A study about fault diagnosis of automobile engine based on neural network

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Abstract. BP neural network is applied on fault diagnosis of automobile engine in this study. Actually tested fault samples of unstable idle speed are used to train network. The results of tests prove that applying BP neural network on fault diagnosis of automobile engine is quite efficient. This method has high diagnostic efficiency and accuracy.

Introduction

The operation of automobile engine is very complex. Faults of engine are featured by multi-position, multi-phenomenon and nonlinear; consequently the fault diagnosis is difficult to conduct. Since the mechanism of fault has not been found out yet and no sufficiently precise model to describe fault in engine, a system which is intelligent like exports, could learn fault cases, and has the ability to find the feature of faults from huge amount of samples and make judgment and forecast is required. The development of artificial neural network theory provides a way to solve this issue. The system's recognition capacity and intelligence is significantly high due to its self-adoptive study ability. In this study, the neural network is applied on fault diagnosis of automobile engine to raise the accuracy of fault diagnosis.

BP neural network

The multilayer feed forward network trained by error back propagation algorithm is normally called BP neural network. The basic principle of BP algorithm is composed by signal forward propagation and error back propagation. In forward propagation, the model acts on input layer, after processed by buried layer, directs to output layer. If the expected output is not get by output layer, the process turns into error back propagation stage. The error of output will be back to input layer via buried layer in a certain mode and divided to all the units on every layer thereby the reference error (error signal) of units on each layer is obtained to serve as the basis for modifying each unit's weight. This process of signal forward propagation and error back propagation which is used to modify weight matrix of each layer, is the learning (or training) process of network. The process is circulating until the output error of network is reduced to an acceptable level or the set times of study is reached. By circulating the calculating process of forward and back propagation, the output value of BP neural network will go consist with the expected value at last.

Sample collections

The unstable idle speed of SANTANA 2000 GSI with AJR engine is took for example to explain the selection and extraction of faults' features.

Analyzing the reason of unstable idle speed

Unstable idle speed is a common fault in automobile engine, for which the reasons could be jammed fuel injector, leakage of vacuum, and fault in ignition system, etc.. An intelligent model is established to identify the reason of unstable idle speed in AJR engine by applying neural network[1]. Refer to Fig.1.

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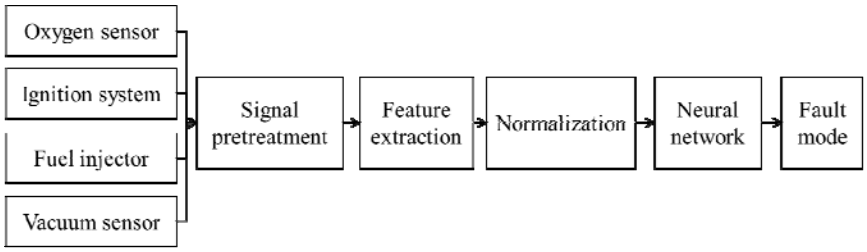

Fig. 1 model of mode identification of neural network

Pretreatment of signal and extraction of features

Since the extraction of information is affected by random disturbance seriously, the signal needs pretreatment before extracting features. As for input variable of neural network, the study is divided into two situations.

1)selecting parameters by features

The task of features selection is to select m (m<n) features from n features. The most direct method is to select the most influential feature by export's experience. Another method is to screen out the most featured feature by mathematic approaches. In this study, the former method is applied. As for faults of unstable idle speed, four kinds of wave of oxygen sensor, ignition system, fuel injector and vacuum sensor are chose for diagnosis. All the information of the wave form of sensors or actuators is mainly indicated on the structure of wave form; the structural feature of wave shape could be extracted directly from the time domain waveform. The selected factors are average voltage of waveform of oxygen sensor, whether clutter exists; breakdown voltage of ignition system, sparking voltage, and dwell angle; injecting time of fuel injector; vacuum degree of vacuum sensor.

2)Extracting feature factors based on expansion of Karhunen-Loeve [2]

Extracting feature factors based on expansion of Karhunen-Loeve could compress the samples by feature to reduce the space dimensionality of features. With the view to obtain correct statistical result, large amount of experiment is conducted under three kinds of idle speed situations of AJR engine, normal, injector jammed and vacuum leakage; and 100 data samples are collected.

Normalization

During practical fault diagnosis work, as features the factors normally have different dimension and magnitude. In order to identify each kind of status by applying neural network, the disturbance of each feature factor's physical unit needs to be eliminated. The analysis should be conducted on quantitatively and between [0, 1].

Applying normalization, $x_i^0 = 1 - \frac{|x_i - \bar{x}|}{x_{\max} - x_{\min}}$, Where, x_i^0 is normalized data, x_i is the practically measured data, $x_{\max} = \max\{x_i\}$, $x_{\min} = \min\{x_i\}$, $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$.

The feature factors could be used as input feature vector of neural network after being normalized.

Designation of neural network

BP algorithm is applied to establish the center of diagnosis. Currently the size of neural network is determined by demand and experience. The number of phenomenon of fault is corresponding with number of input nods; and the number of position of fault is corresponding with the number of output nods. The selection of the number of layers of buried layers and units on buried layers is normally determined by experience since there is no theory support now. The selected amount is only required for sufficient capacity and certain learning speed.

Determining number of layers

Theoretical analysis demonstrate that neural network with single buried layer can map any continuous functions [3-4] . Although adding number of layers could reduce the error of training network and increase accuracy, meanwhile the structure of network become more complex which

leads to a long training time. Normally the accuracy of network could be improved by increasing the number of buried neuron. The structure, single buried layer, is used in this study. Refer to Fig. 2.

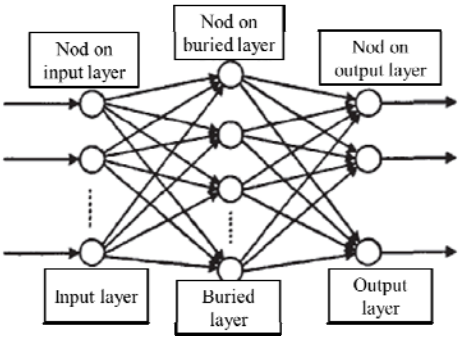

Fig.2 central structure of neural network

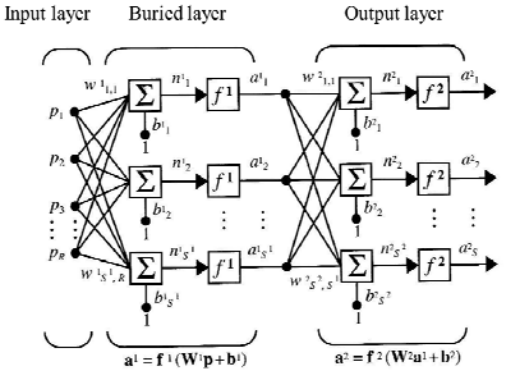

Fig. 3 structure of BP network

Determining number of nods of buried layer

When the nods of buried layer is not enough, the amount of information got by network would be too less. But if too many nods are used the training time would be longer and a phenomenon called "over fitted" would occur. The common way to determine the number of nods of buried layer is training network with different number of buried nods with same sample set until the weight doesn't change any more and network becomes stable.

Selecting transfer function

Transfer function could control the activation of input to output. Converting output with infinite field into input with specified finite field could affect the capacity of solving problem of neural network directly. The activation function of BP network must be differentiable, so threshold function with two values or sign function could not be used. The common choice is S-type function such as logarithmic or tangent function (LOGSIG or TANSIG) and linear function (PURELIN). In this study, the transfer function of buried layer is S type function and of output layer is linear function.

Designation of output layer

The expression of output variable varies. In this study, binary code is employed since it could save internal memory and reduce operating time. Using eight feature factors of 4 kinds of sensors, oxygen sensor, ignition system, fuel injector and vacuum sensor, to identify the two fault modes of unstable idle speed, injector jammed and vacuum leakage. The mean of output vector is as follows:

[0, 0, 0]-normal; [0, 1, 0]-injector jammed; [0, 0, 1]-vacuum leakage.

Result and discussion

In order to research the effect of different algorithm and different input vector to neural network, 100 learning samples and 50 test samples are used to train and test network. The input of network structure is set as eight feature factors of four sensors, oxygen sensor, ignition system, fuel injector and vacuum sensor. Input and output training pair is 30; average square error is 0.001; algorithm is Levenberg-Marquardt. The structure is shown in Figure 3. R means the number of input samples; S means number of output samples; the output of last layer is the input of next layer; every layer has a different amount of neurons and different transfer function. In figure, the letters' superscript represent number of layer; a represents output of certain layer; f represent transfer function; w is weigh matrix or weight vector, b is threshold.

In figure, p=[average voltage of oxygen sensor, whether clutter exists; breakdown voltage of ignition system, sparking voltage, and dwell angle; injecting time of fuel injector; vacuum degree of vacuum sensor]; f1 uses S-type transfer function (LOGSIG); f2 uses linear transfer function (PURELIN).

1)Number of buried nods

The effect of number of nods on buried layer is shown in Table 1. In the table, learning error is the result of training network by preliminarily determined network structure and learning condition; test

error is the error result of testing network with test sample set; Epochs is times of training. It can be seen that increasing nods on buried layer could reduce learning error and time, but when the amount exceed a certain number, the test error becomes larger and learning time becomes longer. The number of nods on this buried layer is set as 10.

As shown in Table 1, when the number of nods on buried layer is 10, the test error is very small. The test error could be reduced to less than 1% within 1.20s. Therefore applying this network in fault diagnosis of automobile engine possesses high efficiency and accuracy.

2)Transfer function

The result of affect from transfer function to network's performance is shown in Table 2.

Table1 Effect of number of nods on buried layer to Performance

No. of buried nods	Learning error	Testing error	time / s	Epochs
5	0.008 44	0.010 33	19.78	22
10	0.009 05	0.009 98	1.20	7
15	0.005 96	0.013 82	2.73	8
20	0.006 59	0.030 98	10.24	6
30	0.001 73	0.060 97	26.78	**5**

Table 2 effect of transfer function to performance

Buried-output layers' transfer functioin	Training errors	Epochs
TANSIG-PURELIN	1.66385×10^{-4}	52
TANSIG-LOGSIG	2.6998×10^{-7}	39
LOGSIG-PURELIN	2.19097×10^{-4}	68
LOGSIG-TANSIG	9.904643×10^{-5}	25

The result in Table 2 shows that when transfer function of output layer is linear function, the training error is larger and training time is longer than S-type function. But when the transfer functions of buried and output layer both are S-type function (TANSIG-LOGSIG and LOGSIG-TANSIG), the training error and time has small difference. When the transfer function of buried layer is S-type and the transfer function of output layer is linear (TANSIG-PURELIN and LOGSIG-PURELIN) the difference in training error and time is the smallest. It's thus clear that although buried layer with S-type and out layer with linear function could approach any functions, its capacity of nonlinear mapping is bad poorer than that of the network with buried and output layer are all S-type. Obviously former is easy and fast to calculate and performance much better in training large network.

Conclusion

1) Applying BP neural network has good effect and high accuracy and efficiency.

2) The research about this method would promote the combination of fault diagnosis expert system and neural network, and then raise the system's self-learning ability. Fault diagnosis of automobile belongs to mode identification of kinetic status study of nonlinear system. Neural network has good capacity of nonlinear mapping, which make it appropriate in identifying fault in electronic control system in automobile. The topological structure of neural network has huge effect on accuracy and efficiency of training, which means different numbers of neuron nods on buried layer and different set of transfer function have direct effect on accuracy and efficiency of training.

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