Hindawi
Mobile Information Systems
Volume 2022, Article ID 9013862, 9 pages
https://doi.org/10.1155/2022/9013862

Research Article

Research on Synchronized Data Acquisition System Based on Distributed Clock

Yuyu Hao, Shugang Li, Tianjun Zhang, and Zongyong Wei

College of Safety Science and Engineering, Xi'an University of Science and Technology, Xi'an, Shaanxi 710000, China

Correspondence should be addressed to Yuyu Hao; haoyy@xust.edu.cn

Received 12 May 2022; Accepted 16 August 2022; Published 22 September 2022

Academic Editor: Muhammad Muzammal

Copyright © 2022 Yuyu Hao et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

The clock synchronization of mine distributed acquisition system is the key to its normal operation, and the realization of a unified time benchmark is the premise of subsequent data processing. To capture a more accurate gas migration process, in the physical similarity simulation experiment of coal and natural gas, a synchronous data acquisition system based on SQL database and distributed clock is developed to obtain synchronous real-time data. SQL database is used to establish a data collection center to solve the data exchange problem between the three units of storage, collection, and display in the system. The three units are connected in parallel, which simplifies the data flow structure in the system and improves the communication efficiency. In addition, the security and reliability of data storage are greatly improved. Based on the distributed clock, the communication structure of the data acquisition unit is constructed. In a distributed way, the data are aggregated according to the object and finally uploaded to the data acquisition center through TCP/IP (Transmission Control Protocol/Internet Protocol). It meets the requirements of synchronous communication between acquisition boards and provides a reliable data acquisition scheme for the physical simulation system of simultaneous exploitation of coal and natural gas. The physical similarity simulation experiment takes a mine in Shanxi Province as the simulation object. On the basis of this system, the physical similarity simulation experiments of gas emission under different mining conditions are carried out. In this process, the distribution maps of mining stress changes in overlying strata and gas concentration changes in different mining areas are obtained. The results of data acquisition are verified by numerical simulation. The results show that the system can effectively maintain the data acquisition of various areas in the mine.

1. Introduction

The current situation of information construction of coal enterprises in China is that state-owned coal mines have widely used information technology in production, safety, management, market, and other fields. With the development of computer technology, network technology, database technology, automation technology, sensor technology, digital video technology, and modern management technology, coal mine informatization is developing in the direction of information expansion, high integration, comprehensive application, automatic control, prediction, and intelligent decision making. However, the informatization development of the coal industry is currently in an extremely unbalanced state. The informatization construction of key state-owned enterprises is in good condition. Generally, the informatization construction of local small coal mines is generally poor or not. As far as the whole industry is concerned, it is still at a relatively backward level compared with other domestic industries. However, in the development course of China's national economy, there is still a long-term strong demand for coal resources. As a large coal resource country, China takes coal as the main energy source, which has sped up coal mining to deeper areas at a depth of 10 m to 25 m per year [1, 2]. With the deepening of the coal seam, the over-standard gas density in the coal face and the upper corner occurs frequently. In addition, gas explosion or gas outburst, or the like, is prone to happen, which brings hidden danger to the mine production [3–7]. For the study of gas accidents and other disaster accidents, it is because of the high reliability, intuitiveness, and repetitiveness that large-scale 3D physical similarity simulation experiments are used as one of the research methods gradually [8, 9]. By establishing a geological simulation platform similar to the actual environment, the coal mining methods under different advancing degree, air volume, and gas emission rate are simulated. Consequently, the gas migration data can be obtained to commence research on gas migration mechanism. To this end, a few scholars have made great contributions. Cao et al. [10, 11] simulated the aggregation, excitation, development, and termination of coal and gas outburst owing to the construction of the large-scale 3D physical similarity simulation experiment platform. Hu Shengyong, et al. [12–15] made multi-component gas enrichment test device to simulate the migration of gas with different concentrations in the mining district. Yin et al. [16, 17] used a self-developed physical simulation test system to probe into the dynamic evolutionary rule of parameters, including the amount of coal flushed out during hydraulic punching, the hole pattern after punching, the gas pressure, and flow rate in gas extraction. Presiding over the development of a large 3D physical simulation testbed of coal and gas co-mining, Li et al. [18] made a thorough inquiry in the distribution of mining-induced stress and damage law of overlying strata during the mining process and conducted relevant research on gas migration mechanism.

It can be seen that large-scale 3D physical similarity simulation experiments have been conducted widely, but many sensors need to be arranged in the process of such kind of large-scale experiments. Therefore, how to effectively obtain the effective data of each sensor in real time has become one of the difficulties in the platform construction. There are more than 300 measurement and monitoring points and more than 100 control points in 3D physical simulation experimental system of coal and gas co-mining independently designed by the authors. Meanwhile, there are high working environmental requirements for the existing high-precision real-time synchronous acquisition board which is expensive. That is, high costs of R&D and maintenance are needed. Hence, in the construction of such a large physical similarity simulation experimental system, it becomes an issue of how to reduce the design cost and realize the synchronous detection and control of over 400 points. Given all this, the authors designed a synchronous data acquisition and control system on the basis of distributed clock and SQL database. The system can efficiently acquire the parameter signals of each sensor in the physical similarity simulation experiment platform so as to realize the synchronous acquisition of more than 300 monitoring points and the control output of over 100 channels.

2. Systematic Platform Architecture

This system is mainly applied in 3D physical simulation experimental system of coal and gas co-mining to monitor and control various parameters in the experiment al system, so as to study the distribution of mine pressure in typical coal seam environment, the storage and transportation of relief-pressure gas, and the selection of gas extraction parameters under different conditions. The system is equipped with many acquisition and control units, containing helium sensor, stress sensor, intelligent flowmeter, or the like. Besides, monitoring and control units are also designed, including gas extraction, mine ventilation, and gas emission measurement data. With the implementation of the monitoring and control of all data in the experiment system, the test data of various parameters under different simulation conditions can be also acquired. The specific composition is shown in Figure 1.

3. Communication System Architecture

During the systematic experiment, synchronous acquisition and display of system parameters such as gas extraction, mining-induced stress change, and gas extraction is required. Meanwhile, it is necessary to regulate and monitor each key parameter of gas emission simulation control system, with more than 100 roads in total control points and 300 monitoring points. For this purpose, the system is based on the SQL database to set up the acquisition data center and divided into three units including display, storage, and acquisition. The communication among individual units is implemented through the network. The system structure is shown in Figure 2, and the upper computer software interface is shown in Figure 3.

The acquisition data center in this system is constructed by the SQL database, and its data could be recorded and utilized by collecting units and displaying main programs. Each submodules' summarized data could be acquired through network communication, establishing multiple storage blocks based on its data characteristics. Each block establishes an index sprout in accordance with its parameter category, making progress in searching and recording data.

3.1. Data Summary Module Design. Communication between the acquisition data center and the acquisition unit adopts the TCP/IP network communication protocol to achieve efficient and stable transmission of data. Each data summary module has concluded the data acquisition work conditions of each function, reducing the pressure of synchronous communication between the upper computer and a large number of acquisition boards. In order to ensure the synchronous acquisition of the data, the communication mode of distributed clock is used between the various summary modules and the acquisition board. Add sampling time information on conventional data information to indicate the data sampling time of each group. During the data summary, the host machine queries the sample data time information on its internal dynamic storage unit by issuing the board, and the corresponding sample data are fed back to the data summary module. Hence, synchronization of each acquisition board sample data is required to ensure that each acquisition board is consistent with the time between subsystems. Modern distributed data acquisition systems generally add GPS clock module to realize time synchronization. But it is too expensive to equip every base station with GPS module. In this paper, the current loop is used to transmit the synchronization signal, so as to achieve highly accurate synchronization at a low cost. The GPS clock receiving module is added to the master station, and the starting command and second pulse calibration signal are sent to the base station through the current loop circuit with transconductance amplifier as the core.

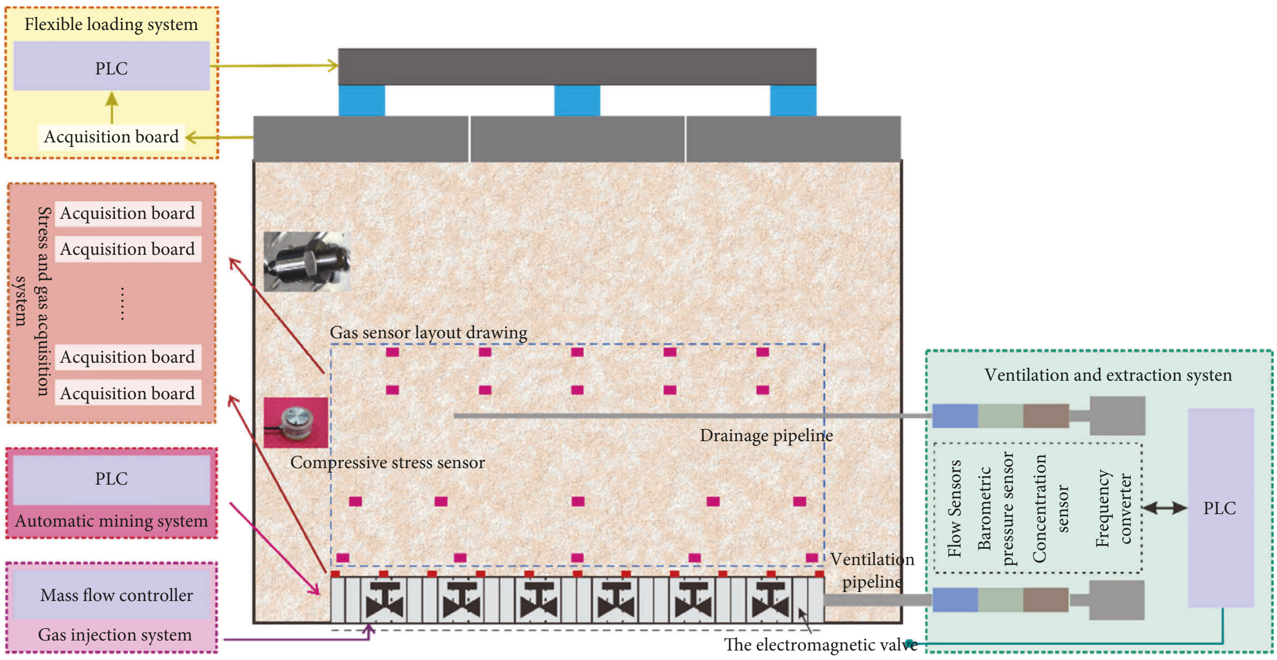


Figure 1: Structure diagram of coal and gas co-mining experimental system.

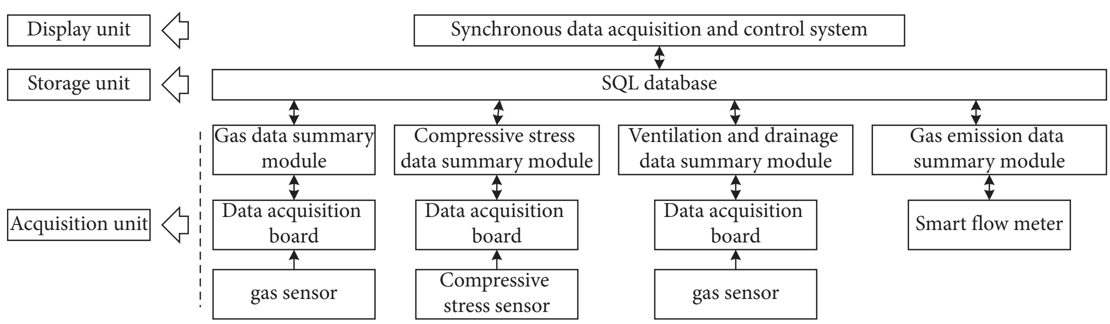


Figure 2: Structure diagram of synchronous data acquisition and control system.

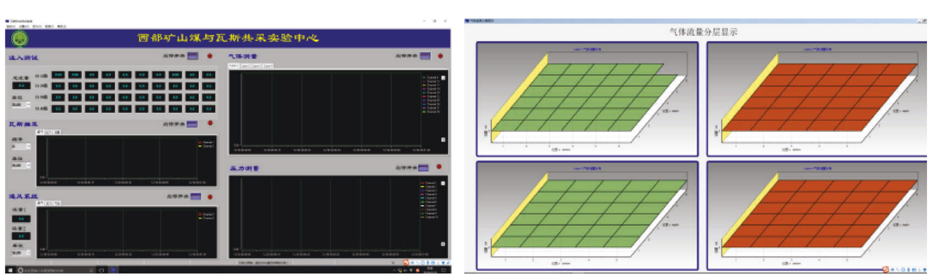


Figure 3: Upper computer interface of synchronous data acquisition and control system.

Before acquiring data, the data summary module will perform a table process between each acquisition board. The summary module issues time information to each of the acquisition boards through the broadcast communication method, and each acquisition board obtains time information to correct it. By reading the high and low levels of the initialization state signal line on each acquisition board, the initialization state of the acquisition board is determined. After the initialization of all boards is completed, enter the data summary mode and send the request data with time and machine number information to each acquisition board according to the set frequency, and the acquisition board returns the sampling data at the required time point according to the machine number in the request data. The communication structure is shown in Figure 4.

For the sake of the synchronization of data of each channel on the acquisition board, the acquisition board uses parallel interface to communicate with AD chip on each channel, so as to synchronously acquire the current sampling data. The data collected by clock chip are marked with time point and finally stored in the internal data storage unit, waiting for the summary module to extract its data.

3.2. Design of Data Acquisition Board. The acquisition board adopts 8-channel high-precision data collection. synchronous sampling design, and the control core uses STM32 Series MCU. For the mining-induced stress sensor mV sampling model and long-distance transmission to avoid signal interference and achieve sampling accuracy in the process of transmission, a second-order active filter circuit is designed in the front end of signal input. The input signal is filtered and amplified by the circuit. At the same time, 24 bit sigma delta single-channel ADC chip is used for data collection sampling to obtain high-precision and effective measurement data within the range of −10 mV~10 mV. Also, the effective acquisition of experimental data such as gas displacement and mine pressure distribution is realized. In order to ensure the synchronous acquisition of 8-channel data collection sampling chip data, the control core and 8-channel data collection conversion chip are connected by parallel port, so that they can synchronously obtain the effective data of 8-channel sensors. For the purpose of ensuring the accurate acquisition of the time tag on the board, the clock chip is designed to time the system. During the acquisition process, the control core can obtain the current time in real time through the clock chip and add it to the sampling data as index information.

According to the two sets of requirements of the system for the table and data acquisition, when receiving the request of the upper computer for the table, the lower computer will initialize its internal clock according to the issuing time and then control the setting of its status signal line. When the data collection module detects that all the acquisition boards are initialized, the acquisition command is issued. The acquisition board will synchronously acquire 8 channels of data collection acquisition data through parallel port communication. According to the design requirements, the board is designed with 2 seconds of data cache space. After receiving the time information of the data summary module, index the data cache space and feed it back to the data summary module. The communication object between the acquisition boards is determined by the machine number to avoid the bus collision in the process of multi-computer communication. Acquisition board structure diagram is shown in Figure 5.

4. Simulation Experiment

In this three-dimensional physical simulation experiment, the working face of a coal mine in Shanxi Province is selected as the prototype. On the basis of the principle of physical similarity simulation, the working face is arranged in accordance with the strike of coal mine. According to the parameters of the experimental platform, the surface length is 198 meters and the strike is 2025 meters. According to the geological state of the coal mine, the layered characteristics of its internal materials are arranged. At the same time, based on the coal seam dip angle and other parameters, the physical similarity simulation scheme is set according to the similarity ratio of 1 : 100. The full-seam mining method is adopted, and the roof is managed by the full caving method. The signal is connected to the large line filter through the detector, which is composed of a differential mode filter cascaded with a common mode filter to filter out the interference introduced by the signal in the transmission process. The fully differential audio amplifier OPA1632 constitutes the pre-drive circuit of the analog-to-digital converter ADS1282, and the common mode voltage is controlled by an external voltage stabilizing source through the VOCM pin, which cooperates with the sampling of ADS1282. By adjusting the feedback resistance of ADC drive circuit and the built-in program-controlled amplifier of ADS1282, the input can be adjusted the amplitude of the signal. The input clock frequency of ADS1282 is 4.096 MHz, which realizes command and data communication with MCU through SPI bus. MCU controls synchronization (sync), reset (/reset), and low power mode selection (/pwdn) of ADS1282. ADS1282 triggers an external interrupt through drdy pin to inform MCU to read the data just collected.

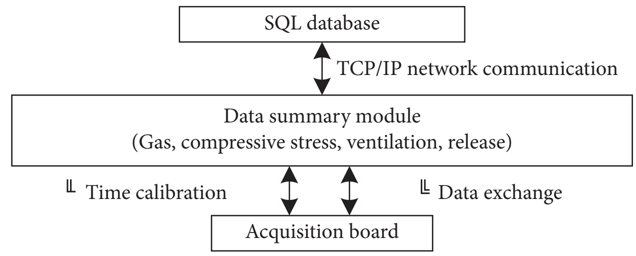


Figure 4: Communication structure.

Depending on the actual mining test requirements, in the process of building the model, there are 100 stress sensors and 72 helium sensors inside the model to monitor the overburden stress changes and gas migration data in the mining process. On this basis, the gas emission simulation system, simulation mining system, gas ventilation system, and other modules are designed with corresponding flow, concentration, and stress sensors according to their monitoring and control parameters, so as to complete the control and monitoring of more than 200 physical parameters in the process of coal mining. In this way, the simulation of gas mining process, mining speed, gas emission, and ventilation conditions can be realized. Figure 6 shows the layout of platform sensor and acquisition board.

The software design of this paper is divided into lower computer program design and upper computer program design. The program design of the lower computer mainly includes the program design of the main control box and the base station. The program design of upper computer is mainly the design of PC terminal program. The main control box is the core of the command channel of the distributed

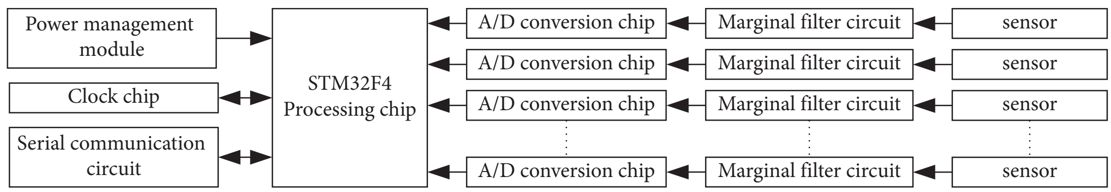
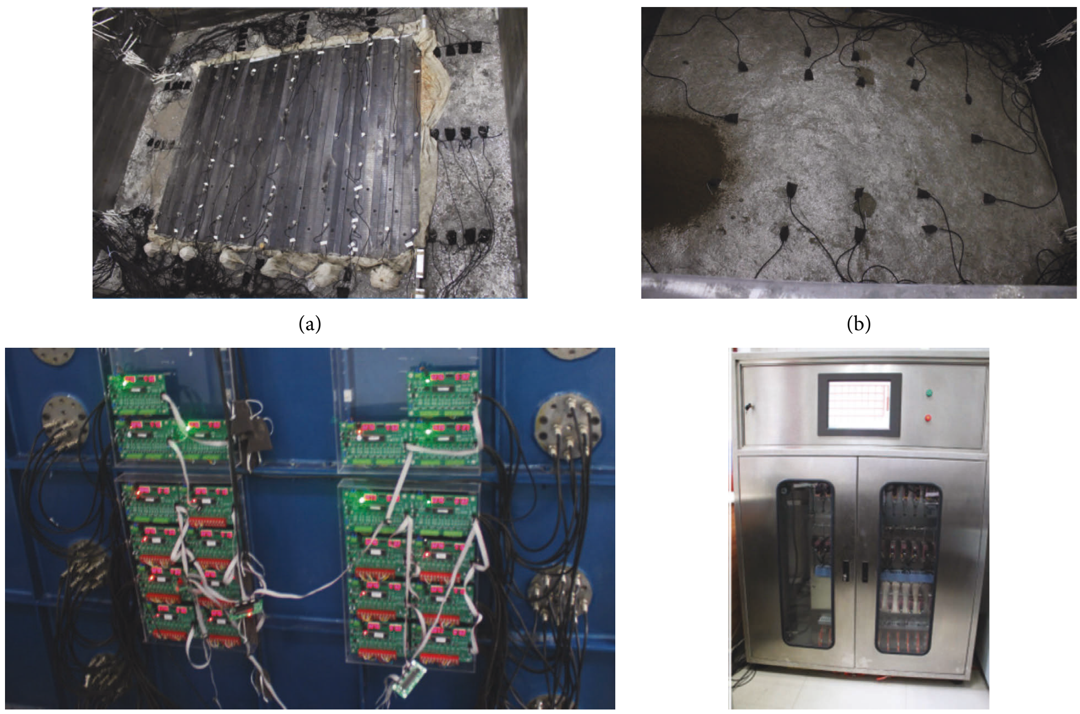


Figure 5: Structure diagram of acquisition board.



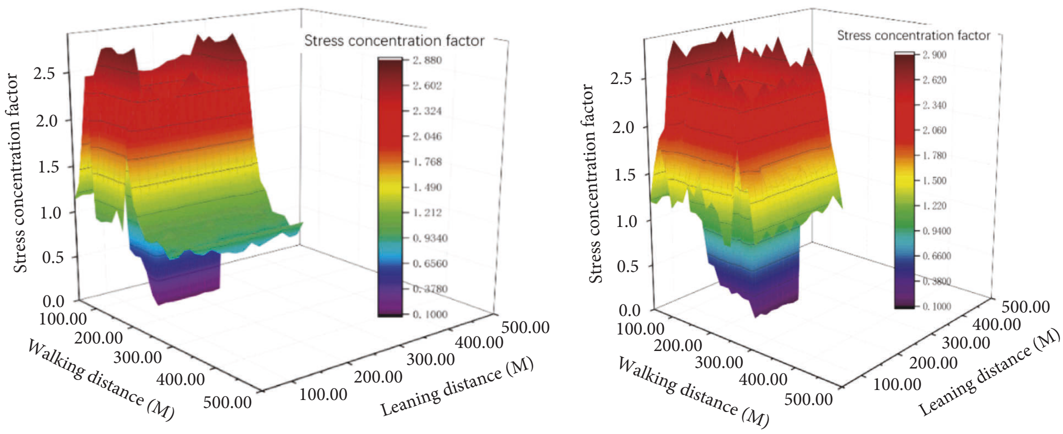
(a) (b) (c) (d)

Figure 6: Layout of sensor and acquisition board of experimental platform. (a) Stress sensor layout. (b) Partial gas sensor layout. (c) Stress and gas acquisition board layout. (d) Gas emission system.

data acquisition system. It receives the start command and configuration information sent by the upper computer through the USB to serial port circuit and then sends it to each base station through the current loop. After the acquisition starts, the GPS second pulse calibration signal is sent to each base station every second. The tasks of the base station master controller STM32F207 in the base station system are as follows. (1) Receive the acquisition start command of the master control box (received and analyzed by the synchronization module, including the configuration information of sampling rate and duration). (2) Initialize ADS1282 and configure various parameters. After starting to collect data, receive the external interrupt triggered by ADS1282, read the data, and store it in the relevant buffer. (3) Initialize two pieces of W5300, one of which is set as a server to receive the data uploaded by the subsequent base station. The other is set as the client, which connects to W5300 of the previous base station and uploads all data. In TCP mode, the number of effective bytes of each packet of W5300 data can reach 1460 B at most. If the data are collected and sent once every time, the efficiency of network communication will be seriously reduced, and it is not convenient for the data management of the master station. In this paper, the size of packet data is 1206 bytes, of which 1200 bytes are valid sample data (sensor measurement data), plus 6 bytes packet header identification information, which is used to mark the base station and packet number. Each base station sets up a corresponding buffer, and the sampling data of this station and the received sampling data of subsequent base stations are temporarily stored in the buffer. The MCU will query the storage status of each buffer in turn after reading the ADS1282 collection results each time. When it is found that there is a whole packet of data in the buffer, the TX of W5300 responsible for sending data is sent using the ADS1282 external interrupt interval. FIFO writes data and finally sends it to the previous base station.

5. Experimental Result

5.1. Vertical Stress Distribution of Mining Overburden. In the process of coal mining, the goaf will collapse, separate from the stratum, and bend and subside with the mining. This results in the change of the stress in the stope, and the original stress balance state in the rock stratum is broken.



(a) (b)

FIGURE 7: Stress distribution map. (a) Stress distribution map under 100 m mining distance. (b) Stress distribution map under 200 m mining distance.

The vertical stress concentration area and pressure relief area appear in the roof in front of part of the coal wall, which eventually leads to cracks in the rock. In this experiment, combined with the actual mining situation of coal mine, the real-time simulation of mining speed, ventilation parameters, gas emission, and other conditions was carried out by using each system. In this way, the physical simulation environment similar to coal mining is obtained, and the gas stress distribution map under different mining conditions is obtained by the stress sensor buried in it, and the change of overlying strata stress field with mining is intuitively observed. The stress distribution diagram after data processing is shown in Figure 7. It can be seen from the figure that the multi-channel synchronous data acquisition system can effectively obtain the stress field changes at the same time and show the real-time trend of vertical stress distribution with the advance of the working face.

5.2. Numerical Simulation of Compressive Stress Distribution. Based on the relevant simulation parameter values established by the coal-rock relationship of the working face selected in the experiment, FLAC3D three-dimensional explicit finite difference simulation calculation software is selected for model calculation. Then, the model size is set to $300 \times 250 \times 120$ m, and the working surface size is determined to be $200 \times 150 \times 5$ m. When the coal stratum is in an unmined state, overburden is basically in a state of stress balance. After the coal stratum is excavated, the overburden stress field is redistributed. As a result, an unloading pressure zone and a stress rise zone are formed; with the continuous coal stratum mining, the overburden stress distribution also changes dynamically. Figure8 shows the vertical stress distribution along the strike profile and the inclined profile during the advancing process of the working face.

It can be seen from the figure that during the advancing process of the working face, a pressure relief zone is generated in the overburden of the goaf along the strike and incline. The stress gradient of the pressure relief zone gradually increases from the inside to the outside and from the center to the periphery. The full pressure relief zone is also in the shape of a semi-elliptical parabola, which is symmetrically distributed with the center of the mined-out area as the axis. As the working face advances, the range and height of the full pressure relief zone gradually increase. The position of the cut and the working face in the strike direction, and the rock mass near the air inlet and return lanes in the inclined direction gradually form stress rise areas from near to far, and they are basically distributed axisymmetrically in the middle of the mined-out area. It can be seen from this figure that the simulation results are consistent with the actual measurement.

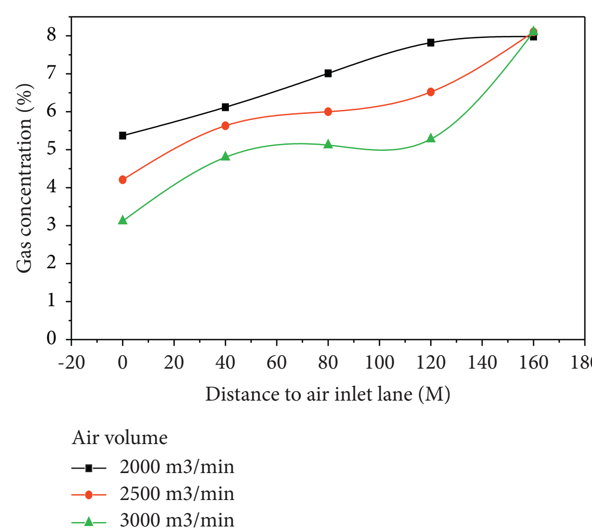


FIGURE 8: Gas distribution of working face 28 m away from the working face along dip direction.

5.3. Gas Release Distribution Results in Mining Fractures. In the process of advancing the working face, the gas emission parameters are set according to the similar proportion. In order to simulate the gas emission in the process of mining, the gas sensors inside the box are used to obtain the gas

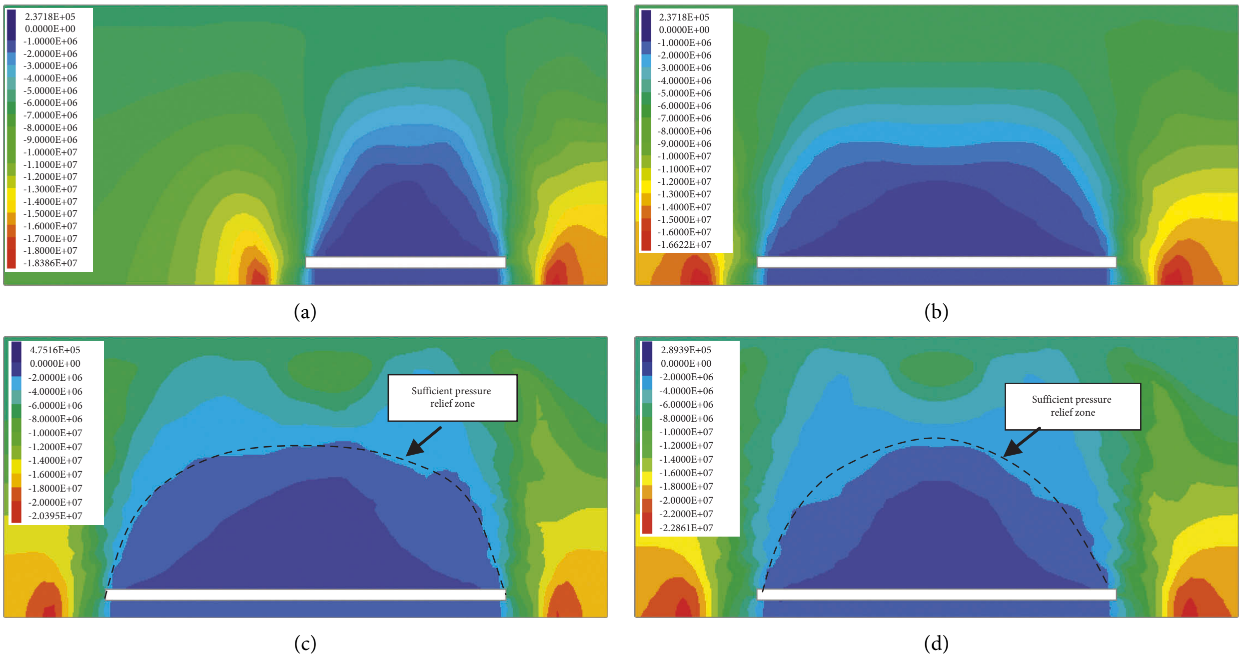


FIGURE 9: Compressive stress distribution diagram in the formation strike and dip direction. (a) Advance 100 m vertical stress distribution on dip direction.. (b) Advance 100 m vertical stress distribution on strike direction. (c) Advance 200 m vertical stress distribution on strike direction. (d) Advance 200 m vertical stress distribution on dip direction.

concentration changes at different positions in real time, so as to analyze the gas migration inside the box. Through the experiment, the distribution of gas concentration under different conditions is shown in Figures 9 and 10. It can be seen in the figures that when the working face is pushed to 200 meters, the gas concentration decreases with the increase of air flow at different distances from the working face. The gas concentration decreases along the dip direction. Figure 8 shows the gas distribution of the working face along the dip direction at 28 m away from the working face.

5.4. Numerical Simulation of Gas Migration and Distribution. According to the physical similarity simulation experiment, a numerical model of gas transport corresponding to the physical similarity simulation experiment was established. The flow field in the goaf and the gas concentration distribution in the goaf based on the *U*-shaped ventilation method are analyzed, and the analysis results are shown in Figure 11.

Figure 11 shows the gas distribution in the goaf. The data in the figure show that the air flow mainly flows in from the air intake lane and flows out from the return air lane. Due to the blockage of coal and rock mass in the goaf, only a small amount of air flow leaks into the deep part of the goaf through the gap. There is high negative pressure in the high pumping lane, and the maximum flow velocity in the goaf appears at the entrance of the lane. At the same time, the closer the return air side, the more abundant the cracks in the goaf, the smaller the air flow resistance. The maximum value of the flow rate is also greater. In the meantime, from the gas concentration distribution on the formation strike, the gas volume fraction in the goaf increases with the distance from the working surface; from the dip direction, the gas volume fraction goes from the lower corner of the air intake lane to the diagonal corner of the goaf. The gas concentration increases; from the vertical direction, it is located in the natural accumulation area and the load-affected area, fresh air flow can be reached, and the gas volume fraction in the goaf area gradually increases from bottom to top. From the above data, it can be concluded that the simulation results are consistent with the actual measurement results.

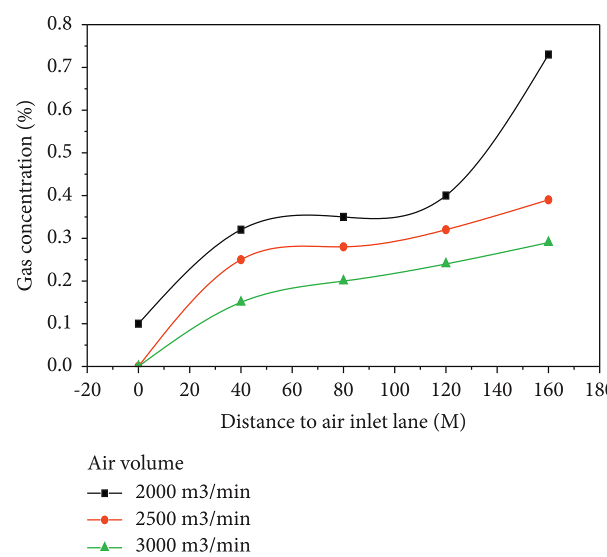
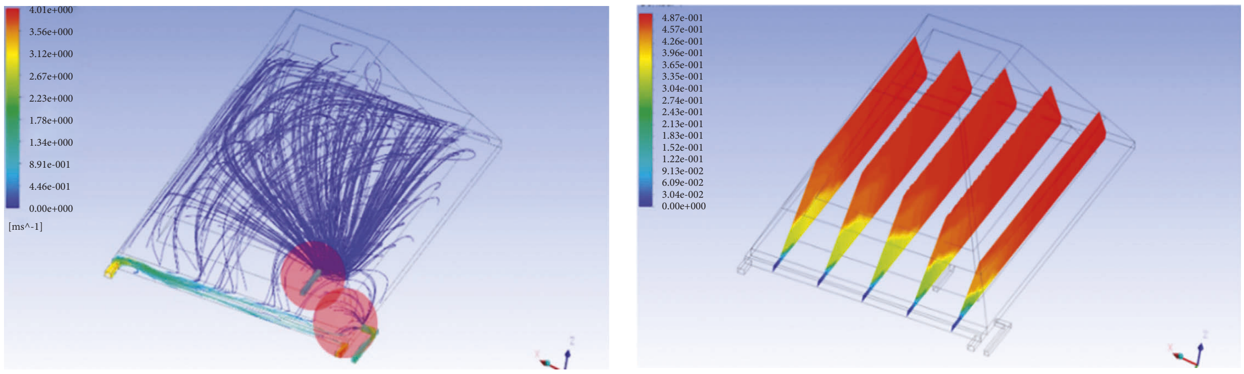


FIGURE 10: Gas distribution of working face along dip direction.



(a) (b)

Figure 11: Gas distribution in the goaf. (a) Flow field distribution in the goaf. (b) Plane gas distribution on different towards.

6. Conclusion

Through the design of layered transmission communication structure, this paper realizes the effective interconnection of three functional modules: acquisition, storage, and display. SQL database is used to realize the synchronous interaction of data and realize the multi-threaded data interaction tasks between different functional modules. It effectively improves the efficiency of data interaction. The data aggregation layer is introduced to package and process the data of multiple boards, so as to reduce the bus pressure of retrieving data from multiple boards. Also, by establishing a small database in it, with the help of time index, it ensures the consistency of the collected data uploaded by different boards at the time point. The distributed clock communication mode further simplifies the data transmission structure and improves the efficiency of data transmission. Finally, more than 200 gas and pressure stress data channels are detected, and the real-time control and monitoring of gas release and coal mining are realized. The application of the system in the large-scale three-dimensional physical similarity simulation experiment system has completed the control and data acquisition tasks of gas release, coal mining, and other systems and obtained the pressure stress and pressure relief of the mine under different mining conditions and positions distribution map of natural gas migration trend. As we all know, with the increase of air volume in the working face, the gas concentration decreases along the dip direction; with the increase of air volume, the gas concentration also shows a gradient downward trend; with the increase of the distance from the working face, the larger the air volume is, the larger the impact area behind the goaf is and the larger the pressure difference between the inlet of air and the reflux side is. By using numerical simulation software to verify and analyze the results of this physical similarity simulation experiment, it can be concluded that the simulation results are consistent with the actual measurement data. This paper verifies that the system can effectively study the laws of mine pressure distribution, pressure relief gas migration, gas drainage, and so on at the same time. The research results provide a theoretical basis for optimizing coal mining and gas safety under co-mining conditions.

However, the research has certain limitations. The test of the direct connection between the timing server and the acquisition node through the switch is not clear enough. This needs further analysis and elaboration in the future.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This study was supported in part by the National Natural Science Foundation of China under grant no. 51804248.

References

[1] L. Yuan, “Scientific problem and countermeasure for precision mining of coal and associated resources,” *Journal of China Coal Society*, vol. 44, no. 01, pp. 1–9, 2019.

[2] S. J. Peng, J. Xu, H. W. Yang, and D. Liu, “Experimental study on the influence mechanism of gas seepage on coal and gas outburst disaster,” *Safety Science*, vol. 50, no. 4, pp. 816–821, 2012.

[3] L. I. Qi and Y Qin, “Study on gas adsorption law of deep coal,” *Industrial Safety and Environmental Protection*, vol. 44, no. 08, pp. 35–37, 2018.

[4] E Tang, L. Dang, and G. Yan, “Practices on precision gas pre-drainage based on time-space attribute in Huangling Mining Area,” *Coal Science and Technology*, vol. 46, no. 08, pp. 87–92, 2018.

[5] B. X. Liu, Z. L. Shu, K. Zhang, J. H. Wan, and M. Zhang, “Experimental study of the mechanism of coal and gas delay outburst,” *Disaster Adv*, vol. 4, pp. 55–62, 2011.

[6] B. Yu, C. Su, and D. Wang, “Study of the features of outburst caused by rock cross-cut coal uncovering and the law of gas dilatation energy release,” *International Journal of Mining Science and Technology*, vol. 25, no. 3, pp. 453–458, 2015.

[7] D. D. Yang, Y. J. Chen, J. Tang et al., “Experimental research into the relationship between initial gas release and coal-gas

outbursts," *Journal of Natural Gas Science and Engineering*, vol. 50, pp. 157–165, 2018.

[8] R. Yang, Y. Zhang, and Z. Wang, "A newly-built geomechanical model test system and its application," *Journal of China Coal Society*, vol. 43, no. 2, pp. 398–404, 2018.

[9] A. D. Alexeev, V. N. Revva, N. A. Alyshev, and D. M. Zhitlyonok, "True triaxial loading apparatus and its application to coal outburst prediction," *International Journal of Coal Geology*, vol. 58, no. 4, pp. 245–250, 2004.

[10] J. Cao, H. Sun, Bo Wang et al., "A novel large-scale three-dimensional apparatus to study mechanisms of coal and gas outburst," *International Journal of Rock Mechanics and Mining Sciences*, vol. 118, pp. 52–62, 2019.

[11] S. Hu, J. Zhang, and G. Feng, "Research on methane enrichment mechanism in coal mine goaf," *China Safety Science Journal*, vol. 26, no. 02, pp. 121–126, 2016.

[12] J. Sobczyk, "A comparison of the influence of adsorbed gases on gas stresses leading to coal and gas outburst," *Fuel*, vol. 115, no. 2, pp. 288–294, 2014.

[13] Q. Y. Tu, Y. P. Cheng, P. K. Guo, J. Y. Jiang, L. Wang, and R. Zhang, "Experimental study of coal and gas outbursts related to gas-enriched areas," *Rock Mechanics and Rock Engineering*, vol. 49, no. 9, pp. 3769–3781, 2016.

[14] A. Nelieki and J. ToPolnicki, "Experimental stand for the investigation of outbursts of porous materials saturated with gas," *Archives of Mining Sciences*, vol. 39, no. 3, pp. 301–312, 1994.

[15] M. H. Li, G. Z. Yin, J. Xu, W. P. Li, Z. L. Song, and C. B. Jiang, "A novel true triaxial apparatus to study the geomechanical and fluid flow aspects of energy exploitations in geological formations," *Rock Mechanics and Rock Engineering*, vol. 49, no. 12, pp. 4647–4659, 2016.

[16] G. Z. Yin, C. B. Jiang, J. G. Wang, J. Xu, D. M. Zhang, and G. Huang, "A new experimental apparatus for coal and gas outburst simulation," *Rock Mechanics and Rock Engineering*, vol. 49, no. 5, pp. 2005–2013, 2016.

[17] J. Xu, X. Wu, and D. Feng, "Physical simulation test of hydraulic borehole flushing," *Safety in Coal Mines*, vol. 49, no. 1, pp. 21–24, 2018.

[18] S. Li, Z. Wei, and H. Lin, "Research and development of 3D large-scale physical simulation experimental system for coal and gas co-extraction and its application," *Journal of China Coal Society*, vol. 44, no. 1, pp. 236–245, 2019.