysis

Numerical simulation and geohazard are the first two of the cite space keyword clustering (Fig. 3 and Fig. 4.). This means that in the slope geohazard knowledge map, the research is mainly carried out with the above two contents. Therefore, constructing the cluster analysis of these two highly cited can provide a clearer analytical idea for the path of research realization in this field.

Path analysis with "numerical simulation" as clustering.

Numerical modeling is the core content of slope geohazard research. It is the main evolution path of "meteorological prediction - displacement monitoring - three-dimensional remote sensing - risk evaluation." Two types of numerical modeling, namely slope geologic monitoring and prediction, are presented to show their development paths. In the research about monitoring, Chen et al. proposed a landslide disaster monitoring method based on the fusion of spatial and temporal spectral features of multi-source remote sensing, which was verified in Yizhao Expressway [21]. Moreover, in the research on disaster prediction, Wu et al. established a more efficient, economical, and energy-saving remote monitoring system for geologic hazards based on the gray-time model in Hunan Louxin Expressway as an example [22]. Table 4 shows the numerical models of slopes in historical studies.

Table 4. Advantage table of disaster simulation model

Typology	Mould	Features and benefits
Disaster monitoring simulation	Mathematical elevation model (DEM)	Constant accuracy, variety of expressions, real-time updating, high integration of scales
	High-speed iterative cavity convolutional neural net (HIDCNN combinatorial model)	Capable of obtaining global features, and effectively improving the problem of poor convergence of the depth model
	Dynamic monitoring model for geologic hazards	Superior performance, high precision, wide range of applications
Disaster prediction models	TFPSO-v-SVM model	Higher prediction accuracy and shorter training time
	Polynomial mathematical forecasting models	Good localized trend coupling in short-term forecasts
	WOE-BP modeling	Higher accuracy for landslide geohazards
	Mudslide hazard prediction model	Predictive forecasting methods are simple and easy to apply.
	BIM information modeling	High prediction accuracy utilizing 3D modeling
	RS-CPM model	Higher slope safety coefficients, greater stability, and reliability

Path analysis from “geohazards” as a cluster.

This path takes the “emergency response-image segmentation-satellite positioning-recognition method” as the evolution route. It mainly explores different prediction means or countermeasures in the face of geological disasters. Pei et al. mentioned the multi-technology fusion monitoring technology used in Sichuan and Guizhou [23]. They proposed constructing an intelligent system based on the fusion of 5G technology and cloud computing [23]. Wang et al. proposed a semi-automatic object-oriented processing method based on a mean drift algorithm for extracting geohazard targets in high-resolution remote sensing images verified in actual geohazard applications [24]. Huang and Xie analyzed various types of SAR satellite image parameters of the Dongde Canyon of the Jinsha River [25]. They obtained the optimal time, angle of incidence, and wavelength of SAR for monitoring hazardous deformation in alpine canyon zones to guarantee the best monitoring results [25].

The above analysis shows that the numerical simulation analysis in slope geohazards has gone from proposing measures to disaster early warning prediction to accurate prevention with multi-source data. The field of geohazard research includes both the construction of ideas with risk assessment as the primary goal and the identification method with satellite image segmentation and monitoring. The geohazard research methods are constantly improving and progressing continuously in the face of different slope hazard categories.

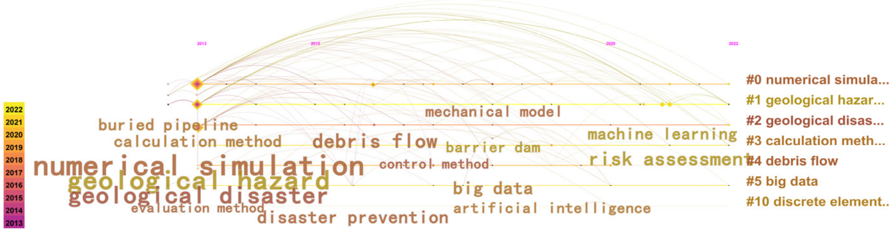


Fig. 4. Keywords co-occurrence timeline diagram

4 Prospects of geohazard research on infrastructure slopes based on the application of intelligent algorithms

In slope geological hazard monitoring, people have expanded from single monitoring to diversified monitoring. This indicates that more intelligent theoretical methods for geological monitoring will be applied. With the development of Satellite imagery technology, China has completed the practical storage of essential data from remote sensing and InSAR satellites. It is needed to constantly build mathematical models and high-precision algorithms based on different application fields to improve the ability of accurate early warning and prevention and control of disasters. Based on this, a multi-dimensional and systematic technical system in slope geological hazards still needs to be constructed, and cross-domain research needs to expand further. This article believes that future research will show the following trends.

4.1 Multi-source data fusion

Monitoring slope geological hazards requires a large amount of multivariate data to support, so data acquisition remains one of the focuses of research. Traditional monitoring methods are relatively costly and inefficient. The future development trend is to adopt multi-source remote sensing data. This requires integrating and processing information data from different remote sensing sensors or spatiotemporal resolutions and constructing accurate and detailed data information technology support throughout the entire lifecycle for different disaster manifestations. By integrating multi-source data, high-precision and comprehensive monitoring can be achieved, as shown in Fig. 5.

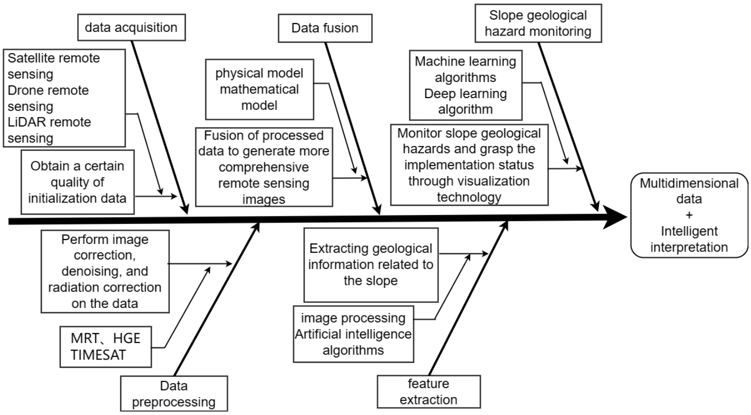


Fig. 5. Multi-source remote sensing data fusion process

4.2 Multi-disciplinary cross-coupling

The research on slope geological hazard monitoring spans multiple disciplines. Geology is the core discipline of slope disaster monitoring. It is used to study the properties, structures, causes, and evolution processes of geotechnical materials to construct slope morphology and stability characteristics identification. Geographic information systems and remote sensing technology can obtain regional-level slope disaster information data, thereby expanding the research scope of the original geological field. Surveying and mapping technology can be used to obtain slope geological morphology data and other refined data. It can carry out refined retesting conditions based on regional slope deformation. Engineering geology can use geological principles and methods to evaluate slope stability and provide surface disposal conditions from the practical engineering application field. Therefore, slope geological hazard monitoring must integrate effectively with engineering technology applications and practice. These specialties span many disciplines, such as civil engineering, geological engineering, geotechnical engineering, and hydrology. (Fig. 6).

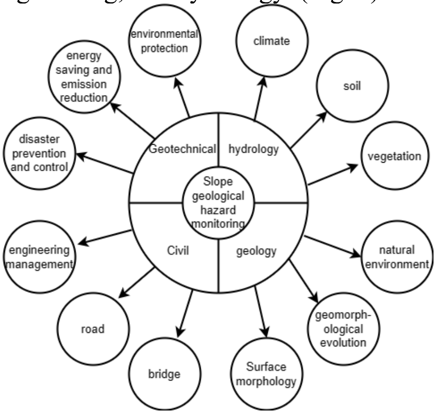


Fig. 6. Multidisciplinary cross-coupling

5 Conclusion

The research trend of intelligent algorithms in the field of infrastructure slope geological disasters mainly reflects in the following aspects:

1) Data mining and analysis. Intelligent algorithms can assist in in-depth excavation and analysis of various aspects of slope geological disasters to obtain information about disaster prediction, occurrence mechanisms, and other aspects.

2) Model prediction and simulation. Intelligent algorithms are used to construct geological hazard models and predict and simulate them to help people understand the characteristics and development trends of geological hazards.

3) Autonomous control and decision-making. The intelligent geological disaster monitoring system can independently control and make decisions, achieving real-time monitoring, early warning, and response.

4) Risk assessment and management. By utilizing intelligent algorithms to assess and manage the risks of geological disasters, effective response measures can formulate and reduce disaster losses.

Therefore, the research trend of intelligent algorithms in geological disasters is becoming increasingly widespread. Scholars are conducting in-depth research around real-time monitoring, early warning, response, and decision-making to enhance their disaster prevention and control capabilities.

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