Mine Safety Monitoring and Early Warning System Based on 5G Network Technology

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Abstract. With the continuous development of industry, the demand for various minerals is also increasing. However, restricted by factors such as environment and equipment, mining safety problems continue to occur. Therefore, research on mine monitoring and early warning has been put on the agenda. The maturity of 5G technology provides technical support for current monitoring and early warning. This article first summarizes the research status of mine safety monitoring system, and combines the advantages of 5G technology to analyze the feasibility of the mine safety detection and EWS based on 5G network technology studied in this article. Afterwards, the functional modules of the mine safety monitoring and EWS were designed in detail. This article systematically expounds the Newton iterative method and other seismic source location methods. Research shows that the mine safety monitoring and EWS based on 5G network technology studied in this article has higher accuracy in monitoring data and positioning personnel.

Keywords: 5G · Mine safety · Monitoring and early warning system · Application research

1 Introduction

With the rapid development of science and technology, the problem of energy shortage has come to the attention of the world people again. The same is true in China. With vast territory and abundant resources, China has a great advantage in mineral resources compared with other countries. Mineral resources are indispensable material basis for improving people's living standard and developing national economy. They are also valuable natural resources in China, which are non-renewable and relatively scarce. Regrettably, in recent years, driven by economic interests and the increase of mining scale and depth, mining safety accidents such as roof caving, deep rock burst, surface collapse, underground water inrush and large area caving emerge in endlessly, making mining safety issues become the focus of attention of the government and enterprises. In the process of mine safety production, as production safety policy of "safety first,

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prevention first, comprehensive treatment", security is a prerequisite, and is to keep the material basis for the safety in production, but there are still certain contradictions between, when certain input resources, share proportion increase, which means that the relative reducing production resources, on the other hand, Because many enterprises only care about immediate interests and lack long-term strategic goals, they tend to invest most of their resources into production, in exchange for unique profits through the safety of personnel and equipment. In addition, the mining geological environment is complex and the infrastructure is poor, leading to more unsafe mining production.

With the rapid development of my country's economy, the demand for various types of energy is also increasing [1, 2]. The continuous mining of industry has made the traditional mine safety monitoring and EWS unable to meet the increasing demand due to its limited geographical location and difficulty in real-time monitoring of underground operations, which has brought huge losses and casualties to related personnel [3].

This article focuses on improving the efficiency of mine safety construction, and aims to study the mine safety monitoring and EWS based on 5G network technology. The feasibility analysis of the research content of this article is carried out by comparing the data monitoring and personnel positioning with the actual value on the simulation software.

2 Related Work

Mine safety monitoring system is a necessary condition for safe production. The development of foreign coal mining monitoring systems began as early as the 1960s [4]. So far, it has experienced four stages: space division, frequency division, time division system signal transmission and distributed micro-processing technology [5].

Coert introduced a mine safety system that utilizes wireless sensor Networks (WSN). Sensor design and wireless communication in underground mining environment are studied. This information is used to design and implement a powerful hardware-based sensor node with independent microcontrollers that collect data from six different sensors, namely temperature, humidity, airflow speed, noise, dust and gas level sensors, and transmit the processed data to a graphical user interface [6]. Ankit believes the Internet of Things (IoT) can play a huge role in mining operations to improve worker safety and improve productivity. Wireless communication, as a component of Internet of Things, has played an important role in underground mine communication. A mining safety system based on Internet of things is proposed [7]. Ali monitors a person's health data and uses fuzzy logic to calculate the early warning score score. Therefore, a test platform for real-time applications was simulated according to the Health Informatics – Medical/health Device Communication standard [8].

Compared with foreign countries, my country began to study coal mining monitoring systems in the 1970s. At that time, Western countries already had relatively mature coal mine safety monitoring technologies and finished products [9]. Our country has introduced various coal mine safety monitoring systems from the West for many times, so that coal mining monitoring technology has been developed rapidly [10].

To sum up, due to the reasons of natural occurrence conditions and economic entities, there are few studies on mine safety warning abroad. Domestic non-coal mine warning is still in the theoretical research stage, even the developed application system only has the alarm function because of the low degree of system integration, the warning function is relatively single, the accuracy is not high. Therefore, it is of great practical significance to carry out systematic research on the theory and technology of early warning and increase the investment in its application to comprehensively improve the level of mine safety management and the situation of safe production.

3 Application Research of Mine Safety Monitoring and EWS Based on 5G Network Technology

3.1 5G Network Technology Analysis

The safety monitoring and EWS designed in this research is applied to mining operation monitoring. Most of the mining monitoring is in deep mountains or underground, which is greatly affected by the geographical environment [11, 12]. Therefore, the safety monitoring and EWS should include the following characteristics:

(1) Strong anti-interference ability, not affected by weather;
(2) Very long transmission distance;
(3) Fast transmission speed;
(4) High real-time requirements;
(5) Good stability.

3.2 System Requirement Analysis

(1) Feasibility analysis

1) Technical feasibility analysis
The security monitoring and EWS created by the 5G network has high performance requirements for transmission delay, throughput, power consumption, etc. It has the characteristics of ultra-low delay, ultra-low power consumption, high reliability, and large-scale connection, and can completely solve the problem of mines.
2) Economic feasibility analysis
With this system, coal mine safety observers can grasp all kinds of underground data anytime and anywhere, adjust equipment that may cause safety problems in time, avoid production accidents and unnecessary losses, and reduce economic losses, have a very broad market application space.

(2) Role analysis

1) Operation user
The operating user is actually a security monitoring staff. Safety monitoring personnel monitor the production status of the mine in real time, mainly through

the safety production, staffing, video monitoring and other modules of the mine safety monitoring and EWS client to solve some unexpected phenomena or factors in the first time. At the same time, safety observers can view these data information through daily production reports and key engineering modules to control mine output or work group tasks.

2) Server system

a. Application server system

The application server system connects the various subsystems of the mine safety monitoring and EWS, obtains the data information of the relevant monitoring objects in time, organizes the data information, and provides data services for the monitoring system. The monitoring objects processed by the application server system include daily production data, key project data, safety production data, and staffing information data.

b. Video server

Video streaming is more professional than regular data information, so a dedicated video server is needed for transmission. Nowadays, most coal mines use more mature video servers to provide different data interfaces for different mobile devices. The video server in this study sends it to the mobile device through a proprietary compression process.

3.3 System Function Design

(1) Monitoring module design

The monitoring system mainly includes information concentrator and wireless sensor nodes.

1) Information concentrator

The information concentrator is mainly composed of supporting modules such as a single chip microcomputer, a wireless radio frequency module, a serial port transceiver module, and an alarm module. Among them, which completes the scheduling and processing of various tasks; the serial port transceiver module completes the data transmission interaction between the information concentrators; the alarm module can complete the sound and light threshold alarm, cross-border personnel are equipped with alarms, warning signs and other functions.

2) Wireless sensor node

The wireless sensor node is mainly composed of supporting modules such as a single chip microcomputer, a wireless radio frequency module, and environmental sensors. The single-chip microcomputer, the wireless radio frequency module and the information concentrator have similar functions, while the wireless sensor node has only one radio frequency module chip, which simultaneously completes the data sending/receiving function. Environmental sensors are responsible for collecting data.

(2) Design of personnel positioning module

The personnel positioning function is mainly composed of the reader (that is, the information concentrator in the monitoring module) and the personnel positioning node. The personnel positioning node is used for the positioning information interaction with the reader. The personnel positioning node (identification card) in the mine can interact with the reader in full duplex. In addition to passively uploading positioning information to the ground command center, you can also actively upload an emergency distress signal to the ground command center through the emergency call button. The ground command can also issue various instructions (buzzers, light warnings of different colors) to underground mine operators, such as evacuation alarms, requiring operators in specific areas to contact the ground. When an emergency occurs underground, the emergency communication system is only installed in the second room and key location of the main motor room, so it cannot cover the work area of all personnel. However, the personnel positioning module covers almost all underground working areas and has a certain range of communication.

3.4 Analysis of Common Source Location Methods-Newton Iteration Method

(1) Principle

Iterative methods are often used to solve approximate roots of nonlinear equations. It is important to be able to determine the iteration function. The classic iterative method is to directly solve the unknown number through the function itself, thereby obtaining the iterative function, but this method requires multiple iterations and is relatively slow. Newton iteration is usually used to calculate the location of the microseismic source, because they choose another iteration format with faster convergence speed, and other iteration forms can be obtained through corresponding transformations.

Let x_n be the approximate root of the nonlinear equation f(x) = 0, and expand f(x) at x_0 through Taylor polynomial expansion:

$$f(x) = f(x_0) + f'(x_0)(x - x_0) + \frac{f''(x_0)}{2!}(x - x_0)^2 + \ldots \tag{1}$$

To simplify the problem, linearize the equation and use only the first two terms to approximate f(x), then it can be expressed as:

$$f(x) \approx f(x_0) + f'(x_0)(x - x_0) = 0 \tag{2}$$

Suppose $f'(x_n) \neq 0$, let the solution of the equation be x, then we can get

$$x = x_0 - \frac{f(x_0)}{f'(x_0)} \tag{3}$$

Let $x_1 = x_0 - \frac{f(x_0)}{f'(x_0)}$, similarly, expand f(x) = 0 to a Taylor polynomial of x_1 and take only the linear part:

$$x_2 = x_1 - \frac{f(x_1)}{f'(x_1)} \tag{4}$$

By analogy, Newton's iterative form can be obtained:

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)}, n = 1, 2... \tag{5}$$

(2) Geometric meaning and advantages and disadvantages

Draw the tangent of f(x) at point x_0, the slope is represented by $f'(x_0)$, and the tangent equation is as follows:

$$y - f(x_0) = f'(x_0)(x - x_0) \tag{6}$$

Set y = 0, the intersection point of the tangent equation and the x-axis can be obtained as x_1, namely:

$$x_1 = x_0 - \frac{f(x_0)}{f'(x_0)} \tag{7}$$

In the same way, draw a point $(x_1, f(x_1))$, that is, the tangent of f(x), and get the intersection point with the x-axis as x_2, and iterate all the time, and finally approach the root of the equation. As shown in Fig. 1.

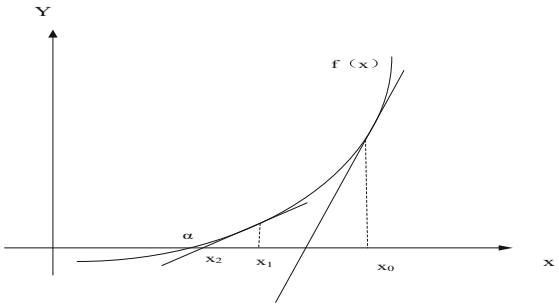

Fig. 1. Schematic diagram of Newton's iteration method

Newton's iteration method converges by a square factor, so it usually only takes a few iterations to obtain a more accurate solution. The advantage of this form of Newton' iteration method: it can solve the roots of nonlinear equations accurately and effectively. However, Newton's iteration method is very sensitive to initial values, and incorrect initial values may not converge. At the same time, it contains the derivative of the function, and the amount of calculation is relatively large.

3.5 Design of the Signal Detection Algorithm in the Mine Based on 5G Technology

The mine signal detection algorithm based on 5G technology mainly eliminates interference, linearly weights the received vector to meet specific detection standards, separates

the transmitted signals of different users, and then detects the transmitted signals of different users. This time, a large antenna array is used to form a TDD cell, which is composed of M receiving terminals and K transmitting ports.

The M × 1 dimensional column vector at the receiving end is expressed as:

$$y = \sqrt{p_n} G_x + n \tag{8}$$

$$r = A^n y = \sqrt{p_n} A^n G_x + A^n n \tag{9}$$

r_k, x_k is the k-th element of the K-dimensional column vectors r and x, respectively.

$$r_k = \sqrt{p_u} a_k^H Gx + a_k^H n = \sqrt{p_u} a_k^H g_k x_k + \sqrt{p_u} \sum\nolimits_{i=1, i \neq k}^{k} a_k^H g_i x_i + a_k^H n \tag{10}$$

a_k, g_k is the k-th column vector of the matrices A and G, respectively.

4 Experimental Research on Mine Safety Monitoring and EWS Based on 5g Network Technology

4.1 Experimental Protocol

This experiment uses simulation software for the data monitoring module and personnel positioning module of the mine safety monitoring and EWS based on 5G network technology studied in this paper. In this experiment, 4 groups were set up to ensure the scientific validity of the experimental data. In the data monitoring experiment, this experiment is tested by monitoring the gas concentration. In the personnel positioning experiment, this experiment uses the error between the monitoring and EWS studied in this article and the traditional EWS for experimental analysis, and finally uses mathematical statistics for statistics and analysis of the data obtained.

4.2 Research Methods

(1) Comparative analysis method

In this experiment, the mine safety monitoring and EWS based on network technology 5g studied in this document is compared to the traditional monitoring system. The information received shall provide a reliable reference to the final results of the investigation of this document.

(2) Observation method

In this study, the gas concentration was observed and recorded and the recorded data were classified and analysed. This evidence provides strong support for the final results of the investigation of this document.

(3) Mathematical Statistics

The relevant software is used to compile statistics and analyses of the research results of this document.

(4) Simulation experiment method

In this experiment, the safety monitoring and EWS studied in this article is tested on simulation software, which provides data support for the feasibility analysis of the subject of this article.

5 Experimental Analysis of Mine Safety Monitoring and EWS Based on 5G Network Technology

5.1 Monitoring and Analysis of Gas Concentration

In order to make the experiment more scientific and effective, the mine safety monitoring and EWS based on network technology 5 shall be simulated on simulation software. The results are presented in Table 1.

Table 1. Gas concentration monitoring and analysis

	Test 1.	Test 2.	Test 3.	Test 4.
Detection value	0.46%	0.52%	0.44%	0.48%
Actual value	0.45%	0.54%	0.41%	0.50%

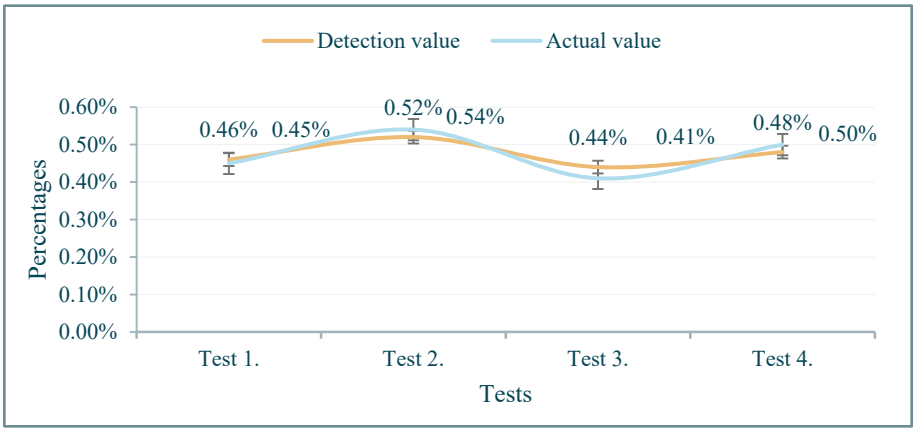

Fig. 2. Gas concentration monitoring and analysis

As shown in Fig. 2, the error of the first test is 0.1%, the error of the second test is 0.02%, the error of the third test is 0.03%, and the error of the fourth test is 0.02%. The average error is 0.02%, less than 0.05%. This shows that the mine safety monitoring and EWS based on network technology 5g studied in this document has the following characteristics: the high gas monitoring rate, which fully reflects the appropriateness of this research content.

5.2 Personnel Location Monitoring Experiment

In order to study and further analyse this experiment, the experiment compares the traditional monitoring system with the monitoring system based on network technology 5g, which has practical value. The results are given in Table 2.

Table 2. Personnel location monitoring experiment

	Test 1.	Test 2.	Test 3.	Test 4.
5G	100.53	151.04	198.79	250.44
Traditional	103.45	147.41	203.70	244.48
Actual value	100.00	150.00	200.00	250.00

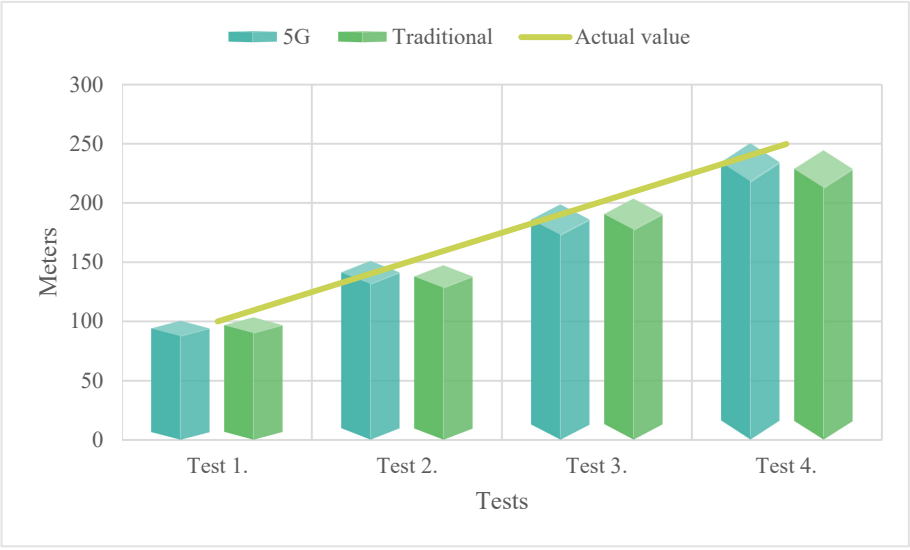

Fig. 3. Personnel location monitoring experiment

As shown in Fig. 3, on the contrary, the traditional safety monitoring system, safety monitoring and EWS, Based on network technology 5 studies the position of personnel at a shorter distance than the actual distance, which is of high precision, which fully reflects the designers.

6 Conclusion

This article aims to study the mine safety monitoring and EWS based on 5G network technology, through the analysis of common seismic source location methods-a detailed overview of the Newton iteration method, and designing the safety monitoring and EWS based on the 5G technology-based signal detection algorithm in the mine. The monitoring module and personnel positioning module are designed and researched. Finally, the simulation operation on the simulation software proves that the system can effectively improve the safety level of mining.

References

1. Yang, Y.: Study on mine safety monitoring system with emergency voice communication based on wireless sensor network. Hans J. Wirel. Commun. **08**(5), 209–215 (2018)
2. Jo, B.-W., Khan, R.M.A., Lee, Y.S., Jo, J.H., Saleem, N.: A fiber bragg grating-based condition monitoring and early damage detection system for the structural safety of underground coal mines using the internet of things. J. Sensors **2018**, 9301873:1–9301873:16 (2018)
3. Henriques, V., Malekian, R., Bogatinoska, D.C.: Mine safety system using wireless sensor networks. In: MIPRO, pp. 515–520 (2017)
4. Wibowo, A., Pratama, C., Sahara, D.P., Heliani, L.S., Rasyid, S., Akbar, Z., Muttaqy, F., Sudrajat, A.: Earthquake EWS using ncheck and hard-shared orthogonal multitarget regression on deep learning. IEEE Geosci. Remote. Sens. Lett. **19**, 1–5 (2021)
5. Cremen, G., Bozzoni, F., Pistorio, S., Galasso, C.: Developing a risk-informed decision-support system for earthquake early warning at a critical seaport. Reliab. Eng. Syst. Saf. **218**(Part), 108035 (2022)
6. Jordaan, C., Malekian, R.: Design of a monitoring and safety system for underground mines using wireless sensor networks. Int. J. Ad Hoc Ubiquitous Comput. **32**(1), 14–28 (2019)
7. Singh, A., Kumar, D., Hötzel, J.: IoT Based information and communication system for enhancing underground mines safety and productivity: genesis, taxonomy and open issues. Ad Hoc Netw. **78**, 115–129 (2018)
8. Çalhan, A., Cicioglu, M., Ceylan, A.: EHealth monitoring testbed with fuzzy based early warning score system. Comput. Meth. Prog. Biomed. **202**, 106008 (2021)
9. Heyns, A.M., Du Plessis, W.P., Curtin, K.M., Kosch, M., Hough, G.: Decision support for the selection of optimal tower site locations for early-warning wildfire detection systems in South Africa. Int. Trans. Oper. Res. **28**(5), 2299–2333 (2021)
10. Debauche, O., et al.: Towards landslides EWS with fog – edge computing and artificial intelligence. J. Ubiquitous Syst. Pervasive Netw. **15**(2), 11–17 (2021)
11. Tubis, A., Werbinska-Wojciechowska, S., Sliwinski, P., Zimroz, R.: Fuzzy risk-based maintenance strategy with safety considerations for the mining industry. Sensors **22**(2), 441 (2022)
12. Pillay, M., Tuck, M.: Permit-to-work systems as a health and safety risk control strategy in mining: a prospective study in resilience engineering. In: AHFE, vol. 5, pp. 145–154 (2017)