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Prediction of mine coal layer spontaneous combustion danger based on genetic algorithm and BP neural networks

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Abstract

The prediction of danger state in mine coal layer spontaneous combustion correctly has an important practical meaning for the mine production safety. There is a kind of complicated nonlinear relation between the danger of coal layer spontaneous combustion and its influencing factors. And the neural network can truly show the nonlinear relation. In this paper, for the purpose of predicting it in mine coal layer correctly, a kind of method combined the advantages of genetic algorithm (GA) and BP neural network is introduced based on the demonstration of the necessity and possibility of combining BP with GA. At first, the notion of using multilayered BP as the representation method of genetic and the searching technique is introduced, and a novel method of using GA to train connection weights of BP neural network is designed. According to the characteristics of mine coal layer spontaneous combustion danger, three key influencing factors are selected as the judging indexes. Then the model for predicting the danger of mine coal layer spontaneous combustion is built. Practical application indicates that the capability of the new method in fast learning of ANN and escaping local optima. And the results show that the model is a very efficient method for predicting the danger of coal layer spontaneous combustion.

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Keywords: Genetic algorithm; BP neural network; Coal spontaneous combustion; Danger; Prediction; MATLAB

1 Introduction

Like coal or rock dynamic disasters such as gas and/or coal outburst, the mine fires caused by coal spontaneous combustion also seriously threats the safety of coal industry, greatly threatens the worker's life and property safety, affects society and economic benefit of coalmines, and leads to large loss of life and

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property[1-3]. The coal spontaneous combustion is one of the inducing factors which leads to the coal or gas explosion. There are two kinds of fire in collieries: fire ignition to external heat, and to internal heat, in light of the different heat sources. According to statistics, the number of collieries with spontaneous combustion danger accounts for 46 to 49 percent of the total of state-owned collieries in China. So how to stop efficiently the occurrence of these disasters is the key problem needed to be deal with now in the field of coal industry. And how to develop the effective predicting methods and how to increase its predicting accuracy is also the key to prevent and cure the mine fires efficiently.

The happening tendency and danger of coal stratum spontaneous combustion during excavation depend on; on the one hand, the oxidation spontaneous combustion features of coal itself, and on the other hand, are related to such factors as coal mine geology, exploitation, excavation and ventilation and so on. So we should consider the above influencing factors to predict the tendency of spontaneous combustion and its danger [4-6].

In fact, there exists a kind of complicated nonlinear relationship between the danger of coal spontaneous combustion and its influencing factors. The artificial neural network (ANN) has strong ability to truly describe the nonlinear relation between the input variables and output variables [7-8]. Artificial Neural Network (ANN) has become one of idea tools in modeling nonlinear relationship between inputs and desired outputs. However, the training of ANN by conventional back-propagation method, i.e. the BP neural network, has intrinsic vulnerable weakness in slow convergence and local minima. So in order to overcome the problems of slowly convergence and over-fitting of normal neural net work, the improved genetic algorithm was used to search the topology structure and learning step number of BP network. BP algorithm can establish the high nonlinear mapping between the object and the seismic attributes. GA can select the survival of the fittest. The BP algorithm can quickly converge.

In this work, for the purpose of forecasting the coal spontaneous combustion and its danger efficiently in coal mines during excavation, a combination method of BP network and GA is proposed. The predicted results of the modeling are reliable and practical.

2 BP model based on MATLAB and genetic algorithms

2.1 BP model based on MATLAB

In the latest years, the research on neural network has been the hotspot in the field of artificial intelligence. It is mainly used in such fields as pattern recognition, forecasting, classification, nonlinear regression, and process-controlling and has good application effect[9-11]. The BP (back-propagation) network is also called an error back-propagation network, which is composed of input, hidden and output layers. During the forward propagation, input signals are dealt with from the input layer across the hidden layer and transferred to the output layer. The state of neurons in one layer only affects the neurons in the next layer. If the expected output cannot be obtained in the output layer, the error value is then propagated backwards through the network，and changes are made to the weights in each layer. The weight changes are calculated to reduce the error signal for the case in question. The cycle is repeated until the overall value of error drops below a pre-determined threshold.

MATLAB is an application software with strong data-processing ability which was developed by MathWorks Company in 1982. MATLAB includes many toolboxes, one of which is neural network tool integrated with nearly all neural network models. BP neural network model is broadly utilized in engineering field and it is verified that BP neural network model has a good effect in the forecast of pattern recognition, danger prediction and so on. Fig.1 shows a three-layer BP network structure.

The basic back-propagation (BP) algorithm is one of simple steepest descent algorithms. The training process is divided into two phases, namely,

$$W_{ij}(t) = W_{ij}(t-1) - \Delta W_{ij}(t) \quad (1)$$

$$\Delta W_{ij}(t) = \eta \partial E / \partial W_{ij}(t-1) + \alpha \bullet \Delta W_{ij}(t-1) \quad (2)$$

Where W_{ij} is the combined weights between node i and j , η is the leaning speed (in general it is valued 0.01~0.1), α is impulse parameter (its value is about 0.9), t is the iterative steps, and E is the error super curve face defined in the space of weight {W（t）}.

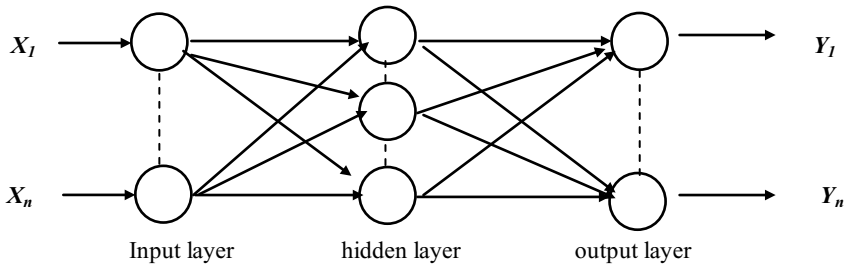


Fig.1 A three-layer BP network structure

First it adapts BP algorithm to approach the best point, then changes gradient descent algorithm to quicken the speed. Its learning process is consisted of forward-propagation and back-propagation. Even though BP network model is utilized broadly, there exist the drawbacks of slow convergence speed.

In view of the existing problems of basic BP (Back Propagation) learning algorithm, MATLAB toolboxes are presented in this paper. MATLAB is a variety of application software with strong data-processing ability in which many toolboxes were developed. There are a lot of toolboxes such as signal processing, control system, neural network, image processing, robust control, nonlinear control system design, system identification, optimization, fuzzy logic, wavelet, and so on. In it, the neural network toolbox nearly includes all neural network models and BP model is only one. Some main functions for design and analysis of BP neural network model are given (Table.1)[12].

Table 1 Main functions of BP neural network model

functions	effects	functions	effects
Errsurf	to calculate error curve surface	Logsig	logarithm *S-type* transfer function
Plotes	to plot error curve surface	Tansig	tangent *S-type* transfer function
Solvelin	to design linear network	Purelin	linear transfer function
Initff	initialization of three-layer forward-network	Simuff	simulation of forward-network
Initlin	initialization of linear-network	Simulin	simulation of linear-network
Learnbp	learning rules of back-propagation	Trainbp	forward training by back-propagation
learnbpm	learning rules with prediction	rainbpx	training by rapid back-propagation

2.2 Combination of BP network and Genetic algorithm

The Genetic algorithm (GA) is a search technique based on mechanics of nature selection and is initially put forward by Professor John Holland in Michigan University [13]. It is for searching global optimization solution by simulating nature's genetic mechanism and biological evolution. The feature is that: no information about searching for the solution is needed and only needs objective function has no limitation of the continuity and differentiability of searching span, available for parallel searching, good robust. GA has already been successfully applied in many diverse areas, such as function optimization, the traveling salesman problems, multi-objective optimization problems, scheduling, neural network

design, system identification, vision, control and machine learning. A detailed review of these applications is provided [14-15]. In general, the genetic algorithm includes 4 parts: encoding mechanism, fitness degree function, genetic operators and control parameters.

(1) Encoding mechanism

Encoding mechanism is the foundation of GA, which is to give all objects specified character string in order by certain encoding mechanism. In simple genetic algorithm, Character string is composed by 0 and 1. By simulating terms in biological evolution, the following terms are used:

Unit: being the basic unit, named chromosome. Each unit stands for one solution.

Gene: the smallest cell of heredity operating, chromosome with specified array mode, chromosome is the character string.

Population: being composed by a lot of units which is a solution set of problems.

(2) Fitness function

Survival of the fittest is the principle in nature; GA describes each unit's fitness degree by using fitness degree function.

(3) Genetic operator

Basically, the most important genetic operators have 3 kinds: selection, crossover and mutation. Selection operator is used to determine the next generation to be rejected or to be reproduced based on the unit's goodness or badness degree. Generally speaking, unit with better fitness has more chance to survive; on the contrary, unit with lower fitness has less chance. Often using the mode of proportional selection , the unit with fitness fi continues to live on probability $fi / \Sigma fi$. . There will be no originality of GA only with selection operator, because the offspring group can not surpass the range of original group. Crossover has many forms, the most simple is single point crossover, The procedure is : pick out two character strings from group, assuming randomly, the length of the string is L, then define randomly crossover point which is positive integer between 1 and $L-1$, the exchange of the right half part of the two strings and get two new strings. Change randomly the placement of a character in the character string based on mutation rate. For duality code string, that is to exchange 0 and 1.

(4) Control parameters

During GA operating, determine some available parameter so as to imp rove superior selection result, these parameters are: the numbers of character in the string, (i. e. string length L); group capacity n defines the numbers of character string in each generation group; app lying crossover rate, pc; applying mutation rate, pm; still the numbers of genetic generation and other indexes for confirming ceasing breed.

The calculation of standard GA is a procedure of seeking randomly superior solution in essence, the ability of seeking local superior solution is low, normally do not converge at global optimal solution, in most cases, only attains global suboptimal solution.

From above, GA and BP algorithm can be combined to form an algorithm: genetic BP algorithm (BP-GA), with the advantages of the two, which overcomes blindness of seeking superior and prevents the condition of local convergence.

3 Application of BP-GA method

3.1 Choice of input and output neural cell

To overcome the defect of basic BP algorithm, a combination of modified BP and genetic (BP-GA) model based on MATLAB software is presented in this paper. For the purpose of forecasting the danger of coal spontaneous combustion in mine coal layer correctly, the BP-GA model was adopted to speed up the network convergence speed and to increase prediction accuracy.

In BP neural network model, the number of input node and output node is decided by the characteristic of research problems. The choice of hidden layer and hidden node is also important. The analysis of theory shows that a BP network model with two hidden layers is enough to deal with any problems with any form. And if only the number of hidden nodes is enough, a neural network model with only one hidden layer can approach a nonlinear function with random precision. So the BP model with three layers is chosen in this paper. The input parameters are the influencing factors on coal spontaneous combustion.

There are three basic conditions for coal spontaneous combustion: the existed coal itself; oxygen and the poor heat dissipation. The influencing factors on coal spontaneous combustion are also complicated, which are composed of: oxygen-sorption rate of coal, ignition temperature, coal seam thickness, coal seam inclination, geology conditions, coal seam depth, excavation ways, excavation speed and direction, excavation rate, ventilation ways, and so on. In general, the above 16 influencing factors can be deduced to three main influencing indexes, namely, coal spontaneous combustion inclination, geology conditions and occurrence features of coal seam, ventilation conditions. According to reference [10], first we score the above 16 influencing factors, then the discriminant values of the above three main indexes are obtained, which are chosen as the input neural cell.

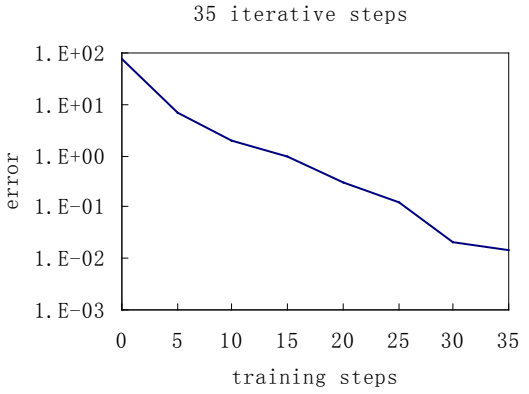
In light of the danger degree of coal spontaneous combustion, it is divided into four varieties: very danger (‘A’), danger（‘B’), potential spontaneous combustion（‘C’), no danger (‘D’). The above four varieties is seen as the output neural cell. Because that the output value of neural network cell is not 0 or 1, the expectation value of the four varieties is chosen as [0.9，0.1，0.1，0.1]（‘A’）, [0.1，0.9，0.1，0.1]（‘B’）, [0.1，0.1，0.9，0.1]（‘C’）, [0.1，0.1，0.1，0.9]（‘D’）respectively.

It is suitable to choose 9 to 15 hidden neural cells by test calculation. So the modified BP-GA network model is consist of three input neural cells, twelve hidden neural cells and four output neural cells in this paper. The transfer function from input layer to hidden layer and from hidden layer to output layer is adopted as the logarithm *S*-type transfer function and linear function respectively.

3.2 Application of BP-GA model

At first, we choose twenty-four traditional testing data in representative coal mines in our country as samples of neural network model. In them, eighteen data is learning samples, six samples belongs to prediction samples to verify the correctness of the above model. Then, the above samples are trained. After trained and iterated, the model can correctly recognize the learning samples. The complicated nonlinear mapping relationship between influencing factors and danger degree of coal spontaneous combustion is constructed.

In order to compare the convergence speed by BP-GA arithmetic with the one by VLBP arithmetic in MATLAB toolbox in the course of prediction, the error curves by the two methods are analyzed respectively (Fig. 2 and Fig.3). The iterative steps are 34 steps and 7036 steps when the model comes to convergence by means of BP-GA and BP method respectively.



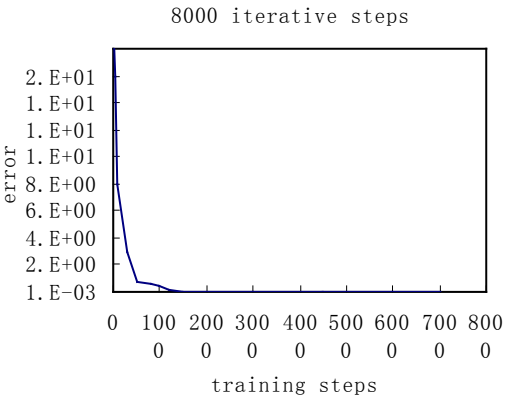


Fig. 2 Error curve by BP-GA model **Fig. 3 Error curve by VLBP model**

Table 2 shows the training results. Then the parameters of six mine work faces in one kind of Mine Group Companies in China are used to verify the correctness of neural network model (Table 3). The results show that the prediction results by means of BP-GA method and VLBP method are nearly same. The prediction results are also consistent with the practical results which show that it is feasible to forecast the danger of coal spontaneous combustion in the course of excavation by the above neural network methods and it is valuable to spread in reality. It is obvious that the convergence speed by BP-GA model is much quick than that by VLBP neural network model.

Table 2 Training results of study samples of neural network model

sample N	spontaneous combustion inclination	geology conditions	ventilation conditions	learning results			
1	60	45	5	A	0.9062	0.0886	0.1068	0 0898
2	60	50	20	A	0.9471	0.0992	0.1253	0.0977
3	60	40	5	A	0.9245	0.0887	0.1065	0.0923
4	60	5	20	A	0.9339	0.0955	0.1156	0.0931
5	60	10	30	A	0.9030	0.0914	0.1038	0.0954
6	60	45	25	A	0.8987	0.0972	0.1063	0.0968
7	30	20	10	B	0.0951	0.9563	0.1069	0.0957
8	30	25	20	B	0.1087	0.9036	0.0966	0.0899
9	30	50	-5	B	0.1657	0.9064	0.1046	0.0823
10	30	25	-5	B	0.0944	0.8648	0.0987	0.0952
11	60	25	-10	B	0.0987	0.9089	0.0997	0.0940
12	30	25	10	B	0.0964	0.9061	0.1016	0.0939
13	30	35	-10	B	0.1053	0.8987	0.0977	0.0888
14	60	15	-35	C	0.0967	0.0806	0.9364	0.0988
15	15	15	5	C	0.1020	0.0885	0.9563	0.0866
16	0	10	25	C	0.1014	0.0894	0.9350	0.0892
17	30	10	-10	C	0.0947	0.0789	0.9182	0.1023
18	30	10	-35	D	0.1096	0.0938	0.1012	0.9424

Table 3 Testing results of forecasting model

N	spontaneous combustion inclination	geology conditions	ventilation conditions	Prediction results								model variety	real variety
				BP-GA				VLBP					
1	60	35	20	0.9406	0.0785	0.0965	0.0923	0.8970	0.0874	0.1817	0.0985	A	A
2	60	35	-10	0.9369	0.0807	0.1148	0.0904	0.9014	0.0957	0.1042	0.0911	A	A
3	30	50	-5	0.9598	0.0874	0.1140	0.0627	0.9010	0.0789	0.1155	0.0868	A	A
4	30	40	5	0.0910	0.9563	0.1243	0.0857	0.0859	0.9167	0.1069	0.0787	B	B
5	30	30	5	0.0988	0.9049	0.1001	0.0917	0.0851	0.9361	0.1558	0.0957	B	B
6	15	30	-5	0.0876	0.0755	0.9379	0.1059	0.1050	0.0895	0.9363	0.0888	C	C

4 Conclusions

Compared with traditional BP and GA, the BP-GA algorithm model has stronger robustness, can lower obviously network error, has high training speed, is available for parallel global searching and has great potentialities for development. The following conclusions can be obtained:

(1) A lot of influencing factors can be sufficiently thought about in the course of prediction for danger of coal spontaneous combustion by means of artificial neural network methods which can map the complicated nonlinear relation between them.

(2) The simulated researching results show that the BP-GA model can overcome the drawback of low convergence speed and quicken the convergence speed. And the calculation speed by BP-GA algorithm model is much quick than that by VLBP arithmetic.

(3) The modified BP-GA model can, on the one hand, predict the danger of coal spontaneous combustion efficiently, and on the other hand, can make the wide experts be free of the complicated calculation programming for the purpose of increasing the work efficiency.

(4) The results show that the BP-GA model is a very efficient prediction method for coal spontaneous combustion in colliery, and has an important practical meaning for the mine production safety.

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