Research on Computer Algorithm of Mine Gas Release Source Location Based on Multi-source Sensor Fusion

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Abstract. Aiming at the problem of gas leakage source difficult to locate or inaccurately located due to the air leakage phenomenon in the goaf of coal mines, this paper proposes a mine gas emission source location algorithm based on multi-source sensor fusion. Firstly, by analyzing the gas distribution law of the goaf in the fully mechanized caving face, the sensor observation model and the gas release source diffusion model of the mine goaf are established, and then the machine learning positioning algorithm is used to estimate the parameters of the gas release source in the goaf and according to the iterative calculation. The coordinate positions of the estimated parameters are obtained. Finally, the data fusion of the wireless sensor target source sensing node and the cluster head node is used to achieve the precise positioning of the gas release source. The results show that: compared with other algorithms, machine learning algorithms have obvious advantages in positioning accuracy. This method can effectively solve the problem of difficulty in locating the gas release source due to the air leakage phenomenon, and then provide a reference basis for gas prominent warning and gas extraction in the goaf.

1. Introduction

Gas is produced along with the mining of coal. It is not static, but flows with time and is always in dynamic change. However, the existing coal mine gas monitoring system still relies on traditional sensor monitoring. Due to some shortcomings of the sensor itself and the complexity and dynamic variability of the underground coal mine environment, it is impossible to accurately evaluate the dynamic changes of coal mine gas concentration using sensor technology alone. In addition, the downhole environment is an environment in which multiple gases coexist. Considering only one parameter of gas and ignoring the dynamic changes of other gas concentrations, it is obviously impossible to make a correct assessment of the downhole environment of the coal mine.

Today's coal mine gas monitoring methods either only construct more intelligent and efficient performance sensors from the perspective of sensors, or realize the transition from a single sensor to multiple sensors. The shortcomings exposed by a single sensor when collecting information are inevitable, so the use of multiple sensors to cooperate with each other to jointly monitor gas is the future development trend of gas monitoring. The existing method of multi-sensor collaborative gas
monitoring simply considers "multiple" or with a kind of blindness, and then processes the data monitored by these sensors. These data contain a lot of redundant and less relevant data, and these data are also added to the calculation process, which will inevitably cause waste of resources and prolonged monitoring time. If there is a large amount of redundant data, it may also lead to the monitoring results have a large error.

In this paper, based on the research of gas emission sources in coal mines, combined with the specific environment of coal mines, the gas in the goaf of fully mechanized caving face is studied, and a method for locating mine gas release sources based on multi-source sensor fusion is proposed to achieve accurate location of the gas release source, and the effectiveness and reliability of this method are verified through experiments [1].

2. The establishment of mining gas desorption-diffusion mathematical model

2.1. Gas flow pattern analysis
Considering that the pressure relief gas flows in the fracture zone, it can be considered that the gas flows in the porous medium, and the Reynolds number (Re) is used to determine the fluid state, that is,

\[ \text{Re} = \frac{q \cdot k}{\nu \cdot d_m} \]  

(1)

In the formula: q represents the seepage velocity of the fluid in the porous medium, m/s; k represents the permeability; \( d_m \) represents the average harmonic particle size, m; \( \nu \) represents the kinematic viscosity coefficient, m²/s.

Relevant literature and experiments show that: when the gas in the porous medium seeps, \( \text{Re} \leq 0.25 \) is the laminar flow state; \( 0.25 < \text{Re} \leq 2.5 \) is the transitional flow state; \( \text{Re} > 2.5 \) is the turbulent flow state. It can be seen that the fluid state is divided into laminar flow zone, transition flow zone and turbulent flow zone. In the small area close to the goal of the coal face of the 8# coal seam, the air leakage and wind speed are larger, while the other two areas are the seepage with smaller Reynolds number. It can be seen that the gas flow in the mining fracture zone complies with Darcy’s law, but it follows the non-linear seepage law in the entire section, which can be expressed by the Ergun equation, namely

\[ \frac{\partial \varphi_i}{\partial x_i} = -\frac{\mu}{k} q_i - C_z \rho_i \frac{q_i^2}{\varphi_i} \]  

(2)

In the formula: \( \varphi_i \) represents the gas pressure function of the mining fracture zone, \( \varphi_i = p + \rho_i \varphi_i \); represents the internal loss rate, \( C_z = 1.75(1-n)/n^2 \); \( n \) represents the porosity, \( n = 1 - 1/K_p \); \( K_p \) represents the fracture expansion coefficient of a certain point of the mining fracture zone, which can be determined by physical similarity simulation experiments.

2.2. Mining pressure relief gas flow dynamics model
After the mining of the working face of 8# coal seam protection layer, the 3# coal seam is in the pressure relief range, and the 3# coal seam is in the fissure zone, then a large number of cracks will be produced between the interlayer rock layer and the 3# coal seam, which will The goal of the coal seam face is connected, and a certain gas pressure staircase is formed inside the interlayer; due to the different gas pressure, the 3# coal seam flows from the high gas area in the protective layer to the low gas area of the protective layer goaf. Thereby formed a certain gas migration law [2]. The main factors affecting its flow velocity are: the gas pressure, permeability and gas pressure and the interlayer distance of the fractured gas in the goaf and its interlayer, as shown in Figure 1.
Figure 1. Schematic diagram of pressure relief gas flow under protective layer mining conditions

Study 3# coal seam pressure relief gas flow law is the basis of pressure relief gas drainage. This article takes protective layer mining as an example of engineering, uses Darcy's law in seepage mechanics, and establishes overburden fracture zone based on ideal gas equation and continuity equation. Gas flow model inside. All gas movement processes are consistent with the law of conservation of mass and energy [3]. As shown in Figure 2, it is the gas flow dynamic model of the protected layer. Therefore:

\[
d(\rho \cdot w \cdot m \cdot d_x \cdot d_y) = -\rho \cdot V \cdot d_x \cdot d_y
\]  

(3)

In the formula: \( m \) stands for coal seam thickness, m; \( \rho \) stands for gas density, kg/m³; \( w \) stands for gas content, m³/t; \( V \) stands for gas gushing speed, m/min; \( t \) stands for time, min.

Figure 2. Gas flow dynamic model of the protected layer

2.3. Mathematical model of gas flow for mining pressure relief

2.3.1. Gas gas equation of state. Under the isothermal process conditions, it is assumed that the gas conforms to the ideal gas state equation. The density \( \rho \) of the gas flow will change with the gas pressure, \( \rho = f(P) \), so there is:
\[
\rho = \frac{P}{P_0} \cdot \rho_0 
\]  
(4)

In the formula, \( \rho \) and \( \rho_0 \) are the gas density when the actual pressure is \( P \), kg/m\(^3\).

2.3.2. Basic equation of gas flow. Because of the relationship between the gas velocity between coal and rock layers and the gas permeability coefficient between coal and rock layers, the default gas flow type is in the laminar flow range. Therefore, gas flow conforms to Darcy’s law:

\[
V = -\frac{K}{\mu} \cdot \frac{\partial P}{\partial l} 
\]  
(5)

In the formula: \( \mu \) represents the absolute viscosity of the fluid, Pa.S; \( \frac{\partial P}{\partial l} \) represents the fluid pressure gradient, Pa/m; \( K \) represents the permeability of the formation, \( \mu m^2 \). From this formula, the gas flow velocity \( V \) in the \( i \)-th rock layer is:

\[
V_i = \frac{K_i}{\mu} \cdot \frac{P_{i+1} - P_i}{m_i} 
\]  
(6)

In the formula: \( P_{i+1} \) represents the upper surface pressure of the \( i \)-th layer, MPa; \( P_i \) represents the lower surface pressure of the \( i \)-th layer, MPa; \( m_i \) represents the \( i \)-th layer thickness, m; \( k_i \) represents the \( i \)-th layer permeability, \( \mu m^2 \);

2.3.3. Continuity equation of gas flow

\[
\rho_i V_i d_x d_y = \rho V d_x d_y 
\]  
(7)

The flow of gas along the layers follows the law of conservation of mass, which is mathematically calculated and organized:

\[
P^2 - P_i^2 = 2 \mu VP \sum \frac{m_i}{k_i} 
\]  
(8)

In the formula: \( P \) represents the gas pressure in the goaf, MPa.

2.3.4. Coal seam gas content equation. According to the theory of porous media, the gas adsorption content per unit volume of coal depends on the coal bed gas pressure. The relationship between the coal bed gas content and the coal bed gas pressure is expressed as follows:

\[
w = a \sqrt{P} 
\]  
(9)

In the formula: \( a \) represents the gas content coefficient of coal seam, \( m^3/(tMPa^{1/2}) \).

2.3.5. Dynamic model of coal seam gas seepage. From (7, 8, 9), the mechanical model definite solution problem is:

\[
\frac{\sqrt{P}}{P^2 - P} \cdot d_r = \lambda \cdot d_t 
\]

\[
P|_{\alpha} = P_0 
\]  
(10)
\[ \lambda = \frac{1}{3 \alpha \mu \gamma m} \sum \frac{m_i}{k_i} \quad (11) \]

2.3.6. Gas flow law of coal seam. By mathematically solving equation (11), the functional relationship of \( P-t \) can be obtained as:

\[ \frac{1}{\sqrt{P}} \arccos \frac{\sqrt{P}}{2 \sqrt{P_i}} \ln \left( \sqrt{\frac{P}{P_i}} - \sqrt{1} \right) + C_0 = \lambda t \quad (12) \]

In the formula:

\[ C_0 = -\frac{1}{\sqrt{P_i}} \arccos \frac{\sqrt{P}}{\sqrt{P_i}} \ln \left( \frac{\sqrt{P} - \sqrt{P_i}}{\sqrt{P} + \sqrt{P_i}} \right) \quad (13) \]

From equation (13) to a complex implicit composite function, the coefficient \( p \) term on the left side of equation (7) is linearized:

\[ \frac{C_i \cdot dp}{\rho^2 - p_i} = \lambda dt \quad (14) \]

Mathematical solution of (14) combined with initial value condition is:

\[ C_i = 2 \frac{p_i}{C_i} \ln \left( \frac{p_i - p}{p_i - P} \right) \quad (15) \]

In order to obtain the relational expression of gas flow velocity and time \( t \), substitute (13) into the available

\[ V = \frac{2p_i}{\mu} \sum \frac{m_i}{k_i} e^{\lambda C_i - C} \left( 1 - e^{2(\lambda C_i - C)} \right) \quad (16) \]

Along the direction of the strike, substitute the function of pressure relief range \( X \) in formula (16):

\[ t = \frac{1440 \times V}{V_c} \quad (17) \]

In the formula: \( C_i = \frac{1440C_i}{V_c} \). From formula 21, the gas discharge amount \( Q \) in the pressure relief range \( x(m) \) along the direction is obtained by integration:

\[ Q = \int_0^x V dl \times \frac{L_{ma} Y C_i}{960} \left( \ln \left( \frac{e^{\lambda C_i} - 1}{e^{\lambda C_i} + 1} \right) - \ln \left( \frac{1 - e^C}{1 - e^C} \right) \right) \quad (18) \]

Equation (18) is the function relationship between the pressure relief gas discharge \( Q \) of the protected layer and the pressure relief range \( x(m) \).
3. Multi-source sensor mine gas leakage location system

3.1. Monitoring system combined with industrial Ethernet

A sensor network is a wired or wireless network composed of a group of sensors in an Ad-Hoc manner. The wired or wireless network is a communication method between sensors and between a sensor and an observer, and is used to establish a communication path. A coal mine needs to have multiple monitoring and monitoring systems to ensure safe production, and each monitoring and monitoring system is ultimately to pass information to relevant departments or staff to facilitate the dynamic organization, management and production of coal mines [4].

In recent years, industrial Ethernet mine comprehensive monitoring system has been more and more widely used in coal mines, such as my country's EPA real-time Ethernet. It forms a certain hardware foundation for the underground monitoring system, and the sensor network can be arranged on this basis. That is, the monitoring information can be transmitted through industrial Ethernet, and each monitoring and monitoring system can be linked together, and the information can be shared to facilitate coordination and unification. To avoid the current monitoring system to do its own thing, information and data cannot be shared, and linkage cannot be formed.

3.2. Gas monitoring system network

Underground coal mines can be divided into roadway areas and mining areas, which are further divided into main roadways and branch roadways. In the main roadway area, due to the open terrain and simple and convenient wiring, the wired monitoring substation mode can be used to ensure the reliable transmission of the data collected by the sensor. With the deepening of mining, it is very difficult to arrange wired sensor networks in relatively narrow terrain roadways, newly mined areas and places where people are not easy or inaccessible, and considering the scalability of the monitoring system and mine production scheduling Actual needs, the traditional model can no longer be satisfied. The wireless sensor network, because of its centerless, self-organizing, multi-hop routing, dynamic topology and other characteristics, is particularly suitable for deployment in areas with harsh environments and difficult to reach people, to achieve seamless coverage of underground detection. Its network structure is shown in Figure 3.
The structure of the network is clearly hierarchical. The first layer is each application node, which has the capabilities of data collection, processing, wireless communication, and automatic networking. They are the initiators and forwarders of packets. The second layer is the fixed node, which is responsible for receiving data from application nodes in the nearby area, performing certain processing, and forwarding it to the base station node or a fixed node closer to the base station node. On the one hand, the base station node is logically a node of Ethernet, which communicates with Ethernet, receives and processes Ethernet data packets; on the other hand, it acts as the largest convergence point in the wireless sensor network and completes the analysis and processing of data and forward. According to actual application needs, multiple base station nodes can be used, and a clustering and layered management mode can be adopted. The base station node aggregates the processed information and transmits it to the monitoring center through the underground Ethernet. The monitoring center can understand the real-time situation of the underground. All the sensor systems involved in the entire monitoring system are the foundation of the entire system, and they are always aware of changes in the external environment. Each sensor node can join or leave the network at any time, so the failure of individual nodes will not affect the operation of the entire network, and has strong invulnerability and scalability [5].

3.3. Multi-source sensor fusion structure
Multi-source information clustering technology (multi-source information strong classification deep fusion technology) is divided into three modules: One is a multi-source information collection module, which is mainly composed of sensors, which are divided into homogeneous sensors and heterogeneous sensors. Homogeneity and heterogeneity are mainly distinguished according to the different principles of sensor monitoring; the second module is a strong classification module (that is, a filtering module), and the function of this module is to filter out large changes before and after from a large number of input parameter information Parameters, filter out those parameters that have not changed or have little change that have little effect on the monitoring results; the third is the information fusion module, the function of this module is to fuse the output parameters in the second step to obtain a More accurate results. The structure hierarchy is shown in Figure 4.

![Figure 4. Multi-source information strong classification deep fusion method structure](image)

A set of sensors is used here to monitor the same gas, such as oxygen, gas, nitrogen, etc., in order to avoid the disadvantages of a single sensor when collecting information. The monitoring of gas by two sets of sensors with different monitoring principles also considers that the same sensor may have the same defects. Due to the large number of sensors included in each group, if you input them into the filter, one will bring a huge amount of calculation to the filter, and the other is because the data from the same sensor in the same group Inevitably, there will be a lot of duplicate data, and there will be a lot of redundancy, which will also extend the calculation time. Therefore, before entering the data into
the filter, let them enter the maximum likelihood device. The function of the maximum likelihood device is to find the closest value to the true value in the shuffled data. Then, input each group of data obtained by the maximum likelihood device into the classifier, calculate and compare the safety zone of each underground gas specified in the "Coal Mine Safety Regulations" according to the pre-assigned threshold, and filter out the large fluctuations. The data is then input into the fusion machine for deep fusion, and finally an accurate result is obtained, thereby judging the safety level of the underground environment. Among these processes, the most important is the source information collection system. Its accuracy and reliability directly affect the accuracy of the final monitoring results.

In practice, the geographical area covered by the roadway is very large, and it is obviously not feasible to arrange only one cluster sensing domain, so a certain number of cluster sensing domains need to be arranged. Each cluster sensing domain contains a certain number of sensors, as well as the intelligent cluster head node of each cluster. Its role is to collect information from all sensors in the cluster sensing domain, and then pass it to a higher-level Smart node.

4. Algorithm experimental verification
Select leak diagnosis examples for analysis. Suppose there are 3 nodes in a cluster, each node is equipped with two sensors of pressure and flow, and after 2 cycles of measurement accumulation. The basic probabilities of each proposition determined by the diagnosis information of different measurement periods of different nodes and different sensors as independent evidence bodies are shown in Table 1.

| BPAF value | A1 | A2 | Θ |
|------------|----|----|---|
| m111(.)    | 0.40 | 0.40 | 0.20 |
| m112(.)    | 0.55 | 0.40 | 0.05 |
| m121(.)    | 0.60 | 0.30 | 0.10 |
| m122(.)    | 0.50 | 0.45 | 0.05 |
| m211(.)    | 0.45 | 0.40 | 0.15 |
| m212(.)    | 0.70 | 0.25 | 0.05 |
| m221(.)    | 0.35 | 0.60 | 0.05 |
| m222(.)    | 0.55 | 0.30 | 0.15 |
| m311(.)    | 0.55 | 0.40 | 0.05 |
| m312(.)    | 0.48 | 0.42 | 0.10 |
| m321(.)    | 0.60 | 0.35 | 0.05 |
| m322(.)    | 0.45 | 0.35 | 0.20 |

According to the BPAF value of each initial evidence in Table 1, using formulas (4)-(10), the basic probability distribution assignment after the synthesis of all levels of evidence can be calculated, and the results are shown in Table 2. Finally, the decision is made, which obviously satisfies the relationship (11), so the diagnosis result is A1, that is, the pipeline has leaked. Comparing Table 1 with the calculation results after the fusion of all levels shows that: compared with single-sensor leak detection, the multi-level evidence fusion algorithm makes the diagnosis results "aggregate" to the proposition with a large basic credibility value, that is, improves the probability of A1. Reliability, while significantly reducing the basic credibility distribution value of A2 and the uncertainty of diagnosis, effectively improve the accuracy of pipeline leak diagnosis.
Table 2. Time domain fusion results

| BPAF value | A1     | A2     | Θ       |
|------------|--------|--------|---------|
| m11(.)     | 0.5645 | 0.4194 | 0.0161  |
| m12(.)     | 0.6552 | 0.3362 | 0.0086  |
| m21(.)     | 0.7284 | 0.2593 | 0.0123  |
| m22(.)     | 0.4823 | 0.5044 | 0.0133  |
| m31(.)     | 0.5945 | 0.3969 | 0.0087  |
| m32(.)     | 0.6522 | 0.3320 | 0.0158  |

5. Conclusion
(1) Aiming at the location of gas emission sources in the mined-out area of mines: a method for locating the release source of multi-source sensor fusion is proposed to achieve accurate positioning of the gas release source. (2) The thesis establishes the gas diffusion model and sensor observation model of the mined-out goaf, and uses the DS evidence combination rule to perform three-level evidence synthesis on the diagnostic information of multiple measurement cycles of multiple nodes and multiple sensors in the network, making the traditional The possible unrecognized or erroneous recognition of the single sensor leak detection method has been significantly improved. The diagnostic system is robust and easy to make decisions.

Acknowledgments
This work is supported by the Scientific Research Program Funded by Shaanxi. Provincial Education Department (Program No.20JK0744)

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