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The Prediction Model of Coal Mine Disaster Based on BP Algorithm

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Abstract. The occurrence of coal mine disaster related with many environmental and social factors. The relationship between them was uncertainty, and was a kind of coupling relationship, and was nonlinear. It was difficult to fit the relationship between them using a mathematical model. This also was the important reason that coal mine disaster was always hard to predict. The artificial neural network based on BP algorithm had highly nonlinear mapping function. It could nonlinear map the relationship between the probability of coal mine disaster's occurrence and its effect factors on the condition of building no complex mathematical model. And then the probability of coal mine disaster could be predicted relatively accurately. It provided technical support for prevention and management of coal mine disaster.

Keywords: coal mine disaster; BP algorithm; nonlinear mapping; prediction model

1. Introduce

Along with the further development of coal resources, safety problem was increased. In recent years, the disaster of coal companies occurred frequently. They caused a huge economic loss and casualties to the society and individual. The root cause of coal mine disaster was closely related with many factors of society, environment, unsafe behavior of people, unsafe state of objects and defect of management. Disaster occurred because unsafe factors, many social; factors and environmental conditions objectively existed during productive process. In the process of disaster forming, objective factor is mainly, but the unsafe behavior of people could bring unsafe state of objective things. Therefore, the occurrence of mine disaster related with many environmental and social factors, but the relationship between occurrences of disaster and these factors was uncertainty, and was a kind of coupling relationship, and was nonlinear. For this uncertain, nonlinear coupling relationship, it could not be simulated by a linear method. And more, the influence degree of disaster which caused by various factors was difficult to describe quantitatively, and artificial neural network just could solve this problem. In this paper, the prediction model of coal mine disaster was established using artificial neural network based on BP algorithm.

2. The principle of artificial neural network model

Artificial neural network is a network formed by large number neural processing units' self-discipline elements and the self-interaction of the network elements. Currently, artificial neural networks technology is widely utilized in the area of classification, decision making, data processing, pattern recognition and some other areas as a nonlinear optimization method. The main characterize are as follows:

(1) It has the function of learning from the data. In training, it can found the delicate relationship between the level from the data, which relationship is difficult to detect using other methods and descriptions.

(2) It has promotional features. The delicate relationship (i.e. network structure) gained in training can be extended to general data, including data with errors and incomplete actual data.

(3) Neural network is a high degree of nonlinear mapping from input to output essentially. When artificial neural network is used to analyze the deep foundation multivariate data, neural networks can implicitly

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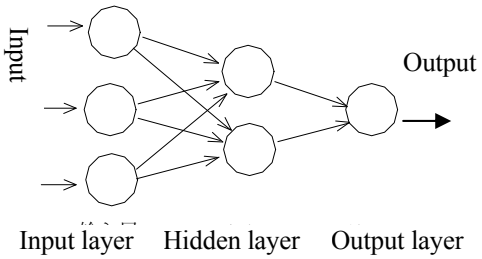

Fig. 1 Sketch of BP artificial neural network model

express the nonlinear relationship between the variables, regardless of mathematical models. Therefore, it is very efficient to analyze the complex relationship between variables with this method. Some multivariate analysis can not be described by specific model, while neural network model may get better results than conventional methods.

BP adaptive learning rate algorithm is a learning algorithm with mapping function basing on the multilayer feed forward network model, consisting of forward-propagation back-propagation. In the process of forward propagation, the samples undergoes layer processing unit from input layer to hidden layers, each neural layer' output only affect the state of the next nerve cell layer until the output layer. If there is a deviation between actual network output and expected output, it will enter the back-propagation process. In the course of back-propagation, the error signal reverse to positive against the original propagation, and amend the nerve cell weight-coefficient in each later according to the negative direction of error function, eventually minimize the expected error function.

3. The mathematical description of BP artificial neural network model of and its algorithm

BP Propagation (i.e. Error Back Propagation) belong to δ learning law, it is a kind of teacher learning algorithm, given a network of training sample set ((x_p, y_p), $x_p \in R^n$, $y_p \in R^m$), (R^n is input units; R^m is output units, similarly hereinafter）. It defines a function F: $R^n \rightarrow R^m$ implicitly through the input - output pairs, the specific form of expression may be unknown, but artificial neural network with the ability of arbitrary approximation can be adopted to express any unknown function, that is to select an appropriate model structure and find a suitable weight constitute forming the network y = NN (x, w, θ), resulting to a minimum error indicator function as follows:

$$E = \frac{1}{2}\sum_{k=1}^{p}\sum_{i=1}^{NL}(t^k - y_j^k)^2$$

Where t^k 、 y_j^k、p、NL are desired output value, the actual output value, training sample size, number of nodes in the output layer.

This kind of network' model structure and weight are obtained through the learning process. Learning process is actually the process of solving the weight, because learning does not necessarily require being very precise, a set of approximate solutions is obtained. Learning process can be divided into two stages: feed forward stage, which is to calculate the actual input, output levels of each layer nodes from the input layer; Reverse error correction stage, amend each connection weights along the reverse, according to the output error in the output layer, thus minimizing the output error.

The feed forward model is:

$$\begin{cases} y_i^l = f(x_i^l) \\ x_i^l = \sum_{j=1}^{N_{l-1}} w_{ij}^l y_j^{l-1} + \theta_i^l \end{cases} \quad (l = 1、2、3.....L)$$

Where y_i^l is the output value of the i node in the l layer, x_i^l is the activation value of the i node in the l layer, w_{ij}^l is the connection weights between j node in the l-1 to i node in the l layer, θ_i^l is the threshold

value of the i node in the l layer, N_l is the number of the nodes in the l layer, L is the total number of layers, f ( ) is neuron activation function.

The back-propagation of error adopted gradient descent algorithm, which means to minimize total error by adjusting of the connection weights between layers of neurons, its mathematical expression is:

$$\Delta w_{ij} = -\eta \frac{\partial E}{\partial w_{ij}}$$ （η is learning rate）

So the weight adjustment formula is as follows:

$$w_{ij}(t+1) = w_{ij}(t) - \eta \frac{\partial E}{\partial w_{ij}}$$

In order to accelerate network convergence and to prevent shock, momentum term α is added generally, then the corrected weight formula is:

$$w_{ij}(t+1) = w_{ij}(t) + \eta \sum_{p1=1}^{p} \delta_{ij}^{p1} y_j^{p1}$$

Steps to approach BP algorithm:

a、Initialization: Select the network structure, number of nodes, the initial input value of layer neurons, α , η , weights, threshold value, accuracy, etc;

b、Given input and expected output value of the sample;

c、Calculate the actual input、output value of all the hidden layer, until the actual output of each output layer neuron is figured out;

d、Calculate the output layer error, starting from the output layer, transmit the error signal to the first hidden layer along the connection path back, and calculate the corrected weight simultaneously;

e、Decide whether the output of reach neuron precision, and if so, the learning process comes to an end, otherwise return to the second step, until it reaches the accuracy.

4. Build BP Artificial Neural Network Model

The model of disaster prediction was established based on BP artificial neural network taking coal and gas outburst as a example.

4.1 Selection of prediction's indicators

By the forming mechanism of coal and gas outburst, it was known that the main factors which influenced coal and gas outburst were geological factors, exploiting factors and production management factors. Specifically, the more important factors were: lithological characters of roof and floor, complexity of regional structure, development degree of coal fracture, thickness of coal, dip angle of coal, rigidity of coal, content of gas, pressure of gas, radiation speed of gas, exploiting depth, exploiting method (shortwall, longwall), had or no pillars of coal, mining method (blasting, mechanized mining), and so on. These 13 indicators were selected as prediction indicators of coal and gas outburst.

4.2 Determination of initial structure

Aforementioned 13 were taken as network's input units.

In the BP neural network model, it is a rather complex issue to determine the number of hidden layer units, and Eberhart called it "this is an art.", since there is no analytical formula can be used to express it well. However, the number of hidden units has a direct relationship with the requirements of the problem, the number of input and output units. For the networks, when the number of hidden units is small, the network may be trained unqualified, or not "strong" enough, or has bad tolerance or poor promotion, however if the study time is too long, the error is not necessarily the best. Therefore, some papers have proposed some reference formulas, this article reference to the following formula to determine an initial number of hidden layer units.

$n_1 = \sqrt{n+m} + a$ （a=1~10）

Where n1 is the number of units in hidden layer, n is the number of unites in input layer, m is the number of units in output layer;

The in the dynamically adjusted according to

In the process of network learning, adjust BP network structure dynamically according to learning situation. According to mapping theorem, given an arbitrary small positive number ε> 0, a continuous function vector h, each of the vector element meet the demands that the following formula: $\int_{[0,1]^n} |h_i(x)|^2 dx$ is available, $h:[0,1]^n \subset R^n \to R^m$, There must be a three-tier B-P neural network approaching the function h, so that the approximation error is within ε. Therefore, a three-tier is selected initially, which contains only one hidden layer of BP artificial neural network, choose 2 as the initial value of a in the hidden layer formula, input samples and begin training. If the networks do not converge in required times of training, a value will increase by 1.If the value of increased a still do not converge in required times of training till to 9 network, adopt the measures of increasing the hidden layer, the second hidden layer still use sigmoid function, determine the number of nerve cell in the same as above.

4.3 Assignment of prediction indicators

Aforementioned 13 prediction indicators were taken as input artificial neuron. Among them, variable such as lithological characters of roof and floor, had or not pillars of coal, exploiting method (short wall, long wall), mining method (blasting, mechanized mining) would be assigned in two states way, i.e. it would be assigned in 1 when prediction unit had them, otherwise would be assigned in 0; variable as thickness of coal, dip angle of coal, rigidity of coal, content of gas, pressure of gas, radiation speed of gas, exploiting depth would be assigned in normalized value of actual value, and normalized transform adopted following formula; variable as complexity of regional structure, developing degree of coal fracture would be assigned in normalized value of fractal dimension based on fractal theory, and normalized transform adopted following formula also. Possibility of disaster occurring (0~1) was taken as output artificial neuron of artificial neural network. The number of neuron in hidden layer would be determined initially referencing aforementioned formula, and adjusted dynamically according to situation of network learning.

$$x' = \frac{x - x_{\min}}{x_{\max} - x_{\min}}$$

5. Model checking

According to the prediction model, 10 typical coal mines which occurred disaster of coal and gas outburst were selected as learning samples and BP network model learn from them. Learning rate η was 0.3; momentum term α is 0.9, the maximum number of training is 10000. Learning results are shown in table 1. And then, 4 known coal mines were selected as prediction samples to check the model, and predicting results are shown in table 2.

It is seen from table 1 and table 2 that, learning effect of network is good, and output satisfies the requirement of accuracy, and predicting results of checking samples agree with the actual situation. These illustrate that the prediction of the model is feasible and it has good application value.

Table 1 Learning samples training

Sample ID	Desire output	Actual output
1	0.93	0.9260
2	0.1	0.0895
3	0.1	0.0985
4	0.12	0.1082
5	0.1	0.0980
6	0.1	0.0975
7	0.3	0.2854
8	0.5	0.5286
9	0.92	0.9234
10	094	0.9368

Table 2 Prediction checking of model

Sample ID	Prediction value	Scale of actual disaster
1	0.0923	no
2	0.1975	minor
3	0.9248	serious
4	0.0915	no

6. Conclusion

Nonlinear prediction model of disaster of coal mine was established by BP artificial neural network based on research in mechanism and influencing factors of disaster of coal mine. It could implicit express the nonlinear relationship between influencing factors and occurring of disaster without complex mathematical model. The possibility of disaster of coal mine would be predicted by this nonlinear model, and it provided method for prediction of disaster of coal mine.

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