Design and optimization of intelligent ventilation system in coal mine

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Abstract: With the continuous development of the coal industry, coal mine safety and environmental protection have gradually become the focus of important attention. The design and optimization of mine ventilation systems is a key factor in ensuring air quality and safety in the working area. In order to improve the application level of automation and intelligent equipment of mine ventilation system, under the existing conditions of mine, the design significance and goal of mine intelligent ventilation system are taken as the starting point, and the design and application effects are analyzed. By optimizing the layout of ventilation routes, increasing the number of sensors, building an intelligent ventilation system, optimizing the ventilation scheme in the main production scenarios such as coal face, driving face and opening up main roadway in the daily production process of the mine, realizing rapid wind regulation and wind counteraction when disasters occur, and using air flow short circuit to form protective measures, effectively avoiding the expansion of disasters and accidents. At the same time, remote automatic control of ventilation facilities and equipment is carried out to effectively improve the optimal utilization of air supply, avoid the phenomenon of insufficient air supply and waste of air volume, and improve the intelligent level of mine ventilation system.

1. Introduction

Coal mine is a dangerous working environment, one of the most important dangers is the poisonous gas and coal dust produced in the mine. Through reasonable design and optimization of mine ventilation system, the harm of toxic and harmful gases and coal dust can be effectively reduced or removed, and the physical and mental health and life safety of relevant personnel in coal mining enterprises can be guaranteed. Most of China's coal mines are underground mining, and the occurrence conditions of coal seams are complex. With the increase of mining depth, the requirements for ventilation safety are becoming more and more stringent, and the research and design of mine intelligent ventilation system has become an important guarantee for coal mine safety production [1-3]. With the construction of intelligent mines and the wide application of 5G technology, coal mines are constantly developing in the direction of automation and intelligence on the basis of improving the mechanization level of modern mines [4-7]. The premise of mine safety production is to have a reliable and stable ventilation system, including perfect ventilation design, ventilation mode, high-power fan and ventilation route. Compared with traditional ventilation methods, the current ventilation system mostly adopts artificial fixed-point wind measuring station detection, and adopts ventilation facilities (such as air doors, wind barriers, wind Bridges, etc.) to adjust air volume and transform wind paths. With the increase in the scale of mine mining and the growth of ventilation routes, relying on artificial wind measurement can no longer meet the needs of long-term and continuous wind measurement operations in special locations, especially in places with toxic and harmful gases, and personnel can not timely detect air volume and wind flow. Based on this, the construction of highly automated intelligent ventilation monitoring system has important practical significance.

Intelligent ventilation system is a new type of mine intelligent ventilation system with science and technology as the core, and is the focus of smart mine construction, catering to the concepts of energy conservation, emission reduction, green and efficient [8]. At the same time, intelligent ventilation is the key to disaster emergency wind control and an effective measure for disaster prevention and reduction. The design and construction of intelligent mine ventilation system can guarantee the stability and safety of mine ventilation, and effectively make up for the shortcomings of manual management, real-time monitoring and perception of mine ventilation, intelligent fault diagnosis and early warning of disasters, active control and response to risks, improve the intelligent, information and automation level of mine ventilation, and meet the needs of intelligent mines.

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2. Analysis of working principle and key elements of ventilation system in coal mine

Coal mine ventilation system is one of the key systems designed to ensure the air quality and safety in the mine. Its working principle is through the continuous operation of the main fan of the surface air shaft to form a circulation of air, the ground fresh air is constantly introduced into the mine to increase the oxygen concentration, to meet the needs of personnel for oxygen; Dilution and removal of toxic and harmful gases and diluted dust concentration control to ensure safe production; Maintain suitable climate conditions in mine and create good working environment. Mine ventilation can be divided into two types: natural ventilation and mechanical ventilation. (1) Natural ventilation: The ventilation method that uses the ventilation power generated by natural air pressure to cause the air to flow in the underground roadway is called natural ventilation. Natural wind pressure is generally relatively small and unstable, so the "coal mine safety regulations" stipulate that every mine must use mechanical ventilation. (2) Mechanical ventilation: The ventilation method that uses the ventilation power generated by the operation of the main fan to cause the air to flow in the underground roadway is called mechanical ventilation. In mines with mechanical ventilation, natural wind pressure also exists all the time, and affects the ventilation work of mines in various periods. Full attention should be paid to the ventilation management work, especially in high-gas mines.

3. Overall scheme of mine intelligent ventilation system

3.1. System composition.

Mine intelligent ventilation system is composed of underground monitoring equipment and ground control center. The architecture of mine intelligent ventilation system is shown in Figure 1. Underground monitoring equipment mainly includes sensors, cameras and industrial Ethernet ring network [9]. Specifically, it includes: 1) Gas sensor, damper switch sensor, wind speed sensor, wind speed and direction sensor, fan on/off sensor and other ventilation-related sensors are installed in the mine. The sensor monitors the underground ventilation environment in real time and collects data, which is collected by the communication sub-station to the underground switch; 2) The AI intelligent intrinsic safety camera is installed in the mine, and the corresponding intrinsic safety video analysis edge computing box is equipped. The camera monitors the ventilation facilities and equipment such as the damper, wind window and fan in the mine in real time, and collects video image data. The artificial intelligence recognition algorithm built into the video analysis edge computing box can understand and analyze video data in real time at the edge end; 3) The sensor data gathered to the switch and the video data identified by the edge computing box are transmitted to the ground control center through the underground industrial Ethernet ring network.

The ground control center is responsible for data analysis and storage, management and display of application systems. The application server is used to deploy the mine intelligent ventilation application system, and realize linkage control with the mine safety monitoring system, the underground personnel positioning system, and the broadcasting system. The data server stores large ventilation monitoring data collected by various sensors; The AI video analysis server deploies artificial intelligence algorithms to identify and analyze the video image content of the mine, and find the abnormal behavior of personnel and the abnormal state of facilities and equipment; The large screen in the dispatching room is used to display information such as numbers, graphics, and videos.

3.2. Research content.

The intelligent mine ventilation system is driven by dynamic monitoring big data, and a 3D ventilation simulation and hidden danger intelligent identification platform is established to realize real-time dynamic analysis of mine ventilation data, 3D visual display, and effective safety early warning and auxiliary decision-making. The main research contents include: 1) Dynamic monitoring large database. Integrate gas, CO, wind speed, wind direction, fan negative pressure, damper, duct, main ventilator, local ventilator and other sensor data to establish a large database of ventilation system. 2) 3D ventilation simulation and hidden danger intelligent analysis platform. The sensor monitoring data, camera monitoring video images, artificial intelligence image recognition algorithm, three-dimensional visualization ventilation simulation, ventilation report design, early warning alarm and auxiliary decision, BI large screen display, historical data query and other modules are integrated on a software platform to form a closed ventilation management system. The functional structure of mine intelligent ventilation system is shown in Figure 1.

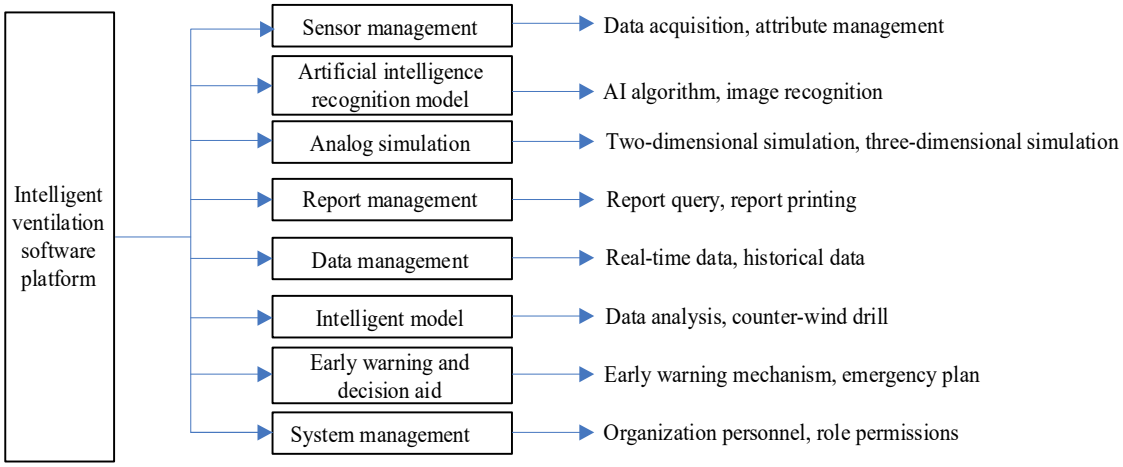


Fig.1 Functional structure of mine intelligent ventilation System

Through the construction of the system, the formation of an integrated comprehensive management platform, improve and improve the informatization level of coal mine ventilation management, timely grasp the operating status of the ventilation system, early detection of safety hazards, do a good job in prevention, and provide auxiliary decision-making basis for the dispatch and command of the mine ventilation system.

4. Function analysis of intelligent ventilation system

4.1. Intelligent optimized wind speed acquisition technology

Due to the objective phenomena such as the different size of the wind cross section and the different wind resistance caused by the roughness of the roadway surface at various points in the mine, precision errors often occur in wind speed monitoring [10-11]. Therefore, by changing the way of distribution, the step grid method is adopted to achieve dense distribution, the original section is cut and subdivided, and then the distribution law of air and wind speed in the section is analyzed, so as to obtain the actual position of relatively accurate average wind speed in the section. After optimization, the wind speed sensor is installed at a fixed point to improve the accuracy of wind speed acquisition. The distribution law of wind speed analyzed by ladder grid method is shown in Figure 2, and the measured wind speed distribution in rectangular section is shown in Figure 3.

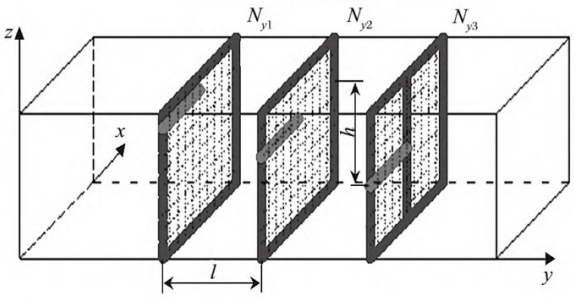


Fig. 2 Analyzing wind speed distribution by using a stepwise grid method

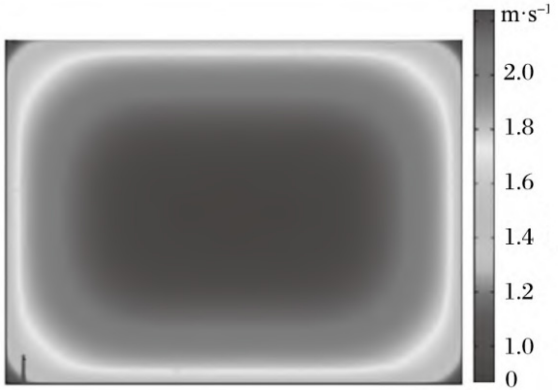
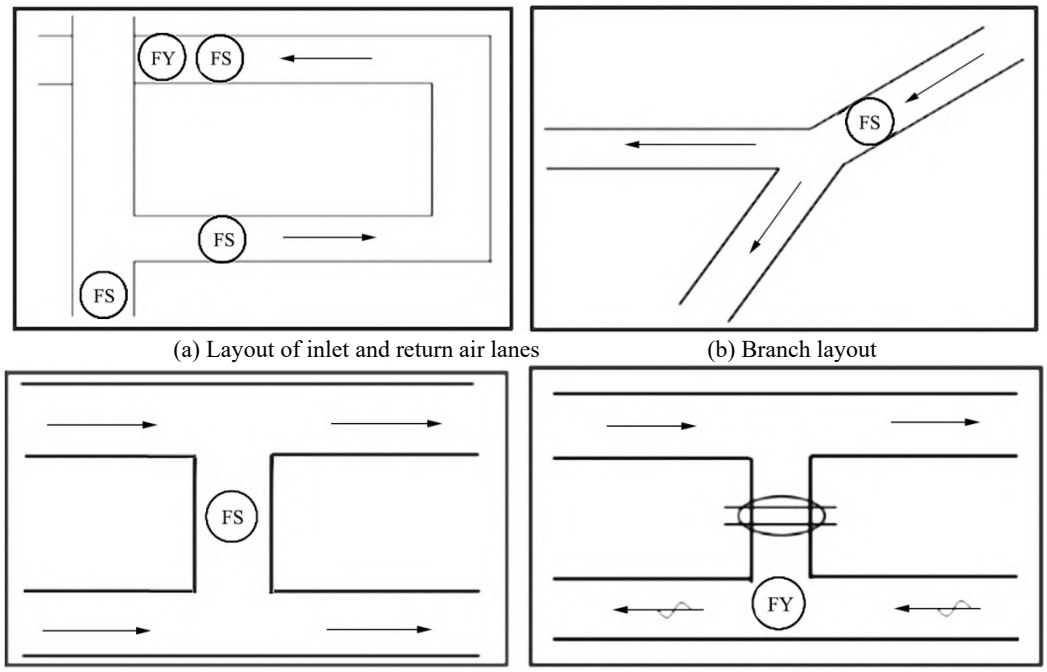


Fig. 3 Distribution of measured wind speed in rectangular section

4.2. Sensor layout optimization

In order to monitor the normal and stable operation of the mine ventilation system, it is necessary to install wind speed and wind pressure sensors on each mining face, and adhere to the principle of installing less equipment and wide monitoring range, so as to meet the purpose of multi-purpose equipment to the maximum extent [12]. Through the analysis of air flow route, ventilation mode, section shape and area, and wind supply purpose, the wind pressure sensor (FY) and wind speed sensor (FS) are arranged according to the route shown in Figure 4 to give full play to the maximum function of their monitoring points.



(a) Layout of inlet and return air lanes (b) Branch layout

(c) Corner roadway layout (d) Layout of return air lane

Fig. 4 Sensor layout of different ventilation routes

It is necessary to install sensors to monitor the different operation contents and ventilation methods at different points in the underground, especially at the detour yard, branch roadway and liaison roadway. In addition, the air flow instability is easy to occur on the return air flow side of the coal face with Y - and U-shaped ventilation modes. Before and after the air door for adjusting the air window is set in the main transportation roadway and the driving face, the air door is often opened in transportation, which is easy to cause a large influence of wind disturbance, resulting in local wind speed and wind pressure changes. These locations need to be monitored by sensors.

4.3. Intelligent decision and control function

Before building the intelligent ventilation monitoring system, the ventilation parameters and harmful gases of all mine laneway are measured and collected, and the upper warning value of safety index can be set in advance in the warning system according to the classification of monitoring content and functional needs. When the monitoring data exceeds the warning index, the program operation is carried out according to the automatic control instructions, and intelligent operations such as automatic air reverse, opening and closing the damper, adjusting and adjusting the Angle of the wind sash blade, fire information monitoring and alarm are issued at different levels, so as to realize automatic and unmanned supervision of dangerous work locations.

5. Software system design

5.1. System workflow

The stable and safe operation of the system is inseparable from the close cooperation between the underground and the surface equipment. The sub-station data processing of each underground safety monitoring system is particularly critical. After the data processing process of the sub-station starts, the sub-station starts to initialize the sensor of each node by relying on the CAN bus, and monitors the data, and judges and analyzes the information fed back by the ground monitoring system. If the system does not receive the data of the industrial Ethernet network, it needs to judge and analyze the CAN bus sensor data. Moreover, based on the actual states of methane sensor, wind speed sensor and wind pressure sensor, the operating state of the fan is judged and analyzed [13]. When it is determined that there is an abnormal operation of the fan, it is necessary to effectively control the equipment such as frequency converter and relay, and promptly report and dispose of the abnormal state; On the contrary, when the fan is in the normal state, the data can be transmitted by Ethernet. If the system receives Ethernet data during operation, it should be disposed of based on instructions and determine its status so that the system can interact. The data processing flow of the system sub-station is shown in Figure 5.

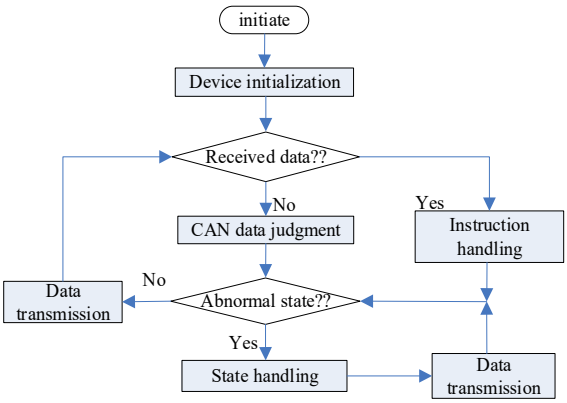


Fig. 5 Data processing flow chart of system sub-stations

5.2. System Display interface Design

The display interface of the intelligent ventilation system software in coal mine can comprehensively monitor and visually present the operating status of each node of the entire ventilation system, and remote control of related equipment in the system can be carried out with the help of the upper computer software. The display interface of the intelligent ventilation system is shown in Figure 6.

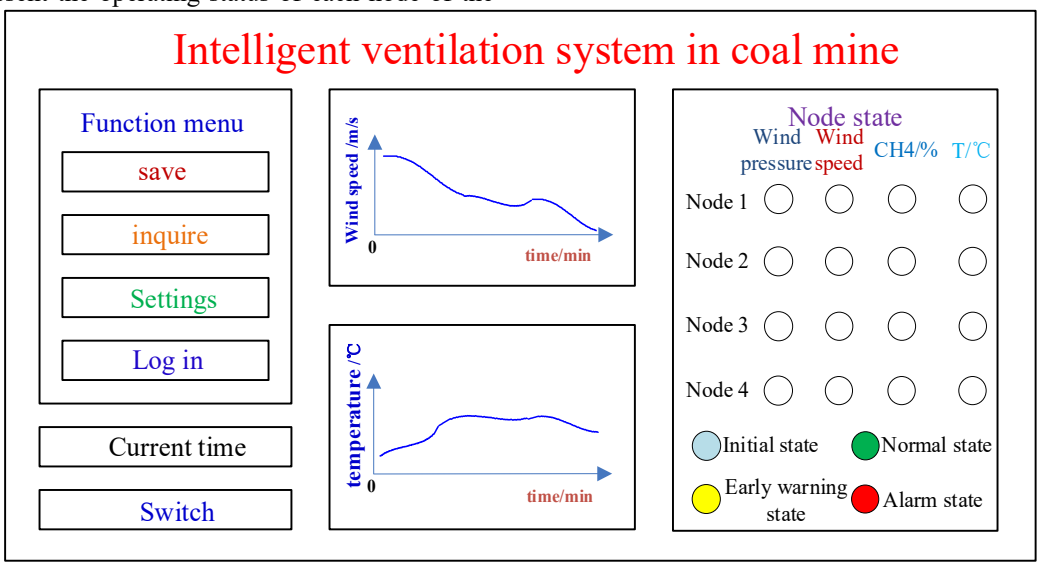


Fig. 6 Display interface design of intelligent ventilation system in coal mine

The whole interface contains three important departments: function menu, data curve and node status. The function menu can save and query node logo, time and other data. At the same time, it also has transmission parameter setting function and background system maintenance account login function, etc., which can fully present the status of time and device function partition. The data curve fully reflects the changes of temperature, humidity and wind speed at specific time nodes; According to the node status, you can understand the status of each node, such as the initial state, normal state and alarm state, etc. The setting function menu button can scientifically set the change of each state and the category of closed value, so as to coordinate with the change of node parameters, dynamically control the key fan parameters such as wind pressure, CH4, wind speed and temperature, and provide real-time and effective monitoring. For the monitoring system in the ground control room, the RGB high-definition large-screen electronic display system is installed, and the backup UPS power supply is continuous and stable, and the field data is continuously presented.

5.3. System Software Functions

5.3.1 Environmental monitoring function.

The system has related functions such as safety monitoring system and gas sensing equipment, which can dynamically and real-time monitor various harmful gases, connect the volume fraction with the intelligent ventilation platform, accurately analyze and control the underground environment, timely warn the situation of exceeding the standard, and propose wind control strategies for coping with disasters.

5.3.2 Intelligent analysis function.

Scientific methods such as neural network, machine learning and big data analysis can be selected to compare

the equipment operation monitoring data, environmental monitoring data and ventilation perception data with the early warning threshold determined by the platform. If there is insufficient air volume, short circuit and inverter of air flow, it should be the first time to warn and make intelligent decisions quickly.

5.3.3 Intelligent control function.

The function can adjust and control the damper, window and other conditions intelligently with one key, and generate surveillance video data. At the same time, the operation of the ventilation equipment can be controlled remotely, and the switching quantity can be simulated to provide a basis for the ground command.

5.3.4 Intelligent decision-making function.

Real-time monitoring of ventilation network, and dynamic calculation of its air volume, the use of machine learning, artificial intelligence and other methods, simulation and decision-making of underground air flow, early warning of ventilation hazards and abnormal changes, rapid research and judgment of disaster, the development of emergency control measures, joint ventilation emergency, regulation and other equipment, the construction of a plan library, and put forward suggestions. At the same time, the optimal air flow control plan is determined intelligently and efficiently according to the conditions of the coal face, the air flow is adjusted by braking, and the adjustment results and suggestions are uploaded to the intelligent ventilation platform.

5.3.5 Mobile APP function.

Install and use mobile APP to provide timely feedback and comprehensive display of equipment operation status, intelligent control results, early warning and alarm information.

5.3.6 Camera AI learning control function.

According to the situation of pedestrians, vehicles and damper switches, accurate video recognition can be implemented to understand the actual situation of the scene and timely find the abnormal situation of the vehicle top impact damper and damper device, and carry out targeted early warning processing of these abnormal situations. At the same time, it also has the function of automatic locking of intelligent control damper, which can timely understand the trend and situation of underground disasters.

6. Field test and application effect

After the design of the intelligent ventilation system in the coal mine, the hardware template can be installed according to the design scheme through field test and application, and the related program of the control system can be arranged in the coal mine. The monitoring interface can fully display the air volume, wind speed and temperature of the underground ventilation system, and automatically control it, so as to intelligently supervise the entire coal mine ventilation system. Table 1 shows the field measurements of this ventilation system.

Table 1. Historical data of online fault monitoring of intelligent ventilation system

Serial number	Fault characteristics	Fault identification	Date of failure
1	The retarder vibrates badly	Gear lubrication is poor	2023.5.21
2	Local high temperature of machine	The bearings are badly worn	2023.5.24
3	High temperature of blade root	Fatigue damage occurred to the structure	2023.5.26
4	Rotor position high temperature	Bearing failure	2023.6.1
5	Motor vibration	Bearings are poorly lubricated	2023.6.12

The analysis of the above data can accurately judge the fault of the ventilation system and warn the accident in advance. The response time of intelligent fault identification of the intelligent ventilation system is only 0.63S, and the misjudgment rate does not exceed 0.25%, which saves the on-site manpower input, and the efficiency of the ventilation system has also been significantly improved, which effectively and timely prevents the launch of ventilation safety accidents in coal mines, enhances the safety management ability, and is conducive to the sustainable and stable development of coal mines.

7. Conclusion

Through the evaluation of the current situation of the ventilation system in the mine, it is pointed out that there are drawbacks such as low efficiency, short duration, easy to produce inspection blind area, and possible missing detection, which reflects the urgent need for upgrading and reforming the ventilation system.

Intelligent ventilation system can not only strengthen the intelligent degree of mine, but also effectively guarantee the safety of production and improve the level of ventilation construction. Mine leaders should pay attention to the optimization of ventilation system design, based on production, actively introduce the latest technology, constantly upgrade and optimize the mine ventilation system, improve the intelligence level, realize remote and real-time detection and regulation of the underground ventilation system operating status, more intuitive analysis can reduce energy consumption, ensure the normal and stable operation of the ventilation system, and contribute to the safety and efficient operation of mine ventilation. It can effectively avoid the occurrence of fire and other accidents, and lay a foundation for realizing high yield and high efficiency and essential

safety of mine. For coal enterprises to build green environmental protection mine, to achieve the balance between sustainable economic development and environmental protection, has a broad market prospect.

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About the Author

Wan Yong (1980-), male, bachelor degree, senior engineer, has obtained 4 national authorized invention patents, mainly engaged in digital mining, monitoring and monitoring, intelligent instruments and other aspects of research and technology promotion, E-mail:280210058@qq.com.

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