

Study on the Prediction Method of Fusion Recognition for Characteristic Information of Coal Spontaneous Combustion

Wei-Feng Wang, Jun Deng, Yuan-Bin Hou, and Nai-Guo Wang

Abstract—To solve the technical problems of identification for the dangerous degree of coal spontaneous combustion, the coal spontaneous combustion process is divided into three stages: slow oxidation, accelerating oxidation and intense oxidation in the paper. The prediction method of fusion identification for characteristic information of coal spontaneous combustion is proposed and the sensitivity index of coal spontaneous combustion degree is determined. The quantitative relationship of the characteristic temperature of coal spontaneous combustion and the gas concentration of each index is determined by polynomial least squares fitting method according to the sample test data. The different feature states are classified by SVM and PSO-SVM algorithm. The criterion of the diagnosis and early warning of coal spontaneous combustion is given according to the results of the data level and feature level. The proposed method can effectively solve the problem of low recognition rate. The experiment shows that the prediction classification accuracy of SVM is 80%, the prediction classification accuracy of PSO - SVM is approximately 100%. The PSO-SVM algorithm can significantly improve the prediction accuracy compared with the traditional method, which provides criterion for the diagnosis and early warning of coal spontaneous combustion. The classification identification of the dangerous degree of coal spontaneous combustion is implemented. It is of great significance and practical application value for improving the level of prevention and control technology of coal spontaneous combustion early hazards.

Index Terms—Coal spontaneous combustion, characteristic information, fusion recognition, prediction method.

I. INTRODUCTION

In recent years, with the continuous development of the shallow coal resources and mine mining strength increase, the scope of goaf is larger and larger, and generates a lot of air leakage passage, mining activity and atmospheric pressure are changed, goaf is dynamic. It is easy to appear

Manuscript received November 17 2016; revised March 28, 2017. This work was supported in part by the financial support National Natural Science Foundation Funded Project (51504186, 51574193), Industrial Technology Research of Shaanxi Province Government (2016GY-191), Scientific Research Special of Education Department of Shaanxi Province Government (14JK1477).

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"breathing" phenomenon, and then causes the coal spontaneous combustion [1], [2]. The data resources "dig" degree of the existing monitoring system is not enough, it's a lack of information in the danger degree of coal spontaneous combustion and the decision-making of prevention and control. The evolution environment of the coal spontaneous combustion is complicated, the liquidity of gas is poor, early hidden danger is difficult to identify in a timely manner. Poor heat conductivity properties, high temperature point hidden, single index, the degree of coal spontaneous combustion is judged not easily. The scope of coal fire area is very broad, artificial inspection workload is larger, blind area is more, non-response rates is higher. The internal connection of index gases and the temperature is not clear, the criterion of danger degree diagnosis and early warning is lack. The pertinence of the existing fire prevention and control means is not strong, the conventional measures do not have efficiency and boast skillful [3]. These problems have brought a lot of confusion for prevention and control work of goaf coal spontaneous combustion. For a long time, many scholars at home and abroad has carried on the basic theory research and scientific experiments to conquer these difficulties [4]-[7]. Due to the complexity of the problem, many influence factors, the limitation of the detection means, although some progress has been made, but has not been satisfactory solution. Therefore, the research of the prediction method of the fusion recognition for the characteristic information of coal spontaneous combustion is of great significance to the improvement of early coal spontaneous combustion hazard prevention and control technology.

The prediction method of the fusion recognition for the characteristic information of coal spontaneous combustion refers to coal in low temperature oxidation stage, external characterization information is not clear and not obvious signs of coal spontaneous combustion. Based on the characteristics of the coal oxidation heat release, the danger degree of coal spontaneous combustion is the anticipation in advance by fusion recognition algorithm. Therefore, it is necessary for the fusion recognition of the characteristic information of coal spontaneous combustion, the threat estimation and trend prediction. The fusion results are as a criterion of the diagnosis and early warning of coal spontaneous combustion, it will reduce the rate of false positives and non-response rates.

II. INFORMATION FUSION ALGORITHM

Information fusion algorithm main application fields

include: automatic flight control, automatic target recognition, medical diagnosis, remote sensing, image processing, pattern recognition, robot, etc. [8]-[10]. Comprehensive literature both at home and abroad, multi-sensor information fusion technology has a big advantage. Each sensor information in time and space has certain complementary and redundancy. The time, space and frequency range of the system have been expanded. The blind area of single sensor is inevitable. The information collection and update rates were increased. All in all,

multi-sensor information fusion technology is through a certain algorithm "merge" the information from multiple sources. Reliable and accurate information of sensors is produced more than single sensor information. And according to the information, reliable decision is made. Common fusion algorithm can be summarized as two categories: classical methods and modern methods. Two types of information fusion algorithm are shown in Table I [11]-[13].

TABLE I: THE ADVANTAGES AND DISADVANTAGES OF TWO KINDS OF INFORMATION FUSION ALGORITHMS

| Algorithm class | Main Algorithm | Advantages | Disadvantages |
|----------------------------|--------------------------------|--|---|
| Classical Fusion Algorithm | Bayesian Estimation Method | It has the axiomatic foundation, intuitive, easy to understand, a small amount of calculation. | It needs more prior knowledge, the applicable conditions are harsh. |
| | Statistical Methods | | |
| | Estimation Methods | Information loss is little, it is suitable for the raw data fusion. | It needs to get the accurate mathematical model, for the occasion of complex and difficult to model cannot apply. |
| | Maximum Likelihood Estimation | | |
| Modern Fusion Algorithm | Information Theory Methods | The priori knowledge of objects not demanding or no request, it has strong adaptive capacity, it is easy to implement information fusion between the subjective and objective. | Computational cost is larger, the rules are difficult to establish or learning time is long, It is not easy to implement. |
| | Clustering Analysis | | |
| | Artificial Intelligence Method | Support Vector Machine (SVM) | |
| | Fuzzy Logic | | |
| Neural Network | | | |

III. THE SENSITIVITY INDICATORS OF QUANTITATIVE RECOGNITION FOR THE DEGREE OF COAL SPONTANEOUS COMBUSTION

In the experiment process of coal spontaneous combustion, each indicator gas can mutate at a certain temperature, its scope and characterization has certain regularity. According to the development change rule of gas concentration of O₂, N₂, CH₄, CO, CO₂, C₂H₂, C₂H₄, C₂H₆ and their ratio along

with the coal temperature, coal spontaneous combustion process is divided into three stages: slow oxidation, accelerating oxidation and intense oxidation. Each stage has a corresponding characterization parameters and a corresponding temperature range. The sensitivity indicators of quantitative recognition for the degree of coal spontaneous combustion are shown in Table II.

TABLE II: SENSITIVITY INDICATORS OF QUANTITATIVE RECOGNITION FOR COAL SPONTANEOUS COMBUSTION DEGREE

| The Name of Characteristic Temperature | The experiment of coal spontaneous combustion | | | Note |
|--|--|------------------------|--------------------------|--|
| | Characterization Parameters | Temperature Range (°C) | Extreme Temperature (°C) | |
| Critical Temperature | CO ₂ / CO greatly; CO and CO ₂ concentration increase; O ₂ concentration decline further | 60 ~ 70 | 63 | Oxygen consumption increases, fast chemical reactions |
| Pyrolysis Temperature | C ₂ H ₄ / C ₂ H ₆ surge; O ₂ concentration drops; CO concentration increases; C ₂ H ₆ concentration gets bigger | 105 ~ 135 | 113 | Fast pyrolysis such as side chain, bridge bond and other small molecules |
| Fission Temperature | C ₂ H ₄ / C ₂ H ₆ greatly | 135 ~ 145 | 143 | Benzene ring structure begins to fracture to speed up |

IV. THE ANTICIPATION MECHANISM OF FUSION RECOGNITION FOR THE CHARACTERISTIC INFORMATION OF COAL SPONTANEOUS COMBUSTION

The anticipation mechanism is to identify the current risk degree of coal spontaneous combustion and prevent the happening of the coal spontaneous combustion by the gas concentration and temperature of coal spontaneous

combustion. The prediction method of fusion recognition for the characteristic information of coal spontaneous combustion was put forward based on the experiment data of coal spontaneous combustion and the support vector machine (SVM) algorithm.

Data level adopts the method of the polynomial least squares fitting, the correlation of coal temperature and indexes are established, and the corresponding relational

expression is fitted. The quantitative relationship of the characteristic temperature of coal spontaneous combustion and the gas concentration of each index was determined according to the correlation expression between index gas and coal temperature based on least squares fitting.

PSO-SVM (Particle Swarm Optimization - support vector machine) fusion recognition prediction model of feature level of is established [14], [15]. PSO is used to analyze the SVM parameters C and γ search optimization, SVM and kernel function parameters optimization is implemented, the sample data characteristic information of coal spontaneous combustion are used to train SVM. The change rule and trend prediction is implemented.

According to the results of the data level and feature level, the tendency and interconnectedness between coal spontaneous combustion index gases and temperature is determined. The diagnosis and early warning criterion of coal spontaneous combustion is given, the dangerous degree classification anticipation of coal spontaneous combustion is implemented.

V. THE PREDICTION METHOD OF THE FUSION RECOGNITION FOR THE CHARACTERISTIC INFORMATION OF COAL SPONTANEOUS COMBUSTION

A. Data Level Fusion Recognition

The polynomial of each index gas parameters about temperature is fitted out by the least square method, Equation (1) is showed as follows:

$$T_j = \sum_{i=0}^n a_i * Q_j^i, j = 1, 2, \dots, 6 \quad (1)$$

Among them, T represents temperature, Q_j represents waiting for fitting gas concentration, $a_i, i = 0, 1, \dots, n$ is need fitting parameters.

The relation between the temperature and the gas concentration is fitted respectively, temperature and fitting result of the gas concentration of CO, CH₄ is shown in Fig.1, Fig. 2. The upper part of each figure is the comparison of the fitting values and the original value between temperature and gas concentration. The lower part of each figure is the comparison of the initial temperature and the fitting temperature using gas concentration.

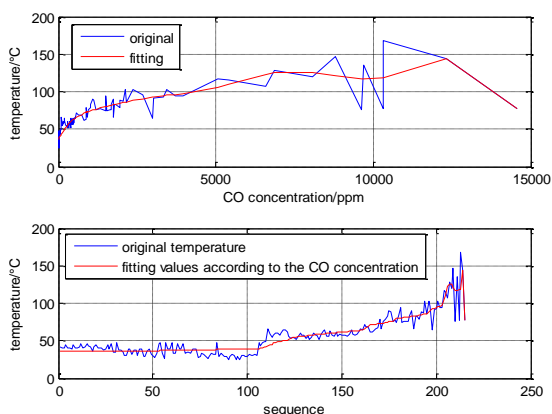


Fig. 1. The fitting relationship of temperature about CO concentration.

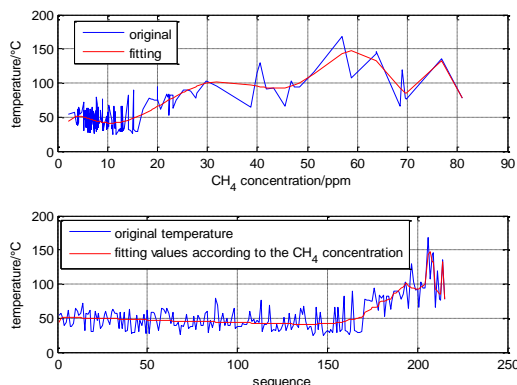


Fig. 2. The fitting relationship of temperature about CH4 concentration.

Fig. 1 and Fig. 2 shows the fitting relationship of the temperature about the gas concentration of CO and CH₄, if given the gas concentration, multiple fitting relationship about temperature is derived. Temperature fitting value about the gas concentration is the weighted average, and then gets mean value. According to the fitting expression of temperature of the gas concentration, and then fitting once more with the method of least squares, the express is showed as Eqs. (2):

$$T = b_0 + \sum_{j=1}^n b_j * T_j, n = 6 \quad (2)$$

Among them, T represents integrated temperature fitting values, T_j represents fitting temperature values about each index gas concentration, $b_j, j = 0, 1, \dots, 6$ is need fitting parameters.

Temperature of each gas concentration is quadratic fitting, the result is shown in Fig. 3. It can be seen that the result of the quadratic fitting by the weighted average is closer to the test values of temperature, least squares method is used to implement data level fusion and the effect is better.

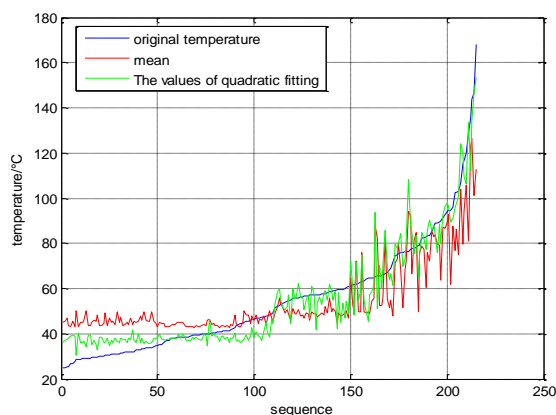


Fig. 3. Temperature about the fitting mean of the gas parameters and quadratic fitting values.

B. Feature Level Fusion Recognition

By the experiment platform of XK - III coal spontaneous combustion of Xi'an University of Science and Technology, coal spontaneous combustion characteristics of coal samples of a mine were studied. O₂, N₂, CO, CO₂, C₂H₄, C₂H₂, CH₄ and C₂H₆ gas concentration was used as input information of feature level.

Level of coal spontaneous combustion is divided into three

stages: critical temperature ~ pyrolysis temperature, pyrolysis temperature ~ fission temperature, > fission temperature.

The scope of the corresponding characteristic temperature are: 60 ~ 70 °C, 105 ~ 70 °C and 135 ~ 145 °C. Risk grade as output, the original data is divided into three categories, grade 1, 2, 3, respectively. Among them, 215 groups of data is regarded as the training sample, 30 groups of data is regarded as test samples.

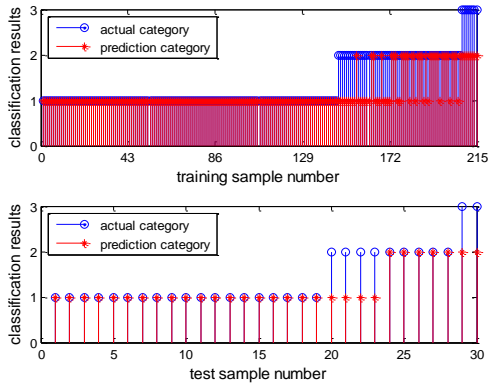


Fig. 4. The training and prediction results of SVM classification model.

In the matlab environment, SVM and PSO - SVM algorithm program is written by Libsvm toolbox, and then classified recognition, training and test results is shown as in Fig.4, Fig.5. It can see that the SVM model in Fig.4, the forecast accuracy of training samples is 81.86% (176/215), the prediction accuracy of test samples is 80% (24/30), test samples have six group forecast classification error.

It can see that the SVM model in Fig.5, the forecast accuracy of PSO - SVM model is 95.35% (205/215), the forecast accuracy of test sample is approximate 100% (30/30). Comparing the SVM prediction results, the prediction model of PSO - SVM can significantly improve prediction accuracy.

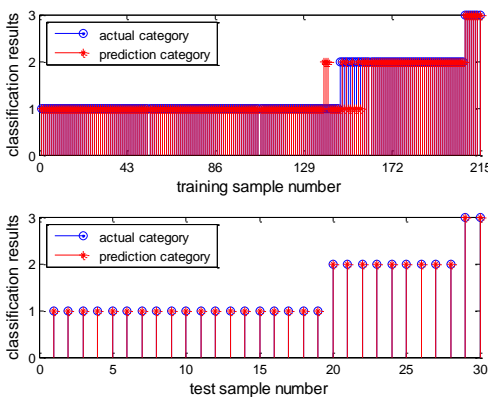


Fig. 5. The training and prediction results of PSO - SVM classification model.

By the same token, the PSO - SVM regression prediction model is established, and the mean square error of cross-validation is selected as fitness function value. The training and testing results of the regression prediction model of SVM and PSO - SVM are shown as in Fig.6, Fig.7, respectively. It can be seen that the difference of training - prediction results and the actual value is very large in Fig.6. The prediction results and the actual value are basically

identical in Fig. 7. In other words, PSO - SVM model can significantly improve the prediction accuracy, it provides more accurate and reliable information for policy makers.

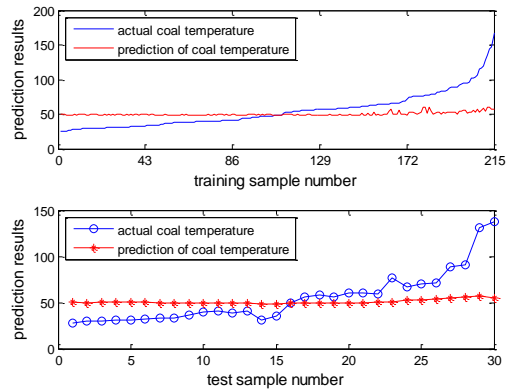


Fig. 6. The SVM regression model training and prediction results.

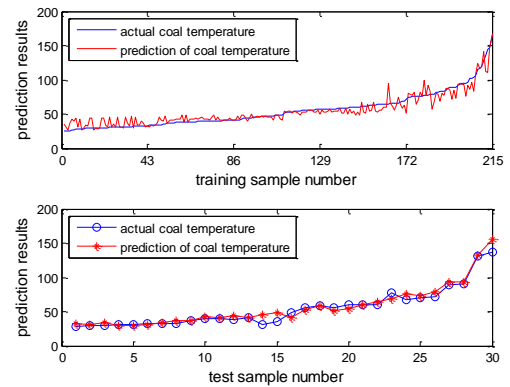


Fig. 7. PSO - SVM regression model training and prediction results.

C. Decision Level Fusion Recognition

According to the results of the data level and feature level, the prediction methods of decision level fusion recognition is as follows: in order to determine the danger grade of coal spontaneous combustion, it can be classified according to the classification results of PSO - SVM. In order to determine temperature, the test data can be classified by the least squares fitting temperature value and PSO - SVM regression. If temperature value fitted by the least squares and the PSO - SVM regression results are not in the same level range, the classification prediction value of PSO - SVM can be determined the temperature value.

VI. CONCLUSIONS

- 1) Coal spontaneous combustion process is divided into three stages: slow oxidation, accelerating oxidation and intense oxidation according to the development change rule of gas concentration and their ratio along with the coal temperature. The sensitivity indicators of quantitative identification for the degree of coal spontaneous combustion are determined, the critical temperature: 60 ~ 70 °C, the pyrolysis temperature: 105 ~ 135 °C, the fission temperature: 135 ~ 145 °C.
- 2) The prediction method of fusion recognition for characteristic information of coal spontaneous combustion is put forward, and the anticipation mechanism is determined based on SVM algorithm and

mathematical model.

- 3) Combined with the test data, data level adopts polynomial least squares fitting method, the correlation of the coal temperature and the indexes are established. According to the temperature of the gas concentration fitting out, it has carried on the quadratic fitting, then the quantitative relationship of the characteristic temperature of coal spontaneous combustion and the gas concentration of each index was determined.
- 4) In feature level, the prediction model of PSO - SVM fusion recognition is established, PSO is used to analyse the SVM parameters C and γ search optimization, SVM and kernel function parameters optimization is implemented, the accuracy of classification prediction is approximate 100%, the prediction accuracy of the danger degree of coal spontaneous combustion is improved.
- 5) In decision level, according to the results of the data level and feature level, the diagnosis and early warning criterion of coal spontaneous combustion is given, the classification anticipation criteria of the dangerous degree of coal spontaneous combustion is identified, the classification anticipation and effective decision-making of the dangerous degree of coal spontaneous combustion is achieved.

The error of fitting function is discussed in the future work. Furthermore, the mechanism of coal spontaneous combustion is revealed based on experiment.

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