Study on gas emission prediction of working face based on GM (1, 1) model

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Abstract. At present, the prediction method of gas emission in coal mining face has low precision, based on grey system theory system, grey GM (1, 1) gas emission prediction model is constructed, the real-time, dynamic and non-linear prediction of gas emission is realized, and the application test is carried out in a mine of Huainan mining area. The results show that the average relative error between the predicted value and the measured value is 6.14%, the predicted Index C value is 0.48, P value is 0.90, and the prediction accuracy reaches the second level, which may guide the real-time, dynamic and accurate prediction of gas emission in the coal face.

1. Introduction

With the continuous development of China's economy, the demand for coal energy is increasing year by year, and the mining depth and output of the mine are increasing gradually. Typical dynamic disasters such as coal and gas outburst and rock burst occur frequently, which cause serious consequences and threaten the safe production of the mine [1]. Gas disaster is the "first killer", a series of safety production problems caused by gas need to be solved. The design of ventilation network system, the design of gas drainage system and the formulation and implementation of gas disaster prevention measures all need the prediction of gas emission. Therefore, to improve the accuracy of gas emission prediction results is of great significance to improve the safety and efficiency of mine production.

At present, the prediction methods of gas emission mainly include mine statistics method, separate source prediction method, speed prediction method, analogy method, gas geological mathematical model, etc. With the increasing demand for coal in China, the mining depth of the mine is increasing, and the factors affecting the gas emission are more and more complex. There is a very complex nonlinear relationship between the gas emission and the influencing factors. But the linear prediction method can not predict the actual change of gas emission truly and accurately [2-4]. Based on this, this paper uses the grey system theory to predict the gas emission non-linear.

2. Establishment of grey GM (1,1) model

Grey GM (1,1) prediction model is a first-order one variable grey prediction model based on grey theory. When using this model to predict the development and change trend of system safety accidents, it does not need a large number of statistical data, it does not need to list all the factors that affect the accidents,
but only needs to explore the internal changes of accidents according to the changes of the characteristics of coal mine accidents in time and space. Grey theory has the advantages of less modeling data, simple calculation and higher prediction accuracy [5].

The grey GM (1,1) modeling process used in this paper mainly includes: determining the original sequence of the system, grey accumulation generating operation (AGO Technology), and establishing differential equations.

2.1. Determine the original sequence of the system
The original sequence of the analysis system is equation (1).

\[
\begin{align*}
\{x(0)\} &= \{x(0)(1), x(0)(2), \ldots, x(0)(n)\} \\
\end{align*}
\]

2.2. Grey accumulation generating operation (AGO Technology)
A new sequence is obtained by accumulating the original sequence, weakening the randomness of the data and enhancing the regularity among the factors of the system \(x^{(i)}(k)\).

\[
\begin{align*}
\{x^{(i)}\} &= \{x^{(i)}(1), x^{(i)}(2), \ldots, x^{(i)}(n)\} \\
\end{align*}
\]

\[
\begin{align*}
k &= 1, 2, \ldots, n \\
x^{(i)}(k) &= \sum_{m=1}^{k} x^{(0)}(m) \\
\end{align*}
\]

2.3. Establishing differential equations
The differential equation of GM (1,1) grey model is:

\[
\begin{align*}
d^{(i)}(k) + aX^{(i)}(k) &= u, \quad k = 1, 2, \ldots, n \\
\end{align*}
\]

In style: \(a, u\) is constant; \(d^{(i)}(k)\) is grey derivative.

\[
\begin{align*}
d^{(i)}(k) &= x^{(0)}(k), \quad X^{(i)}(k) = Z^{(i)}(k), \quad Z^{(i)}(k) = 0.5 \cdot x^{(i)}(k) + 0.5 \cdot x^{(i)}(k-1) \\
\end{align*}
\]

The whitening equation of GM (1,1) grey differential equation is equation (5).

\[
\begin{align*}
\frac{dx^{(i)}}{dt} + ax^{(i)} &= u \\
\end{align*}
\]

Using the least square method to solve the coefficient to be determined, assuming that the parameter vector is \(\hat{a} = [au]^T\), it can be obtained:

\[
\hat{a} = (B^T B)^{-1} B^T Y_n \\
\]

Among:

\[
B = \begin{bmatrix}
-Z^{(i)}(2) & 1 \\
-Z^{(i)}(3) & 1 \\
\ldots & \ldots \\
-Z^{(i)}(n) & 1 \\
\end{bmatrix}
\]

\[
y_n = \begin{bmatrix}
X^{(0)}(2) \\
X^{(0)}(3) \\
\ldots \\
X^{(0)}(n) \\
\end{bmatrix}
\]

Thus, the solution of equation (6) is obtained, that is, its response formula is equation (7), (8).
\[ X(k+1) = X(k+1) - X(k) \tag{8} \]

The constant in the model becomes the development coefficient, which reflects the development trend of \( X^{(1)} \) and \( X^{(0)} \). \( u \) is called ash dosage. Its size reflects the changing relationship of data, which is equivalent to the dosage in the system.

If the error between the simulated value and the actual value meets the accuracy requirements, the model can be used for system prediction. See Tab 1 for inspection formula.

**Tab. 1** Error test calculation formula

| Residual | Raw data |
|----------|----------|
| Mean deviation \( \bar{e} = \frac{1}{n} \sum_{i=1}^{n} e_i^{(0)} \) | \( \bar{X} = \frac{1}{n} \sum_{i=1}^{n} X_i^{(0)} \) |
| Variance \( s_1^2 = \frac{1}{n} \sum_{i=1}^{n} (e_i^{(0)} - \bar{e}) \) | \( s_2^2 = \frac{1}{n} \sum_{i=1}^{n} (X_i^{(0)} - \bar{X}) \) |
| Posttest ratio C | \( C = \frac{s_1}{s_2} \) |
| Small error probability P | \( P = P \left\{ (e_i^{(0)} - \bar{e}) < 0.6745s_2 \right\} \) |

Among them, the accuracy inspection grades of C and P indexes are shown in Tab 2.

**Tab. 2** Accuracy inspection level

| Prediction accuracy level | P | C |
|---------------------------|---|---|
| Good (Level 1)            | > 0.95 | < 0.35 |
| Qualified (Level 2)       | > 0.8 | < 0.5 |
| Reluctantly (Level 3)     | > 0.7 | < 0.65 |
| Unqualified (Level 4)     | ≤ 0.7 | ≥ 0.65 |

3. Application example
Using the grey GM (1,1) model, the gas emission of a coal mine driving face in Huainian mining area is predicted. Fig 1 shows the 35 day monitoring data of gas emission in the driving face of the coal mine. The former 28 groups of data are fitting samples, and the latter 7 groups of data are prediction samples to predict the gas emission in the working face.

![Fig. 1 Change curve of gas emission](image-url)
According to the modeling steps of the grey GM (1,1) model, the gas emission is the analysis sequence of the system. Use the grey ago technology to carry out the first-order cumulative generation operation of the gas emission, and calculate the Z value, as shown in Tab 3.

Tab. 3 Calculation result of Z value

| k | \( Z^{(1)} \) | k | \( Z^{(1)} \) | k | \( Z^{(1)} \) | k | \( Z^{(1)} \) |
|---|---|---|---|---|---|---|---|
| 1 | -4.28 | 8 | -20.75 | 15 | -34.86 | 22 | -54.41 |
| 2 | -6.67 | 9 | -22.94 | 16 | -36.85 | 23 | -53.28 |
| 3 | -8.84 | 10 | -24.86 | 17 | -38.97 | 24 | -56.16 |
| 4 | -11.22 | 11 | -26.78 | 18 | -41.23 | 25 | -59.04 |
| 5 | -13.53 | 12 | -28.70 | 19 | -43.49 | 26 | -61.85 |
| 6 | -15.84 | 13 | -30.61 | 20 | -45.41 | 27 | -64.83 |
| 7 | -18.29 | 14 | -32.74 | 21 | -47.60 | 28 | -67.57 |

Using MATLAB software to calculate the whitening parameter sequence value of each model is \( a = -0.0274, u = 1.5216 \).

According to equation (8), the whitening response formula is as follows:

\[
X(k+1) = 58.45e^{0.0274k} - 55.53
\]

According to the calculation results, the prediction results of gas emission are shown in Tab 4, the comparison between the predicted value and the actual value is shown in Fig 2, and the error curve of the prediction results is shown in Fig 3.

Tab. 4 Prediction value of gas emission

| k | Predictive value | k | Predictive value | k | Predictive value | k | Predictive value |
|---|---|---|---|---|---|---|---|
| 1 | 2.92 | 8 | 2.31 | 15 | 2.13 | 22 | 2.81 |
| 2 | 2.32 | 9 | 2.37 | 16 | 2.06 | 23 | 2.89 |
| 3 | 2.07 | 10 | 2.02 | 17 | 2.13 | 24 | 2.97 |
| 4 | 2.12 | 11 | 2.08 | 18 | 2.20 | 25 | 3.05 |
| 5 | 2.16 | 12 | 2.14 | 19 | 2.27 | 26 | 3.13 |
| 6 | 2.21 | 13 | 2.01 | 20 | 2.34 | 27 | 2.76 |
| 7 | 2.26 | 14 | 2.07 | 21 | 1.93 | 28 | 3.31 |

Fig. 2 Comparison of gas emission results
According to the analysis of Tab 4 and Fig 2, the prediction results of the prediction model are basically consistent with the overall change trend of the actual gas emission in the driving face. It fully shows that the prediction model can meet the prediction of the dynamic trend of gas emission.

According to the analysis of Figure 3, the prediction error of gas emission is relatively large in the early and later stages, with an average relative error of 6.14%.

![Fig. 3 Prediction error curve of gas emission](image)

The prediction accuracy of grey GM (1, 1) prediction model is tested, and the results are shown in Tab 5.

| Inspection index | C   | P   | Accuracy grade |
|------------------|-----|-----|----------------|
| Numerical value  | 0.48| 0.90| Level 2        |

It can be seen from Tab 5 that the posterior error ratio of GM (1, 1) model of gas emission is 0.48, and the small error probability is 0.90; according to Tab 2, the prediction accuracy of the prediction model reaches the second level, which can meet the demand of real-time, dynamic and accurate prediction of gas emission in the working face.

4. Conclusion

1) With the increasing demand for coal in China, the mining depth of the mine is increasing, and the factors affecting the gas emission are more and more complex. There is a very complex nonlinear relationship between the gas emission and the influencing factors. The original linear prediction method can not truly and accurately predict the actual change of the gas emission.

2) The established grey GM (1,1) prediction model is applied to the prediction of gas emission in coal mine, which has high prediction accuracy, can reflect the change of gas emission in driving face, and can realize real-time and dynamic prediction.

Acknowledgments

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