Design and Simulation on Gas Security Monitoring System

Zhang Peng, Liu Liang, Cheng Zilong, Chen Bin

College of Information and Management, National University of Defense Technology

Changsha, China

Email: zhangpeng_yes@163.com

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Abstract. Coal mine security is related to national economy and personal safety. Efficient monitoring system is urgent for safety mining, according to the frequent accidents in colliery recently. In this paper, U-shaped model is involved to simulate the structure of coal mine. Moreover, gas diffusion model, sensor model and evacuation model are also designed in our work. Based on these models, the process of gas diffusion, alarming and personnel evacuation is simulated. Finally, the proposals on the design and implementation of monitoring systems are proposed.

Introduction

Recently, coal mine security has involved high concerns, and all kinds of monitoring systems have been installed [1]. Dynamic data from monitoring systems provides technology support for analyzing and preventing potential disasters. Moreover, immediate measures are taken once exceptional situation emerges, such as warning and shutting off power automatically [2]. Finally, timely rescue will decrease the economy loss and guard personnel security.

Traditional monitoring systems always detect some key parameters in coal mines, such as mine pressure, gas, hydrology, water, dust and natural fire [3]. Especially, gas explosion is one of the typical accidents, which always causes serious harm to the society. Therefore, many scholars have studied the cause of gas explosion and developed some monitoring systems. Literature [4] has established a gas security monitoring system which provides timely data online for data acquisition and analysis. Literature [5] also designs and implements the monitoring system based on ZigBee technology. It enhances the scalability, flexibility and stability of current systems, and solves the problems of blind spots in safety monitoring.

However, the effectiveness of a monitoring system is always associated with the installation of sensors and the reliability of data analysis. Generally, two main methods are presented in the gas supervision [6]: qualitative methods, including judge prediction, expert assessment, market surveys and scenario analysis; quantitative methods, including sub-source prediction, gray prediction, regression analysis and neural network. In this paper, the compound method is select. The scenarios of gas diffusion under different conditions are simulated, and gas concentration at various points are also calculated and detected. Moreover, the response mechanisms of warning and evacuation are also discussed.

The remainder of this paper is arranged as follows. Section 2 presents all models in the experiment. In section 3, a serial of experiments along with the corresponding analysis are discussed. Finally, some conclusions and proposals are given in section 4.

Models

A. Structure model

The structure of coal main is variety, which directly affects the diffusion process of gas. In this paper, U-shaped model [7] is involved to simulate the typical structure of coal mine, as shown in figure.1. It consists of inlet, outlet, intake entry, return airway, working surface and gas channel.

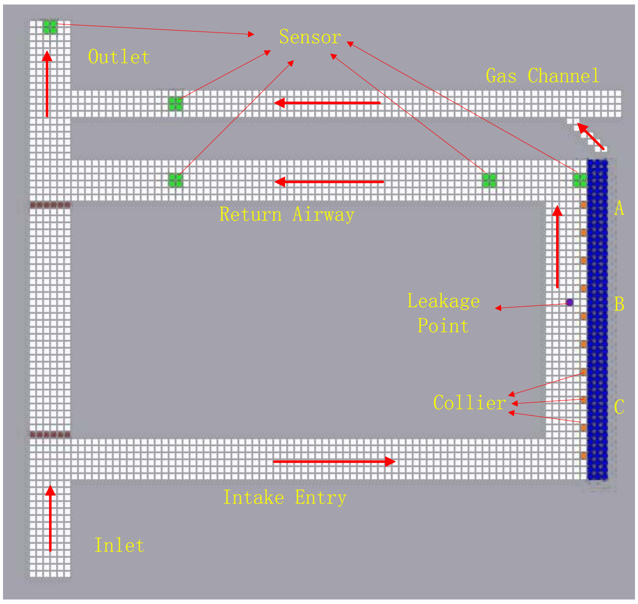


Figure 1. Typical U-shaped structure of coal mine

Generally, leakage points are always on the working surface. In the paper, a single leakage point and 10 colliers are supposed on the working surface. In this map, there is a gas channel, which is used for gas exhausting in an ordinary way. In an emergency case, the working surface will leak gas. Gas spreads towards to the wind direction, as shown in this map. In our design, workers in the working surface will move to the outlet once alarm rings.

B. Diffusion model

Under the condition of no wind, gas spreads toward to all possible corners. In this experiment, gas will spread along the wind direction, as shown in figure.1.

Suppose the volume of gas passing through the cross sectional area in per unit time is calculated in (1). In the formula, $\sum Q_o$ is the gas volume flowing out; $\sum Q_i$ is the gas volume flowing in the area; Q is the current gas volume in the area.

$$\sum Q_O - \sum Q_i = Q \quad (1)$$

Actually, gas concentration is always monitored by sensors, and the gas volume in the zones can also be calculated, as shown in the following formulas:

$$Q_s = C_g \times Q_f \quad (2)$$

$$Q_s = 60 \times V_s \times S \quad (3)$$

$$C_g = \frac{60 \times V_s \times S}{Q_f} \quad (4)$$

Q_s is the gas volume flowing in the area (m^3/s); C_g is the gas concentration; Q_f is the total volume of air in the zones (m^3/s); V_s is the wind speed (m/s); S is the area of cross sectional (m^2).

C. Sensor model

Generally, physical quantities of gas concentration are converted to electrical signals through sensors [7], and the alarm will ring once accidents emerge. It avoids the gas explosion due to illegal operations and exceptions in electrical equipments. Moreover, it also reminds leaderships and workers to escape, and prevents gas explosions and subsequent accidents.

In our work, five gas sensors are designed and installed, and they are names as Detector 1, Detector 2, Detector 3, Detector 4 and Detector 5 respectively from northwest to southeast, as shown in figure.1. According to the safety standards, gas detectors should be installed at special locations. It should be less than 3m from the working surface, and no more than 30cm from the ceiling. Therefore, Detector 5 is installed near to the working surface, which always reaches to the warning concentration firstly. Detector 4 is installed in the return airway, and the concentration is always far higher than Detector 1 and Detector 3. Moreover, Detector 2 is installed in the gas channel.

In our design, four blocks with green color stand a sensor or detector. The color will turn red once the gas concentration exceeds a special value. The number of red blocks stands for the concentration level of gas, and four red blocks always trigger the warning. As previously discussed, the rules of warning are listed as follows.

- If gas concentration of a detector exceeds 6%, four blocks of the detector will turn red.
- If only a detector turns red for more than 30s, the alarm will ring, and all operations will be stop;
- If two or more gas detectors turn red, the power will be shut off, and all workers begin to evacuate.

The sensitivity, linearity and response time of sensors are all taken into account in the design. Moreover, a database is established for collecting periodic data.

D. Evacuation model

Personnel evacuation requires workers to evacuate from dangerous zones in case of emergency. In the process, some factors may affect the efficiency of personnel evacuation, such as the number and distribution of individuals [8]. Moreover, the structures of different coal mines are also the main factors.

In this paper, cellular automaton is introduced to simulate the evacuation process. Cellular automaton describes a large number of individuals by simple contacts, and develops the complex phenomena or dynamic evolution. Therefore, each block is viewed as a cellular, which can fill gas, worker or barrier. Under emergency condition, workers will move from one cellar to another, and finally escape the dangerous situation.

Once alarm rings, colliers will escapes from the working surface to the outlet. The rules of evacuation are designed as follows: collier will go straight up in each tick until there is a barrier; if the barrier exists, the collier will turn left. Finally, all colliers will move to the outlet in the northwest of the map. According to the design, the concentration of gas will decrease with the distance increasing from the gas leakage point.

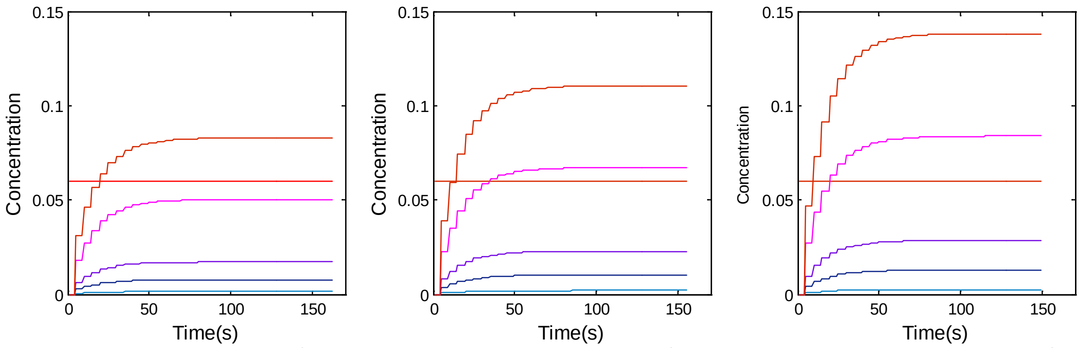
Experiment and analysis

Assuming that there is only a gas leakage point exists, as shown in figure.1. In this section, different gas leakage rates are simulated, the leakage points are analyzed, and the effect of wind speed is also studied.

A. Different leakage rate

In this experiment, the diffusion scenes under different gas leakage rates are discussed. Assuming that the gas leakage point (B) is fixed in the middle of working surface and the ventilation rate is $10m^3/s$. In our design, the gas leakage rates are set as $3m^3/s$, $4m^3/s$ and $5m^3/s$ separately, and the gas concentrations for each detector are shown in figure.2.

Five curves depict the variation trends of five detectors about gas concentration separately. The top curve stands for the Detector 5, and the bottom one is the Detector 1. Moreover, the straight line is the threshold of warning concentration. Once the gas concentration exceeds the value, the detector will turn red.



(a) leakage rate is $3m^3/s$ (b) leakage rate is $4m^3/s$ (c) leakage rate is$5m^3/s$

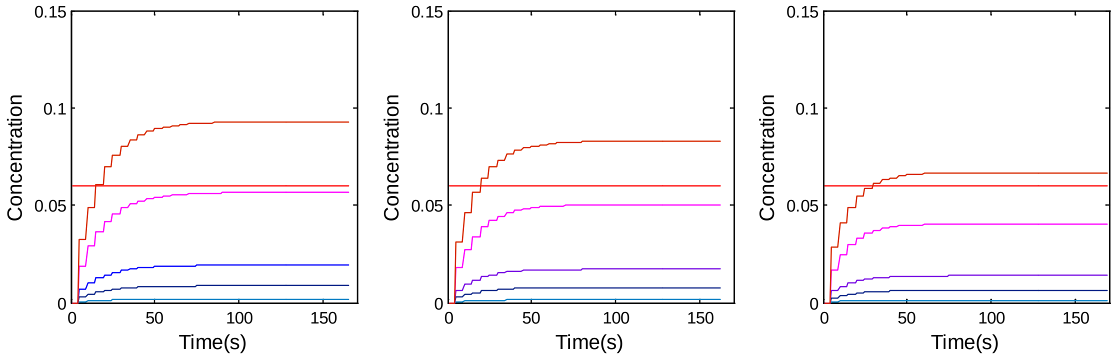
Figure 2. Gas concentrations for each detector under different leakage volumes

Comparative analysis on the gas concentration, it's easy to find that high leakage rate will trigger the alarm easily. If gas leakage rate reaches to $3m^3/s$, only Detector 5 will exceed the threshold values. If gas leakage rate exceeds $5m^3/s$, both Detector 4 and Detector 5 will trigger the alarm. Finally, the result corresponds to the common sense.

Therefore, stemming the leakage points or decreasing the leakage volume is necessary. Under an emergency case, immediate actions are especially important in coal mine security. The main task of response is to affirm the location of gas leakage, and take corresponding measures.

B. Different leakage point

The diffusion scenes under different leakage points are also discussed in this experiment. Assuming that the leakage rate is fixed at $3m^3/s$ and the ventilation rate is $10m^3/s$. The leakage points are set at the top, middle and bottom of the working surface, labeled as A, B, C separately. The gas concentration trends for each detector are shown in figure.3.



(a) leakage point A (b) leakage point B (c) leakage point C

Figure 3. Gas leakage at different points

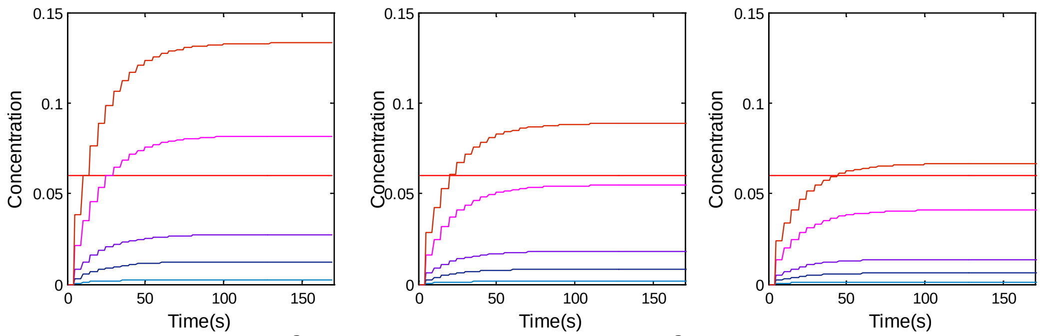
Generally, the observation values of different detectors are related to the leakage positions. However, the correlation is week, as the leakage volume in the channel is the same. Comparing the diffusion scenes when the leakage locations are set as point A, B, C, the concentration of each detector only varies a little. Therefore, the leakage point of working surface is weekly related to the gas diffusion.

Actually, three leakage points are in the same working surface, and the distance between them are always short. If the structure of coal mine is not the same as figure.1, the leakage point directly affects the gas spreading. Moreover, the corresponding response will emphasize the task to detect the leakage point.

C. Different ventilation

Ventilation depicts the factor of wind in gas diffusion. As previously discussed, it is associated with the wind speeds. In a sense, ventilation equals the product of wind speed and cross section. Generally, high ventilation rate always lead to low gas concentration if the leakage rate is the same. Wind always dilutes the gas concentration, and gas exposition is impossible in low concentration.

In this experiment, assuming that the leakage point is fixed in the middle of working surface and the leakage rate is $3\ m^3/s$. Gas leak under different ventilation rate is discussed, and the detailed data of each detector is shown in figure.4. If the ventilation is $10m^3/s$, two detectors will reach the threshold concentration and trigger the alarm. If the ventilation is more than $20m^3/s$, almost no detectors will trigger the alarm. Therefore, high speed of wind is always significant for gas spreading, and decreases the possibility of gas explosion. Actually, wind speed is always less than 4m/s, and strong wind may lead to other accidents. Moreover, it will also lead to gas exposition if the speed reaches a threshold.



(a) ventilation rate is $10m^3/s$ (b) ventilation rate is $15m^3/s$ (c) ventilation rate is $20m^3/s$

Figure 4. Gas leak under different ventilation rate

D. Personal evacuation

As previously discussed, personal evacuation is the main task in coal mine accident. The evacuation scene is shown in figure.5, workers begin to escape when two detectors turn red, and the evacuation line is shown in the map. In practice, it's the response for coal mine to make emergency plans and design the scientific evacuation lines. Of cource, it's depends on the structure of coal mines. Therefore, regular fire drills are also necessary in coal mines.

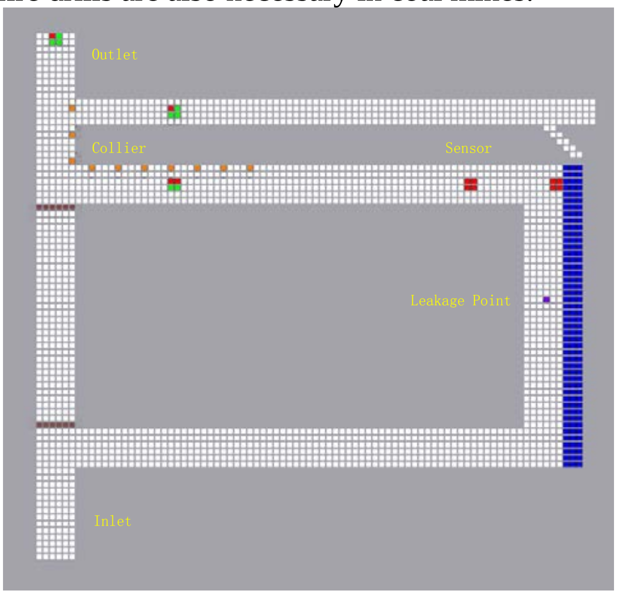


Figure 5. Personal evacution in an emergency case

Conclusion

Generally, many factors will affect the efficient of gas monitoring systems. As previously discussed, leakage volume, leakage point and the ventilation rate are the main factors in gas diffusion. From the simulation result, joint monitor and alarm system is necessary for the security of coal mines. Under emergency situation, it's urgent to affirm the leakage points and take immediate actions. Especially, personal evacuation should be organized in order.

Currently, the category of domestic monitoring systems is incomplete, and the accuracy is also limited [9]. Moreover, traditional methane sensors are always poor in stability and lives. Therefore, high-quality, low-cost and intelligent sensor devices is needed [10]. Of course, the compatibility of the monitoring system should be improved. Moreover, it's urgent to make up the uniform technical standards, and promote the popularization and application of mine monitoring system.

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