Design and Development of 3D Visualization Platform for Data Fusion in Mining Process

Chi Zhang [1, 2, *], Puxian Jiang [3], Yin Chen [4], Hu Ji [1, 2], Jinyang Li [1, 2]

[1] BGRIMM Technology Group, China

[2] National Centre for International Research on Green Metal Mining, China

[3] Yiliang Chihong Mining Co., Ltd., China

[4] Xinjiang Xinxin Mining Co., Ltd., China

* Corresponding Author Email: zhangchi@bgrimm.com

Abstract. In view of the common problems such as ground pressure disasters, water inrush, ventilation heat damage that may be induced by mining activities, this paper designs and develops a multi-source data fusion 3D visualization platform with a separation structure of front-end and back-end based on the multi-type online monitoring system established by Yiliang Chihong Mining Co., Ltd. and based on the three-js technical framework, so as to realize real-time online management of multiple types of data including mine production operations, ground pressure monitoring, ventilation heat damage and water inrush. Classified statistical analysis, three-dimensional visual integrated display of risk early warning information and early warning push ensure mine production safety, improve the emergency response efficiency of mine safety risks, and significantly improve the level of mine safety risk information management and control.

Keywords: Mining, Data fusion, Three.js technology, 3D visualization, Risk warning.

1. Introduction

The mining process of metal mines is usually accompanied by the disclosure of the original rock mass. After a long and complex mineralization process, the rock and its surrounding hydrogeomechanical environment have been in a relatively balanced state. However, under the influence of external mining activities, the hydrogeomechanical environment of the original deposit will also change. Especially with the shrinking of shallow metal mine resources in China, underground mining and even deep mining will become the general trend of mining in the future. The hydrogeological conditions of deep resources are complex, the underground water and water channel are concealed, the ground stress is high, the ground temperature is high and the ventilation is difficult, resulting in the difficulty of resource mining, the deterioration of the operating environment and the sudden increase of operating risks. It is of great importance to carry out research on monitoring and early warning of hydrogeomechanical environment in mining process, build monitoring and early warning system of mine hydrology, ventilation, ground pressure and production in full space, open up silos of mine safety monitoring data, and realize integration and analysis of multiple types of monitoring data to ensure the essential safety of mining process.

Many scholars at home and abroad have carried out a lot of effective research work on the construction of monitoring and warning platforms for ground pressure, ventilation and water damage that may be induced by mining. Among them, Zhang Da et al. [1-2] proposed a new Internet of Things system for mine micro-power safety monitoring. It has been successfully applied in tailings reservoir online monitoring, slope monitoring and ground pressure monitoring of mining enterprises, realizing online intelligent analysis and rapid early warning of typical engineering applications. Ge Husheng et al. [3-4] proposed an open pit mine communication system based on dual 5G network, built three platforms including intelligent mining management and control, comprehensive production execution and three-dimensional visualization management and control, integrated mine safety monitoring and monitoring system, and promoted the safe, efficient and intelligent construction of my production. Liu Yanhong et al. [5] built a true 3D underground scene based on Unity3D, and used virtual reality technology to carry out a true 3D visual display, realizing the visualization and integrated management of geology, structure, hydrology, microseismic, surrounding rock deformation, site inspection and other information of ultra-deep mine. Xiao Chunying et al. [6-8] Based on the open-pit slope of Shangfanggou Molybdenum mine in Luoyang Fuchuan, established a targeted online slope monitoring scheme, and then built an online slope monitoring system with high reliability, high scalability and high intelligence, realized online viewing of slope deformation and real-time push of early warning data, and ensured mine production safety. Yu Wan et al. [9-10] carried out the design and application research of tailings pond safety online monitoring system based on SaaS model, and established a graph display of tailings pond safety monitoring based on GIS technology, which realized the visual display of tailings pond slope monitoring and deformation statistical data and real-time push of early warning information. It provides technical guarantee for tailings pond safety. Liu Qiang et al. [11] designed and built a microseismic monitoring system to meet mine safety monitoring in view of frequent ground pressure disasters such as roof plate caving, pillar sheet caving and rock burst during deep mining, analyzed the spatial-temporal evolution law of positioning events, evaluated the stability of rock mass within the monitoring range, and provided guarantee for mine safety production. Tan Aiping et al. [12] introduced the architecture of Internet of Things application for metal mine construction safety risk monitoring to provide reference for Internet of Things application for metal mine risk monitoring and related research, aiming at the safety hazards of water seepage, mine collapse and toxic gases in the process of metal mine mining. Jin Kaiming [13] Based on the current situation of the initial dam of a newly built tailings pond in Xinjiang, designed an online monitoring system scheme suitable for the current construction of the tailings pond, and established a safety monitoring and management platform, which provided strong auxiliary support for the safety management of the tailings pond. Liu Guanzhou et al. [14], aiming at the safety monitoring and early warning of high and steep open-pit slope, conducted research on key technologies such as multi-source monitoring information collection and fusion, cloud data storage, slope stability analysis, three-dimensional modeling, and comprehensive early warning. A set of multi-source monitoring and early warning information integration platform was established to realize the whole process of intelligent monitoring and disaster warning of high and steep slopes. Ma Hongcheng et al. [15-18] conducted a series of studies on the smart street 3D visualization platform based on the open source Cesium framework, introduced a variety of currently popular WebGL development frameworks, and expounded the processing flow of terrain data and 3D model data displayed on the Web side. It provides some reference for the construction of intelligent mine.

The above research work covers system construction, data collection, network transmission, data analysis and early warning and release, and has achieved certain results, but most of the research work is only for a single monitoring object subject, but mining is a process in which production operations interact with hydrological environment, ventilation conditions and geomechanics. Therefore, it is easy to form information island through single factor analysis, resulting in the early warning results can not serve the mine production, which is not conducive to the mine to make accurate and effective decisions. On this basis, this paper proposes to build a 3D visualization platform for mining process data fusion. Based on cloud service framework and three.js3D engine, it realizes a mine production safety monitoring and early warning system that integrates multi-source data collection, storage, statistical analysis, visual display, classification and classification of early warning and real-time push during mining process. Mine production relies on the new service model of safety.

2. Overview of Mine Monitoring System Construction

In Maoping lead-zinc mine area of Yiliang Chihong Mining Co., LTD., the fault structure develops, rock burst events occur sporadically in deep mining operation area, stope and roadway deformation is obvious, and ground pressure problems are serious. The mining area belongs to the karst fissure water directly filled deposit with complicated hydrologic environment and large water inflow. The mining depth of the ore body increases year by year, the section of the stope return air pipeline is small and the resistance is large, and some roadways fail to form a through-flow that meets the requirements of dust, smoke, cooling and dehumidification. After various heat and moisture gather, the operating environment temperature and humidity become higher and higher. In this context, Yiliang Chihong Mining Co.,Ltd. has built several sets of mine safety online monitoring systems, including microseismic, stress displacement, ventilation and water level, to ensure mine production safety.

2.1. Ground Pressure Monitoring System

The ground pressure monitoring system of Maoping lead-zinc mine of Yiliang Chihong Mining Co., Ltd. consists of 36 channel IMS microseismic monitoring system, 8 channel Jikang stress monitoring system and 10 channel Jikang displacement monitoring system. It covers the middle of 670m, 610m, 490m, 430m and 370m in the east of Maoping Mining area, and the middle of 670m and 610m in the west of Hexi. The specific ground pressure monitoring system architecture is shown in Figure 1 below. Among them, IMS microseismic monitoring system obtains on-site rock rupture, blasting and other vibration signals through the on-site microseismic monitoring sensor, and then converts them into voltage analog signals through the data acquisition base station, and then transmits them to the surface service station through the dedicated optical fiber network. After that, the voltage analog signals are converted by the data acquisition software and saved as waveform files in fixed format. Jikang stress and displacement monitoring system obtains the change of the characteristic parameters transmitted to the monitoring equipment due to the change of stress or displacement at the installation position through the sensor installed on the field, and automatically calculates the change of stress or displacement of rock mass through the background of data acquisition software. At a certain time interval, the stress or displacement change results of each monitoring point are saved to the server in the form of a fixed table.

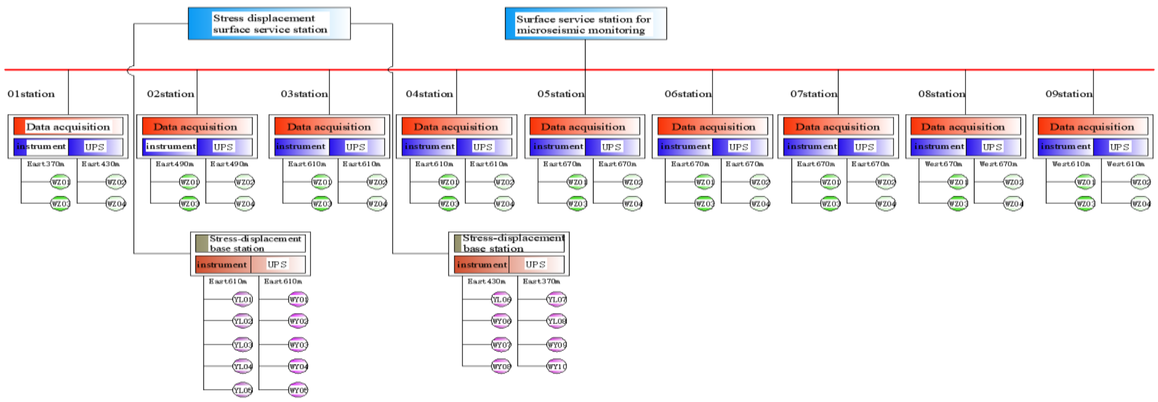

Figure 1. Architecture diagram of ground pressure monitoring system

2.2. Ventilation Monitoring System

According to the actual situation on site, Mauping lead-zinc Mine of Yiliang Chihong Mining Co., Ltd. has established an online monitoring and analysis system for regional climate parameters of stope and nearby roadway, the main monitoring parameters include ventilation volume, wind pressure, temperature, humidity, air pressure, etc. The main wind speed data of stope and roadway area is obtained by climate parameter acquisition sensor on site, and connected to the intelligent acquisition sub-station through the private network. Then the relevant monitoring results are transmitted to the surface service station through the underground industrial Ethernet ring network and the monitoring data is saved to the local in the form of a table at a fixed time interval. Fig. 2 below shows the architecture diagram of the online monitoring and analysis system for climate parameters.

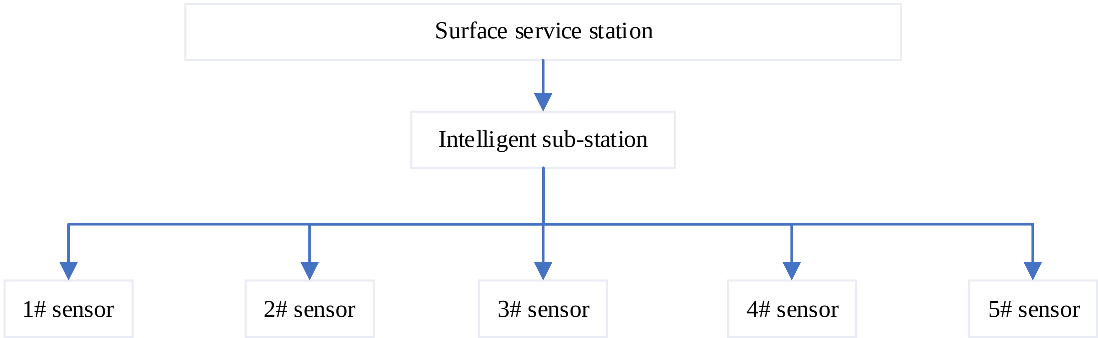

Figure 2. Architecture diagram of online monitoring and analysis system for climate parameters

2.3. Hydrological Monitoring System

The Maoping lead-zinc mine of Yiliang Chihong Mining Co., Ltd. has established a perfect water level information monitoring network with the help of deep hydrogeological investigation project, and 38 observation holes are set up on site. A groundwater level monitoring instrument is installed in the borehole, which is transmitted to the water level collecting instrument through the wire, and then transmitted to the groundwater level monitoring platform through the wireless network in the form of a message queue. Fig. 3 below shows the architecture diagram of the hydrological intelligent monitoring system.

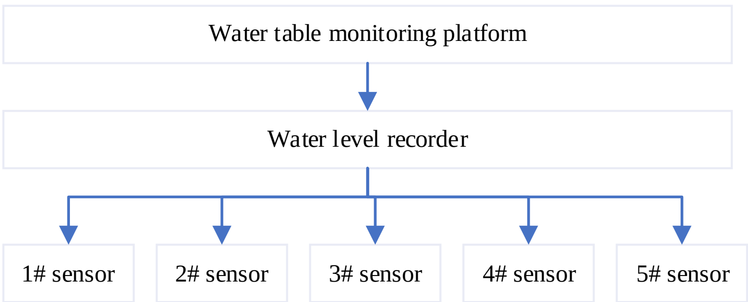

Figure 3. Architecture diagram of hydrological intelligent monitoring system

3. Mine monitoring Data and Cloud Service Construction

According to the above multi-type monitoring system architecture of mine construction, it is not difficult to find that the data obtained by each type of monitoring system is either saved in the local server or transmitted to the third-party platform, and there are problems such as difficult data management and maintenance, strong data isolation, and data analysis and application are separated from mine production. With the development of cloud computing technology and the popularity of cloud service concept, relying on the existing monitoring system, the establishment of a set of integration of mine production and potential mine safety risk monitoring in one of the visual platform, to achieve offline data WAN real-time view and fusion analysis, for the service of mine production safety is of great significance.

3.1. Platform Architecture

The platform as a whole adopts the front end separation structure, modular design concept, the front-end application adopts the form of one integrated big map and four business small maps, and the mine integrated big map overtakes the four business small maps to form a three-dimensional visual data management cockpit integrating multiple business types, realizing business functions including mine safety monitoring and risk control. The four business maps are connected to mine production, ground pressure, ventilation and hydrology monitoring respectively, and upload data offline to achieve separate management by business type. The back-end management is independent of the front-end application, and the implementation includes the front-end application and service function configuration, user permission configuration, menu, monitoring type and other general management functions.

The main architecture of the 3D visualization platform researched and developed in this paper includes four levels: data awareness layer, service layer, gateway layer and business application layer, as shown in Figure 4 below. Among them, the data perception layer mainly realizes the collection of multiple types of data through the ground pressure monitoring system, hydrology monitoring system, ventilation monitoring system and data entry function established on site. The service layer uploads the sub-type business data collected on site to the database through the 4G network for storage and logical calculation. Since the platform adopts the SaaS software as a service model, the database is deployed in the cloud. The gateway layer provides interface services according to the requirements of authorized users, receives and responds to requests, and distributes them to the corresponding service layer for processing. Application layer is also the view layer. In the development of this platform, three.js technology framework is adopted to realize the type loading, rendering and early warning display of 3D model files, sensor model files and data model files.

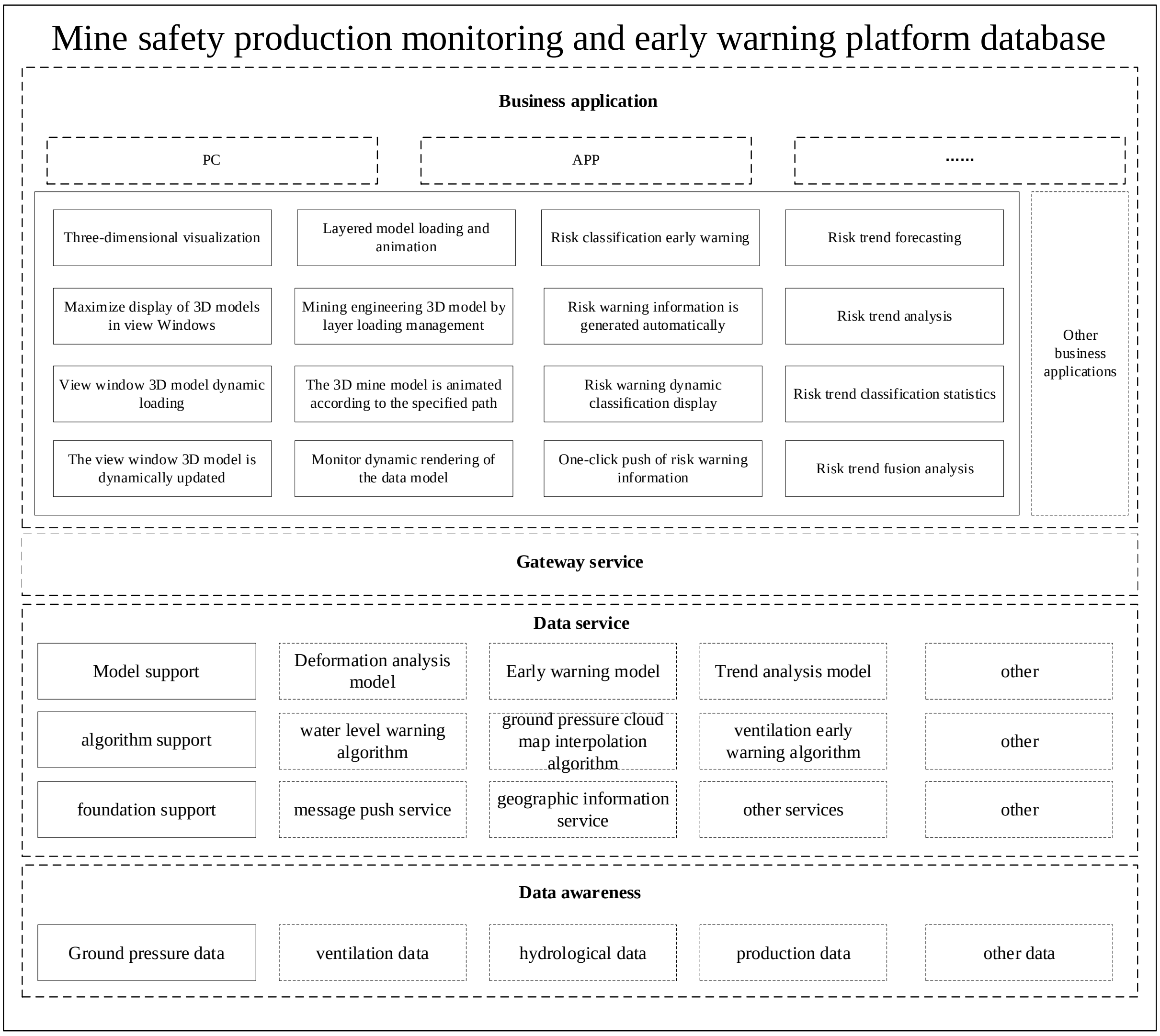

Figure 4. Mining process data fusion 3D visualization platform

3.2. Database Design

The multi-source monitoring type database of mine safety production risk early warning is constructed, and the business logic and table structure of the database are designed according to the field monitoring business type and manual recording table style. In view of the complexity of the data structure, and in order to improve the efficiency of data retrieval, the key data information is extracted according to the application requirements, the standard data table is established, and the index field is set. Based on the analysis of the on-site monitoring business requirements, this paper establishes the mine safety production risk early warning business model as shown in Fig.5 below.

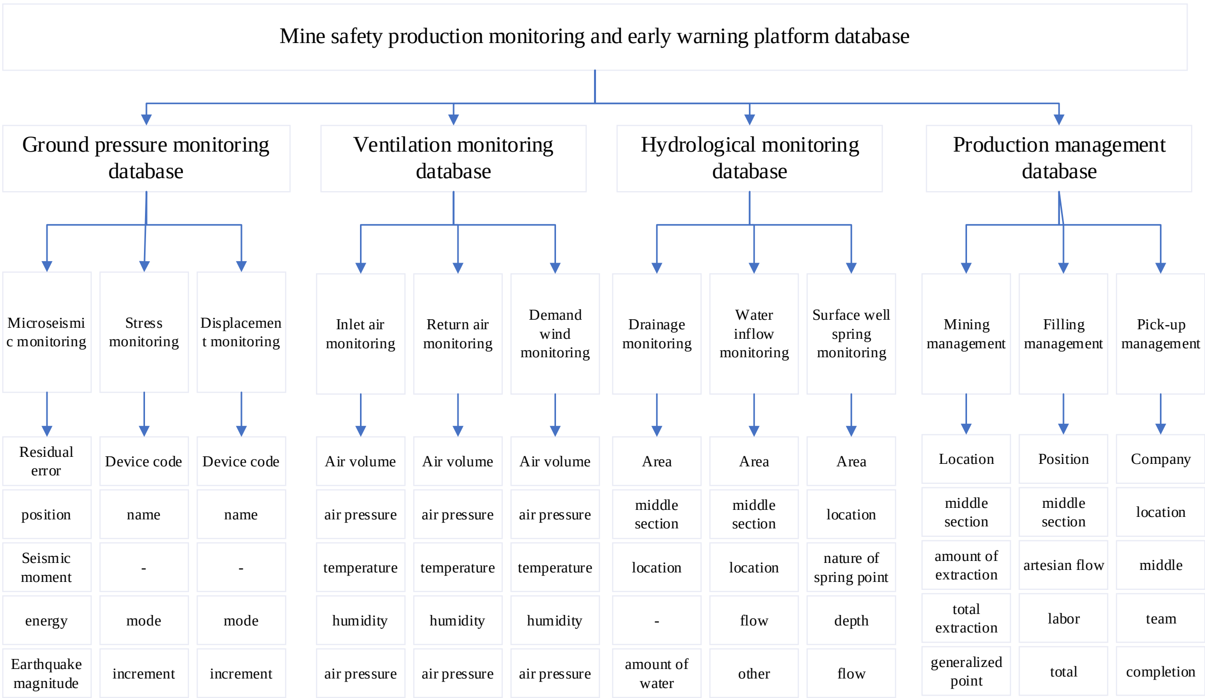

Figure 5. Database design of mine safety production monitoring and early warning platform

3.3. Data Storage and Application

The database used in the development of this platform is MySQL database, which is deployed in cloud storage and provides services for data upload storage, data access and release of the mine production safety monitoring and early warning platform through database management services. In practical application, the mine production safety monitoring and early warning platform designs professional interfaces according to the four business types of ground pressure, hydrology, ventilation and production. The on-site monitoring system pushes corresponding monitoring result data to cloud storage in the form of message queue according to the designed interface type, and authorized users call relevant data and perform related logical calculations according to preset rules. Finally, it is displayed on the home page of each business subsystem and a mine map.

4. Mine Safety Production Monitoring and Early Warning Platform

4.1. Business Data Classification Collection

According to the platform design framework, the data collected on site can be divided into four categories according to the business: ground pressure monitoring, ventilation monitoring, hydrology monitoring and production monitoring. According to the data access type, it can be divided into real-time monitoring data and offline filling data. The ground pressure monitoring data, some regional ventilation data and some monitoring point water level data are uploaded in real time through each independent subsystem. Production data, some location ventilation data and some regional hydrological data were uploaded by manual entry or batch import. Table 1 below shows the delivery management data table in the production data.

Table 1. Transportation management data sheet

date	corporation	Wellhead coordinates			Drawing level /m	Morning shift		Middle shift		Night shift		total		Actual completion /t	Target quantity /t	Difference /t
		X/m	Y/m	Z/m		Ore /t	Waste rock /t	Ore /t	Waste rock /t	Ore /t	Waste rock /t	Ore /t	Waste rock /t			
2022 /3/1	XX	XX	XX	XX	430	41	0	60	4	78	one	179	5	184	162	22

4.2. Business Data Classification Statistics and 3D Display

The main body of the platform is displayed with a three-dimensional model as the carrier, and the conventional statistical functions are designed in the form of configurable functional kanban according to business categories. The three dimensional model is divided according to the business needs, the main body includes three dimensional model of surface topography, three dimensional model of shaft and roadway structure, three dimensional model of fault structure, three dimensional model of hydrologic funnel and three dimensional model of ore body. The platform is designed according to different business data types, including the proportion of the total amount of completed transportation at each transport point under the production module, the number of regional events and the corresponding displacement change rate under the ground pressure module, the change of the measured air volume at the demand air point under the ventilation module, and the total water inflow and total drainage and drainage curves under the hydrological module. Fig.6 below shows the statistical standard of the number of regional events and the corresponding displacement change rate curve under the ground pressure module.

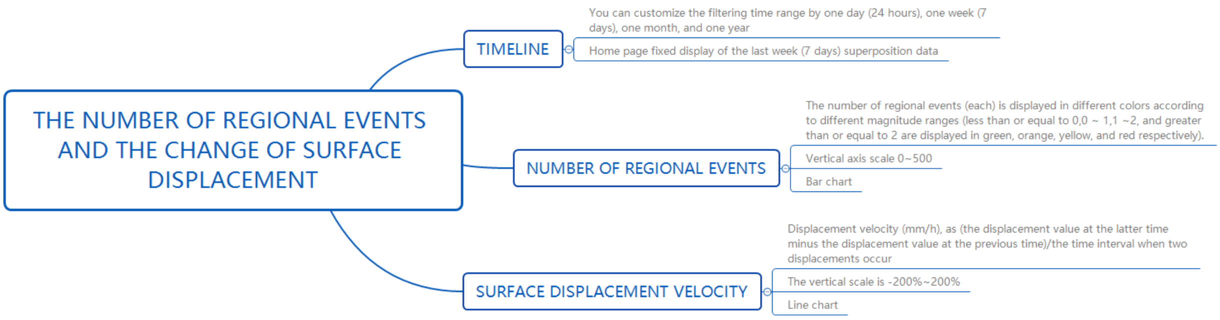

Figure 6. Statistical standard of regional event number and land displacement rate change curve

4.3. Security Risk Warning and 3D Visualization

For the four types of business planned by the platform, the corresponding security risk warning standards are designed according to each type of business. The overall setting is in accordance with the four-color warning level. When the monitoring data exceeds the set threshold, the warning icon under the corresponding functional module on the home page is triggered and displayed in the corresponding color, and the risk warning information is displayed in the form of circular animation at the corresponding position in the three-dimensional space. Table 2 shows the setting of a single warning indicator by service type.

Table 2. Set standards for a single indicator of mine safety risk early warning

Business type	Early warning parameter	Warning level			
		Level 1 / Red	Grade II/Orange	Level 3 / Yellow	Level 4 / Green
Ground pressure monitoring	Earthquake magnitude	> 0	P - 1	P - 2	other
Ventilation monitoring	Air volume	10 or less	8 or less	6 or less	other
Hydrological monitoring	Water level	P 800	P 750	P 700	other
Production management	Target quantity	1000 or less	1200 or less	1400 or less	other

4.4. Development of Safety Production Monitoring and Early Warning Platform

According to the platform architecture and data collection methods of various business types, data statistics and safety risk warning characteristics, three-dimensional visualization requirements, etc., in accordance with the front and back end separation structure design mode, the development and design concept of "One mine map", the three-dimensional model is loaded hierarchically on the home page according to the engineering category, and the statistical curves of various types of business data are flexibly configured. The classification and real-time display of early warning and forecasting information, and the animation simulation of early warning types, classifications and precise positions form the homepage of the mine safety production monitoring and early warning platform.

5. Engineering Application

The mine safety monitoring and early warning platform takes the mine production process safety risk management as the main line, and achieves the goal of balancing mine production and controlling safety risks through multi-dimensional management of real-time and offline data. Mauping lead-zinc Mine of Yiliang Chihong Mining Co., Ltd. completed the deployment of the first phase of the platform as early as June 2022, including the construction of in-situ monitoring systems such as ground pressure monitoring system and hydrological monitoring system, data analysis and storage, data processing and analysis, early warning, three-dimensional visual display, generation of briefings and release. This study takes the ground pressure monitoring related services as an example to illustrate the application of the platform.

5.1. Data Analytic Processing

A 36-channel microseismic monitoring system and a stress displacement monitoring system are deployed at the mine site, and the data of the two systems are saved to the local computer. Among them, the microseismic monitoring system saves the original monitoring waveform data and the combined data file after positioning. Since the combined data file after positioning cannot be directly analyzed, In this part, the original monitoring waveform data is read directly and the self-positioning algorithm is used to complete the waveform data combination positioning. After the above work is completed, the stress displacement data is pushed to the cloud storage database in the form of message queue

5.2. Statistical Analysis of Data

After the data uploaded to the cloud storage is stored according to standard table files, statistical analysis of the data is carried out according to business needs. Based on parameters such as time, positioning residual, focal location, seismic moment, energy, magnitude and event source, microseismic monitoring can be statistically analyzed, including microseismic time history curve, microseismic event distribution histogram, microseismic energy-seismic moment parameter statistical diagram and magnitude-frequency statistical diagram. Stress displacement monitoring based on events, equipment identification code, equipment name and incremental value and other parameters can be counted including different time range of stress change, displacement change, stress change rate and displacement change rate curves.

5.3. Early Warning Push and Visualization

Early warning is the core of the platform. Based on the data obtained from on-site real-time monitoring, it is crucial to set appropriate early warning parameters for different mines by setting corresponding thresholds and guiding production managers to make quick decisions. Here, we take single-factor parameters as an example and set earthquake magnitude indicators. When the monitoring microseismic event magnitude is greater than or equal to 0, the red warning is displayed; when the monitoring microseismic event magnitude is greater than or equal to -1 and less than 0, the orange warning is displayed; when the monitoring microseismic event magnitude is greater than or equal to -2 and less than -1, the yellow warning is displayed; in other cases, no warning is displayed. When an early warning occurs, the early warning result will be displayed in real time through the ground pressure early warning icon on the home page of the platform, and the corresponding three-dimensional model area will be simulated and demonstrated in the form of animation.

5.4. Generate a Brief and Publish it

According to the preset briefing template of the platform, the platform automatically reads the statistical curve of key data and the statistical parameters of the early warning of major earthquake events, and sends the early warning briefing to the contact person set in advance to prompt relevant personnel to make security risk disposal decisions.

6. Conclusion

Aiming at the problems of ground pressure, hydrology, ventilation and production safety commonly faced in the mine production process, a three-dimensional visualization system integrating mine production management and safety risk monitoring and early warning was developed. It realizes real-time online management, classified statistical analysis and three-dimensional visual integrated display and early warning push of multiple types of data such as mine production and operation, ground pressure monitoring, ventilation and heat damage, and water inrush, which is of great significance for ensuring mine production safety, improving the emergency response efficiency of mine safety risks, and improving the informatization management and control level of mine safety risks.

Acknowledgments

(1) Project supported by the National Key Research and Development Program of China (2024YFC2909500).

(2) Project supported by the National Key Research and Development Program of China (No.2022YFC2903804).

(3) Project supported by the Xinjiang "Tianshan Talents" the second batch of outstanding engineers (Chen Yin) training program.

References

[1] Zhang Da, Wang Jinong, Ji Hu, et al. Research and Application of iot System for Mine Micro-Power safety Monitoring [J]. Journal of Communications, 20, 41(2):44-57.

[2] CHENG Gang, WANG Zhenxue, SHI Bin, etal. Research progress of DFOS in safety mining monitoring of mines [J]. Journal Of China Coal Society, 2022, 47 (8): 2923-2949.

[3] Ge Husheng, Gong Fuhui, Sun Yanyan, et al. Construction and application of open-pit intelligent mine system under dual 5G network [J]. Metal Mine, 2022, 555(9):167-173.

[4] Feng Gong. Study on on-line monitoring and early warning method and early warning system of open-pit slope stability [D]. Wuhan: Wuhan University of Technology, 2021, (1-63).

[5] Liu Yanhong. Application research of multi-source information integration and safety control platform for ultra-deep Wells [J]. Mining Research and Development, 202, 42(1):181-186.

[6] Xiao Chunying, Zhang Da, Lu Changwei, et al. Application of intelligent safety assessment and monitoring technology in Shangfangou Molybdenum Mine [J]. Non-ferrous Metals (Mine Section), 2021, 73(6):46-52.

[7] Li Kemin, Wang Shuzhong, Zeng Zhao-Hong, et al. Comprehensive processing system of open pit production information [J]. Journal of China University of Mining & Technology, 2000, 29(5):484-486.

[8] ZHANG Chuanliang, Su Jun.Analysis and application of Surface displacement monitoring technology for pit slope in open pit mine [J]. China Mining Industry, 2022, 31(Supp.1), 269-274.

[9] Yu Wan, Zhang Da, Ji Hu. Design and application of online monitoring system for tailings pond safety based on SaaS [J]. Nonferrous Metals (Mine Section), 2022, 72(6):101-106.

[10] Li Wanfeng. Design and main function realization of data visualization platform based on Java EE [D]. Beijing: University of Chinese Academy of Sciences, 2017. (1-66).

[11] Liu Qiang, Wei Yinhong, Wang Ping, et al. Monitoring Analysis and early warning study on roof stability of natural caving method [J]. China Work Safety Science and Technology, 201, 17(8):91-96.

[12] Tan Aiping, LIU Chunde, DENG Qingxu. Research status and development trend of iot key technologies for Metal mine risk monitoring [J]. Metal Mine, 2020, 523(1):26-36.

[13] Jin Kaiming. Scheme design of online monitoring system for a newly built tailings pond [J]. China Mining Industry, 2019, 28 (Supp. 2), 233-235.

[14] JIN Kaiming. Scheme design of on-line monitoring system for a new tailings reservoir [J]. China Mining Magazine, 2019, 28(Suppl 2),233-235.

[15] Liu Guanzhou, ZHANG Da, ZHANG Yuansheng, et al. Research on integrated platform of multi-source monitoring and early warning information of high and steep slope [J]. Metallurgical Automation, 2018, 42(6):1-7. (in Chinese)

[16] Ma Hongcheng, Zhang Yuju, Liu Weimin. Research and application of Intelligent Street 3D visualization platform based on open source Cesium framework [J]. Surveying, Mapping and Spatial Geographic Information, 2019, 42(8):121-123.

[17] Li Xiangying, Wang Jianmin, Feng Xing-Hao, et al. Three-dimensional visualization platform of space target observation based on Cesium [J]. Application of Computer Systems, 202, 31(8):108−114.

[18] Tan Qiong, Zhang Tao, Ding Lele, et al. Design and development of multi-source 3D data visualization and analysis platform based on Cesium [J]. Surveying, Mapping and Spatial Geographic Information, 2002, 45(6):120-123.

[19] Ma Zhaoyang, Liang Yinping, Zhu Guifan, et al. Research on 3D visualization platform of geological drilling data based on VTK [J]. China Mining, 2019, 29 (Suppl. 1):136-140.