Research on Gaussian Plume Model of Gas Diffusion in Coal Mine Roadway Based on BP Neural Network Optimized by Genetic Algorithm

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Abstract: Intelligent monitoring and control of harmful gas in a coal mine is an important aspect of the building on intelligent and green mine. It is a hot spot of artificial intelligence research in the coal mine to study the new technology of dynamic prediction of harmful gas by using artificial intelligence, big data and other interdisciplinary fusion methods, and gradually replace the artificial monitoring work. By researching the gas diffusion theory and the characteristics of the coal mine environment, this paper uses the Gaussian plume model to simulate the gas diffusion law of coal mine roadway, and puts forward a gas prediction model optimized by genetic algorithm and BP neural network. The algorithm takes the absolute error between the predicted output of gas source term and the field measured value as the peculiar fitness value and optimizes it. The results show that the optimized BP neural network can obtain the best concentration prediction value for short time and a small error. Compared with the traditional gas prediction method in coal mine, this method has the advantages of small calculation amount and high prediction accuracy, and it can improve the reliability of the model by continuous machine learning combined with daily monitoring, which provides a new technical solution for the intelligent detection of environmental information in coal mine roadway.

1. Introduction
At present, the monitoring mode on gas environment in a coal mine is mainly carried out by the combination of manual inspection and online monitoring. However, the disadvantages of online monitoring and manual inspection, such as high input cost, low maintenance efficiency, small coverage area, and the high labor intensity, are always difficult to overcome, which has become one of the weak links of safety production in coal mine management. Now, on the basis of digital mine construction, it is an important trend of intelligent and green development and a hot spot of artificial intelligence research in coal mine to adopt the method of interdisciplinary fusion of artificial intelligence and big data to study the distribution law of harmful gas, and to build a new technology of dynamic prediction of gas concentration in coal mine, then replace the work of artificial monitoring gradually.

Khosravi proposed an effective method to construct the optimal prediction interval (PIs) by using bootstrap technology. In the training of the neural network (NNs), a new cost function based on PI was used to estimate the variance of the target.\textsuperscript{[1]} Ronay used multi-layer perceptron neural network trained by multi-objective genetic algorithm and limit learning machine of the nearest neighbor method to
predict wind speed in the time series of wind turbine.\cite{3} Zhang Yiwen proposed a method to predict gas concentration based on the hidden random layer neural network (BNSGA-II\textsuperscript{N}) trained by NSGA-II.\cite{3}

Wang Peng proposed a real-time prediction model of gas concentration based on Lagrange Arima. Compared with the traditional Arima static learning model, the learning window scale of the established Lagrange ARIMA model is reduced by 90.3\%, and the modeling complexity MAE is reduced by 16.3\%.\cite{4} Guo Siwen put forward a dynamic prediction method of gas concentration based on time series, and used wavelet decomposition technology to construct the real-time dynamic autoregressive moving average (ARMA) model.\cite{5} Wei Lin combines the dynamic clustering algorithm with the Gaussian regression model to build the interval prediction model of gas concentration.\cite{6} Zhang Zhaozhao put forward a dynamic neural network gas concentration real-time prediction model, using historical data to establish a preliminary prediction model, and through the real-time collected gas concentration data to adjust the learning parameters and structural parameters of the prediction model in time.\cite{7}

In summary, a large number of coal mine underground monitoring data are mainly used, and machine learning method is used to model the change characteristics of the data, so as to realize the prediction of gas quantity, these methods have a positive impact on the construction and optimization of the gas prediction model. However, most of the above prediction methods use the conventional static learning method to train the gas monitoring data, the workload of data collection is large and the coal mine monitoring data contain a lot of interference noise. In this paper, the author simulated the law of gas diffusion by building the Gaussian plume model of gas diffusion in coal mine roadway, and optimized the parameters of the model by using the BP neural network optimized by genetic algorithm, which can not only predict the gas concentration in time, but also continuously train and learn according to the data in time, so as to improve the prediction accuracy.

2. Gaussian plume model of gas diffusion in coal mine roadway

The Gaussian plume model is widely used in the research of gas diffusion, which is suitable for the continuous leakage of light gas. In the coal mine roadway, the gas is mainly released along with the operation of coal caving in the working face and goaf, and then diffused along the main direction of the air flow x-axis. The gas diffusion cross section of the tunnel is small, equivalent to point source diffusion, which meets the modeling requirements of the Gaussian plume model, for example the wind direction is stable, and the point source of continuous diffusion. Therefore, the Gaussian plume model can be used to study the diffusion law of gas in the coal mine.\cite{8,9}

Assuming that the gas reaches the return air roadway continuously with a constant speed, the concentration and temperature inside the gas cluster are evenly distributed at the initial time; the change of temperature inside the cloud cluster is not considered in the diffusion process, and the heat transfer, convection and radiation are ignored; the leaked gas follows the ideal gas state; in the horizontal direction, the atmospheric diffusion coefficient is isotropic; the speed and the direction of wind remains unchanged; the bottom plate does not absorb the leaked gas; no chemical reaction occurs in the whole process, etc.

The Gaussian plume model formula is as follows:

\[
C(x, y, z) = \frac{Q}{2\pi \sigma_x \sigma_y \sigma_z} \exp \left[ - \left( \frac{y^2}{2\sigma_y^2} + \frac{(z-H)^2}{2\sigma_z^2} \right) \right]
\]

(1)

Where, \(x, y, z\) are the coordinates of the point, m; \(C\) is the gas diffusion concentration; \(\sigma_x, \sigma_y, \sigma_z\) respectively are the diffusion coefficients of gas in \(X, Y, Z\) direction; \(u\) is the air flow velocity in \(X\) direction, m/s; \(H\) is the height of leakage source, m; \(Q\) is the gas source strength, m\(^3\)/s.

The diffusion coefficient \(\sigma_x, \sigma_y, \sigma_z\) is linked to the atmospheric stability, wind speed and the distance from the leakage source. Practical, the diffusion coefficient \(\sigma_x, \sigma_y, \sigma_z\) is often determined by an approximate estimation method. Firstly, the atmospheric stability is determined by the sunshine intensity, cloud amount and wind speed of the current environment, and then the diffusion coefficient is
determined according to the atmospheric stability table. According to Pasquell's classification method, with the increase of stable line of meteorological conditions, the atmospheric stability can be divided into six categories: A, B, C, D, E and F. Among them, A represents the most unstable meteorological condition, and F represents the moderately stable meteorological condition. Underground coal mine belongs to a unique environment, there is not any radiation in the underground roadway, and the underground atmospheric stability is treated approximately. In view of the general wind speed in the coal mine is about 2m/s, the atmospheric stability of the coal mine roadway is selected as grade E, and the mathematical expression of the diffusion coefficient $\sigma_y$, $\sigma_z$ is determined according to the P-G diffusion curve method, as shown in formula (2) and formula (3):

$$\sigma_y = \frac{0.06 x}{(1 + 0.0001x)^{0.5}}$$  \hspace{1cm} (2) \\
$$\sigma_z = \frac{0.03 x}{(1 + 0.0003x)}$$  \hspace{1cm} (3)

3. Model solution based on BP neural network

3.1. Model establishments

BP neural network is a type of multilayer feedforward neural network. The main characteristics of this network are signalled forward transmission and error back propagation. The prediction model of the source term coefficient of harmful gas in coal mine roadway consists of three steps: BP neural network construction, BP neural network training and BP neural network prediction. Firstly, according to formula (1), the BP neural network structure is established, besides that, the diffusion coefficient and gas source intensity are taken as the input parameters of the network system. and the predicted gas concentration is taken as the output parameters; the neural network is trained with the input and output data of nonlinear function to predict the output parameters of the system, that is, the predicted gas concentration.

3.2. Example calculations

Coupled with the measured data of gas concentration in a mine, the feasibility and practicability of neural network algorithm in gas concentration prediction are verified. Set the atmospheric stability as E, the average wind speed at 2m/s, and place 24 sensors in the downwind direction of the leakage source. Specific settings and observe values of the sensors are shown in Tab.1.

| Tab.1 Sensor placement position and observed concentration value |
|------------------|---------|---------|---------|---------|
| Sensor number    | 1       | 2       | ......  | 23      | 24      |
| Sensor position coordinates | 230 | 220 | ...... | 10     | 0       |
| Measured value of concentration | 0.3  | 0.3   | ...... | 0.33   | 0.34   |

In the calculation process of BP neural network, the number of iterations is set to 100, and the learning efficiency is set to 0.2. The trained BP neural network is used to predict the gas concentration value, and the prediction results are presented in Fig.1. Furthermore, the hidden double layer BP neural network is used to predict, and the output results are shown in Fig.2.
Compared with Fig.1 and Fig.2, double hidden layer has strong generalization ability and high prediction accuracy. The above analysis verifies the feasibility of BP neural network algorithm in addressing the issue of gas concentration. The algorithm can obtain the concentration information quickly and accurately, which is appropriate to the needs of emergency rescue decision-making. However, although BP neural network has superior fitting ability, there are still some errors in the network prediction results. When the grid accuracy meets the requirements, a single hidden layer can be chosen to speed up the prediction. Based on the limitation of traditional BP neural network algorithm, genetic algorithm is used to optimize BP neural network in order to get better prediction results.

4. Model optimization using genetic algorithm

4.1. Establishment of genetic algorithm model

Genetic algorithm is a parallel random search optimization method, which is formed by simulating natural genetic mechanism and biological evolutionary theory. BP neural network optimized by a genetic algorithm is divided into three parts: BP neural network structure determination, genetic algorithm optimization and BP neural network prediction. In structure determination part of BP neural network, it is determined by the input and output parameters of Gaussian plume model, and then the individual length of genetic algorithm is determined. Genetic algorithm optimizes the weight and threshold value of BP neural network. Each individual in the population contains a network ownership value and threshold value, and calculates individual fitness value through the fitness function. Genetic algorithm finds the characteristic corresponding to the optimal fitness value through selection, crossover and mutation operations. The optimal individual obtained by the genetic algorithm is used to assign the initial weight and the threshold value of the network by a BP neural network prediction, and the prediction function is output after the network training.

It can be seen from the Gaussian plume model and the gas concentration to be predicted that the individual coding method adopts the real number coding, uses the training data to train the BP neural network and then forecasts the system output, and takes the absolute value of the error between the source intensity prediction output and the field measured value as the individual fitness value $K$, namely:

$$K = k \left( \sum_{i=1}^{m} \text{abs}(q_i - o_i) \right)$$  \hspace{1cm} (4)

Where, $m$ is the number of network nodes, $q_i$ is the expected output of the $ith$ node of BP neural network, $o_i$ is the predicted output of the $ith$ node, and $k$ is the coefficient. The roulette method is used in the selection operation of the genetic algorithm, and the real number crossover method and mutation operation are used to individuals. The algorithm flow is illustrated in Fig.3.
4.2. Example calculations

The experimental environment and data are similar to above. In the genetic algorithm optimization BP neural network algorithm, the population size is 30, the crossover probability is 0.3, and the mutation probability is 0.2. The optimal initial weight and threshold are assigned to the neural network, and the gas concentration is predicted after 50 time of training with the training data. The prediction results are presented in Fig.4, and the errors of the predicted output and the expected output are shown in Fig.5. It can be seen from the figure that in the early iteration process, the optimal prediction value and Gaussian plume diffusion model is improved, and gradually tend to be stable as they approach the ideal value, and finally the optimal prediction value is obtained. The change of the individual optimal fitness value in the optimization process of the genetic algorithm is shown in Fig.6. The individual optimal fitness value calculated is 0.296, and the optimal individual is [14.09, 5.98]. The optimal individual fitness value is very close to the actual measurement value of 0.3, and the corresponding diffusion coefficient calculation value, (13.64, 6.45), which shows the effectiveness of the method.

Comparing the two calculation methods, it can be seen that the prediction of BP neural network optimized by a genetic algorithm is more accurate, and it can get the gas concentration prediction in coal mine roadway more quickly and accurately. Although the time and iteration times of the two methods are different, both of them can meet the accuracy requirements and can be applied to the prediction of gas concentration in the roadway, and the prediction effect of the BP neural network optimized by genetic algorithm is higher.
5. Conclusion
Based on the Gauss plume model of atmospheric diffusion, this paper constructs the Gauss plume model of gas diffusion in coal mine roadway combined with the gas environment factors, and solves the model by using BP neural network optimized by genetic algorithm, so as to obtain the best gas concentration information in a short time and with a small error. Compared with the traditional gas prediction method, this one has the advantages of small calculation amount, high prediction accuracy, and it can improve the reliability of the model by continuous machine learning combined with daily monitoring, which provides a feasible technical choice for the intelligent detection of gas environment in the daily inspection and emergency rescue of coal mine.

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