Application of fuzzy cluster in prediction coal and rock dynamic disasters

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Abstract

Fuzzy mathematics is introduced in fuzzy cluster, and the fuzzy relation between samples is quantified in fuzzy cluster, so fuzzy cluster is more objective and accurate. Fuzzy clustering is applied in coal and gas outburst prediction in the paper. The drilling cuttings desorption index K\textsubscript{1}, maximum drilling cuttings quantity S, electromagnetic radiation intensity maximum etc index of different place are considered in the classification, and different categories is classified according to different levels of intercept. According to analogy, coal seam can be judged if it is outburst coal seam. The study can provide reference for coal and gas outburst prediction.

Key words: fuzzy cluster; coal and gas outburst; index

1 Introduction

Clustering is classifying samples that have no class markers into different class according to certain standards, and the purpose of cluster is that similar sample is in the same class and different sample is classified into different class. Clustering is a method classifying samples according certain standard. Fuzzy cluster introduces fuzzy mathematics into cluster, and is a multivariate statistical method about classification. The basic idea of fuzzy cluster is constructing fuzzy matrix according to attributes of research object, and on this basis clustering relation is determined according to certain subordinate relations\textsuperscript{[1-2]}. 

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Coal and gas outburst is one of natural disasters seriously threatened safety production of coal mine. Reliable and accurate prediction of coal and gas outburst is an important research subject of coal mine safety technology. Many scholars at home and abroad put forward multiple prediction methods after extensive research: single index method, gas geology statistics method comprehensive index D and K method, drilling cuttings index method, borehole gas emission initial velocity method, R value comprehensive index method and grey forecasting method, spherical shells instability method and electromagnetic radiation method[3-4]. Because coal mining process system is complexity and uncertainty, there are many factors affecting coal and gas outburst, and outburst is complex dynamic process which is affected by combined action of gas, stress and coal physical and mechanical properties, and probably there are other influence parameters which has not been recognized. In the actual production process, it is difficult to determine which prediction indexes is important, and influence degree of every index to coal and gas outburst is fuzzy and uncertain. So it is difficult to determine the possibility and dangerous level of coal and gas outburst if one or several indexes are used to predict coal and gas outburst. Sometimes one or several indexes exceed critical value, but coal and gas outburst don't happen. However, sometimes one or several indexes are below critical value, but coal and gas outburst happen. To solve this problem, fuzzy cluster based on equivalence relation method is used to classify indexes of different site. Many indexes of different site are considered in the cluster, and different group is determined according to different intercept. This method considers different prediction indexes, which can provide reference for coal and gas outburst prediction.

2. Principle of fuzzy cluster based on equivalence relation

2.1 principle of cluster

Supposed R is equivalence relation on set \( X = \{ x_1, x_2, \cdots, x_n \} \), set \( X \) is class which is composed by equivalence relation \( R \), and the both don't intersect each other. Because fuzzy equivalence relation \( \tilde{R} \) is a fuzzy set on discourse domain \( X \) Descartes product \( X \times X \). However any \( \lambda \) \((0 \leq \lambda \leq 1)\) cut set \( \tilde{R}_\lambda \) of fuzzy set is common set on \( X \times X \), and it is common equivalence relation of \( X \), which can get one of class of object elements in \( X \). When \( \lambda \) decrease from 1 to 0, the class can become from thin to thick, which can form dynamic cluster hierarchical diagram[5-6].

2.2 Method and step of cluster

2.2.1 data normalization

In actual application, object data of cluster is complex in general, and the date is not in \([0, 1]\) region. So data to be clustered must be normalized first. Supposed the object to be clustered is \( n \) in total, each dimension characteristic \( x_k \) have \( n \) origin data supposed \( x_{1k}', x_{2k}', \cdots, x_{nk}' \), which can be called \( n \) element of the characteristics. In order to standardize data, average and variance must first be computed, which is shown as equation(1) and equation(2).

\[
\bar{x}_k' = \frac{1}{n} \sum_{i=1}^{n} x_{ik}' \quad (1)
\]

\[
S_k^2 = \frac{1}{n} \sum_{i=1}^{n} (x_{ik}' - \bar{x}_k')^2 \quad (2)
\]

Then normalized date \( x_{ik}'' \) of each date can be get from the following equation:

\[
x_{ik}'' = \frac{x_{ik}' - \bar{x}_k'}{S_k} \quad (3)
\]
The normalized date $x_{ik}$ is not necessarily in $[0, 1]$ closed interval. In order to compression normalized data to $[0, 1]$ closed interval, extremum standardization formula can be used:

$$x_{ik} = \frac{x_{ik} - x_{kmin}}{x_{kmax} - x_{kmin}} \quad (4)$$

In the equation, $x_{kmax}$ and $x_{kmin}$ represent respectively maximum date and minimum date of $x_{1k}$, $x_{2k}$, \ldots, $x_{nk}$.

2.2.2 Establishing fuzzy similarity relation

Establishing equivalence relation is calculating similarity statistics of each classification object. Fuzzy similarity relation $\tilde{R}_s$ on classification object set $X$ should be established first.

$$\tilde{R}_s = [r_{ij}]_{n \times n} \quad (5)$$

In the equation, $r_{ij}$ represents degree of similarity between classification object $x_i$ and $x_j$, $0 \leq r_{ij} \leq 1$.

Common methods to calculate similarity statistics are angle cosine method, volume integral method, correlation coefficient method, index similarity coefficient method, maximum and minimum method, arithmetic average minimum method, geometric mean minimum method. Angle cosine method is used in the paper, and other methods will not be discussed in the paper. It is calculated as followed:

$$r_{ij} = \frac{\sum_{k=1}^{s} x_{ik} x_{jk}}{\sqrt{\sum_{k=1}^{s} x_{ik}^2} \sqrt{\sum_{k=1}^{s} x_{jk}^2}} \quad (6)$$

In the equation $i, j = 0, 1, \ldots, n$, $x_{ik}$ represents $K$ dimension characteristic of $x_i$.

2.2.3 Transform and clustering

After obtaining fuzzy similarity relation $\tilde{R}_s$ of classification set $X$, $\tilde{R}_s$ should be further transformed into fuzzy equivalence relation. Fuzzy similarity relation $\tilde{R}_s$ is transformed into fuzzy equivalence relation $\tilde{R}_e$ in the step. Specific method is to construct transitive closure to form similarity relations to do compositional operations:

$$\tilde{R}_e^2 = \tilde{R}_s \circ \tilde{R}_s, \quad \tilde{R}_e^4 = \tilde{R}_s^2 \circ \tilde{R}_s^2, \quad \ldots (7)$$

In the end, there must be a natural number $K$ making $\tilde{R}_s^K = \tilde{R}_s^K \circ \tilde{R}_s^K$. This is a fuzzy equivalence relation. On this basis, we can get different level clustering.

3 Application and analysis of results
In this example, 12 group monitoring results from 12 working face are used, as is shown in Table 1. Conventional prediction methods include drilling cuttings desorption index K1 and maximum drilling cuttings quantity Smax.

Electromagnetic radiation method is proposed by He Xueqiu from China University of Mining and Technology. Electromagnetic radiation is radiate electromagnetic energy process or physical phenomena when coal deformation and fracture. Electromagnetic radiation can reflect comprehensive information of coal and gas outburst.

Maximum electromagnetic radiation intensity Emax, average electromagnetic radiation intensity Eavg and average pulse of electromagnetic radiation Navg are used in the example. Electromagnetic radiation intensity E reflects actual electromagnetic radiation intensity caused by different gas pressure and stress of the working face, number of pulses is set by the threshold value to calculate rock damage frequency statistic of working face [7-9].

| No. | K1 (mL/(g.min1/2)) | Smax (N/m) | Emax (mV) | Eavg (mV) | Navg (Hz) |
|-----|------------------|------------|-----------|-----------|-----------|
| X1  | 0.4              | 42         | 17        | 16        | 11828     |
| X2  | 0.3              | 32         | 19        | 16        | 18608     |
| X3  | 0.2              | 19         | 20        | 13        | 49217     |
| X4  | 0.2              | 22         | 17        | 16        | 77808     |
| X5  | 0.3              | 32         | 20        | 16        | 40400     |
| X6  | 0.37             | 32         | 21        | 16        | 13510     |
| X7  | 0.21             | 26         | 20        | 16        | 78792     |
| X8  | 0.4              | 30         | 40        | 20        | 50000     |
| X9  | 0.12             | 18         | 12        | 16        | 55139     |
| X10 | 0.38             | 24         | 19        | 16        | 32881     |
| X11 | 0.15             | 26         | 50        | 40        | 14699     |
| X12 | 0.45             | 120        | 19        | 16        | 50633     |

According to equivalence principle and method, based on C program, fuzzy equivalent matrix can be obtained after computing. 

\[ R_e = \begin{bmatrix} 1 & 0.985 & 0.867 & 0.867 & 0.953 & 0.985 & 0.867 & 0.941 & 0.867 & 0.963 & 0.603 & 0.853 \\ 0.985 & 1 & 0.867 & 0.867 & 0.953 & 0.988 & 0.867 & 0.941 & 0.867 & 0.963 & 0.603 & 0.853 \\ 0.867 & 0.867 & 1 & 0.975 & 0.867 & 0.867 & 0.975 & 0.867 & 0.961 & 0.867 & 0.603 & 0.853 \\ 0.867 & 0.867 & 0.975 & 1 & 0.867 & 0.867 & 0.997 & 0.867 & 0.961 & 0.867 & 0.603 & 0.853 \\ 0.953 & 0.953 & 0.867 & 0.867 & 1 & 0.953 & 0.867 & 0.941 & 0.867 & 0.953 & 0.603 & 0.853 \\ 0.985 & 0.988 & 0.867 & 0.867 & 0.953 & 1 & 0.867 & 0.941 & 0.867 & 0.963 & 0.603 & 0.853 \\ 0.867 & 0.867 & 0.975 & 0.997 & 0.867 & 0.867 & 1 & 0.867 & 0.961 & 0.867 & 0.603 & 0.853 \\ 0.941 & 0.941 & 0.867 & 0.867 & 0.941 & 0.941 & 0.867 & 1 & 0.867 & 0.941 & 0.603 & 0.853 \\ 0.867 & 0.867 & 0.961 & 0.867 & 0.961 & 0.867 & 0.961 & 0.867 & 1 & 0.867 & 0.603 & 0.853 \\ 0.963 & 0.963 & 0.867 & 0.867 & 0.953 & 0.963 & 0.867 & 0.941 & 0.867 & 1 & 0.603 & 0.853 \\ 0.603 & 0.603 & 0.603 & 0.603 & 0.603 & 0.603 & 0.603 & 0.603 & 0.603 & 1 & 0.603 & 0.853 \\ 0.853 & 0.853 & 0.853 & 0.853 & 0.853 & 0.853 & 0.853 & 0.853 & 0.853 & 0.853 & 1 & 0.853 \end{bmatrix} \]
When $\lambda = 1$, $X_1 \cdot X_2 \cdot \ldots \cdot X_{12}$ are all in different class. When $\lambda = 0.997$, cutting matrix can be obtained:

$$R_{0.997} = \begin{bmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1
\end{bmatrix}$$

From the matrix, When $\lambda = 0.997$, cluster result is as follow:

$$X = \{X_1\} \cup \{X_2\} \cup \{X_3\} \cup \{X_4\} \cup \{X_5\} \cup \{X_6\} \cup \{X_7\} \cup \{X_8\} \cup \{X_9\} \cup \{X_{10}\} \cup \{X_{11}\} \cup \{X_{12}\}$$

So when $\lambda = 0.997$, $X_4$ and $X_7$ are in the same group, and other data are in different group.

When $\lambda = 0.988$, cluster result is as follow:

$$X = \{X_1\} \cup \{X_2\} \cup \{X_3\} \cup \{X_4\} \cup \{X_5\} \cup \{X_7\} \cup \{X_8\} \cup \{X_9\} \cup \{X_{10}\} \cup \{X_{11}\} \cup \{X_{12}\}$$

Then $\lambda = 0.985, 0.975, 0.963, 0.961, 0.953, 0.941, 0.867, 0.853, 0.603$, different cutting level can get different cluster. Cluster hierarchical graph is as following.
From figure 1, it can be seen that monitor data of different places can be classified into a category in the end. Considered the degree of intimacy, when $\lambda = 0.997$, the monitor data of forth group ($X_4$) and the monitor data of seventh group ($X_7$) is the most similar. In dealing with practical problems, they should be classified as a group. If coal and gas outburst happen in the monitoring place of the fourth groups data ($X_4$), outburst may likely happen in the monitoring place of seventh groups data ($X_7$). It can provide reference for coal and gas prediction. When $\lambda = 0.988$, the monitor data of forth group ($X_4$) and the monitor data of seventh group ($X_7$) is in the same category, and the monitor data of second group ($X_2$) and the monitor data of sixth group ($X_6$) is in the same category, That is to say when dealing with practical problem, second group and sixth group can be considered in the same way.

Fuzzy cluster can provide reference for coal and gas outburst prediction. Monitoring data from places that have happened coal and gas outburst can be clustered with monitor data form place to be predicted. According to cluster result, similar degree between place happened coal and gas outburst and place to be predicted can be determined, which can provide reference for coal and gas prediction. Besides the same group coal seal which is clustered in the method can be managed in the same way.

4 Conclusions

There are lots of methods to predict coal and gas outburst, and it is difficult to determine which index is important. So the importance of the indexes is fuzzy. Each index can be considered comprehensively using fuzzy cluster method, and monitor data of different place can be classified. It can provide reference resources do decide if it is outburst coal seal according to the cluster analysis.

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