Sensors & Transducers, Vol. 159, Issue 11, November 2013, pp. 385-390

Sensors & Transducers

A Multiple Factors Safety Prediction Algorithm Based on Genetic Neural Networks in Coal Mine Safe-state

Qi Li-Xia
School of Management & Economics, North China University of Water Resources and Electric Power, Zhengzhou, 450046, China

Received: 6 November 2013 /Accepted: 20 November 2013 /Published: 30 November 2013

Abstract: System safety prediction is usually forecast system future state based on time series. However, the problem of system security are often affected by multiple factors such as human factors, machine, environment and so on, these factors are often not reflected in the time series. This study presents a prediction algorithm of multi factor security mode association system state. Neural networks were used to solute the correlate factors of the future state. As the neural network easily falling into local optimum, genetic algorithm is applied to improve the algorithm. A coal mine instance which influenced by human, machine and equipment, environment, management and information was used to verify the algorithm. Experiment results show that the method is adaptable and high accurate. *Copyright © 2013 IFSA.*

Keywords: Prediction, Multiple factor, Neural network, Genetic algorithm, Coal mine safety.

1. Introduction

System security is a very important problem. If predicting the future state of a system based on past data, people can prepared and prevented to the impending danger in advance, and this will have a positive impact on disaster control. System prediction is normally performed by building a time series regression model or measurement model (Fu, 2009). But the system safety is mainly decided by the system state of closer time, and the system state is always associated with multiple factors, these factors in time series model can not reflect. Also, more difficult to solve is that, when the system is complex, the contribution values of these related factors to the system state, namely the factor weights, are very difficult to determine. The common method is use of analytical hierarchy process (AHP) (Gao et al., 2008; Sun et al., 2009) determined by expert experience. But these methods are subjective, the more complex the system, the greater the controversy. Therefore, this study presents a security system model of multiple factors. Neural network algorithm is used to realize self-learning of the system. From the system self-learning, weight distribution of factors is determined by the historical data. Artificial neural networks was used to evaluate the safety grade of coal mines (Huang and Li, 2007; Gao et al., 2011, Zhou and Wang, 2011). In order to avoid falling into local optimal, genetic algorithm is used to accelerate the convergence speed (Schaffer et al., 1992). This theory is applied to a coal mining enterprises to carry out the test and calculation, and the calculated result is in accordance with the actual situation.

2. Methods

The essence of system safety prediction is obtained the future state of the system by evaluation of to the historical factors. The security of the system is generally used risk rating to characterize, it is divided into 5 stages, namely highest risk, higher risk, medium risk, lower risk and lowest risk level. Let this as the output of the system, then

$$d = (d_1, d_2, d_3, d_4, d_5)$$

In multi-factor model, contribution of each factor (weight) to the final system state is a very difficult problem to determine. So it is best to establish self-learning model of the system to determine weights. The neural network can change the connection weights in the external input samples stimulated, Thus the network output constantly close to the desired, then the connection weights are dynamic adjust. According to this theory, establish the model as follows:

Hypothesis there are n associated factor, then

$$net = \sum_{i=1}^{n} x_i \bullet w_i$$

Define:

Input vector:

$$X = (x_1, x_2, \cdots x_n)$$

Output vector:

$$d = (d_1, d_2, d_3, d_4, d_5)$$

Input vector of hidden layer:

$$hi = (hi_1, hi_2, ...hi_n)$$

Output vector of hidden layer:

$$ho = (ho_1, ho_2, ...ho_p)$$

Input vector of output layer:

$$yi = (yi_1, yi_2, ...yi_p)$$

Output vector of output layer:

$$yo = (yo_1, yo_2, ...yo_n)$$

The Error and weight calculation:

Error function:

$$e = \frac{1}{2}\sum_{o=1}^{q}(d_o(k) - yo_0(k))^2$$

Hypothesis connection weights of the input layer and the middle layer are w_{ih}, hidden layer and output layer weights are w_{ho}, then

$$\frac{\partial e}{\partial w_{ho}} = \frac{\partial e}{\partial yi_o}\frac{\partial yi_o}{\partial w_{ho}}$$

$$\frac{\partial yi_o(k)}{\partial w_{ho}} = \frac{\partial(\sum_{h}^{p} w_{ho}ho_h(k) - b_o)}{\partial w_{ho}} = ho_h(k)$$

$$\frac{\partial e}{\partial yi_o} = \frac{\partial(\frac{1}{2}\sum_{o=1}^{q}(\mathrm{d}_o(k) - \mathrm{y}o_o(k)))^2}{\partial yi_o}$$

$$= -(d_o(k) - yo_o(k))yo_o'(k)$$

$$= -(d_o(k) - yo_o(k))f'(yi_o(k) - \delta_o(k))$$

$$\frac{\partial e}{\partial hi_h(k)} = \frac{\partial((\frac{1}{2}\sum_{o=1}^{q}(d_o(k) - yo_o(k))^2))}{\partial ho_h(k)}\frac{\partial ho_h(k)}{\partial hi_h(k)}$$

$$= \frac{\partial(\frac{1}{2}\sum_{o=1}^{q}(d_o(k) - f(yi_o(k))^2)}{\partial ho_h(k)}\frac{\partial ho_h(k)}{\partial hi_h(k)}$$

$$= \frac{\partial(\frac{1}{2}\sum_{o=1}^{q}(d_o(k) - f(\sum_{h=1}^{p} w_{ho}ho_h(k) - b_o)^2))}{\partial ho_h(k)}\frac{\partial ho_h(k)}{\partial hi_h(k)}$$

$$= -\sum_{o=1}^{q}(d_o(k) - yo_o(k))f'(yi_o(k))w_{ho}\frac{\partial ho_h(k)}{\partial hi_h(k)}$$

$$= -(\sum_{o=1}^{q}\delta_o(k)w_{ho})f'(hi_h(k) - \delta(k))$$

Then

$$\Delta w_{ho}(k) = -\mu\frac{\partial e}{\partial w_{ho}} = \mu\delta(k)ho_o(k)$$

$$w_{ho}^{N+1}(k) = w_{ho}^{N} + \eta\delta_o(k)ho_h(k)$$

$$\Delta w_{ih}(k) = -\mu\frac{\partial e}{\partial w_{ih}} = \mu\frac{\partial e}{\partial hi_h(k)}\frac{\partial hi_h(k)}{\partial w_{ih}} = \delta_h(k)x_i(k)$$

$$w_{ih}^{N+1} = w_{ih}^{N} + \eta\delta_h(k)x_i(k)$$

Through the iterative algorithm, the network can realize self-learning. But only using neural network algorithm is easy to fall into local optimum, the calculation will into the endless iteration. In order to avoid this problem, genetic algorithm is used to optimize the network. Genetic operator is similar with the evolutionary process of Biological. This process was completed by crossover and mutation among different chromosome.

On the combination process of neural network and genetic algorithm, the method of connection weight code is adopting (Bornholdt and Graudenz, 1992; Janson and Frenzel, 1993). For the weights of neural network learning is a complex continuous parameter optimization problem，If binary code is used, it will cause the code string too long. What more, the weight will be decode into real. This approach can make the weight change for the step, thus affecting the learning accuracy. So the way for weight still adopts real coding in this study, the weights cascade of a long string according to an order, each location on the string corresponds to a weight in the network. Through crossover and mutation of the weight, the algorithm achieve fast search in the global.

Genetic algorithm to optimize the neural network can be computer as the following steps:

1) Initialize population p. The initial objects include confirm cross-scale, cross probability Pc, mutation probability Pm, and determination of initial values for w_{ih} and w_{ho}.

2) Calculate each individual evaluation function and sort. The network individual could be selected by probability value.

$$P = \frac{f_i}{\sum_{i=1}^{N} f_i},$$

where f_i represent adaptation value of individual i, it can be measured by the sum of squared errors.

$$f(i) = 1 \Big/ \sum_{i=1}^{n} e^2$$

3) According to probability of Pc, individual Gi and Gi +1 were operated crossly, and then produced new G'_i, G'_{i+1}. No cross-operating individual was copy directly.

4) The mutation of new individual Gj was produced by Gi with probability Pm.

5) Insert new individuals to the population P, and calculate the new individual's evaluation function.

6) If the satisfactory individual was found, then terminated the process, otherwise will go to step (3). Optimized weights of network connection can be obtained by decoding best individual among final groups after achieving the desired performance indicators. Select the neural network which has minimum errors and thresholds to train until the error reaches the precision. The termination condition and the error is less than 0.0001 in this study.

3. Materials and Results

3.1. The Prediction Index

The production of coal mine is a very large and unascertained production system (Yan et al., 2004). The prediction index of system should be selected carefully based on coal mine accidents caused mechanism analysis combined with the actual production situation. Coal mine safety production has close contact with the human, machine, environment, management, information factors in system. Zhang, 2008) Xu et al., 2009; Sun et al., 2009) consider that the accident was caused due to unsafe state of human, machine and environment. Sun Jian-Hua (Sun et al., 2009) thinks that the coal mine safety evaluation index system should include the factors of human, machine, engineering technology and disaster prevention. In the actual production of the coal mine, management plays an important role in the process of coal mine production. What more, coal mine safety is affected by information feedback structure and mechanism in coal mine enterprise.

In this study, combined with the actual production situation of a coal production enterprises, 5 aspects of human, machine, environment, management measures and information factors affecting the safety production were studied. 36 observation indexes are mainly extracted as predictors which can affect the safety of coal mine. A large number of coal mine production safety accident data prove that the accident was the interaction of these factors' defects. Therefore, these factors are used as the prediction index (shown in Table 1) of coal mine safety in this study. Correspondingly, these indexes also determine the number of input vectors in calculation model.

Table 1. The prediction indexes for the study.

Rule Layer Index	Specific Items
Human factors (A)	The proportion of safety technical personnel(A_1)
	The proportion of safety management personnel(A_2)
	The proportion of mining engineering and technical personnel(A_3)
	Workers education(A_4)
	The average length service of workers(A_5)
	The average breaches of discipline proportion (A_6)
	Monthly training time(A_7)
Machine factors (B)	Normal condition of support equipment (B_1)
	Normal condition of ventilation equipment (B_2)
	Normal condition of dust-proof equipment (B_3)
	Normal condition of fire-fighting equipment (B_4)
	Normal condition of drainage equipment (B_5)
	Normal condition of lifting equipment (B_6)
	Normal condition of electromechanical equipment (B_7)
	Normal condition of transport equipment (B_8)
	Normal condition of gas drainage equipment (B_9)
	Normal condition of communications-equipment (B_{10})
	Level of mining mechanization (B_{11})
	Level of transportation mechanization (B_{12})

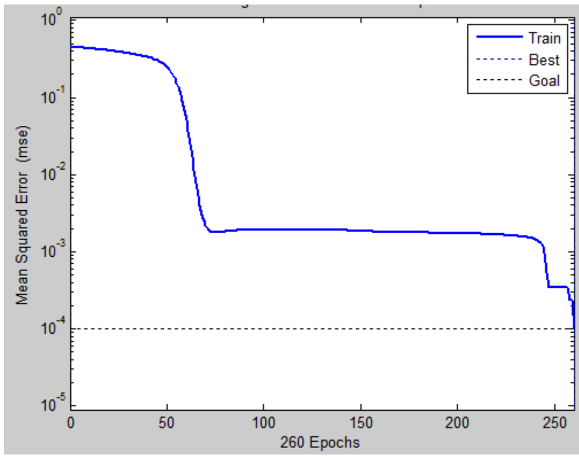
Table 1 (Continue).

Rule Layer Index		**Specific Items**
Environment factors (C)	The factors of geological environment	The average fault throw (C_1)
		Coal seam dip angle(C_2)
		The reliability of roof and foundation(C_3)
		Spontaneous combustion period (C_4)
		Coal dust explosion index(C_5)
		Average Gas Emission(C_6)
		Mining surface rich water coefficient(C_7)
	factors of work environment	Dust concentration (C_8)
		Noise figure(C_9)
		Supporting reliability(C_{10})
Management factors (D)		Safety input index(D_1)
		Degree of perfection on management system(D_2)
		Degree of perfection on emergency response system(D_3)
		Implementation of safety inspection(D_3)
		Rectification of hidden safety(D_5)
Information factors (E)		Level of information technology (E_1)
		Effective degree of information communication (E_2)

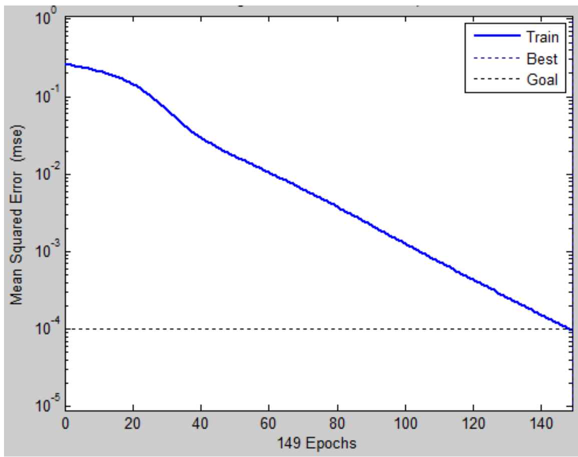
In this table,
A- human factors
B- machine factors
C- Environment factors
D- Management factors
E- Information factors
A_1-The proportion of safety technical personnel
A_2-The proportion of safety management personnel
A_3-The proportion of mining engineering and technical personnel
A_4-Workers education
A_5-The average length service of workers
A_6-The average breaches of discipline proportion
A_7-Monthly training time
B_1-Normal condition of support equipment
B_2-Normal condition of ventilation equipment
B_3-Normal condition of dust-proof equipment
B_4-Normal condition of fire-fighting equipment
B_5-Normal condition of drainage equipment
B_6-Normal condition of lifting equipment
B_7-Normal condition of electromechanical equipment
B_8-Normal condition of transport equipment
B_9-Normal condition of gas drainage equipment
B_{10}-Normal condition of communications-equipment
B_{11}-Level of mining mechanization
B_{12}-Level of transportation mechanization
C_1-The average fault throw
C_2-Coal seam dip angle
C_3-The reliability of roof and foundation
C_4-Spontaneous combustion period
C_5-Coal dust explosion index
C_6-Average Gas Emission
C_7-Mining surface rich water coefficient
C_8-Dust concentration
C_9-Noise figure
C_{10}-Supporting reliability
D_1-Safety input index
D_2-Degree of perfection on management system
D_3-Degree of perfection on emergency response system
D_4-Implementation of safety inspection
D_5-Rectification of hidden safety
E_1-Level of information technology
E_2-Effective degree of information communication

3.2. The Network Training Data

The relevant data of five coal enterprises is collected to as the sample data of prediction model. Parts of sample data of training are show in Table 2. In the model calculation，BP algorithm and BP-GA algorithm were used to calculate the sample data respectively. In order to compare the efficiency of operations, the mean squared error curves are recorded and shown in Fig. 1. The mean squared error curve using BP is shown in Fig. 1-a. By comparison, the curve using GA-BP is shown in Fig. 1-b. As can be seen from the graph, the curve using BP showed a platform, this shows that trapped in a local optimum. And it can be seen that BP algorithm achieve the goal at the 260 epochs of training. Correspondingly, the curve using GA-BP achieve target in the 149 epochs, and convergence is more rapid and stable. The results show that the BP-GA algorithm is faster and more efficient than the BP algorithm.



(a) The mean squared error of using BP algorithm.



(b) The mean squared error of using GA-BP algorithm.

Fig. 1. Efficiency comparison of BP and BP-GA algorithm.

Table 2. The sample data for calculation.

		Dec. 06	Jun.07	Dec. 07	Jun.08	Dec. 08	Jun.09	Dec. 09	Dec. 10	Dec. 11
The System State data of last month (The sample data of Inputs)	A_1	4.34 %	4.51 %	4.55 %	4.60 %	4.63 %	4.72 %	4.79 %	4.92 %	5.19 %
	A_2	1.25	1.26	1.29	1.33	1.35	1.4	1.49	1.65	1.8
	A_3	2.13 %	2.20 %	2.30 %	2.45 %	2.53 %	2.68 %	2.78 %	2.94 %	3.01 %
	A_i	…	…	…	…	…	…	…	…	…
	A_7	7.5	8	8.2	8.8	8.2	7.7	7.9	8.5	9.5
	B_1	85 %	86 %	88 %	88 %	89 %	91 %	91 %	93 %	97 %
	B_2	72 %	74 %	77 %	77 %	80 %	82 %	85 %	88 %	90 %
	B_3	78 %	78 %	79 %	81 %	83 %	83 %	88 %	89 %	90 %
	B_i	…	…	…	…	…	…	…	…	…
	B_{12}	81 %	81 %	85 %	86 %	88 %	88 %	90 %	91 %	93 %
	C_1	34	35	37	40	40	41	41	45	49
	C_2	3	5	6	8	10	12	11	13	14
	C_3	88 %	90 %	92 %	92 %	94 %	94 %	95 %	94 %	96 %
	C_4	…	…	…	…	…	…	…	…	…
	C_{10}	87 %	86 %	89 %	93 %	92 %	94 %	91 %	95 %	96 %
	D_1	1.42	1.48	1.69	1.7	1.79	1.83	1.9	2.08	2.26
	D_2	89 %	90 %	90 %	92 %	92 %	93 %	93 %	95 %	96 %
	D_i	…	…	…	…	…	…	…	…	…
	D_5	97 %	97 %	98 %	98 %	98 %	100 %	100 %	100 %	100 %
	E_1	62 %	65 %	66 %	70 %	71 %	73 %	74 %	77 %	80 %
	E_2	83 %	84 %	85 %	88 %	88 %	89 %	90 %	93 %	95 %
The specified output data		01000	01000	00100	00100	00100	00100	00100	00010	00010

(Data source: A coal industry group of Zhengzhou. Abbreviations are same to Table 1.)

3.3. Test and Prediction

In order to test the validity of the network, 2009-2011 data in June were used to test (Table 3). As can be seen from the table，the test results are consistent with the practical situation. The data in 2012 June into the network to predict the safety state at that time, the summary data proved to be consistent with the fact. Therefore, it is proved that the model that build in this study have right evaluation to the safety situation of coal mine, and it provides a scientific basis for policy-makers to judge the safety conditions and formulate the countermeasures.

Table 3. Forecast examples of using GA-BP algorithm.

		Jun. 2009	Jun. 2011	Jun. 2012
input data	A_1	4.83 %	5.12 %	5.23 %
	A_2	1.57	1.71	1.89
	A_i	…	…	…
	A_7	9	9.2	8.8
	B_1	92 %	95 %	98 %
	B_2	85 %	90 %	93 %
	B_i	…	…	…
	B_{12}	91 %	93 %	94 %
	C_1	44	47	49
	C_2	14	13	14
	C_i	…	…	…
	C_{10}	95 %	94 %	97 %
	D_1	1.99	2.2	2.31
	D_2	94 %	95 %	98 %
	D_i	…	…	…
	D_5	100 %	100 %	100 %
	E_1	76 %	78 %	82 %
	E_2	90 %	93 %	95 %
Output data	-	00100	00010	00010
The actual dangerous grade	-	medium	lower	lower
Correspondence degree	-	100 %	100 %	100 %

(Data source: A coal industry group of Zhengzhou. Abbreviations are same to Table 1.)

4. Discussion and Conclusion

The prediction system is a significant process that can prevent and control the accident. In the multi factors prediction and decision problems，BP neural network is used to calculate and predict the safety status because it has the characteristics of self-learning. This result was also confirmed by many literature such as Huang, Gao, Zhou et al (Huang and Li 2007; Gao et al., 2011, Zhou and Wang, 2011).

Even so, it also need to be aware of the fact that, while the neural network can predict the problem of multi-factors very good, but it still has defects needs to overcome, such as efficiency, easy to fall into local optimum and so on. In the process of resolving this problem, combined with the genetic algorithm is a good choice.

Through appropriate encoding and crossover, GA can contribute to BP neural network to skip the local optimal, increase operation efficiency. Theoretical analysis and experimental results indicated that the

Genetic Algorithms, as a new kind of global optimized search algorithm, can get better results than BP Algorithms in the hand of training the neural network weights. For the prediction of coal mine safety and other multi-factors influence problems, BP combined with GA algorithm is an effective method to solve problems.

Acknowledgements

This research is supported by National Social Science Foundation of China（12CGL101）and the Henan Province Social Science Planning (2009BSH005). An express gratitude should be given to my graduate Ju Yong-Wen. In the process of compilation, he made great contribution on data collecting and analyze. Thanks for the coal industry group provide the data for this study.

References

[1]. Bornholdt, S. and D. Graudenz, General asymmetric neural networks and structure design by genetic algorithms, *Neural Networks*, 5, 1992, pp. 327-334.

[2]. Janson, D. J. and J. F. Frenzel, Training product unit neural networks with genetic algorithms, *IEEE Expert,* 8, 1993, pp. 26-33.

[3]. Fu, Y. S., Study the applied research of gray theory in the coal mine safety evaluation, Ph. D. Thesis, *Coal Science Research Institute,* Beijin, China 2009.

[4]. Gao, W. H., H. Z. Chen and K. M. Xie, Application of fuzzy comprehensive evaluation in Local coal mine safety, *Min. Saf. Environ. Prot.,* 35, 2008, pp. 83-85.

[5]. Gao, X. X., D. W. Dong and R. L. Yang, Application of BP neural networks to coal mine intrinsic safety assessment model, *J. X'an Univ. Sci. Technol.,* 31, 2011, pp. 780-785.

[6]. Huang, H. Y. and C. D. Li, Research on the model for safety grade evaluation of coal mines based on artificial neural networks, *Ind. Eng. J.,* 10, 2007. pp. 112-115.

[7]. Schaffer, J. D., D. Whitley and L. J. Eshelman, 1992, Combinations of genetic algorithms and neural networks: A survey of the state of the art, in *Proceedings of the International Workshop on Combinations of Genetic Algorithms and Neural Networks,* June 6, 1992, Baltimore, MD., USA., pp. 1-37.

[8]. Sun, J. H., Y. X. Guo, J. P. Zhang, X. L. Qin and K. C. Zhang, The method based on multi-level fuzzy comprehensive in coal mine, *Safety Coal Mines*, 5, 2009, pp. 125-128.

[9]. Xu, Y., Y. Zhou, X. Sun and Y. Yue, Synthesized assessment method for coal mine safety based on fuzzy analytic hierarchy process, *China Safety Sci. J.,* 19, 2009. pp. 147-152.

[10]. Yan, L. L., J. C. Xu, M. G. Xu and G. Q. Wang, Application of unascertained mathematics in preliminary evaluation of coal mine safety, *Min. Saf. Environ. Prot.,* 31, 2004, pp. 24-25.

[11]. Zhang, Y. L., Research on coal mine safety evaluation. Ph. D. Thesis, *Shenyang Institute of Technology,* Shenyang, China, 2008.

[12]. Zhou, Z. K. and L. J. Wang, Study on safety early-warning assessment in coal mine based on bp neural networks, *J. Saf. Sci. Technol*., 7, 2011, pp. 134-138.