Accord Ignition Diagnosis Based on Improved GA-BP

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Abstract
BP neural network as a kind of intelligent method is widely used in fault diagnosis, due to the single BP neural network's error is big, GA algorithm is often used in optimizing BP neural network, but the standard GA algorithm's searching efficiency is low and it is easy to fall into local convergence. According to the characters of Accord car ignition diagnosis and BP neural network, this article puts forward an improved scheme of the standard GA algorithm optimizing BP net, calculate and analyze different simulation results gotten by MATLAB program. Through calculation: the single BP neural network's convergence step number is 101, the final mean square error is 0.000997167; the convergence step number that standard GA algorithm optimizes the BP neural net is 83, the final mean square error is 0.000142126; the convergence step number that GA algorithm improved optimizes the BP neural net is 73, the final mean square error is 0.000137508. By the comparison, the improved GA algorithm has a better search efficiency and it's computation can avoid falling into a local convergence.

Keywords: failure diagnosis, BP neural network, improved GA algorithm

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1. Introduction
Along with the progress of science and technology, the mechanical fault is becoming more and more complicated. At the end of the last century, the researchers gradually developed many artificial intelligence methods, such as expert system and neural network. Those methods always used in the field of fault diagnosis, BP (Back Propagation) neural network is the most widely used among them.

BP neural network's application and operation are simple [1-3], but the limitations of network's structure and the randomness of its weights and thresholds cause it have a big error and a slow convergence speed and unable to search the global optimal solution. GA (Genetic Algorithm) as the representative of the intelligent algorithm often is used to optimize BP neural network’s initial weights and thresholds, it not only can reduce the error of the neural network, but also can improve the BP neural network’s training speed[4-6]. In the practical application, we find the standard GA algorithm also has some disadvantages, mainly includes two aspects:
(1)Search efficiency is low.
(2)Easy premature and stuck in local minima.

2. The Basic Idea of Improving GA
GA [7-9] is an algorithm which is based on biological genetic simulation, it simulates the natural process, mainly concludes selection, crossover and mutation. The basic idea of GA algorithm is starting from any initial group, using the random selection, crossover and mutation operation, produce a new group which is more adapt to the environment and make the group evolve into a better regional in all search space; the evolution is continuously converge to points that obtain the optimal solution of the problem. Various improved GA can increase the efficiency and make the results more accurate.

2.1. GA Adaptive Improvement
(1) The standard genetic algorithms crossover probability is often a value from 0.6 to 1, but it is easy to cause the algorithm un-converge. Crossover operation is the process of global search, in the early stage of the evolution, population’s diversity is high, the single crossover
can get large search space, in the later stage of the evolution, individual’s differences is small, so it need to use multiple point crossover. When the fitness of the population remains constant, the operations may have entered into the local optimal, so the cross point should be changed, strides out from the current part [10]. We selects pc as the adaptive crossover probability.

When \( F(i) \geq F_{\text{avg}} \), pc is:

\[
pc = pc_1 + \frac{pc_1 - pc_2}{2} \times \frac{F(i) - F_{\text{avg}}}{F_{\text{avg}} - F_{\text{max}}}
\]  

(1)

When \( F(i) < F_{\text{avg}} \), pc is:

\[
pc = pc_2
\]  

(2)

Here, \( pc_1 \) is the upper limit of the crossover probability, \( pc_2 \) is the lower limit of the crossover probability, \( F(i) \) is the fitness value of individual i, \( F_{\text{avg}} \) is the average fitness value, \( F_{\text{max}} \) is the largest individual fitness value in current population.

(2) Mutation probability is similar with crossover probability, the mutation probability of standard genetic algorithm is also fixed. The conclusion of theory analysis are when the fitness of population is concentrated, the mutation probability should be increased, when the fitness of population is decentralized, the mutation probability should be reduced, so that we can maintain the diversity of population, increase the search scope of optimal value, avoid falling into local extreme points. This article selects \( pm \) as the adaptive crossover probability.

When \( F(i) \geq F_{\text{avg}} \), pm is:

\[
pm = pm_1 + \frac{pm_1 - pm_2}{2} \times \frac{F_{\text{max}} - F(i)}{F_{\text{max}} - F_{\text{avg}}}
\]  

(3)

When \( F(i) < F_{\text{avg}} \), pm is:

\[
pm = pm_2
\]  

(4)

Here, \( pm_1 \) is the upper limit of the mutation probability, \( pm_2 \) is the lower limit of the mutation probability.

2.2. Improving Fitness

Abnormal fitness value may exist in the initial population, this phenomenon often leads the optimization of the population to a wrong direction, or the algorithm converges to a local minimum. At the end of the calculation, the algorithm is close to convergence, because the individual’s fitness value in the group is quite close, continuing optimization is difficult, at this time, the fitness of the individual should be changed: first, the individual’s fitness value should be spread out, second, the individual’s fitness value should be enlarged, then improve the ability to choose [11]. Fitness values to improve as following formula:

\[
F_1 = \frac{F \times 2 F_{\text{avg}} - min}{F_{\text{max}} - F_{\text{min}}}
\]  

(5)

\[
F' = \frac{|F_{\text{min}}|}{F_{\text{max}} + |F_{\text{min}}|}
\]  

(6)

Here, F is the unimproved fitness value, \( F_1 \) is the fitness value after dispersed, \( F' \) is the improved fitness value, \( F_{\text{min}} \) is the minimum fitness value of current population.
3. Fault Diagnosis by BP Net

In this article, Accord car with F23A1 engine is experimental model, and ignition failure of this model is the experimental case.

Four ignition failures of the experimental model can be gotten by the maintenance manual [12-13].

Fault a: Engine is difficult to start, the engine lack power and be easy to flameout.
Fault b: Engine idling is instability and fuel economy decline, the pollutants of tail gas exceed the standard.
Fault c: Engine has Poor fuel economy, is easy blasting and bad engine power.
Fault d: The actual engine displacement decreases, the engine power become bad, when the vehicle is running accompany with engine knock, and increase the wear of the engine.

Those four kinds of ignition faults are mainly determined by ignition voltage, firing voltage, firing time and oscillating voltage. Through the oscilloscope, the fault data in various speeds can be obtained. In the article, the sample data is the failure data when the engine's speed is 3000r/min. Fault data table as Table 1 (The four parameters are expressed by A, B, C, and D, and the data have been normalized):

<table>
<thead>
<tr>
<th>Table 1. Fault Sample Data Table</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Fault a</td>
</tr>
<tr>
<td>Fault b</td>
</tr>
<tr>
<td>Fault c</td>
</tr>
<tr>
<td>Fault d</td>
</tr>
</tbody>
</table>

Through the Table 1, we determine the neuron number of BP neural network's input layer be 4. For output layer, there are four kinds of fault condition, each fault condition is corresponding to the vector as Table 2 shown, and all 2 dimensional vectors of Table 2 is composed by 0 and 1.

<table>
<thead>
<tr>
<th>Table 2. The Fault Corresponding Output Table</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fault type</td>
</tr>
<tr>
<td>Fault a</td>
</tr>
<tr>
<td>Fault b</td>
</tr>
<tr>
<td>Fault c</td>
</tr>
<tr>
<td>Fault d</td>
</tr>
</tbody>
</table>

The hidden layer's node number of BP neural network is always determined by formula (7).

\[ L < \sqrt{m + n + a} \] (7)

Here, m is the node number of input layer, n is the node number of output layer, L is the node number of hidden layer, a is a real number. In this article, the hidden layer node number of BP neural network is 10.

Set the basic parameters of BP neural network: the node number of input layer is 4, the node number of hidden layer is 10, the node number of output layer is 2, the learning efficiency is 0.01, the largest training steps is 20000, the minimum training error is 0.001 [14].

Figure 1 is the training error simulation figure of single BP neural network.
It can be seen from Figure 1, when the epochs is 101, the network is convergence, the mean square error is $M_1$ when the network is convergence, $M_1 = 0.000997167$.

This article chose the four representative faults as the diagnostic sample when the engine's speed is 3000r/min, the diagnostic sample is used to diagnose the trained network. The test sample data is shown in Table 3. (The data have been normalized).

Table 3. The Test Sample Data Table

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fault a</td>
<td>0.7013</td>
<td>0.0583</td>
<td>0.2489</td>
<td>0.0484</td>
</tr>
<tr>
<td>Fault b</td>
<td>1.0000</td>
<td>0.0612</td>
<td>0.2020</td>
<td>0.0</td>
</tr>
<tr>
<td>Fault c</td>
<td>0.9716</td>
<td>0.0882</td>
<td>0.2219</td>
<td>0.0882</td>
</tr>
<tr>
<td>Fault d</td>
<td>0.8862</td>
<td>0.0114</td>
<td>0.1977</td>
<td>0.0085</td>
</tr>
</tbody>
</table>

Put test data input the trained network, we can get the output result $Y_1$.

$$Y_1 = \begin{bmatrix} 0.0320 & 0.0191 & 0.9958 & 0.9888 \\ 0.0081 & 0.9993 & 0.0219 & 0.9947 \end{bmatrix}$$

The desired output is $O$:

$$O = \begin{bmatrix} 0 & 0 & 1 & 1 \\ 0 & 1 & 0 & 1 \end{bmatrix}$$

Through $Y_1$ and $O$, we can get the single BP neural network's simulation error $E_1$.

$$E_1 = (0.0200, 0.0099, 0.0130, 0.0082)$$

4. Standard GA Optimizing BP Net

In this article, $F$ as the fitness function is expressed as formula (8).

$$F = N \times \frac{1}{\sum_{i=1}^{n} (O_i - Y_i)^2} \quad (8)$$

Here, $O$ is the predict output, $Y$ is the actual output, $n$ is the node number of hidden layer nodes.

Set the basic parameters of the standard GA: individual number is $NIND=40$, the maximum genetic algebra is $MAXGEN=20$, the generation gap is $GGAP=0.95$, the crossover probability is $pc=0.7$, the mutation probability is $pm=0.01$. Neural network’s parameters are constant.
Figure 2 is training error simulation that using standard GA optimize BP neural network. It can be seen from Figure 2, when the network’s training steps is 83, the network become convergence, the mean square error is $M^2=0.000142126$.

Figure 3 is the evolution process figure of the standard GA algorithm. It can be seen from Figure 3 when the iteration number is 10 times, the error is very small [15].

Through the training, we can get $Y_2$, $Y_2$ is network’s output that the standard GA optimize BP net.

$$Y_2 = \begin{bmatrix} 0.0057 & 0.0059 & 0.9999 & 0.9791 \\ 0.0020 & 0.9992 & 0.0125 & 0.9972 \end{bmatrix}$$

$E_2$ is the final error of standard GA to optimizing BP neural network used in fault diagnosis.

$$E_2 = (0.0039, 0.0034, 0.0063, 0.0119)$$

5. Improved GA Optimizing BP Net

Set the basic parameters of the improved GA algorithm: Individual number is $N_{IND}=40$, the maximum genetic algebra is $MAXGEN=20$, the generation gap is $GGAP=0.95$, the upper limit of the crossover probability is $pc_1=0.8$, the lower limit of the crossover probability is $pc_2=0.6$, the upper limit of the mutation probability is $pm_1=0.012$, the lower limit of the mutation probability is $pm_2=0.008$. Neural network's parameters are constant.
Figure 4 is network training error simulation figure that use the improved GA to optimize BP net.
It can be seen from Figure 4, when the network’s training steps is 73, the network become convergence, and the mean square error is $M_3=0.000137508$.
Figure 5 is the evolution process figure of improved GA.

![Evolutionary Process Figure of Improved GA](image)

Figure 5. The Evolutionary Process Figure of Improved GA

It can be seen from Figure 5, the error become smaller and the number of iterations becomes less.
The contrast of the network’s training result is shown in Table 4.

<table>
<thead>
<tr>
<th>Training steps</th>
<th>mean square error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single BP</td>
<td>101</td>
</tr>
<tr>
<td>Standard GA-BP</td>
<td>83</td>
</tr>
<tr>
<td>Improved GA-BP</td>
<td>73</td>
</tr>
</tbody>
</table>

Through the training, we can get $Y_3$, that $Y_3$ is network’s output of improved GA optimizing the BP net.

$Y_3 = \begin{bmatrix} 0.0102 & 0.0050 & 0.9998 & 0.9809 \\ 0.0005 & 0.9999 & 0.0059 & 0.9981 \end{bmatrix}$

$E_3$ is the final error of improved GA to optimizing BP net used in fault diagnosis.

$E_3 = (0.0054, 0.0025, 0.0030, 0.0105)$

The contrast of final simulation error is shown in the Table 5 (The average error rates are expressed by AER).

<table>
<thead>
<tr>
<th>Fault a</th>
<th>Fault b</th>
<th>Fault c</th>
<th>Fault d</th>
<th>AER</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>0.0200</td>
<td>0.0099</td>
<td>0.0130</td>
<td>0.0082</td>
</tr>
<tr>
<td>E2</td>
<td>0.0039</td>
<td>0.0034</td>
<td>0.0063</td>
<td>0.0119</td>
</tr>
<tr>
<td>E3</td>
<td>0.0054</td>
<td>0.0025</td>
<td>0.0030</td>
<td>0.0105</td>
</tr>
</tbody>
</table>

6. Conclusion

BP neural network as a kind of intelligent method is widely used in fault diagnosis, due to the single BP neural network’s error is big, GA algorithm is widely used in the optimization of
BP neural network, but the standard GA searching efficiency is low and fall into local convergence easily. This article puts forward three kinds of improvement scheme to GA optimizing BP neural network that diagnose F23A1 engine ignition fault of Accord car.

This article respectively made the single BP neural network’s error simulation experiment, the standard GA optimizing BP neural network’s error simulation experiment and the improved GA to optimizing BP neural network’s error simulation experiment. It can be seen from the comparison among Figure 1., Figure 2 and Figure 4, optimized BP neural network’s error is smaller than single BP neural network, the training steps of the optimized BP neural network become less, at the same time, compared with the standard GA to optimize the BP neural network, the improved GA to optimize the BP neural network’s convergence speed is faster, and the performance is better. Through Figure 3., Figure 5 and Table 5, we can conclude that compared with the standard GA to optimize the BP neural network, the error of improved GA optimizing the BP neural network is smaller, the number of iterations is less. The improved GA algorithm can improve the search efficiency, it’s computing result can avoid falling into local convergence.

References