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Model of Gas Concentration Forecast Based on Chaos Theory

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Abstract

By means of chaos system predictability in the short term, model of coal gas concentration forecast was constructed. Based on Takens theorem, the phase space was reconstructed from the time series of gas concentration, and the optimal time delay and embedding dimention was proposed by using C-C arithmetic. In high dimention phase space, the model of gas concentration forecast using add-weighted one-rank local-region method was constructed, the real gas concentration data was analyzed, and the future data of the coal mine were forecasted. The results show that maximum Lyapunov exponent is 0.049, the time series is chaotic, and in the phase space, time delay is 7, embedding dimention is 2, the model parameter a is 0.0228, b is 1.0859, the relative error is -0.2~0.2, and RMSE(root mean square error) is 0.0423. The predictive results tally with the real ones, which can be used to forecast the coal gas concentration in the short future.

Keywords: chaos; gas concentration; reconstructed phase space; weighted one-rank local-region method

1. Introduction

Gas explosion is one of the major disasters threatening coal mines. Prediction of gas concentration change trend and adoption of corresponding measures to prevent gas concentration is the effective means to prevent gas explosions. At present, gas concentration prediction methods include statistics prediction

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method[1,2], nonlinear prediction method[3,4] and integration method[5]. The nonlinear prediction method dominates. Chaos theory is widely applied in the field of electric load, stock prices and slope displacement, etc.[6]. NIE Bai-sheng et al[7] analyzed the characteristics of electromagnetic emission and acoustic emission in coal and rock fracturing. CHENG Jian[8], CUI Xiaoyan et al[9] successfully applied the chaos theory in gas prediction. Reasonable selection of time delay τ and embedding dimension m is the key to correct prediction. This paper employed C-C arithmetic in simultaneously determining time delay τ and embedding dimension m, and used weighted one-rank local-region method to establish gas concentration prediction model used to predict the changing trend of gas concentration in a short period. The research is of important significance to preventing gas explosions in coal mines.

2. Identification of Chaos

The gas concentration prediction method targets only at the time series of chaos. Hence, it is necessary to identify the chaos of times series of gas concentration before prediction is made. Lyapunov index represents the average index percent in which the system converges or diverges between neighboring orbits of the phase space. A positive Lyapunov index means that the orbis in the phase space rapidly separate, long time behavior is sensitive to initital conditions, and motion is in chaos state[6]. Therefore, whether maximal Lyapunov index is larger than zero can be taken as the criterion to judge whether time series is chaos series.

Small data amount method is used to compute maximal Lyapunov index with the following steps[10]:

(1) Perform FFT transform for the gas concentration time series $x(1),x(2),\cdots,x(N)$, and estimate average period P through the derivative of the average power of energy spectrum.

(2) Reconstruct the phase space of time series according to time delay τ and embedding dimension m.

$$X_i=[x(i),x(i+\tau), x(i+2\tau),\cdots, x(i+(m-1)\tau)] \tag{1}$$

Where, $i=1,2,\cdots,M$, M is phase point number, $M=N-(m-1)\tau$.

(3) Look for the closest point $X_{\hat{i}}$ of each point Xi in the phase space, and restrict temporary separation, namely

$$d_i=\min_i\|X_i-X_{\hat{i}}\|,\quad |i-\hat{i}|>P \tag{2}$$

(4) As for each point Xi in the phase space, compute the distance between its neighboring point and the j[th] discrete time step $d_i(j)$

$$d_i(j)=|X_{i+j}-X_{\hat{i}+j}| \tag{3}$$

Where, $j=1,2,\cdots,\min(M-i,M-\hat{i})$

(5) As for each j, solve the mean value $y(j)$ of $\ln d_i(j)$ of all i

$$y(j)=\frac{1}{q\cdot\Delta t}\sum_{i=1}^{q}\ln d_i(j) \tag{4}$$