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The Current Status and Future Prospects of Intelligent "One Ventilation and Three Prevention" Technology

Shixiong Hu, Sen Xu

Shaanxi Changwu Tingnan Coal Industry Company, China

Abstract

In the safe production of mines, it is necessary to ensure that the mine has good ventilation and a good working environment exists below the mine. In order to meet the ventilation requirements of the mine, many mine ventilation technologies have emerged and have achieved good results in practical applications. With the continuous development of various technologies, it is required that mine ventilation technology should also move towards intelligence. Based on this, the current status of mine ventilation technology and the prospects for intelligent development are discussed. Starting from the significance of mine ventilation, the current status of mine ventilation technology and the intelligent technology of mine ventilation application are analyzed, and the development of mine ventilation intelligent technology is prospected for reference.

Keywords

Mine Ventilation System; Intelligent Ventilation Equipment; High Speed Transmission Technology; Intelligent Algorithms.

1. Introduction

The "one ventilation and three prevention" work in coal mines mainly involves four aspects: mine ventilation, dust prevention, gas prevention, and fire prevention. Among them, mine ventilation is the lifeline of the underground, the core and foundation of coal mine safety production; Mine dust not only causes serious harm to the health of underground workers, but also seriously affects the stability of the performance of advanced equipment in the mine, restricting the safe and efficient production of the mine; For most domestic mines, gas and natural combustion are the two main factors that directly affect the normal production of mines. Therefore, in order to achieve intelligent and safe production in coal mines, the first step is to achieve the intelligence of "one ventilation and three prevention" in coal mines. The basic data of "one ventilation and three prevention" should be monitored and monitored in real-time, and through system platform analysis and decision-making, intelligent linkage of ventilation, dust prevention, gas prevention, and fire prevention should be achieved. This article conducts research and analysis on the development status, research direction, and application prospects of intelligent technology and equipment for the "One Ventilation and Three Prevention" work in coal mines based on the existing situation of intelligent construction in coal mines[1].

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2. Intelligent Ventilation

2.1 Analysis of the Development Status and Existing Problems of Intelligent Ventilation Technology in Mines

The evaluation criteria for intelligent ventilation construction in mines mainly involve three aspects: precise automatic perception of mine ventilation parameters, intelligent decision-making of ventilation management, and remote intelligent control of ventilation facilities and equipment[2].

At present, most mines have only achieved the embryonic form of intelligent ventilation, and most rely on existing monitoring and control systems. The main components include sensors for monitoring parameters such as wind speed and gas, display and analysis systems that integrate communication modules, alarm modules, human-machine interfaces, and remote ventilation facility control systems such as dampers and windows. The foundation of intelligent ventilation in mines is the real-time and accurate perception of ventilation parameters (such as wind speed, gas, carbon monoxide, etc.)[3]. When the wind speed is perceived to exceed the lower limit of the sensor, relevant warning information is pushed to the intelligent ventilation system to achieve automatic control of ventilation facilities such as air doors and windows in the corresponding area of the mine, achieving remote adjustment of wind speed, quickly restoring the wind speed to the specified range, and achieving intelligent ventilation in the mine, in order to save manpower and material resources. When the gas concentration in the mine is too high and cannot be reduced through ventilation facilities and equipment, the laser methane sensor at the end of the monitoring and monitoring system will immediately alarm, transmit the information to the central processing unit, and immediately activate the alarm system to notify the staff in the area to evacuate quickly[4]. Compared with the traditional tile inspection inspection, the mine intelligent ventilation system can realize 24 hours of uninterrupted monitoring in the same area, achieve zero delay in the alarm of ventilation factors such as gas, wind speed and carbon monoxide, and make timely treatment, minimize the possibility of various harmful gas accidents in the mine, and start treatment from the incipient disaster. It avoids casualties and economic losses caused by various disasters such as gas, carbon monoxide and dust in mines[5].

Mine air volume allocation and main fan performance frequency can be optimized through system software. Meanwhile, the design and transformation of mine ventilation system software can be realized, and various types of data obtained after optimization can be displayed through a visual three-dimensional platform. Optimize the intelligent ventilation system of mine with scientific management and advanced technology.

In terms of the existing intelligent facilities and equipment of mine ventilation, ventilation network, ventilation facilities and fans have been equipped with automation and intelligent functions to varying degrees[6]. However, due to the limitations of analysis model, information technology and communication conditions, technology research and development in the aspects of hierarchical intelligent solution of ventilation network, ventilation situation recognition, automatic regulation, risk and hidden danger identification and other aspects has made slow progress. A complete and effective technology integration has not yet been formed, and there is a significant gap with the intelligent construction goals of coal mines, specifically the following four points:

(1) The core algorithm still needs to be broken through, and the application level of new technologies such as the Internet of Things, cloud platforms, and big data in coal mines is not high, which still lags behind the ultimate goal of intelligent construction in coal mines.

(2) The intelligence level of the ventilation system is insufficient, and the system is not yet perfect. The air volume allocation of the intelligent system decision-making model cannot fully meet the actual air volume needs of various underground areas. The development speed of the ventilation system control equipment cannot match the rapid replacement needs of mining equipment. Dynamic and quantitative automatic adjustment is currently difficult to achieve, and the high sensitivity of instruments leads to a large workload of daily management and maintenance.

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(3) The degree of specialization in ventilation systems is high, and the operation of application platforms is complex, which requires high professional skills from ventilation professionals.

(4) The ventilation system currently lacks effective quantitative disaster resistance analysis and auxiliary decision-making functions.

2.2 Research Direction of Intelligent Ventilation Technology in Mines

The premise of intelligent ventilation technology is first reasonable, stable, and reliable, followed by automation and intelligence. In response to the above issues, in-depth research should be conducted in the following seven directions[7].

(1) Research and development of precise air conditioning devices. Conduct research and development on air conditioning equipment such as remote control dampers, remote precise adjustment windows, fully automatic shaft explosion-proof doors, variable frequency main ventilators, and variable frequency local ventilators.

(2) Research and development of precise wind measurement devices. Research and development of remote automatic wind measurement devices, wind pressure sensors, high-frequency ultrasonic wind speed sensors, temperature and humidity sensors, precision wind pressure sensors, carbon monoxide sensors, carbon dioxide sensors and other wind measurement equipment.

(3) Remote control system. Complete remote start stop, collect key data, and establish an intelligent monitoring subsystem.

(4) Unit intelligent control. Implement intelligent control of the unit based on key parameters.

(5) Regional intelligent control. By combining multiple units, achieve regional intelligent control and establish an intelligent control subsystem.

(6) Intelligent ventilation of the entire mine. Integrate the entire mine's air conditioning equipment and systems, establish an intelligent management analysis and decision-making platform, and achieve on-demand air supply.

(7) Green ventilation. Realize safe, on-demand, and green ventilation to ensure the occupational health of employees.

The intelligent analysis of mine ventilation system needs to break through the traditional wind network solution model, integrate artificial intelligence, cloud computing, high-precision sensing and data acquisition and other technologies, build a "nerve center" integrating monitoring, analysis and control, and realize the intelligent ventilation intensive intelligent control mode with environmental perception, analysis, decision-making, early warning and emergency handling as the core. Monitor static pressure, air volume, CH4 concentration, motor stator temperature, bearing temperature before and after the motor, fan vibration, motor voltage, motor current, active power, power factor, accumulated electricity and other operating parameters, display each operating parameter and equipment operating status, and realize the functions of one-click start, automatic switch of faulty fans, automatic air volume adjustment, etc. The construction of video surveillance, underground video inspection and sound broadcast system, the formation of a set of intelligent ventilation technology and equipment system, and gradually realize the intelligent ventilation of the mine.

3. Intelligent Dust Prevention and Control

The intelligent control of dust prevention and control equipment in coal mines can improve the working environment of mining faces, and is of great significance for the prevention of occupational diseases among mining workers and the elimination of hidden dust hazards in mines[8].

3.1 Analysis of the Current Status of Dust Prevention and Control Technology

Through researching a large number of dust prevention and control technologies in coal mines, the following three dust prevention technologies were summarized and analyzed.

(1) Wet rock drilling and coal seam water injection

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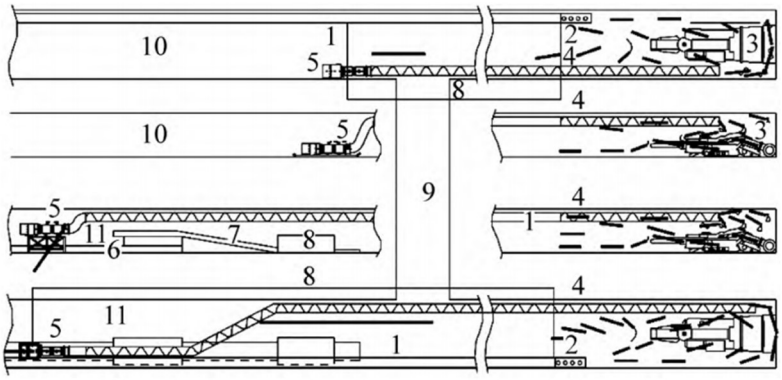
Usually, the place with the highest concentration of coal dust in production mines is the mining face. The principle of wet rock drilling and coal seam water injection is to use the porous characteristics of coal, and use equipment to infiltrate pressure water into the coal body to make it moist, thereby increasing the adhesion between coal dust particles and water, reducing the amount of coal dust generated from the source, and further reducing the generation and diffusion of dust by flushing and discharging the generated dust.

(2) Intelligent automatic spray dedusting

The intelligent automatic spray water spraying dedusting technology is arranged in the main transport lane. The dust concentration in the air is measured by the dust sensor, and the dust concentration information is fed back to the system center. When the dust concentration reaches a certain value, the "nerve center" of the intelligent system gives instructions. The water system pipeline sprays water mist into the dusty air according to the pressure change, so that the floating dust is wetted and sunk. Thus, the concentration of floating dust in the air can be reduced to achieve the purpose of dust removal.

(3) Ventilation and dust removal technology

Ventilation and dust removal is also one of the important measures for comprehensive dust prevention in coal mines. Dust in production can be discharged through the combination of long pressure and short extraction of underground local ventilators and foam dust removal, which can effectively reduce dust accumulation in mining faces and transport roadways and further reduce dust pollution. The layout of long pressure short pumping foam dedusting system is shown in Figure 1.



1- Normal air supply duct; 2- Air outlet controller; 3- Continuous coal mining machine;
4- Dust extraction framework air duct; 5- Dust removal fan; 6- Belt conveyor;
7- Transfer machine; 8- Crusher; 9- Liaison Lane;
10- Auxiliary transportation lane; 11- Transportation Lane

Figure 1. Layout of long pressure short pumping foam dedusting system

3.2 Problems, Research Progress, and Direction of Dust Prevention and Control Technology

At present, dust control is still in the prevention and control stage. Due to the varying spatiotemporal distribution of dust concentration in mining faces under different processes and mining conditions, the prevention and control measures and dust prevention equipment that can be taken are limited[9]. At the same time, dust prevention equipment is usually specialized, and there is a significant difference in intelligence compared to equipment such as coal mining machines and tunneling machines. There is great room for improvement in intelligent upgrading, Therefore, achieving dust prevention and control requires upgrading research on technology and equipment, mainly reflected in the following three aspects:

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(1) The core of intelligent dust control lies in the deep integration of dust prevention and control with big data and artificial intelligence technology. Through research on the concentration distribution of underground main alleys, mining test work flour dust and vehicle exhaust gas, the basic physical and chemical properties of multi-source dust in mining test work faces, the vector flow line of wind flow and dust coupling flow on mining test work faces, and the law of dust flow and diffusion, the physical simulation test platform for the coupling movement of dust and vehicle exhaust under the airflow field of the coal face was built, and the scheme design of the spray dust suppression test system was carried out. The laser Doppler spray dust suppression simulation test platform was built, and the influence of the dust collection network structure on the filter resistance and dust collection efficiency was mastered.

(2) In terms of efficient prevention and control technology and equipment for dust sources in the excavation area, data on the wettability of coal dust was measured, and coal dust molecules were created at the molecular level; The physical and numerical simulation models of spray were established; Obtain the theoretical structure of a track type high-efficiency wet dust collector; A three-dimensional model structure diagram of the multi-directional swirling air curtain generation device was generated, and the mechanism of multi-directional separated control air flow and dust separation was obtained; The research plan for the full section fog curtain dust collection device in the tunnel has been determined.

(3) In terms of online air quality monitoring and intelligent early warning platform construction, it is planned to complete the selection of nitrogen oxide sensors, related power supply and backup power supply design and standard application, monitoring sub-station circuit board making, platform basic function planning and database design. Through accurate data collection of mine dust, the occupational health hazard prediction model and dust exposure quantity model are built based on big data, so as to further explore the dust exposure quantity, physical and chemical characteristics and deposition laws of dust inhalable by underground operators, especially mining face operators, to quantify the degree of dust hazards to occupation and environment, and to build an intelligent pre-control and monitoring monitoring system. Create a new working environment of mine, ensure the safety of workers, prevent occupational diseases, and realize the goal of comprehensive dust removal in mine.

4. Intelligent Fire Prevention

Conduct internal and external research on intelligent fire prevention and extinguishing technology, analyze the current development status and existing problems of fire prevention and control, and propose relevant research directions[10].

4.1 Development Status and Existing Problems of Internal Fire Prevention and Control Technology

(1) The current development status of internal fire prevention and control technology: ① Gas testing based mine fire warning technology mainly includes coal mine safety monitoring system and bundle monitoring system, with high warning accuracy; ② The mine fire warning technology and equipment based on temperature testing mainly include fiber optic temperature measurement system, infrared temperature measurement warning, temperature sensor warning, etc.

(2) The problem in internal fire monitoring is that the monitoring, detection, and early warning of hidden fire sources of residual coal spontaneous combustion in goaf areas are key technologies that need to be urgently addressed. Most coal mines currently adopts comprehensive fire prevention and control measures in the goaf, mainly using yellow mud grouting, supplemented by spraying inhibitor and mobile nitrogen injection. There are corresponding safety monitoring systems and fire prevention and control systems both above and underground, which meet the needs of mine safety monitoring. However, real-time online gas monitoring in the goaf has not yet been implemented, making it impossible to identify and warn early hidden dangers of goaf fires. Therefore, it is necessary to

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establish an intelligent monitoring, classification, and early warning system for goaf fires to effectively ensure mine safety production. The conventional detection technology is not highly targeted, and the development of intelligent monitoring, classification, and early warning technology for goaf fires is an urgent need for modern intelligent mines to achieve safe and efficient mining[11].

4.2 Development Status and Existing Problems of External Fire Prevention and Control Technology

(1) The current development status of external fire prevention and control technology. At present, the monitoring and warning of external fires in mines mainly adopt smoke sensing method, marker gas analysis method, odor detection method, and temperature measurement method; Among them, smoke sensing method, marker gas analysis method, and temperature measurement method are more practical and play a key role in the prevention and control of external fires in mines. However, due to the strong suddenness and wide impact of fires outside the mine, it is easy to cause major accidents; Due to the complexity of external fires in mines, intelligent monitoring and early warning technology lacks specificity and systematicity, resulting in delayed emergency response; After a disaster occurs, there is a lack of research and application on how to scientifically adjust the ventilation system in the disaster area to prevent the expansion of the fire range, guide personnel in the disaster area to avoid danger or evacuate safely, and provide safe and rapid disaster relief.

(2) Problems in external fire monitoring. There are five main problems in external fire prevention and control technology: ① single perception means, large blind spots, and high rates of missed and false alarms; ② The monitoring and warning indicators for external fire risks in mines are not clear; ③ Early hidden dangers of fire are difficult to identify, and emergency response to disasters lags behind; ④ The intelligence level of linkage control for external mine fires is low; ⑤ The utilization rate of data fusion is low, and the risk prediction model is missing.

4.3 Research Direction of Fire Prevention and Control Technology

At this stage, the distributed optical fiber temperature measurement system and safety monitoring system used in the mine only realize the online monitoring of gas indicators, the online analysis and prediction function is not perfect, and only have the alarm function of a single indicator exceeds the limit. When multiple indicators are coupled together, the index weight is not perfect, the cooperation degree of various fire monitoring and prediction indicators and the system is not high, and the information sharing is poor. Lack of comprehensive collection, processing and analysis of fire information, the system false alarm rate is high, it is difficult to accurately judge the ignition position in time.

In the future, the network transmission and communication system, integrated intelligent management and control platform, coal mine safety production big data mobile Internet platform, data center, dispatching command center, intelligent control center, safety monitoring center, production operation management center need to form a comprehensive integration of various heterogeneous systems. A complete coal spontaneous combustion monitoring and early warning processing system integrating fire monitoring, early warning, disaster relief plan automatic generation, fire control equipment, safety monitoring system, disaster relief plan system and personnel positioning system can be formed to realize online analysis and prediction of all kinds of mine fires, and reasonable automatic analysis of multiple indicators coupled together. Fire monitoring and warning system, safety monitoring system, personnel positioning system, dispatching command center, intelligent control center all kinds of system information sharing, and then achieve data, voice, video integrated monitoring, scheduling, protection, management, so that coal spontaneous combustion fire monitoring and warning more accurate, comprehensively improve the current situation of mine production. The mine fire intelligent monitoring, warning and control system is shown in Figure 2.

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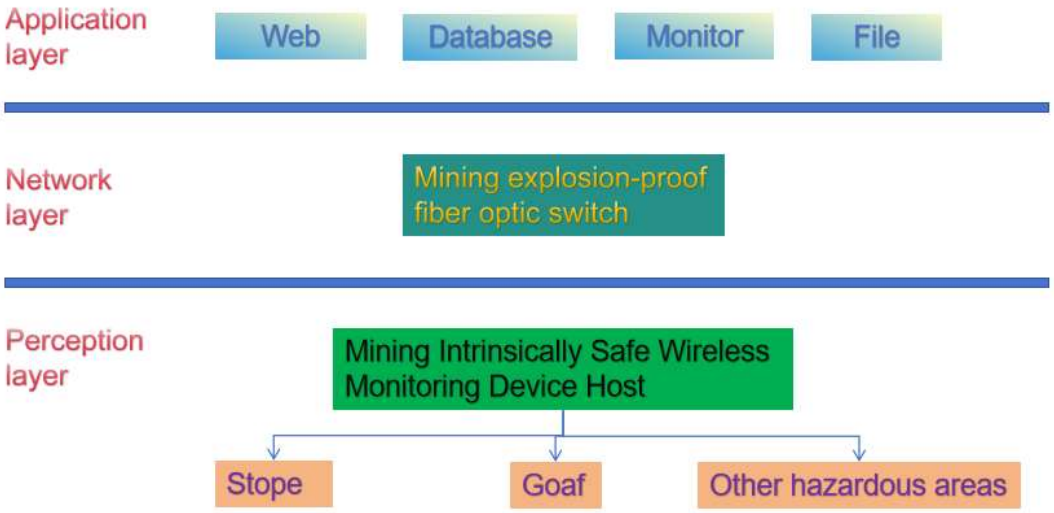

Figure 2. Intelligent Monitoring, Warning and Control System for Mine Fire

5. Intelligent Gas Prevention and Control

5.1 Current Situation and Existing Problems of Gas Monitoring System

At present, coal mines have established a relatively complete gas monitoring and control system, mainly focusing on environmental monitoring and production monitoring, combined with microcontroller, PLC, computer network, and other key technologies. However, in the actual production and application process, there are still problems such as equipment connection, information transmission, sensor accuracy, and mine management, which restrict the application and development of coal mine gas monitoring systems.

According to the survey, currently in the application of coal mine gas monitoring systems, equipment connection, information transmission, sensor accuracy, and mine management are the four main factors that affect the effectiveness of coal mine gas monitoring, and are also the main factors affecting system application. The four impact issues of the coal mine gas monitoring system are manifested as follows:

(1) Device connection transmission issue. Taking the Super Long Working Face of Tingnan Coal Mine as an example, the length of the tunnel is about 2500 meters, and it is generally necessary to monitor dust, gas, carbon monoxide, and the status of the air duct. Due to the large number of monitoring equipment and complex cable connection structures, as the power supply transmission distance increases, the voltage loss generally results in a maximum transmission distance of less than 2000 meters, resulting in a large amount of maintenance.

(2) The lack of communication process information in the intelligent ventilation system. This is because the mine gas monitoring system has been focused on designing various areas underground since its establishment, especially high-risk areas such as mining faces and return air flow. Although its reliability and independence are strong, it inevitably leads to poor compatibility between communication systems, which restricts the upgrading and effective communication of intelligent ventilation systems.

(3) At present, various sensors have shortcomings such as short service life, poor working stability, and sensitivity drift, which seriously restrict the detection of harmful gases underground. In addition, many sensors require regular calibration, which requires high technical proficiency from ventilation workers. If the sensors cannot be calibrated and maintained according to regulations, it will also affect the monitoring of mine gas.

(4) On site management issues. This is manifested in large-scale mines with high production and efficiency, which have a large underground range and multiple measurement points, requiring a large

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amount of manpower and material resources to be invested in installation and debugging. If the on-site personnel have average professional skills, it is easy to make the various equipment in the coal mine gas monitoring system unable to achieve the expected level or effect, resulting in inaccurate connections, configurations, and proofreading between internal components of the system, and unable to fully and accurately achieve the expected effect of intelligent monitoring of gas content.

5.2 Research Direction of Gas Prevention and Control Technology

In the field of mine gas detection, an intelligent gas inspection robot that combines mobile detection and fixed-point monitoring data can be developed to detect and analyze harmful gas data underground, achieving the goal of reducing personnel by machines. In terms of gas detection sensor communication transmission, wireless transmission can be achieved to solve long-distance power supply and communication transmission problems, and to solve practical production problems; Additionally, different types of sensors can be selected based on the actual situation of each coal mine. High gas mines and low gas mines, as well as those with impact ground pressure and no impact, have automatic alarm functions when abnormalities are found. Currently, intelligent gas inspection robots have been used to replace gas workers in hazardous area operation detection, and have been applied to various underground areas to improve mine safety and save manpower and resources. The selection of sensor types with suitable accuracy, safety, and reliability should be based on the objective environment of the coal mine in mines with ground pressure; At the same time, innovative research on sensor types should also be strengthened to continuously meet the increasingly refined and diversified product needs of coal mines. The development and research of system software can improve the scientificity and reliability of the coal mine gas monitoring system by optimizing the design algorithm of the system itself, improve the accuracy of gas sensor transmission data analysis, and provide more reliable and safe control instructions to ensure coal mine safety. At the same time, combining the management method of regularly testing system programs and signal transmission effects can timely simplify cumbersome program design and achieve program improvement, thereby providing a safe, concise, and efficient system operation mode.

After years of technological research, intelligent coal mines now have a gas inspection robot system, as shown in Figure 3. The on-site gas inspection robot is composed of a multi-functional detection module, a multimedia LED true color display module, a intercom broadcast module, a WiFi communication module, and an intrinsic safety power supply. It is transmitted to the cloud computing big data one image system through a ring network. The gas inspection robot system has functions such as all-day automatic gas inspection, on-site display, data record transmission, summary to the cloud brain of the gas inspection robot for analysis, automatic report generation, and automatic alarm when abnormalities are found. Currently, intelligent gas inspection robots have been used to replace gas workers in hazardous area operation detection, and have been applied to various underground areas, improving mine safety while saving manpower and resources.

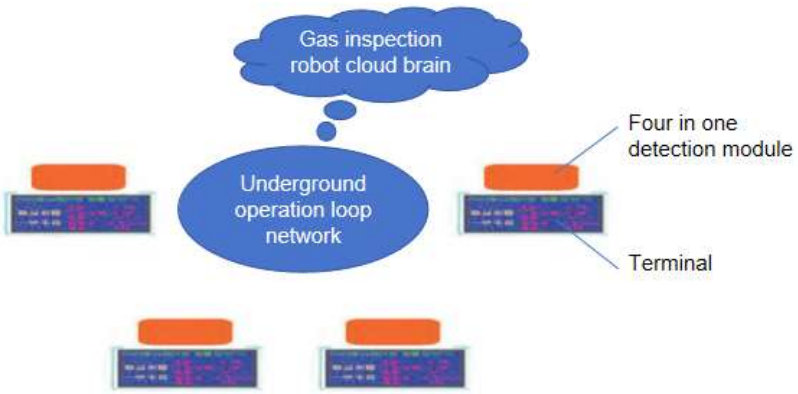

Figure 3. Coal mine gas inspection robot system

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6. Summary and Prospect

(1) The intelligent ventilation system for mines is divided into two parts: infrastructure construction and software platform construction. The infrastructure mainly includes precise wind measurement devices and precise wind control devices; The intelligent ventilation software platform includes four subsystems: intelligent monitoring, early warning diagnosis, wind network calculation and decision-making. The software platform is responsible for ventilation management analysis and decision-making. By creating a three-dimensional data model for mine ventilation, accurately adjusting the wind resistance model of the wind window, variable frequency fan air volume model, ventilation system warning model, and mine roadway air volume model, digital modeling management of intelligent mine ventilation can be achieved.

(2) At present, the main difficulty in intelligent prevention and control of mine dust still lies in dust prevention and control technology. The differences in different mine conditions lead to significant differences in the production and transportation laws of mine dust. Therefore, the focus should be shifted from single dust control to mine air purification. By conducting research on efficient prevention and control technologies and equipment for dust sources in major underground alleys, mining test working faces, and excavation areas, we aim to accelerate the construction of online air quality monitoring and intelligent warning platforms, build an intelligent dust pre control and monitoring system, create a new working environment for the mine, and ensure the safety of employees' lives.

(3) We should further strengthen the research on the basic theory of coal spontaneous combustion, deepen our understanding and understanding of the process of coal spontaneous combustion, optimize the accurate prediction methods of coal spontaneous combustion tendency and coal spontaneous combustion period, and provide a detailed theoretical basis for the intelligent coal spontaneous combustion fire monitoring and warning processing system. We should further improve the intelligent coal spontaneous combustion fire monitoring and early warning system, strive to tap into the potential of systematization, intelligence, and integration of mine fire warning technology and devices, improve the accuracy and reliability of coal spontaneous combustion prediction and prediction, and achieve a comprehensive system that integrates mine fire prediction and prediction, early warning, emergency response, intelligent firefighting, and disaster relief.

(4) The development and application of a gas inspection robot system, on the one hand, based on the basic concept of "machines replace humans and do better than humans", achieves the replacement of over 90% of manual detection. On the other hand, the gas inspection robot system adopts multi-parameter sensing technology, calibration free technology, wireless communication technology, cloud computing big data technology, etc., which also provides more diverse choices for the improvement of coal mine gas monitoring system, and has a positive impact on improving coal mine gas monitoring equipment and innovating the application of coal mine gas monitoring system technology.

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