The Fault Diagnosis of Diesel Fuel Supply System Based on BP Neural Network Optimized by Genetic Algorithm

Jiangjiang He¹, Xiaoquan Li² and Yuwei Zhao²

¹The Graduate School, Air Force Engineering University, Xi’an, China
²Air and Missile Defense College, Air Force Engineering University, Xi’an, China

*Corresponding author e-mail: 2440772267@qq.com

Abstract. As an important power source of diesel engine, the fuel supply system has the characteristics of high failure rate and being difficult to be detected, which is critical to detect and diagnose the fault for the reliable and stable operation of diesel engine. In the paper, principal component analysis (PCA) was used to process the initial data, back-propagation (BP) neural network was used to diagnose fault of diesel engine, BP diagnosis efficacy was analyzed, then the BP neural network fault diagnosis system was optimized by being introduced in the genetic algorithm, and the comparison results of training error and diagnostic analysis showed that: the fault diagnosis of BP neural network optimized by genetic algorithm is more accurate than that of traditional BP, which can effectively improve the fault diagnosis accuracy and reduce the training time.

1. Introduction

As a power source of diesel engine, fuel supply system contains many kinds of precise separate components, which faults account for 27% of diesel engine failure. Therefore, a lot of researches center on the fault diagnosis technology of fuel supply system around the world. The fault diagnosis of fuel supply system develops at an incredible rate promoted by fault tree analysis, thermal parameter detection, vibration signal detection, crankshaft instantaneous speed detection and oil analysis technology. The fault diagnosis faces a severe test because of the large number of fault data and the accuracy of detection equipment. In the 1980s, the artificial neural network technology was refined, and applied to the fault diagnosis, which made the fault diagnosis of fuel supply system develop rapidly. The characteristic parameters of diesel engine and fault type data are extracted to experiment with the artificial neural network. After determining the network structure, the fault data are input into the diagnosis system to get the fault type. However, there are many types of faults in fuel supply system, which require higher diagnostic accuracy. It is necessary to optimize the neural network fault diagnosis system. With the development of a series of optimization algorithm such as genetic algorithm (GA), particle swarm optimization and ant colony algorithm, the accuracy of neural network diagnosis is effectively improved by optimizing the initial value of neural network [9].

In this paper, genetic algorithm and BP neural network is used to diagnose the fault of diesel fuel supply system. The genetic algorithm optimizes the initial weights and thresholds of BP neural network. Using the fault data to train and test the BP neural network optimized or not by genetic algorithm. The experimental comparison comes into being.
2. The fuel supply system and fuel pressure wave

Fully atomized diesel oil transported by the fuel supply system sprays into the cylinders at regular time, quantity and pressure, mixing and burning with air quickly and sufficiently. The fuel supply system is mainly composed of fuel tank, diesel filter, low-pressure oil pipe, fuel pump, injection pump, high-pressure oil pipe, injector and so on [7] (Figure. 1). The complex composition of the system leads to higher failure rate.

Figure 1. Composition of Diesel Fuel Supply System

The waveform characteristics of the high-pressure oil fuel pressure can get the fault cause analysis. The cause of failure can be obtained by analyzing the waveform characteristics of fuel pressure in high-pressure oil circuit. Figure 2 shows normal pressure waveforms and characteristic parameters.

Figure 2. The normal pressure waveform

3. BP Neural Network and Genetic Algorithms

3.1 BP neural network

BP neural network is composed of multi-layers. There is no connection between the neuron in the same layer. BP network, a critical part of the artificial neural network system, belongs to the multi-layers feedforward network, which the linear inseparable problem can be dealt [1]. It is widely used in the fields of recognition, approximation, regression and compression. A typical three-layer BP neural network structure [8] is shown in Figure. 3.
The transfer function of BP network must be differentiable. Sigmoid function is usually used in the hidden layer (approximating linear function from 0 to 1), and linear function is used in the output layer.

The core of BP learning algorithm is the steepest descent method. The gradient descent technique is used to minimize the deviation mean square value between the actual and the expected output value of the network, including the positive signal propagation and the error back propagation. The forward propagation of the input signal passes through the non-linear transformation of the hidden layer to produce the output signal $y_j$. The deviation between the calculation and the expected output $d_j$ is $e_j$.

$$e_j = d_j - y_j$$

The deviation cannot meet the requirements, then shifts to the error back-propagation process. According to the hidden layer output $v_i$, learning impact factor $\eta$, the transfer function of the output layer and the deviation, the weight adjustment amount between the hidden layer and the output layer is $\Delta w_{ij}$.

$$\Delta w_{ij} = \eta e_j v_i$$

Then calculate the weight adjustment amount between the input layer and the hidden layer $\Delta w_{mi}$.

$$\Delta w_{mi} = \eta \sum_j e_j w_{ij} (1-u_i)$$

### 3.2 Model of BP neural network optimized by Genetic Algorithms

Genetic algorithm is a method of searching for the global optimal solution by simulating the genetic mechanism of the theory of evolution. By means of coding schemes forming the initial population, the fitness of individuals in the population is evaluated. The genetic manipulation (selection, crossover and variation) is conducted according to the fitness values, making the solution optimized from generation to generation and almost optimal at last.

BP neural network optimized by genetic algorithm includes three parts: the determination of BP neural network structure, the optimization of genetic algorithm and the training of BP neural network. According to the number of input and output of fault neural network, the network structure is determined, and then the individual length of genetic algorithm population is determined. Before the training of BP neural network, the weights and thresholds among neurons of each layer are arbitrary values between 0 and 1, which makes the training speed of BP neural network slow down, and easy to lead to local optimum value rather than the global optimum value when the number of iterations is small. The genetic algorithm is used to optimize the initial weights and thresholds of BP neural network. The optimal weights and thresholds are found as the initial values of BP neural network’s training. Then the BP neural network is used to search for the local optimization. Finally, the optimal
solution to the problem is obtained. The genetic algorithm optimization model [5] is shown in Figure 4.

![Diagram showing the genetic algorithm optimization model for BP neural network flow optimization.]

**Figure 4. GA Optimizes BP Neural Network Flow**

### 4. Fault Diagnosis and Simulation

There are many reasons for the fault of fuel supply system, which will cause great changes in the shape and amplitude of the waveform in the high-pressure oil pipeline. According to the eight state parameters of the waveform of the high-pressure oil pipeline, i.e., maximum pressure, seating pressure, injection pressure, sub-maximum pressure, waveform amplitude, width of rising edge, width of waveform and width of maximum after-winds, the fault states including the needle valve stack, the needle valve leaking and the delivery valve failing and insufficient oil supply, and normal state is recognized and diagnosed.

There are 100 sets of training data and 5 sets of test data. Firstly, the data are processed by PCA. The main flow is sketched as follows: after the covariance matrix being obtained from 8 state parameters data, the eigenvalues (from large to small) and eigenvectors are calculated, then the cumulative contribution rate of the principal component is calculated, and the principal component parameter data is obtained finally. The number of principal components and the cumulative contribution rate are shown in Table 1.

#### Table 1. Number of principal components and cumulative contribution rate

| Number of Principal Components | 1    | 2     | 3     | 4     |
|-------------------------------|------|-------|-------|-------|
| Accumulated contribution rate | 44.319 | 70.790 | 86.720 | 99.435 |

When the number of principal components is 4 in Table 1, 99.435% of the data of the original system can be reproduced, so four principal components are selected in this paper. According to the original data with MATLAB, the principal data is obtained.

The experiment is divided into two parts: the first part uses BP neural network for fault diagnosis, the second part uses genetic algorithm to optimize the initial weights of BP neural network, the optimization results is assigned to the initial weights and thresholds, and then the BP neural network is trained and tested. The structure of BP neural network is 4 - 6 - 1, 1000 iterations, the target error is 0, the learning rate is 0.1, the genetic algorithm of population size is 10, the evolution is 30 times, the crossover probability and mutation probability is 0.1 and 0.3.

In Figure 5, after 2500 iterations of BP network training without optimization, the error tends to be stable and the error is 0.14. In Figure 6, after 16 iterations of GA-BP, the error rapidly decreased to $10^{-10}$. 

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Figure 5. BP training error curve

Figure 6. GA-BP training error curve

The genetic algorithm fitness curves shown below in Figure 7. In this paper, the genetic manipulation leaves individuals with smaller (better) fitness. With the continuous evolution, the average fitness of the population decreases.

Figure 7. The fitness curve of genetic algorithm

Figure 8 shows that the network test output before GA optimization can reflect the true value and
classify the faults, there are large errors existing compared with the optimized network test output.

![Plot](image.png)

**Figure 8.** Test Output of BP and GA-BP

5. Conclusion

The traditional BP neural network, using the steepest descent method for fault diagnosis, being easy to lead to reach local optimum rather than the global optimum. The training takes time, especially in the case of a great quantity of training data, network layer and the number of neurons. This paper adopts GA algorithm to optimize the initial weights and thresholds, then trains the network, and the diesel fuel supply system fault diagnosis is conducted at last. The results show that the training speed of the optimized BP neural network is improved, the training error is significantly reduced, and the diagnosis results are more real.

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