Fault diagnosis expert system for large-scale railway maintenance equipment based on BP neural network

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Abstract

According to the characteristics of the neural network and expert system, a fault diagnosis method for large-scale railway maintenance equipment based on Back Propagation (BP) neural network and expert system is proposed. Fault diagnosis for large-scale railway maintenance equipment on BP neural network and expert system model are constructed. A weak of collection and expression of knowledge on traditional expert system is overcome. Availability of the method based on BP neural network system and expert system is verified by experimental results of large-scale railway maintenance equipment fault.

Keywords: BP neural network; neural network-knowledge base; expert system; fault diagnosis

1 Introduction

Tamping machine is a complex large-scale railway maintenance equipment, it often appears various faults inside and outside the tamping machine because tamping machine always work in field with influence of weather, temperature, humidity, dust, etc. [8]. Once a part of tamping machine fails, the whole system will cause malfunction, therefore the system performance will decline, serious faults will lead to a loss of most of the original features of system. Expert system and neural network methods both can be used in fault diagnosis, but single expert system and neural network fault diagnosis both have certain limitations. Theoretical analysis and experimental studies have shown that expert system based on symbolic logic specializes in reasoning work and artificial neural network based on practice specializes in information perception, both complement each other in function. A combination of expert system and neural network can make themselves mutually reinforcing. In order to make full use of the advantages of expert system and neural network, this paper will organically integrated diagnosis method based on rule-based reasoning of expert system and artificial neural network. Thus we can solve problems that existed in system such as “Knowledge Acquisition Bottleneck”, “Match Conflict”, “Combinatorial Explosion”, “Infinite Recursion” and apply in fault diagnosis of tamping machine.

2 Principles and characteristics of expert system based on BP network

Since the system of tamping machine is very complex, working environment is very bad and the existence of other common phenomenon such as “high fault rate” and “hard to find fault reason” [10]. The system measures working parameters through monitoring status of tamping machine in real-time and uses these parameters to make a contrast with normal condition value [7]. When the measured working parameter does not match normal condition value, it can be shown that there exist at least one or more faults in tamping machine. We can consider using functions which conclude learning and memory in a neural network to replace the role of knowledge engineers. The main content is to learn from faults and complete automatic acquisition of fault diagnosis expert system and automatic updates. The reasoning process of building expert system in a neural network is actually a process of computing, it means that the neuron of neural network constantly parallels until convergence on solving space problems through the relationship among knowledge which are stored in a neural network. Because the parallel mathematical reasoning process in neural network replaces the matching search and backtracking problems in the processing of traditional artificial intelligence (AI) symbol, neural network has a higher efficiency of reasoning.

BP neural network will change diagnosis information into the weights and thresholds, and make them stored in network separately [12]. A combination of BP network and traditional expert system can overcome many defects in expert diagnosis system. BP network has a strong ability of adaption because diagnosis information which are distributed stored in the connected weights of the whole network, and each neuron stores various kinds of information, even though parts of neurons lost, the impact on BP network storage diagnosis information is not much, thus BP network can handle large disturbed input information, furthermore, BP network can solve problems about the bottleneck of knowledge acquisition in traditional expert system – self-learning [11].

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3 Technical basis of BP neural network

In system based on neural networks, method of knowledge representation is completely different from method of traditional AI system. Traditional AI system uses the method of explicit knowledge representation, on the contrary, neural network uses implicit knowledge representation [9]. In Artificial Neural Network (ANN), knowledge is not expressed as a set of rules, unlike traditional methods, it is expressed a certain knowledge as the weights distribution in the same network. Figure 1 and 3-layer threshold BP network show the following 4 "XOR" logical formula rules:

IF x_1 =0 AND x_2=0 THEN y=0;
IF x_1 =0 AND x_2=1 THEN y=1;
IF x_1 =1 AND x_2=0 THEN y=1;
IF x_1 =1 AND x_2=1 THEN y=0

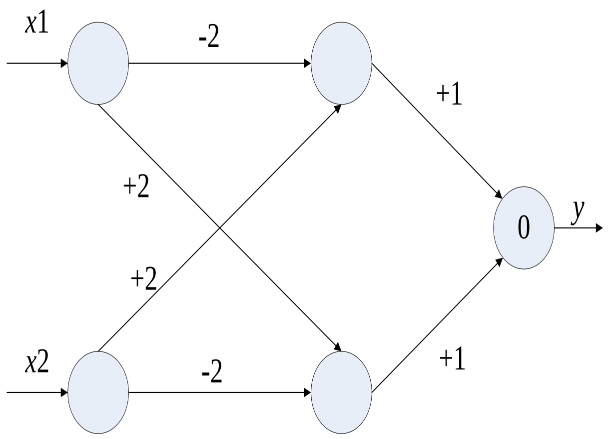

FIGURE 1 ANN representation of "XOR" logic

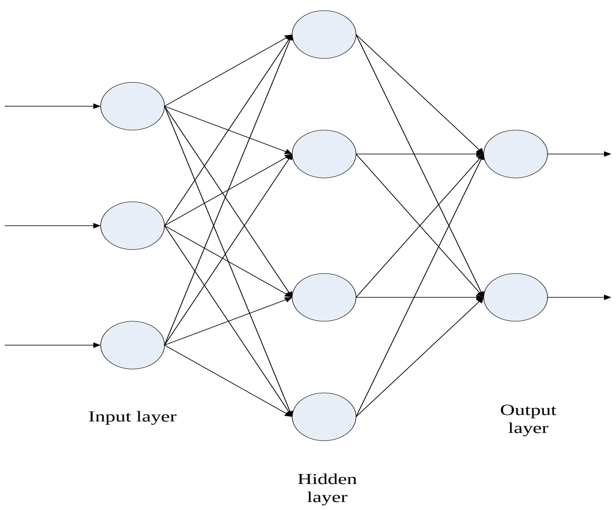

FIGURE 2 Network structure

Based on this network knowledge representation structure, its BP network structure is shown in Figure 2. Experts provide examples of problems and corresponding solution, BP network learns samples through learning network modules and modifies the weights until required learning through adaptive algorithm in network is accurate [12]. The learning process is as follows: Firstly, input fault symptoms and spread them forward to hidden nodes, secondly, spread the information of hidden nodes to the output nodes through output transfer function, thirdly, give results of output. Sigmoid function is chosen for the output transfer function. The learning process of this algorithm is composed of forward-propagation and back-propagation.

4 Corresponding formula

4.1 ORWARD-PROPAGATION STAGE

Set *k-th* sample of input vector $x_k=(x_{k1}, x_{k2},\ldots, x_{kl})$, get the output of y_j of *j*-th nodes in the hidden layer:

$$y_j = f\left(\sum_{i=1}^{L} W_{ij} x_{ki} + \theta_j\right). \tag{1}$$

The output of O_r of *r-th* nodes in the output layer is:

$$Q_r = f\left(\sum_{j=1}^{M} W_{rj} y_j + \theta_r\right). \tag{2}$$

4.2 BACK-PROPAGATION STAGE

Set L pairs of learning samples (X_k, O_k) (K=1,2,…,l), the mean square error of actual output Y_k and required output O_k is:

$$E_k = \frac{1}{2}\sum_{p}^{m}\left(Y_{K,p} - O_{K,p}\right)^2. \tag{3}$$

The total error of sample set is:

$$\mathrm{E}=\sum_{k=1}^{l} E_k\ . \tag{4}$$

Modifying weights along negative gradient direction of error function so that network convergence, the weights in the output layer is modified as ΔW_{rj}:

$$\Delta W_{rj} = \frac{\partial \mathrm{E}(t)}{\partial W_{rj(y)}} = -\left[O_r'(t) - O_r(t)\right]\cdot\left[1 - O_r(t)\right] y_i(t). \tag{5}$$

Weighs in the output layer which is modified is:

$$W_{rj}(t+1) = W_{rj}(t) - \eta \Delta W_{rj} \tag{6}$$

Similarly, weights in the hidden layer which is modified is ΔW_{ji}:

$$\Delta W_{ji} = \frac{\partial \mathrm{E}(t)}{\partial W_{ji(t)}} = -\left[y_j(t)\left[1 - y_j(t)\right]\right]\cdot x_{ki}(t)\sum\nolimits_r \delta_r W_{rj}\ . \tag{7}$$

Weights in the hidden layer is modified as:

$$W_{ji}(t+1) = W_{ji}(t) - \eta \Delta W_{ji}\ . \tag{8}$$

Let us introduce the following terms:

f - sigmoid function;

L - numbers of neurons in the input layer;

W_{ij} - connection weights between input layer and hidden layer;

x_{ki} - the input of k-th sample;

k - the number of sample;

θ_j - thresholds of j-th neurons in the input layer;

M - numbers of neurons in the hidden layer;

W_{rj} - connection weights between hidden layer and output layer;

θ_r - thresholds of j-th neurons in the hidden layer;

m - numbers of units in the output layer;

$\mathrm{E}(t)$ - error function;

$\mathrm{O}_r(t)$ - desired output;

η - steps, experience;

δ_r - sensitivity of r-th nodes correspond to output error function E(t);

5 Design of fault diagnosis expert system

Based on the analysis of fault diagnosis expert system and BP neural network technology above, expert system and neural network must be combined to play their strong point when problems can't be solved using expert system or neural network alone. So I design a fault diagnosis expert system. The basic structure of the process is shown in Figure 3.

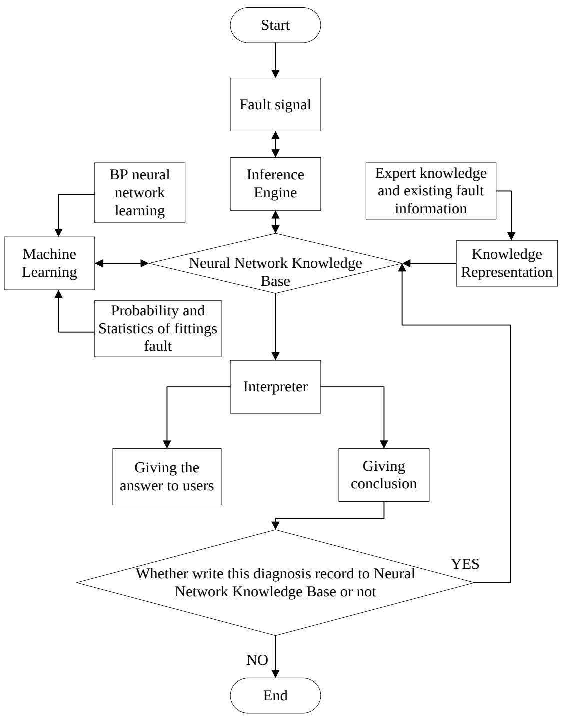

FIGURE 3 Fault diagnosis process of tamping machine

6 Simulation of tamping machine fault diagnosis expert system

The size of neural network is determined by need, the number of fault symptoms is corresponded to the number of input nodes; the number of fault is corresponded to the number of output nodes. The select of the number of hidden nodes in the hidden layer doesn't have theoretical guidance, the selected number is merely to meet capacity and requirements of certain learning speed.

This paper selects common engine fault diagnosis of 09-32 taming machine as the research object, illustrating the practice and diagnosis process of expert system and neural network fault diagnosis system [8].

Tamping machine mainly uses diesel engine, diesel engine often appears many faults such as electrical fault, mechanical fault and oil path fault [8]. Electrical fault shows mainly the line-to-ground fault, line empty pick up fault, damaged components fault and unreliable grounding fault. Line-to-ground fault is most common, as long as grounding can cause a short circuit and automatically cut off the power supply. Virtual connect circuit fault is mainly due to loose caused by vibrations in long-term work, effective way to avoid this is to strengthen the line inspection and tight of terminals. Mechanical faults are relatively less, but there are always several typical faults such as governor throttle trolley balance spring results in only idling, bolts of governor transmission shaft sheared causes failure of work, nozzle jammed results in a mass of diesel leaking into the machine and diluting the oil. The typical fault of oil path fault is diesel tank blocked, the main reason is that diesel tank not cleaned for a long time or some foreign matters get into the tank. When suction pipe appears loosen or the installation of filter element is unqualified, it will result in air suction, low back pressure of suction pipe, air into high-pressure oil pump.

The engine of this diagnosis system has 5 symptoms and 7 faults (Table 1). The 5 symptoms and 7 faults are designed for 5 input nodes and 7 output nodes, hidden nodes are calculated as 5. To calculate the answer, using the formula $h=\sqrt{n+m}+a$ (h is the number of neurons in the hidden layer; n is the number of input neurons; m is the number of output neurons; a is the network layer, which is a constant number between 1-10, here a is 2).

TABLE 1 Neural network output table

Input	Symptom	Output	Fault
x_1	DG08 charging current is high, table shows the maximum and the next to the diesel engine has screaming voice.	y_1	The ground wire of B13box is bad contact.
x_2	5e9 self-healing insurance will jump and can't start when the engine starts.	y_2	The damage of 317 lines in dryer working power supply results in grounding.
x_3	The diesel engine suddenly stalled when working.	y_3	5e9 and 5e7 self-healing are jumping.
x_4	Diesel tank is blocked.	y_4	Engine is damaged.
x_5	Throttle can't lift.	y_5	The damaged 81Re3 results in adjustment can't be passed to post - amplifier.
		y_6	The damaged Si1insurance of 81u1 results in power supply.
		y_7	Diesel tank is not cleaned for a long time.

In the Table 1, x_i represents fault symptom, x_i=0 (i=1,2,…,5) represents no symptom, x_i=1 (i=1,2,…,5) indicates the symptom, y_j =0 (j=1,2,…,7) represents a fault that doesn't exist, y_j =1 (j=1,2,…,7) represents a fault that existed. Based on the above, we selected 7 samples of examples to learn, when the network structure and learning sample are selected, you can train the neural network. First of Table 2 is trouble-free sample.

TABLE 2 Learning sample table

Sample	x_1	x_2	x_3	x_4	x_5	y_1	y_2	y_3	y_4	y_5	y_6	y_7
1	0	0	0	0	0	0	0	0	0	0	0	0
2	1	0	0	0	0	1	1	0	0	0	0	0
3	0	1	0	0	0	0	0	1	1	1	0	0
4	0	1	0	0	0	0	0	1	0	0	0	0
5	0	0	0	0	1	0	0	0	0	0	0	1
6	0	0	1	0	0	0	0	0	0	1	0	0
7	0	0	0	1	0	0	0	1	0	0	1	0

Table 3 shows the desired output and actual output through training.

TABLE 3 Desired output and Actual output

Desired output							Actual output						
y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_1	y_2	y_3	y_4	y_5	y_6	y_7
0	0	0	0	0	0	0	0.0266	0.0268	0.0381	0.0038	0.0337	0.0093	0.0032
1	1	0	0	0	0	0	0.9663	0.9663	0.0042	0.0043	0.0027	0.0170	0.0152
0	0	1	1	1	0	0	0.0024	0.0037	0.9635	0.9342	0.9795	0.0068	0.0091
0	0	1	0	0	0	0	0.0023	0.0024	0.9923	0.0043	0.0199	0.0041	0.0108
0	0	0	0	0	0	1	0.0016	0.0160	0.0110	0.0073	0.0053	0.0233	0.9586
0	0	0	0	1	0	0	0.0027	0.0034	0.0087	0.0110	0.9694	0.0026	0.0152
0	0	1	0	0	1	0	0.0102	0.0093	0.9762	0.0046	0.0860	0.9508	0.0128

In fault diagnosis, according to the input fault symptom, we call the trained weights between the layers to calculate forward and display the results of diagnosis based on output of the output layer.

TABLE 4 Fault diagnosis example

Input					Output						
0	1	0	0	0	0.0019	0.9900	0.0152	0.0427	0.0025	0.0014	0.0

Table 4 shows that fault can be located in the damage of 317 lines in dryer working power supply results in grounding when 5e9 self-healing insurance jumps with diesel engine started. Table 3 also shows that the result of fault is consistent with the actual and this method is feasible in fault diagnosis application of tamping machine.

7 Conclusions

BP neural network has a feature of highly nonlinear function mapping, so it is very convenient for tamping machine fault diagnosis. It can not only improve the reliability of diagnosis, but also develop tamping machine fault diagnosis expert system by using BP neural network technology. This system has a self-learning function, with the growth of time investment, the system will automatically record the result of each test into knowledge base and update network weights constantly based on knowledge base, as a result, the system and the diagnosis accuracy will constantly growing and improving.

Acknowledgements

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