Research on fractal features of time series of gas emission from working face

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Abstract. In order to improve the accuracy of the prediction of gas emission from coal mining face, in view of the multiple correlation and complexity of the influencing factors of gas emission from working face, the R/S analysis method was used to establish the calculation method of the fractal of the time series of gas emission from working face. The Hurst index and R/S fractal dimension of the time series of gas emission from the working face were calculated, and the correlation between the Hurst index and R/S fractal dimension and the prominent hazard was explored. And the N2709 working face of Songzao Yuyang Coal Mine was taken as an example for application practice. The research results show that the Hurst index of the time series of gas emission from N2709 working face is 0.5432, and the fractal dimension D is 1.4568. In the area of no dynamic phenomena, Hurst is generally greater than 0.5, and R/S fractal dimension is generally less than 1.5. However, when entering the dynamic phenomenon area, the Hurst index is mostly less than 0.5, and the R/S fractal dimension is generally greater than 1.5.

1. Introduction
China is one of the countries with the most serious coal and gas outburst disasters [1]. Coal and gas outburst is an extremely complex dynamic phenomenon. It can spray a large amount of gas and crushed coal from the coal body to the roadway or stope in a very short time, forming a special-shaped cavity in the coal body. And it will form a huge dynamic effect, such as wind current retrograde, toppling minecarts and so on. The pulverized coal sprayed out during the outburst can fill hundreds of meters of roadways, and the sprayed gas-pulverized coal flow sometimes has a storm-like nature, and the gas can run against the wind to fill thousands of meters of roadways.

Because the outburst is a complex nonlinear dynamic behavior, and the formation conditions, evolution process and inducing factors of gas outburst have the characteristics of diversity, complexity and randomness. Therefore, the dynamic behavior of the time series data of gas emission from the working face shows the unity of determinism and randomness [2,3]. In recent years, chaotic dynamics has been introduced into the study of prediction of gas emission from working face, and it has become
a research hotspot [4]. Wang Kai [5], Huang Wenbiao [6] and others established a chaotic time series prediction model of gas emission based on the largest Lyapunov exponent. Shan Yafeng et al. [7] used the improved extreme learning machine (IELM) chaotic time series prediction model to predict the amount of gas emission. The maximum relative error predicted by the prediction model is 3.2902%, the minimum relative error is 0.898 2%, and the average relative error is 1.952 8%. Ren Haifeng et al. [8] established a SAPSO-ELM model of gas emission from a coal face using simulated annealing particle swarm optimization (SAPSO), and verified and predicted the gas emission from a coal mining face in Shanxi. The results showed that: the average relative error of the SAPSO-ELM model is 3.45%.

With the development of research, fractal theory has been applied to the research in this area [2,9-13]. Fractal mathematical analysis and traditional mathematical statistics analysis of gas emission data are actually a sequential analysis method, but in some cases, the gas emission evolves over time and has irregular oscillations. These seemingly random, non-linear time series have encountered severe challenges to the usual mathematical statistical methods. The fractal mathematical method is used to analyze the gas emission characteristics of the tunneling face for a period of time, which makes up for the shortcomings of the conventional mathematical statistical methods. Therefore, based on this, this paper uses the R/S analysis method to conduct an in-depth study on the fractal characteristics of the time series of gas emission from the working face, and explores the relationship between the Hurst index and the R/S fractal dimension and the prominent hazard.

2. Calculation method of fractal dimension of time series

2.1. Basic principle

A fractal is a shape in which the part and the whole are similar in some way [14]. Fractals have the following characteristics: Self-similarity, Scale invariance (no characteristic length), Hierarchical and recursive, Self-affine, Fractal element-initial element-generator. Fractal dimension, as the quantitative characterization and basic parameter of fractal, is another important principle of fractal theory. Fractal dimension, also known as fractal dimension or fractal dimension, is usually expressed as a fraction or a number with a decimal point.

There are many calculation methods for fractal dimensions, mainly including the compass method to find the fractal dimension of the curve, the Hurst index and the R/S analysis method to find the fractal dimension of the rough curve [15,16]. Hurst index and R/S analysis method are one of the main methods used to analyze the fractal dimension of the fractional Brownian motion curve.

Suppose the time series curve is:

\[ X(t, \tau) = \sum_{(t=1,2,\cdots, \tau)} [B(t) - B(\tau)] \quad (t = 1,2,\cdots, \tau) \quad (1) \]

\[ R(\tau) = \max X(t, \tau) - \min X(t, \tau) \quad (t \leq \tau) \quad (2) \]

\[ S(\tau) = \left[ \frac{\sum (B(t) - B(\tau))^2}{\tau} \right]^{1/2} \quad (1 \leq t \leq \tau) \quad (3) \]

Where, \( B(t) \) is the records within the time curve \( (t = 1,2,\cdots, \tau) \). \( B(\tau) \) is the average value within \( \tau \) time. \( X(t, \tau) \) is the cumulative amount of difference at time t. \( R(\tau) \) is the range. \( \tau \) is the total time.

It is obtained that the \( R(\tau) / S(\tau) \) rises generally monotonously with time, and has the following power function relationship with \( \tau \):

\[ R(\tau) / S(\tau) \sim \tau^H \quad (4) \]

Here H can also be the Hurst exponent H from the slope of the straight line on the logarithmic graph of \( R(\tau) / S(\tau) \) and \( \tau \). The fractal dimension of the time series curve \( D=2-H \).
2.2. Hurst exponent and R/S fractal dimension calculation algorithm implementation steps

Hurst exponent and R/S fractal dimension calculation algorithm implementation steps are as follows:

1. Import the time series data into the Matlab software workspace, find the average value, and calculate the variance sequence, use the cumsum function to find the cumulative sum vector of the variance, and find the average of the ratio of the range to the standard deviation. In this step, the entire time series is used as a sub-sequence to find the average rescaling range value.

2. Divide the sequence into 2 sub-sequences and repeat the above steps to find the rescale range value again.

3. Divide the entire time series into 3, 4, ..., and finally stop the calculation according to the dimension of the sub-sequence is no longer greater than a given threshold.

4. Take the logarithm of the number of divided subsequences and the obtained corresponding rescaled range value to form a pair of coordinate points in double logarithmic coordinates. The least squares fitting function is used to fit these points, and the slope of the fit is calculated. This value is the Hurst value.

5. According to the Hurst value, the R/S fractal dimension D can be obtained, that is, D=2-Hurst value.

3. Fractal characteristics of gas emission time series

3.1. The fractal dimension of the gas emission monitoring time series curve

The gas emission of the tunneling face has a certain regularity under normal conditions, but when it is in a prominent dangerous area, the gas emission will be found to be abnormally disordered, so that the emission data presents a chaotic phenomenon. Therefore, taking each work shift or a certain time and a certain process as the time section, and making the time sequence fractal of this time period, the degree of disorder of the gas emission can be obtained to a certain extent. The closer the fractal dimension is to 2, the more disordered the gas gushing and the greater the risk of protruding, and vice versa.

Take N2709 working face of Songzao Yuyang Coal Mine as a column, the gas emission monitoring data of each shift (8 hours, 480 minutes) is defined as a set of data, and the fractal dimension of the gas emission monitoring curve is calculated using Hurst index and R/S analysis method, as shown in Figure 1. The Hurst index of the gas monitoring curve in Figure 1 and the curve fractal dimension obtained by the R/S analysis method are shown in Figure 2.

It can be seen from Figure 2 that the Hurst index of the gas monitoring data curve in Figure 1 is 0.5432 and the fractal dimension D is 1.4568 using Hurst index and R/S analysis method.

![Figure 1. Monitoring data of shift gas emission](image)
3.2. The relationship between Hurst index and R/S fractal dimension D and outstanding hazards

Hurst index and R/S fractal dimension are currently the most commonly used methods for calculating the fractal dimension of time series. When Hurst index $H=0.5$, the time series $\{B(t)\}$ is a disorderly independent random sequence, without time series correlation, and historical data cannot be used to predict the future. If $0 \leq H < 0.5$, then $\{B(t)\}$ is an anti-persistent sequence, that is, the time sequence has an upward trend before, then there will be a downward trend in the future. If $0.5 < H \leq 1$, the opposite is true, and the time series $\{B(t)\}$ has long-term memory, which is expressed as a fractal time series, that is, the future and the past present the same trend of change.

R/S fractal dimension $D=2-H$.

Similarly, the Hurst index and R/S fractal dimension of the gas emission data before and after the nozzle hole at 309.1 meters from the west return wind of N2709 are shown in Figure 3 and Figure 4.
Figure 3. The Hurst index before and after the nozzle hole at 309.1 meters of the west return wind of N2709

Figure 4. R/S fractal dimension before and after the nozzle hole at 309.1 meters from the west return wind of N2709

It can be seen from Figure 4 that in the area of no dynamic phenomenon, Hurst is generally greater than 0.5, R/S fractal dimension is generally less than 1.5, gas emission is more orderly, and there is a longer time memory for gas emission from working face, which is expressed as fractal time Sequence, that is, the future and the past present the same trend of change. However, when entering the dynamic phenomenon area, the Hurst index is mostly less than 0.5, and the R/S fractal dimension is generally
greater than 1.5. The gas emission is relatively chaotic, and the gas emission from the working face shows an anti-persistent sequence. That is, the development trend of gas emission is contrary to the current basic state of gas emission. However, the dividing line between the prominent danger zone and the non-prominent danger zone is obviously not clear enough.

4. Conclusion
(1) Using the R/S analysis method, the fractal analysis method of the time series of gas emission from the working face is established, and the Hurst index and R/S fractal dimension of the time series of gas emission are calculated. Taking the N2709 working face of Songzao Yuyang Coal Mine as a column, the Hurst index of the time series of gas emission from the working face is 0.5432, and the fractal dimension D is 1.4568.

(2) The relationship between the Hurst index and R/S fractal dimension of Songzao Yuyang Coal Mine N2709 face and the outburst hazard was explored. In the area of no dynamic phenomenon, Hurst is generally greater than 0.5, R/S fractal dimension is generally less than 1.5, gas emission is more orderly, and there is a longer time memory for gas emission from working face, which is manifested as a fractal time series. However, when entering the dynamic phenomenon area, the Hurst index is mostly less than 0.5, and the R/S fractal dimension is generally greater than 1.5. The gas emission is relatively chaotic, and the gas emission from the working face shows an anti-persistent sequence.

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