# Fan Improved Algorithm of BP Neural Network Fault Diagnosis Research

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## Abstract

According to the structure of the BP neural network and the algorithm, choose three methods of BP neural network algorithm was improved, through analysis and comparison, computing speed is faster, more accurate judgment Levenberg - Marquardt algorithm as the improved algorithm of optimal; Using the algorithm to the established BP neural network for training analysis; Then use the Matlab software, the fan fault feature data for training; Complete the neural network with the training of a group with different fault types of test data, judge the fault types, validation Levenberg - Marquardt authenticity and validity of the algorithm.

## Keywords

Fan; The BP neural network; Fault diagnosis; Improved algorithm.

## 1. Introductory remarks

Every part of fan in the industrial production has been widely used, in most cases, the fan working environment is very bad, very high failure rate [1]. In recent years, with the continuous development of science and technology, intelligent diagnosis and online diagnosis technology developing rapidly, the development of neural network which is a diagnostic method for quickly [2]. Neural network has the characteristics of input and output nonlinear mapping and parallel processing, especially its high degree of self-organization and self-learning ability, make its fault diagnosis is an effective method and means[3].

## 2. Fan vibration signal collection and analysis of characteristic vector

Acquisition of vibration signal of a steel mill fan, the fan in the production of the rotating speed of 1480 r/min (the fundamental frequency of 24.6 HZ).In rotating machinery equipment acquisition need to select horizontal, vertical, axial vibration signal three directions, as shown in figure 1.Layout of observation points are shown in figure 2.On the basis of fan vibration signal, through the spectrum analysis, to extract the signal amplitude frequency doubling and the frequency as quarantine object. In the actual measurement data of fan 45 sets of measurement data and analyzing the fault characteristics contained.

As shown in figure 3, at 25.2 Hz, the peak value of maximum 31.5, namely the largest at twice the fundamental frequency amplitude, and the double frequency occurred on the four times and increased relatively obvious peak value, can be thought of fan rotor unbalance fault and slight fault in the rotor. As shown in figure 4, the largest at 24.8 Hz amplitude, occupied the main position, and a frequency doubling can determine the fan rotor rubbing fault.

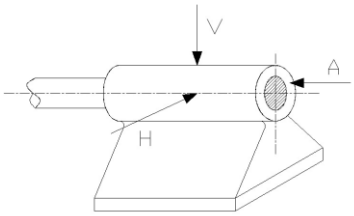


Figure 1. Vibration measuring three directions

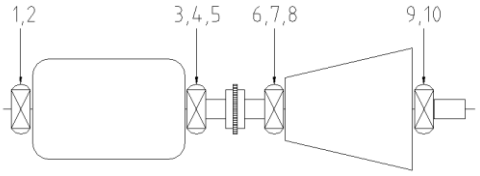


Figure 2. Arrangement of measuring points in the fan


Figure 3. Bearing vertical spectrum diagram


Figure 4. Bearing axial spectrum

## 3. The improved algorithm of BP neural network

### 3.1 Adaptive lr gradient descent method[4]

This method can guarantee the network always with maximum acceptable learning rate for training. The type of adaptive learning rate adjustment formula:

$$\eta(k+1)=\begin{cases}1.05\eta(k), SSE(k+1)< SSE(k)\\ 0.7\eta(k), SSE(k+1)> 1.04SSE(k)\\ \eta(k), \text{Others}\end{cases} \quad (2.1)$$

The range of initial learning rate $\eta(0)$ can have great randomness.

### 3.2 Elastic gradient descent method[5]

The gradient descent method using the error gradient decreases plane. Elastic algorithm introduces the partial derivative of the gradient, in the original case, gradient amplitude of connection weights is work, the partial derivative of the introduction of gradient, in order to eliminate the gradient amplitude on the role of connection weights. Namely

$$\Delta x(k+1)=\Delta x(k+1)\cdot sign(g(k)) \quad (2.2)$$

$$=\begin{cases}\Delta x(k)\cdot k_{inc} sign(g(k)) (\text{When partial derivative symbols at the same time})\\ \Delta x(k)\cdot k_{dec} sign(g(k)) (\text{When partial derivative symbols instead})\\ \Delta x(k) (\text{when } g(k)=0)\end{cases}$$

Formula: g(k)—— k gradient iteration;

$\Delta$x(k)——Weight or the k iteration threshold value, the initial value is user settings;

$k_{inc}$, $k_{dec}$——Incremental investments and the reduction factor, is the user settings.

### 3.3 Levenberg - Marquardt method[6]

Levenberg - Marquardt method is actually the combination of the gradient descent method and quasi-newton method, absorb the advantage of the two. Levenberg - Marquardt method search direction positioning:

$$S(X^{(k)})=-(H^{(k)}+\lambda^{(k)}I)^{-1}\nabla f(X^{(k)}) \quad (2.3)$$

Make $\lambda^{(k)}=1$, Then $X^{(k+1)}=X^{(k)}+S(X^{(k)})$.

When beginning, $\lambda$ take a very large number (such as $1e+4$), at this point is equal to the step size is very small gradient descent method; With the approach of the advantages, $\lambda$ reduce to zero, $S(X^{(k)})$ is from the negative gradient direction towards the direction of the Newton's method. Usually, when $f(X^{(k+1)})<f(X^{(k)})$, reducing $\lambda$ (such as $\lambda^{(k+1)}=0.5\lambda^{(k)}$);Otherwise the $\lambda$ increase (as $\lambda^{(k+1)}=2\lambda^{(k)}$).

## 4. The comparison and selection of improved algorithm

### 4.1 The selection of parameters

Input nodes selected as nine, elected three output node. Number of hidden layer nodes as the 11, Sigmoid function as transfer function, selection of learning rate is 0.0001.Maximum training times elected 10000 times, target for error. BP neural network training samples, all sorts of fault are chosen 45 training sample data, sample data and expected output as shown in table 1.

Table 1. BP neural network training samples and the expected output

| Status | No. | 0.01-0.39f | 0.40-0.49f | 0.50f | 0.51-0.99f | 1f | 2f | 3-5f | Odd Times f | >5f | Desired Output | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rotor Imbalance | 1 | 0.0012 | 0.0010 | 0.0016 | 0.0028 | 0.9128 | 0.5066 | 0.0638 | 0.002 | 0.0006 | 1 | 0 | 0 |
| | 2 | 0.0016 | 0.0007 | 0.0013 | 0.0032 | 0.9250 | 0.0479 | 0.0571 | 0.0012 | 0.0004 | 1 | 0 | 0 |
| | 3 | 0.0014 | 0.0021 | 0.0008 | 0.0014 | 0.8958 | 0.1278 | 0.0765 | 0.0014 | 0.0017 | 1 | 0 | 0 |
| | 4 | 0.0012 | 0.0010 | 0.0022 | 0.0021 | 0.9656 | 0.0549 | 0.0645 | 0.0008 | 0.0003 | 1 | 0 | 0 |
| | 5 | 0.0016 | 0.0006 | 0.0015 | 0.0009 | 0.9428 | 0.0558 | 0.0577 | 0.0007 | 0.0009 | 1 | 0 | 0 |
| Rotor Misalignment | 6 | 0.0007 | 0.0007 | 0.0009 | 0.0009 | 0.4247 | 0.1091 | 0.5528 | 0.0008 | 0.0005 | 0 | 1 | 0 |
| | 7 | 0.0008 | 0.0006 | 0.0013 | 0.0015 | 0.3991 | 0.1270 | 0.5131 | 0.0003 | 0.0015 | 0 | 1 | 0 |
| | 8 | 0.0011 | 0.0007 | 0.0012 | 0.0018 | 0.4541 | 0.0988 | 0.4941 | 0.0008 | 0.0010 | 0 | 1 | 0 |
| | 9 | 0.0005 | 0.0011 | 0.0018 | 0.0007 | 0.4094 | 0.1321 | 0.4842 | 0.0013 | 0.0021 | 0 | 1 | 0 |
| | 10 | 0.0012 | 0.0004 | 0.0008 | 0.0010 | 0.3867 | 0.1431 | 0.5045 | 0.0004 | 0.0009 | 0 | 1 | 0 |
| Rotor Rubbing | 11 | 0.1030 | 0.0481 | 0.0524 | 0.1131 | 0.9091 | 0.3090 | 0.1160 | 0.1242 | 0.1332 | 0 | 0 | 1 |
| | 12 | 0.0993 | 0.2128 | 0.0510 | 0.1025 | 0.9018 | 0.3130 | 0.1024 | 0.1026 | 0.1028 | 0 | 0 | 1 |
| | 13 | 0.1268 | 0.2876 | 0.0485 | 0.0988 | 0.9801 | 0.2981 | 0.1108 | 0.1108 | 0.1129 | 0 | 0 | 1 |
| | 14 | 0.1102 | 0.1952 | 0.0488 | 0.1118 | 0.9462 | 0.2882 | 0.0988 | 0.0960 | 0.0945 | 0 | 0 | 1 |
| | 15 | 0.1135 | 0.2670 | 0.0508 | 0.1090 | 0.9031 | 0.3031 | 0.0936 | 0.0941 | 0.0968 | 0 | 0 | 1 |

### 4.2 The analysis of the improved algorithm

Choose three kinds of improved algorithm to the scene fan different fault characteristics of the measured data for training, training error curve, respectively, as shown in figure 5, figure 6, shown in figure 7.In view of the different features of three kinds of improved algorithm, respectively from the training speed and convergence precision comparison, find the optimal algorithm.

According to the graphics: adaptive lr gradient descent method of the training time of 5.999 seconds, 370 times were conducted training. There was little change in the early stages of the training error curve, the learning rate to the influence of network training, training slowly, the number increased, and the convergence for accuracy $1.2395e-05$, and precision of the $1e-05$ large difference, do not meet the requirements. Elastic gradient descent method to the training time of 1.074 seconds, in the shortest time, 15 were conducted training, smooth error curve, no ups and downs, reached the convergence precision $6.46e-06$, more than the preset accuracy and prove the algorithm for the training. Levenberg - Marquardt method is combined with the advantage of a variety of methods, make the training speed, greatly reduces the number of training. Training time of 1.453 seconds, is longer than elastic time of

gradient descent method, this is because the Levenberg - Marquardt method takes up a larger memory in the process of training, so can make the training time increased. But on the training times is reduced, it only took five times to reach the training target, training convergence accuracy reached $1.6838e-06$ the Levenberg - Marquardt method, more than the preset accuracy and training effect is more ideal.

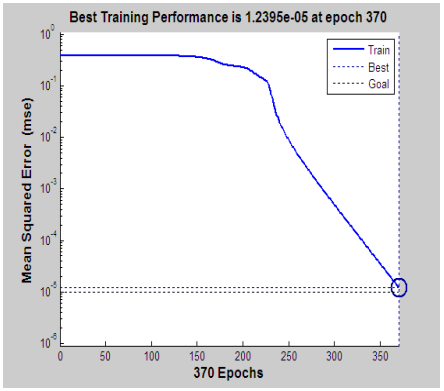


Figure 5. Adaptive lr gradient descent method

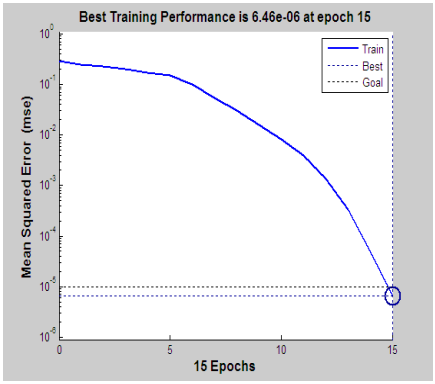


Figure 6. Elastic gradient descent method

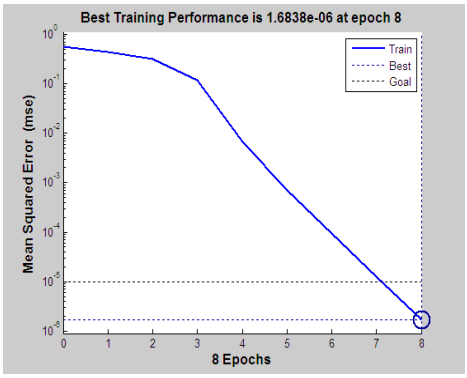


Figure 7. Levenberg-Marquardt method

Known from the analysis: the adaptive lr gradient descent method of training for a long time, the early convergence is slow, the training time was prolonged, and convergence accuracy does not meet the requirements; Elastic gradient descent method convergence speed is high, the curve flat, no substantial fluctuations; Levenberg - Marquardt method in the process of training convergence speed is rapid, high precision, less training, curve smoothing. Comparison comprehensive consideration, decided to choose Levenberg - Marquardt method as the optimal improved algorithm of BP neural network.

## 5. The BP neural network fault test

Measured data, the selection of three groups of the scene fan belong to different fault types, each group data of the three failure types of rotor unbalance of the rotor, respectively, the rotor rubbing, use the above training has been finished Levenberg - Marquardt method improved BP neural network to test of the three sets of data, three sets of data are shown in table 2:

Table 2. Fan different fault measurement data

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 0.0013 | 0.0009 | 0.0014 | 0.0007 | 0.9320 | 0.0501 | 0.0480 | 0.0020 | 0.0009 |
| 0.0015 | 0.0015 | 0.0007 | 0.0005 | 0.4122 | 0.1022 | 0.4891 | 0.0015 | 0.0006 |
| 0.1065 | 0.0835 | 0.0514 | 0.1128 | 0.9894 | 0.2815 | 0.0940 | 0.0905 | 0.0908 |

Desired output and output test result is shown in figure 8, shown in figure 9.

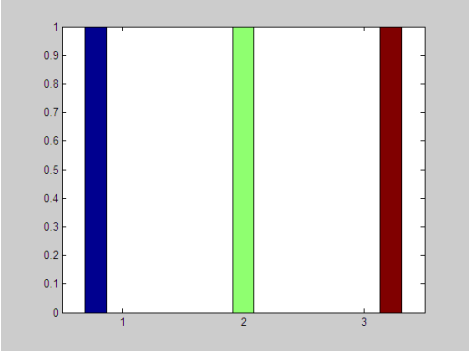


Figure 8. The desired output value

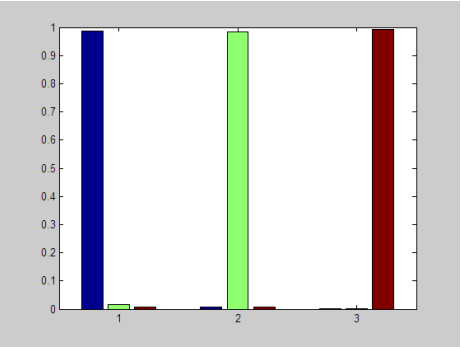


Figure 9. The actual output values

Run time: 0.047 seconds

After Levenberg - Marquardt method, the improved BP neural network with the 0.047 seconds to complete the test of the failure data, the computing speed faster. Can be seen from the figure 8, three groups of great value respectively represent three different fault types, namely the rotor unbalance of the rotor, the rotor rubbing, and amplitude of 1, with the improved BP neural network for feature data testing, each group of great value, the more close to 1, the more accurate result. From figure 9 can be observed through Levenberg - Marquardt method, the improved BP neural network for feature data after the test, each group of faults in the bar graph of the great value is close to 1.Which can prove that the improved BP neural network is accurate to the scene fan of fault diagnosis, it is concluded that a reasonable judgment result. Proved by Levenberg - Marquardt method of BP neural network algorithm to improve effective, accurate.

## 6. Conclusion

In this paper, using the neural network method to fault diagnosis of fan according to the actual data of fault feature vector of the scene fan, at the same time, in view of the shortcomings and limitations BP neural network, puts forward three kinds of improved algorithm, the adaptive lr gradient descent method, the elastic gradient descent method, Levenberg - Marquardt method. Using the measured data of the fan to carry on comparative analysis to three kinds of improved algorithm, so as to select the operation speed is faster, more accurate judgment Levenberg - Marquardt algorithm analysis of the established neural network training. Will collect data (data contains the different fault types) as input data in the neural network testing, the results showed that the improved BP neural network of training completion method can determine the field test and determine the imbalance of spectrum analysis, the rotor rubbing and slightly wrong medium fault type, the method is proven to have certain practicability and reliability.

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