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Study on Neural Network Automobile Fault Diagnosis Expert System

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Abstract: Because of the product variety and structure complexity of automobile, the traditional diagnosis technologies were difficult to meet the requirements of fault detection and maintenance. In order to improve the diagnosis and maintenance level of automobile faults, the application of neural network technology in expert system of automobile fault diagnosis was studied. The basic concepts and methods of fault diagnosis expert system were introduced and neutral network model and BP algorithm were analyzed. The structure of neutral network expert system was brought forward and the key technologies were discussed, including knowledge acquisition, knowledge representation and inference mechanism. Taking the case of abnormal noise of automobile engine, the typical fault phenomenon of abnormal sound were analyzed in detail, an automobile fault diagnosis expert system based on three-layer neutral network was designed and implemented. The experimental results showed that the sample output corresponded to the expected output within the error range, the system was reliable and the requirement of intelligent fault diagnosis was achieved.

Key words: Fault diagnosis, expert system, neural network, BP algorithm

INTRODUCTION

Currently, the total number of vehicle in China is increasing very rapidly, the automobile models are complex, the types are diverse, the internal structures are complicated and the faults are various which are difficult to be found. Many automobile maintenance enterprises cannot repair the faults or meet the maintenance needs due to lack of technical guidance of experts. In order to improve the utilization rate of vehicle and reduce the economic losses, the users want to have convenient vehicle fault detection methods and understand the real-time usage states (Zhu *et al*., 2010).

The expert system is one of the most important and active application areas of artificial intelligence which develops from 1960s (Liao, 2005). It is an intelligent computer program based on knowledge, using expertise of expert to solve particular complex problems in certain fields (Liu and Liu, 2003). After many years of development, a variety of expert systems have been emerged around various professional fields, they have been widely used and developed further in application (Cao, 2004). It has several characteristics, including heuristic, transparency and flexibility (Zhang and Zhang, 2010; Zhang, 2011).

The expert system of automobile fault diagnosis can simulate diagnosis ideas of maintenance experts to find and remove automobile troubles (Chen *et al*., 2003). The system mainly uses the build-in-vehicle sensors to obtain fault information of electronics control units. It makes use of artificial intelligence algorithm to process the obtained comprehensive fault information, analyzes the causes of failures and feedbacks the analysis results to the users.

The fault diagnostic objects include engine, chassis, electrical equipment and so on (Yue *et al*., 2011). Fault diagnosis is an important application direction of artificial intelligence in automotive industry and it is the product of collaboration of field experts and engineers.

At present, there are several models for automobile fault diagnosis expert system, including rule-based diagnosis expert system, instance-based diagnosis expert system, behavior-based diagnosis expert systems, fuzzy logic-based diagnosis expert systems and artificial neural network-based diagnosis expert system. Although the research of fault diagnosis expert system for automobiles has made some progresses but it still cannot fully replace the thought process of experts. It is necessary that the system should cooperate with experts in fault diagnosis field to obtain satisfactory diagnostic results.

The shortcoming of automobile fault diagnosis expert system is mainly focused on weak knowledge acquisition ability and insufficient system knowledge. Wherein, the former is the biggest obstacle which restricts its usefulness and development. In recent years, researchers look for other ways to address the lack of expert systems (Xi, 2009). The important development trends of automobile fault diagnosis expert system lie in networking, intelligence and integration in future (Zhang *et al*., 2008).

The automobile intelligent fault diagnosis expert system is the demand and inevitable trend of the rapid development of automobile industry. Introducing the

neural network technology into the automobile fault diagnosis expert system in recent years is an important development direction of automobile research and technology. From the theoretical study and practical application point of view, the fault diagnosis system based on neural network has unique advantages in knowledge acquisition, knowledge representation, reasoning, learning ability, fault tolerance and so on (Men and Wang, 2007).

On the basis of analyzing the characteristics of expert system, the automobile fault diagnosis expert system based on neural network is designed and realized in this study and the intelligent fault diagnosis is implemented which can provide facility for discovering and removing the faults of automobile and the system has certain value in practice.

BP NEURAL NETWORK

Neural network is an information processing system or a computer system based on the imitation of the structure and function of human brain. Neural network has strong capabilities of learning, memorizing and various intelligent processing which has been widely used in automatic control, artificial intelligence, pattern recognition, fault diagnosis and other fields.

Structure of neural network: Neuron is the basic unit of neural network which can be regarded as a multi-input single-output nonlinear device and its internal state is determined by the weighted sum of the input signals (Li, 1999). Neural network consists of many neurons which are arranged in layers. According to their connection methods, from the functional point of view, the neural network is divided into two types, feed forward network and feedback network.

Feed forward neutral network: Feed forward network is the most common type which system structure is shown in Fig. 1. Each neuron in the network receives the inputs of previous level and output to the next level, the network has no feedback. The network nodes are classified into two categories: Input unit and calculating unit. Each calculating unit may have any number of inputs but only one output. Usually, the feed forward network can be divided into different layers. The inputs of layer i are only connected with the outputs of layers i-1. The input and output nodes of system are connected to the outside, while the other intermediate layers are called hidden layers. All layers constitute a strong learning system which structure is simple and easy to be programed. From a system point of view, the feed forward network is static non-linear mapping. Most of feed forward neural networks do not pay attention to the dynamic behavior of the system. Their capabilities of classification and pattern recognition are stronger than other types of neural networks.

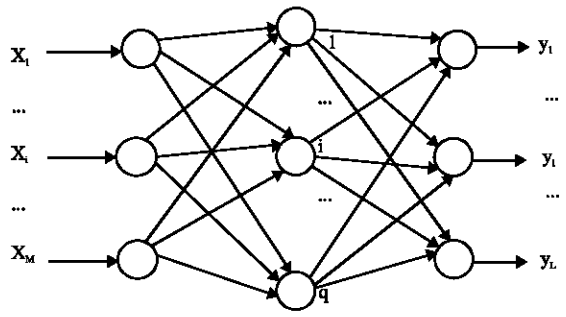

Fig. 1: System structure of feed forward neutral network with three layers (x_i is input, y_l is output and hidden layer has q nodes)

Feedback neutral network: Feedback neural network is also known as recursive network or regression network. In the feedback network, the input signal determines the initial state of the feedback system. After a series of state transitions, the system gradually converges to an equilibrium state. It follows that the stability of the feedback network is one of the most important issues. All nodes of feedback neural network are calculating units. They can not only receive the inputs but also output to the outside.

BP neural network: The artificial neural networks are widely used in pattern recognition and other fields and the most used one is BP neutral network (Wu *et al*., 2008) which is a multilayer feed forward network and can be used in fault diagnosis fields. Usually, the action function of neurons mostly is Sigmoid function. With its conductivity, the leases mean squares learning algorithm is introduced, that is, in the learning process of neural network, the error between actual network output and desired output spreads backward when correcting connected strength to minimize the mean square value of error (Jiaqiang, 2006).

Calculation of forward neural network: In the neural network shown in Fig. 1, assuming that there are M input nodes, L output nodes. There is one hidden layer which contains q neurons in the BP network. In the learning phase of training network, supposing that there are N training samples, the input X_p and output d_p of the sample p are selected to train the network, the inputs and output of neuron i of the hidden layer are, respectively shown in Eq. 1 and 2 under the function of p:

$$net_{pi} = net_i = \sum_{j=1}^{M} w_{ij} o_j \quad (1)$$

$$o_i = f(net_i) \quad (2)$$

where, w_{ij} the link weight; O_i the output of node i, f(.) is Sigmoid function.

The differential of output function is gotten, as shown in Eq. 3:

$$f'(net_i) = f(net_i)\left[1 - f\left(net_i\right)\right] = o_i(1 - o_i) \quad (3)$$

By the weighted coefficient, the output O_i is transmitted forward to the neuron k of the output layer, serving as one of its inputs. The inputs and output of the neuron are respectively gotten, as shown in Eq. 4 and 5:

$$net_k = \sum_{i=1}^{q} w_{ki} o_i \quad (4)$$

$$o_k = f(net_k) \quad (5)$$

If the output is not consistent with the desired output d_k of given mode pair, then the error signal is propagated back from the output side and in the propagation process, the weighted coefficient is modified constantly until the neuron of output layer gets the desired output value (Gong and Wang, 2012). After adjusting the network weight of sample p and then another sample pattern pair is undergone a similar study process until the trainings of N samples are implemented.

Adjustment of network weighted coefficient: For each sample p, a quadratic error function is introduced, as shown in Eq. 6:

$$J_p = \frac{1}{2}\sum_{k=1}^{L}(d_{pk} - o_{pk})^2 \quad (6)$$

Then, the total error function of all N training samples is obtained, as shown as Eq. 7:

$$J = \frac{1}{2p}\sum_{p=1}^{N}\sum_{k=1}^{L}(d_{pk} - o_{pk})^2 \quad (7)$$

It is modified in the direction of error function J_p decreasing until the satisfactory weighted coefficients are obtained.

The correcting formulas of weighted coefficient of input layer and hidden layer are respectively gotten, as shown in Eq. 8 and 9:

$$\Delta w_{ki} = \eta \delta o_i \quad (8)$$

$$\Delta w_{ij} = \eta o_i(1 - o_i)(\sum_{k=1}^{L} \delta_k w_{ki}) o_j \quad (9)$$

where, η is learning rate and $0<\eta$.

The correcting formulas of weighted coefficient of arbitrary neuron k of input layer and hidden layer are respectively shown in Eq. 10 and 11 under the function of sample p:

$$w_{ki}(k+1) = w_{ki}(k) + \eta\delta_k o_i + \alpha[w_{ki}(k) - w_{ki}(k-1)] \quad (10)$$

$$w_{ij}(k+1) = w_{ij}(k) + \eta\delta_i o_j + \alpha[w_{ij}(k) - w_{ij}(k-1)] \quad (11)$$

where, α is inertia coefficient and $0<\alpha 1$.

In summary, the learning process of weighted coefficient is as follows:

- All weighted coefficients are initialized and set to small random numbers
- The training set is provided and the values of input vector X_n and the desired output vector d_n are given
- The error between the expected network output and the actual output is calculated
- The modified value of weighted coefficient of output layer is computed and the weighted coefficient is adjusted
- The modified value of weighted coefficient of hidden layer is computed and the weighted coefficient is adjusted
- Return the step (3) and recalculate the values until the error meets the requirement of system

FAULT DIAGNOSIS EXPERT SYSTEM BASED ON NEURAL NETWORK

Expert system is based on logical reasoning, going through knowledge acquisition, knowledge representation, knowledge reasoning and other stages and it should take long time. Neural network simulates human brain to achieve artificial intelligence and respond from a large number of captured events. Expert system and artificial neural network represent two complementary ways, combining the two methods together can play their unique capabilities, construct more powerful and practical artificial intelligence application systems and solve the problems that cannot be solved by expert system or neural network alone.

Structure of neural network expert system: The basic structure of neural network expert system is shown in Fig. 2. It can automatically obtain the module input,

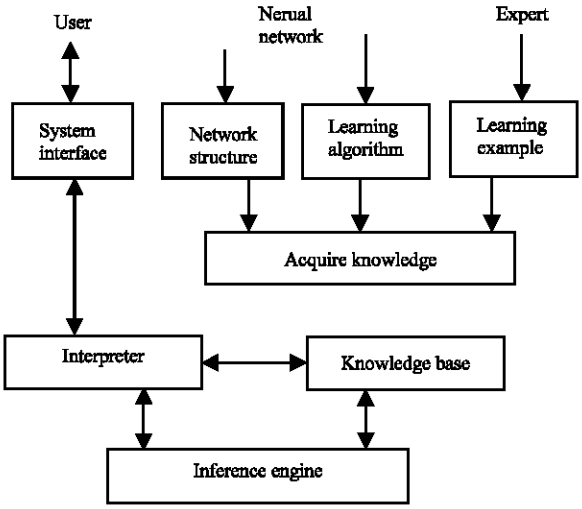

Fig. 2: Basic structure of a typed neural network expert system

organize and store learning examples provided by experts. Selecting neural network architecture and calling learning algorithm of neural network can acquire knowledge for knowledge base. When a new learning instance is input, the knowledge acquisition module automatically gets new distribution of network weights to update the knowledge base by studying new instances.

Knowledge acquisition based on neural network: The knowledge acquisition of neural network is to make the system output be as much as possible with the same answer given by experts in the same conditions of inputs, so that the network has similar capabilities to solve problems with the domain experts. That is, the neural network has expert knowledge and its intelligent behavior in biology is likely to show the changes of connected weights between neurons (Li, 2006).

The knowledge can be formalized as specific examples and the neural network is easy to gain access to such knowledge. Firstly, the model and the network topology are determined, according to the selected learning algorithm and then the network can learn from the samples. By learning it adjusts the weights of neural network and acquires knowledge. Multilayer feed forward neural network model is typical with supervised training. After the normalized processing, the numerical sample sets are constructed. In the learning process, according to the error between actual output value and the desired output of neural network, the network weights are adjusted. The network reaches steady until the mean square of error is less than a predetermined minimum value. In this case, the neural network has gained knowledge from the experience and stores them in the network.

Knowledge representation based on neural network: There are two main ways to express knowledge in neural network.

The first method is to translate the expert experience to rules and express expert knowledge by production rules which are stored in knowledge base. The basic form of production rule is A_B, or, IF A THEN B. The condition A is the premise of production rules, indicating that this rule is available and the result B is a set of conclusion or actions, indicating that the conclusion or operation can be gotten when the conditions indicated by A are met.

Another way is to train the neural network through historical data or experience which summarizes the new diagnostic rules, expanding the contents of knowledge base to make it have self-learning function. It is a prominent feature of fault diagnosis expert system based on neural network (Jiang and Lu, 2004).

Inference mechanism based on neural network: The inference mechanism of fault diagnosis expert system includes three kinds, namely direct reasoning, back reasoning and mixed bidirectional reasoning. The fault diagnosis expert system based on neural network generally uses direct reasoning. The neural network system relies on a trained network to compute, starting from the initial state, forward reasoning, until the target state is obtained. The essence of this reasoning method is the forward calculating process. That is, taking the known symptom vector as the input pattern, the network output mode and fault vector can be calculated through network calculation (Cui *et al*., 2003).

Comparing with the traditional fault diagnosis expert system, this direct reasoning process of neural network expert system has some advantages, such as rapid reasoning, overcoming conflict and so on.

DESIGN OF AUTOMOBILE FAULT DIAGNOSIS EXPERT SYSTEM BASED ON NEURAL NETWORK

The fault diagnosis expert system based on neural network can identify the fault type of device, as long as the network is trained by different types of training samples. The network can be able to monitor the new input information quickly and determine the failure type of certain equipment.

Failure mode analysis of engine abnormal sound: After long-term usage, along with the increase of mileage, the technical conditions of automobile gradually deteriorate which can be usually characterized by abnormal sound, fluid leakage, overheating, power drop, excessive fuel

Table 1: Codes and fault phenomenon of abnormal sound of automobile engine

Code	Fault phenomenon
x_1	Obvious abnormal sound of idle speed
x_2	Obvious abnormal sound of higher idle speed
x_3	Obvious abnormal sound of medium speed
x_4	Obvious abnormal sound of higher medium speed
x_5	Obvious abnormal sound of one-off accelerating of medium speed
x_6	Obvious abnormal sound of continuous accelerating
x_7	Obvious abnormal sound of stepping on the gas at low speed
x_8	Obvious abnormal sound of oil filler
x_9	Obvious abnormal sound of left and right of engine
x_{10}	Obvious abnormal sound of juncture of tank bottom and cylinder
x_{11}	Obvious abnormal sound of bottom of oil pan when accelerating
x_{12}	Obvious abnormal sound of upper or top of cylinder
x_{13}	Body shakes when accelerating
x_{14}	Obvious abnormal sound when low temperature
x_{15}	Abnormal sound reduces or disappears when single cylinder is cut off
x_{16}	Abnormal sound is clear when single cylinder is cut off
x_{17}	Abnormal sound reduces or disappears when adjacent cylinder is cut off

x_i (i = 1, 2,..., 17) indicates the fault phenomenon for abnormal sound of engine

consumption, body vibration and so on. The failures of automotive mechanical system are based on abnormal noise (Huang, 2008). The engine is a complex device which noise in motion has a variety of reasons. The abnormal sound can prompt that the engine may have fault which contains a wealth of meaning (Zhang *et al*., 2012).

This study designs an automobile fault diagnosis expert system based on neural network by making the abnormal sound of engine as an example. The noise is generated by vibration or sound waves of some parts of the engine. It means that the faults occur if the engine has abnormal sound. The common abnormal sounds of engine include piston cylinder knocking, piston pin knocking and connecting rod bearing knocking, crank bearing knocking and so on. They are identified as the codes y_1, y_2, y_3, y_4, which correspond 17 fault phenomenon (Xiao, 2001), as shown in Table 1.

Establishment of automobile fault diagnosis neural network: The size of the neural network is determined based on the abnormal sound and fault phenomenon of automobile engine. According to the previous analysis, a three-layer BP neural network is selected and there are 17 nodes in input layer and 4 nodes in output layer.

The choice of node number of hidden layer is more complex. Too few nodes cannot well train the network and recognize the previously studied samples and fault tolerance is poor; too more nodes need too long learning time and the error is not necessarily smallest. Therefore, there is an optimal node number in hidden layer (Li *et al*., 2001). According to experience, the node number of hidden layer is given, as shown in Eq. 12:

Table 2: Eight training samples of fault phenomenon of abnormal sound of engine for BP neural network automobile fault diagnosis expert system

Sample	1	2	3	4	5	6	7	8
x_1	1	0	1	0	0	0	0	0
x_2	0	1	1	1	0	0	0	0
x_3	0	0	1	1	1	1	1	1
x_4	0	0	0	0	0	0	0	1
x_5	0	0	0	0	1	1	0	0
x_6	0	0	0	0	0	1	0	1
x_7	0	0	0	1	0	1	0	0
x_8	0	0	1	1	0	0	0	0
x_9	0	0	0	0	0	0	0	1
x_{10}	0	0	0	0	1	1	0	1
x_{11}	0	0	0	0	1	1	1	1
x_{12}	1	0	0	0	0	0	0	0
x_{13}	0	0	0	0	0	0	0	1
x_{14}	1	1	0	0	0	0	0	0
x_{15}	0	0	0	0	0	0	1	1
x_{16}	0	0	1	1	0	0	0	0
x_{17}	1	1	0	0	1	1	0	0

x_i (i = 1, 2,..., 17) indicates the fault phenomenon for abnormal sound of engine

Table 3: Eight outputs of training samples of abnormal sounds of engine for BP neural network automobile fault diagnosis expert system

Output	1	2	3	4	5	6	7	8
y_1	1	1	0	0	0	0	0	0
y_2	0	0	1	1	0	0	0	0
y_3	0	0	0	0	1	1	0	0
y_4	0	0	0	0	0	0	1	1

y_i (i = 1, 2, 3, 4) indicates the abnormal sounds of engine

Table 4: Actual output of BP neural network when training samples are input

Output	y_1	y_2	y_3	y_4
1	1.0009	-0.0004	-0.0011	0.0013
2	1.0010	-0.0028	-0.0005	-0.0011
3	-0.0013	0.9976	0.0019	-0.0011
4	0.0008	1.0012	-0.0027	0.0004
5	0.0030	-0.0079	0.9956	-0.0039
6	-0.0067	0.0071	0.9992	0.0027
7	-0.0081	0.0149	-0.0040	1.0062
8	0.0079	-0.0171	0.0023	0.9950

y_i (i = 1, 2, 3, 4) indicates the abnormal sounds of engine

$$n_2 = \sqrt{n_1 + n_3} + a \quad (12)$$

where, n_1 is node number of input layer; n_3 is node number of output layer; α is adjusted value which range is [1, 10] (Wei and Zhang, 2001). By comprehensive consideration, n_2 is set to 7 in this expert system.

Sample selection of neural network: Based on the situation of fault diagnosis, the training sample and the output can be gotten, as shown in Table 2 and Table 3.

Training results and analysis: In this automobile fault diagnosis expert system based on BP neural network, the training error is set to 0.001, the training samples are input into the system program and the test results can be gotten, as shown in Table 4.

As can be seen from Table 3 and 4, the actual output and the desired output values have relatively good

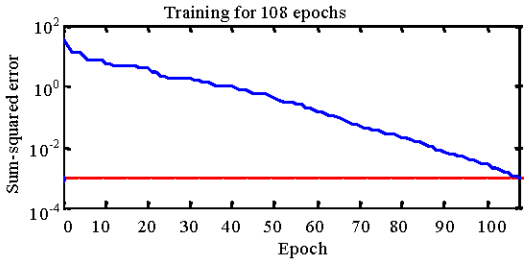

Fig. 3: Relation between learning error and training epochs when inputting the training samples into the system

matching degree, so that this automobile fault diagnosis method based on BP neural network has high accuracy and reliability.

The relation between learning error and training step is shown in Fig. 3. It can be seen that when the training process reaches 108 steps, the error accuracy is to meet the requirement of fault diagnosis. Further, when the error requirement changes it can be found that the training step and time change correspondingly. For instance, if the required training error is smaller, the training time is longer and the training step is more. The results also show that the network has strong diagnosis functions if there are enough training samples.

CONCLUSION

On the basis of analyzing the features of automobile fault diagnosis expert system and the methods of neural network analysis, an automobile fault diagnosis expert system based on a three-layer BP neural network is designed and realized by making the abnormal noise of automobile engine as example. The experiment simulation results show that this method can automatically diagnose and reason and has strong diagnosis functions. The diagnostic results are inaccordancewiththe expectations. The system has good fault tolerance, feasibility and stability and it has certain application value.

It should also be noted that there is contradiction among the error of neural network, training time and training step. Especially in the specific applications it requires more consideration to let the fault diagnosis expert system achieve better application results. In addition, inthematterof failure modes of automobile, the system needs more expert knowledge to form a complete knowledge base. It should be continually improved in the latter practical application and finally the truly practical automobile fault diagnosis expert system can be achieved.

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