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Failure Diagnosis of Transmission Based on Improving Neural Network

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Abstract: In view of the deficiencies like slow learning pace and local extremes of neural network in failure diagnosis, the method of using fuzzy algorithm to pre-teat the input of neural network by means of fuzziness and the output by anti-fuzziness has been proposed. The thesis will establish a knowledge base for common failure of automatic transmission first, pre-treat failure symptom by fuzziness then and do sample training and system simulation to Matlab software used at last. The result of the system simulation proves that the method has the characteristics like high diagnosis precision, superior self-adaptability, fast convergence and effective diagnosis of uncertain failure of automatic transmission.

Keywords: Automatic transmission, failure diagnosis, fuzzy neural network

INTRODUCTION

Nowadays the automobiles with automatic transmissions are becoming more and more popular as they are featured by easy operation and low labour intensity. However, along with the easy and convenient operation is complicated design structure and difficult fault diagnosis. Presently disintegration check is often adopted to detect automatic transmissions, but without detailed test, to blindly disintegrate machines only according to our experiences, sometimes we not only fail to find the exact fault cause, but also destroy the system performance as a whole.

At the end of the 20th century, Artificial Intelligence was for the first time applied to engineering practice. At the same time, people initiated the research of knowledge-based Fault Diagnosis Expert System. The neural network, fuzzy set theory and chaos theory were combined to pave a new way for malfunction analysis which bought multi parameter into fault diagnosis. In this article, we unit self-diagnosis of automatic transmission with fuzzy set theory as well as neural network technology, trying to identify the fuzzy relation between failure symptoms and failure causes in system operation. Finally, we set up a fuzzy fault knowledge base and utilize the neural network into the learning of fault knowledge. Both facilitate the quality and efficiency of fault self-diagnosis.

METHODOLOGY

Fault diagnosis method based on fuzzy neural network: In this paper, the general BP neural network is fuzzified. Specifically, while remaining the original neural network structure, fuzzy processing is conducted on neurons directly, which means that fuzzy quantity represented by membership degree is used to replace input value or weight, and through network learning, the output fuzzy subset is turned into non-fuzzy digital quantity. The specific structure is reflected in Fig. 1.

Input fuzzification module: This module accomplishes the transformation from fault symptom vectors to network input pattern. That is to say the fault signals are turned into fuzzy quantity set represented by membership degree (Li and Yang, 2007). The function is to make fuzzy processing on input signals.

All would-happen faults and various fault causes in a system can be expressed by a set. The sum of faults is m, and trouble reasons set is denoted by Euclidean Vector:

$$Y = \{y_1, y_2, \ldots, y_m\} = \{y_t | \ t = 1, 2, \ldots, m, m\in N\}$$

Various fault symptoms caused by faults are also defined in a set. n represents the total number of fault symptoms. The Euclidean Vector shows:

$$X = \{x_1, x_2, \ldots, x_n\} = \{x_k | k = 1, 2, \ldots, n, n\in N\}$$

In this set, degrees of trouble causes y_t that exist in every component x_k can be represented by membership function $\mu_t(x_k)$. So to transform every component in fault symptom set X into membership degree can construct system fault input fuzzy vectors, i.e.,

$$A_k = \{\mu_1(x_k), \mu_2(x_k), \ldots, \mu_m(x_k)\}$$

The fault input fuzzy set of this system is:

$$A = \{A_1, A_2, \ldots, A_k | k = 1, 2, \ldots, n, k\in N\}$$

Presently there are many methods to determine memb ership function. This paper makes full use of

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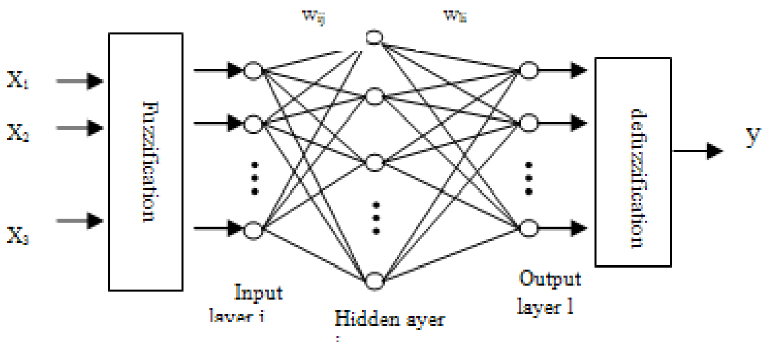


Fig. 1: The structure design of fuzzy neural network

specialists' experience method. According to erperts' actual experience, the process algorithm or the corresponding weight coefficient of fuzzy information are presented to determine membership function. Firstly rude membership function is identified, then through “study” and “practical test”, rectification and improvement are realized step by step.

Neural network diagnosis module:

- **Basic theory of BP neural network:** Artificial neural network is a pioneering and interdisciplinary subject that develops rapidly in recent year. Featured by self-organization, self-learning, association, fault tolerance, anti-interference and nonlinear dynamic processing. ANN can realize a nonlinear mapping relation between network input elements and network output targets. Neural network can reveal the neural network which is contained in data sample, and the diagnosis module is in charge of fault samples' network training as well as the accomplishment of fault inference reasoning.

  Back propagation artificial neural network (Shao *et al.*, 2007; Tang and Feng, 2007) is a typical multilayer feed forward network, which consists of input layer, hidden layer and output layer. The three layers are connected together by all connecting method, and the units in the same layer are not connected. The basic thought of BP network algorithm is to adjust and rectify the connection weight of network consistently through the back propagation of output error, thus the network errors are minimized. The training process of BPANN consists of feed forword calculation and error back propagation. The input signals firstly propagate forward to hidden layer, after the calculation of action function, the output information is propagated from hidden layer to output layer. If the output layer fails to get the expected output, then the error signals will return along the original path. After correcting the weights of neurons in every layer, the error signals are minimized. The node action function of BP neural network is generally “S” function.

  Common activation function f(x) is derivable Sigmoid function:

$$f(x) = \frac{1}{1+e^{-x}} \tag{1}$$

Error function R is:

$$R = \frac{\sum (Y_{mi} - Y_j)^2}{2} \quad (j = 1, 2, \ldots, n) \tag{2}$$

In this formula, Yj is expected output; Ymj is actual output; n is sample length.

The uniform expression of weight modified formula of BP algorithm is:

$$W_{ij}(t+1) = w_{ij}(t) + \eta\delta_{pj}O_{pj} \tag{3}$$

In this formula,

W_{ij} : The connecting weight of neurons
η : Networks learning rate
O_{pj} : The output of sample
p; δ_{pj} : Error correction value

- **BP algorithm:** The specific process of BP algorithm can be generalized as follows (Chen, 2004):

  - Select n samples as a training set.
  - nitialize weight and biases value in neural network.

  The initialized values are always random numbers between (-1, 1).

  Every sample in the training set needs the following processing:

  - According to the size of every connection weight, the data of input layer are weighted and inputed into the activation function of hidden layer, then new values are obtained. According to the size of every connection weight, the new values are weighted and inputed into the activation function of output layer, and the output results of output layer are calculated.

- If there exists error between output result and desired result, the calculation training is wrong.
- Adjust weight and biases value.
- According to new weight and biases values, the output layer is calculated. The calculation doesn't stop until the training set meets the stopping condition.

Defuzzification module: Defuzzification is to defuzzify fuzzy output vector Y after fuzzy neural network training. In the diagnosis of complicated equipment, maximum membership degree method (Sun *et al.*, 2008) is often adopted, i.e. the element with the maximum membership degree in fuzzy output vectors Y is always selected as the fault cause.

RESULTS AND DISCUSSION

Case diagnosis of automobiles' automatic transmissions:

Establish fault knowledge base: The common faults of automobiles' automatic transmission include: autamobiles' refusal to start, malfunction of automatic transimissions' gear, automatic transmission slipping, abnormal sound of automatic transmission and so on Ma (2008).

The fundamental cause of automobiles' failure to start is power transmission interruption. The trouble makers in automatic transmission that result in power interruption include: signals interruption caused by brake switch malfunction, power's failure to propagate from ring rear because of the absence or poor quality of ATF, loosening of the connections between operating handle and manual valve, the wear of the turbine's splines, damage of oil pump, breakdown of planetary gear structure and so on.

Gear malfunction means the automatic transmission fail to realize its function exactly. The causes include: the poor function of vehicle speed sensor, throttle position sensor and oil temperature sensor; gear confusion or absence resulting from poor sealing of control valve, connection terminals corrosion, bond strap and so on. In addition, slipping of clamping stagnation of one-way clutch of hydraulic torque converter's guide wheel will also lead to gear malfunction.

The abnormal sound of automatic transmissions is often caused by the fault of hydraulic system or mechanical system. The absence of ATF in hydraulic system or oil circuit blocking that fails to meet the demand of working normally will cause abnormal sound. The occlusion and collision of mechanical components will also produce noises.

The main reasons for automatic transmission slipping are as follows. As ATF is not replaced timely, the abrasives falling from friction plate and brake band ablate; clutch and brake wear seriously due to over-working for a long period, and friction materials fall down; leaking of accumulator's sealing ring and piston cracking will also lead to the slipping of corresponding clutch or brake.

According to the analysis of the above diagnosis as well as the experience and knowledge of specialists in this field, a knowledge base of common fault phenomenon and fault causes of automobiles' automatic transmissions is expressed in Table 1.

In Table 1, x_1~ x_8 represent fault phenomenon: x_1: refusal to start; x_2: shifting impact; x_3: gear upshifting failure; x_4: shifting delay; x_5: shift hunting; x_6: gear absence; x_7: abnormal sound; x_8: slipping.

y_1~y_{13} represent fault types. y_1: engine malfunction; y_2: ATF level abnormality; y_3: poor ATF quantity; y_4: breakdown of sensor circuit; y_5: control valve fault; y_6: hydraulic torque converter malfunction; y_7: oil pump fault; y_8: shifting actuator slipping; y_9: planetary gear fault; y_{10}: oil filter malfunction; y_{11}: oil circuit leakage; y_{12}: invalid buffer system; y_{13}: improper adjustment of gearshift lever and manual valve.

In the Table 1 indicates the existence of fault cause, "0" indicates the absence of fault caus

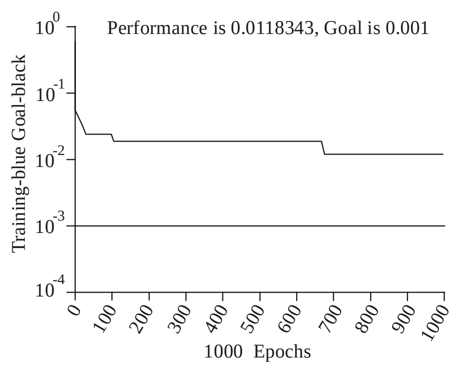
Network training: Due to the complicated structure of automatic transmission and fuzzy fault information, it is very difficult to establish a correct mathematical model between fault symptoms and fault causes. So when

Table 1: Knowledge base of automobiles' automatic transmissions

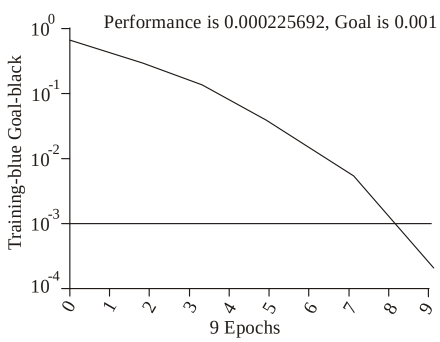
Fault phenomenon	Fault type y1	y2	y3	y4	y5	y6	y7	y8	y9	y10	y11	y12	y13
x_1	0	1	1	0	1	1	1	1	1	0	1	0	1
x_2	1	1	0	1	1	0	0	1	0	0	0	1	0
x_3	1	1	0	1	1	1	0	1	0	0	1	0	0
x_4	1	1	0	1	1	0	0	1	0	1	0	0	0
x_5	0	0	0	1	1	0	0	0	0	0	0	0	0
x_6	1	1	0	1	1	1	0	1	0	0	1	0	1
x_7	0	1	0	0	0	1	1	1	1	1	0	0	0
x_8	0	1	1	0	1	1	1	1	0	1	1	1	0

Table 2: Learning sample of neural network

	Actual input value			Expected output value																		
Sample No.	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8	y_9	y_{10}	y_{11}	y_{12}	y_{13}
1	0.2	0.8	0.4	0.5	0.0	0.6	0.2	0.0	1	0	0	0	0	0	0	0	0	0	0	0	0
2	0.8	0.8	0.5	0.9	0.0	0.5	0.5	0.8	0	1	0	0	0	0	0	0	0	0	0	0	0
3	0.4	0.1	0.0	0.0	0.0	0.0	0.1	0.9	0	0	1	0	0	0	0	0	0	0	0	0	0
4	0.0	0.9	1.0	0.9	1.0	0.8	0.0	0.0	0	0	0	1	0	0	0	0	0	0	0	0	0
5	0.5	0.9	0.8	0.7	0.7	0.9	0.0	0.7	0	0	0	0	1	0	0	0	0	0	0	0	0
6	0.7	0.0	0.8	0.0	0.0	0.6	0.8	0.4	0	0	0	0	0	1	0	0	0	0	0	0	0
7	0.9	0.0	0.1	0.0	0.0	0.1	0.9	0.5	0	0	0	0	0	0	1	0	0	0	0	0	0
8	0.7	0.7	0.8	0.8	0.0	0.9	0.7	0.9	0	0	0	0	0	0	0	1	0	0	0	0	0
9	0.6	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0	0	0	0	0	0	0	0	1	0	0	0	0
10	0.1	0.0	0.3	0.4	0.0	0.3	0.5	0.4	0	0	0	0	0	0	0	0	0	1	0	0	0
11	0.8	0.0	0.7	0.3	0.0	0.8	0.0	0.8	0	0	0	0	0	0	0	0	0	0	1	0	0
12	0.3	0.9	0.1	0.0	0.0	0.0	0.0	0.8	0	0	0	0	0	0	0	0	0	0	0	1	0
13	0.9	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	1
14	0.8	0.7	0.7	0.0	0.7	0.6	0.0	0.9	0	0	1	0	0	0	0	0	0	0	1	1	1
15	0.9	1.0	0.0	0.1	0.0	0.0	0.0	0.8	0	0	1	0	0	0	0	0	0	0	0	1	0
16	0.9	0.9	0.0	0.0	0.0	1.0	0.0	0.8	0	0	1	0	0	0	0	0	0	0	0	1	1
17	1.0	0.0	1.0	0.9	0.0	0.8	0.8	1.0	0	0	1	0	0	1	1	0	1	1	0	0	1



(a) BP algorithm (1000 times) learning curve



(b) Fuzzy BP algorithm learning curve

Fig. 2: Simulation result

building fault samples, it is necessary to apply the above fuzzy theory and make a fuzzification of automatic transimissions' fault input vectors. The membership degree is ascertained according to specialists' experience method and the actual condition of maintenance.

The existence degree of faults consist of 5 levels: absence (0, 0.1), not likely to exist (0.1, 0.3), unclear (0.3, 0.5), maybe exist (0.5, 0.7), must exist (0. 7, 1). According to this method, variable common faults of automobiles' automatic transmission in Table 1 are fuzzified. We can get the fuzzified network learning sample as shown in Table 2 (Wei, 2011).

Table 3: Neural network input

Group number	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8
1	0.0	0.9	1.0	0.9	1.0	0.8	0.0	0.0
2	0.1	0.8	0.9	0.7	0.8	0.9	0.2	0.1

Sample training and simulation:

- **Sample training:** By using the above-mentioned 3-level BP neural network algorithm, we respectively conduct network training on 17 groups of fault samples, which have undergone fuzzy processing or not. Among them the 8 neurons in input layer represent 8 fault phenomenon. 13 neurons in output layer represent 13 fault reasons. 19 neurons are selected from hidden layer according to Kolmogorov theorem. Systematic error is set as 10-3, the maximum learning times are 1000. Initial learning rate is 0.01, and momentum constant is 0.95. By applying Matlab software, the simulation result of this network training is presented in Fig. 2.
  It is shown in Fig. 2a that convergence rate of the network is very fast. After 8 times of learning, errors meet requirements. In Fig. 2b, the samples are not fuzzified. Only after 1000 times of network learning can errors be reduced to 0.0118343. This can prove the necessity of applying fuzzy theory to the fault diagnosis of automobiles' automatic transmission.

- **Simulation:** To test the precision of diagnosis network and the generalization ability of neural pattern, two groups of fault samples which have the same fault causes of learning samples are selected

Table 4: Neural network output

	y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8	y_9	y_{10}	y_{11}	y_{12}	y_{13}
1	0.00056121	1.6312e-008	2.7903e-017	1	5.7478e-007	1.7667e-013	1.1445e-021	4.9805e-008	3.3762e-015	9.8924e-014	6.7573e-010	4.3187e-009	4.7528e-012
2	0.004360	21.4504e-009	4.359e-019	0.99997	1.5224e-009	1.3525e-011	9.3143e-022	2.2648e-008	5.6477e-014	3.4023e-012	2.8897e-010	1.3498e-009	8.8759e-011

randomly for test. The first group of fault sample is the learning sample from Fig. 2. The second group of fault sample is the non-learning sample which is expressed in Table 3.

To input the above two groups of fault samples which need to be recognized into well-trained neural network and operate, we can obtain the output of neural network as shown in Table 4. Then maximum membership degree method is used to defuzzify. According to the description of fault causes' membership function in chapter 2.2, there must exist fault cause y4 in the two groups of samples, i.e. the fault of sensor circuit. Thus through the comparison between the diagnosis output result of these two groups of samples and the output data of the given sample, we get to know that the diagnosis result is totally correct.

CONCLUSION

The combination of fuzzy theory and BP neural network realized the diagnosis of automatic transimission's common faults, overcome the neural network's weakness of expressing indefinite information, and improve the precision of neural network fault diagnosis as well as network convergence rate. It is proved that this method not only can optimize neural network structure, but also make precise recognition on the faults of automobiles' automatic transmission. As the structure of automobiles' automatic transmission is becoming more and more complicated, the application of this method enjoys a bright future.

REFERENCES

Chen, J.M., 2004. Data Warehouse Principle Design and Application. Press of Chinese Water Resources and Hydropower, Beijing, China.

Li, G.Y. and Q.F. Yang, 2007. Intelligent fault diagnosis system of vehicle engine based on BP neural networks. J. Syst. Simulat., 19(5): 1034-1037.

Ma, C.F., 2008. Diagnosis and Elimination of vehicle automatic transmission' typical faults. Agric. Equipment Vehicle Eng., 21(10): 50-52.

Shao, Y.J., H.H. Hui and Y.Z. Zhang, 2007. Metallogenic prediction of Xiangxi gold deposit based on BP neural networks. J. Cent. South Univ. Sci. Technol., 38(6): 1192-1198.

Sun, W., J.L. Bai Jianlin and Y.J. Lei, 2008. The Application of maximum membership degree in multisensor information Fusion and track correlation. Electro-Optic Control, 15(8): 10-13.

Tang, Q.Y. and M.G. Feng, 2007. DPS Data Processing System: Experimental Design, Statistical Analysis and Data Mining. Science Press, Beijing.

Wei, S.Y., 2011. Fault diagnosis system of vehicle automatic transmission based on fuzzy theory. Mach. Design Manufact., 32(01): 230-232.