Fault Diagnosis of Mine Fan Bearing Based on Beetle Antennae Search

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Abstract. Mine fan is the lifeblood of coal mine safety production, which plays an important role in ensuring the safety of the lives of mine workers. Once it fails to operate, it will cause irreparable serious consequences. Therefore, in order to ensure the safe operation of mine fan, this paper takes the common motor bearing faults in fan faults as the object of study, proposes a method of using rough set attribute reduction combined with Beetle antennae search to optimize BP neural network to establish diagnosis model, and compares it with genetic algorithm, particle swarm optimization, imperial competition algorithm and ant lion optimization algorithm. The experimental results show that the method achieves 90% accuracy in fault diagnosis of mine fan bearing, and has faster convergence speed and shorter operation time. Compared with other optimization algorithms, the method has greater advantages. After many tests, the diagnosis results are stable, which proves that the method is feasible and effective in fault diagnosis of mine fan.

Nomenclature

\begin{itemize}
\item \textit{n}: dimension
\item \textit{x}: centroid
\item \textit{x}_l: left antenna
\item \textit{x}_r: right antenna
\item \textit{d}: distance between the two antenna
\item \textit{t}: iteration times
\item \textit{x}': position of the center of mass
\item \textit{f}_l: fitness values of left antenna
\item \textit{f}_r: fitness values of right antenna
\item \(\delta^t\): moving step in the \textit{t} th iteration
\item \textit{eta}_d: distance attenuation coefficient
\end{itemize}

List of abbreviations

\begin{itemize}
\item BAS: Beetle Antennae Search
\item BPNN: BP Neural Network
\item GA: Genetic algorithm
\item PSO: Particle swarm optimization
\item ICA: Imperial competition algorithms
\item ALO: ant lion optimization
\item RS: Rough set
\end{itemize}
1. Introduction

At this stage, coal is in the main position in the energy system. With the continuous expansion of the production scale of coal mining enterprises, the underground situation becomes more and more complex. How to balance the contradiction between safety and production is imminent. Because of the bad natural environment and working conditions in the mining area, the death rate of the average coal production per million tons in the coal mine remains high. Take China as an example, in 2009, there were 1616 casualties, 2632 deaths and 0.892 deaths per million tons of coal produced; in 2010, there were 1403 casualties, 2308 deaths and 0.749 deaths per million tons of coal produced; in 2011, there were 1205 casualties, 2004 deaths and 0.637 deaths per million tons of coal produced in China's coal mines; in 2012, there were a total of injuries and deaths in China's coal mines. There were 1008 fatalities, 1813 deaths and a death rate of 0.531 per million tons of coal. Although we can see from the data that the trend of coal mine safety production is improving year by year, the number of accidents and the casualty rate are declining, but far from reaching the ideal level [1]. Mine ventilation is the most important among many factors affecting safety in production. Mine ventilator plays the role of diluting or discharging all kinds of harmful gases and coal dust in the production process of coal mine enterprises, so as to ensure good underground air conditions [2].

Figure 1. Mine ventilator

At present, there are some research results on fault diagnosis of mine ventilators. In document [4], the graph of grey theory is used to diagnose the fault of fan, and an on-line monitoring and diagnosis system for mine fan fault is developed. The system has the functions of on-line monitoring, fault diagnosis, fault alarm and data storage. In document [5], Industrial Ethernet is used to complete the collection and monitoring of fan operation status data in many workplaces. Vibration data collected are used to analyze the condition monitoring data, optimize the fault maintenance model and optimize the maintenance strategy. In document [6], the author proposes a fault diagnosis method for mine ventilator based on EMD and SVM. This method is suitable for intelligent diagnosis and fault pattern recognition of mine ventilator status, and it is possible to develop an automatic and online monitoring and diagnosis system for mine ventilator status. In order to solve the parameter optimization problem of classification algorithm, intelligent optimization algorithm is used to improve the effect of fault
diagnosis to a certain extent, including time series algorithm [7], genetic algorithm [8], particle swarm optimization algorithm [9]. However, it has some shortcomings, such as poor accuracy and easy to fall into local optimum.

In order to improve the fault diagnosis performance of mine fan bearing, this paper uses rough set to reduce the attributes of the original data set of mine fan bearing fault, and combines the reduced decision table with the optimized BP neural network algorithm of Longhorn whisker to diagnose the fault, and compares it with genetic algorithm, particle swarm optimization, imperial competition algorithm [10] and ant lion algorithm [11].

2. Introduction of Rough Set and BP Neural Network Algorithms

2.1 Rough set

2.1.1 Discretization theory. Rough set attribute discretization is an important step in rough set data preprocessing. A large number of rules need to be discretized to improve the performance of the algorithm [12]. Rough set discretization is based on the unchanged correlation between decision attributes and conditional attributes before and after reduction. According to the breakpoints determined in the data, those attributes are divided into regions. Then these regions are re-classified and divided into more intervals, but the premise is to ensure that the decision attributes of these partitioned intervals are consistent.

The main methods of discretization include equal frequency discretization method, equal distance discretization method and discretization method based on attribute importance [13].

2.1.2 Attribute reduction. Attribute reduction is another crucial aspect of rough set theory [14-15]. Its purpose is to eliminate redundant conditional attributes and simplify data. Attribute reduction needs to satisfy two conditions: firstly, the discernibility between before and after reduction remains unchanged; and secondly, redundant information is not included in the data set after reduction as far as possible.

2.2 BP Neural Network

BP neural network is a multi-layer feed forward neural network trained by error back propagation algorithm. The network model consists of input layer, hidden layer and output layer [16-17], as shown in figure 2.

![Figure 2. Structural Chart of BP Neural Network](image-url)
In the process of forward transmission of input signal, the output of each layer node and the error between actual output and expected output are calculated. In the process of error signal back propagation, the error signal is returned to the direction of error reduction according to certain rules, and the weights of the network are constantly adjusted. The forward and reverse processes are carried out continuously until the output error reaches the required range. Because of its simple structure and high learning ability, BP neural network has been widely used in the field of fault diagnosis in recent years.

3. Beetle antennae search

Beetle antennae search is an efficient intelligent optimization algorithm proposed by Li S et al. in 2017 [18-20]. It has the advantages of fast solving speed and high precision. Its bionic principle is as follows: when the beetle is foraging, the food is in an unknown position, and the beetle moves according to the taste of the food. If the left antenna senses a stronger odor than the right antenna, the next step will be to fly left, otherwise to fly right. The foraging principle of beetle is shown in figure 3. In the foraging principle of beetle, the odor of food is equivalent to a function. The purpose of beetle is to find the point with the greatest odor, that is, the global optimal value. BAS does not need gradient information and the specific form of function to achieve efficient optimization and solution. At the same time, the algorithm only needs an individual, that is, a battle, which greatly reduces the computational complexity of the algorithm.

![Figure 3. beetle foraging](image)

BAS algorithm flow:

For the n dimension optimization problem, let the centroid be expressed as x, the left antenna xl, the right antenna xr, and the distance between the two antenna be d, where x, xl, xr is a n dimension vector.

Establishment of random vector oriented by beetle and normalization

\[
b = \frac{\text{rands}(n,1)}{\|\text{rands}(n,1)\|}
\]  

(1)

Rands (n, 1) denotes the generation of n dimensional random vectors.

So the left and right antenna can be expressed as
\[ x_i = x' + d' \cdot b \]  
\[ x_r = x' - d' \cdot b \]  \hspace{1cm} (2)

\[ d' \text{ and } x' \text{ denote the distance between the two antennae and the position of the center of mass at the } t^{th} \text{ iteration, respectively.} \]

The fitness values \( x_i \) and \( x_r \) of antennae \( f_i \) and \( f_r \) were calculated, and the direction of beetle was determined according to their size relationship.

\[ x' = x'^{-1} - \delta' \cdot b \cdot \text{sign}(f_i - f_r) \]  \hspace{1cm} (4)

Sign is a symbolic function, \( \delta' \) and \( t \) is the moving step of beetle in the \( t^{th} \) iteration.

Calculate the fitness value of beetle after moving and the distance and step length between two antennae

\[ d' = \eta d \cdot d'^{-1} \]  \hspace{1cm} (5)
\[ \delta' = \eta \delta \cdot \delta'^{-1} \]  \hspace{1cm} (6)

\( d' \) is the distance between the two antennae in the \( t^{th} \) iteration, \( \eta d \) and \( \eta \delta \) are the attenuation coefficients of the distance between the two antennae and the step size.

Determine whether the iteration termination conditions are met, if not, return to step (2) and continue to calculate until the conditions are met.

4. Fault Diagnosis of Mine Fan Bearing

4.1. Establishment of Fault Diagnosis Model

The detailed steps of establishing fault diagnosis model of mine fan bearing based on RS-BAS-BPNN is as follows. In figure 4, each step of work is summarized and presented in the form of a flow chart.

- The original bearing fault data set is sorted out, and the rough set is used to discretize and attribute reduction, and the reduced decision table is obtained.
- The reduced decision table is divided into two parts, a large part of which is used as training samples and a small part as testing samples.
- Build the BPNN model of BAS optimization, and bring the training samples into it for training, select the optimal weight and threshold.
- The BAS-BPNN model is evaluated with test samples, and the accuracy of fault classification is obtained.
4.2 Data Attribute Reduction

In this paper, 400 sets of data are used, including 8 conditional attributes and 4 decision-making attributes. The fault types are outer ring fault, inner ring fault, rolling element fault and non-fault. On the premise of keeping the classification relationship unchanged, rough sets are used to discretize and reduce the data. Table 1 and table 2 are the data of bearing fault of mine ventilator and the results of attribute reduction.

Table 1. Data of bearing failure of mine ventilator

| Sample size | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    |
|-------------|------|------|------|------|------|------|------|------|
| Conditional attribute | 0.2098 | 0.1224 | 0.1019 | 0.3546 | 0.6086 | 0.3133 | 0.5380 | 0.8926 |
|               | 0.0279 | 0.0102 | 0.0399 | 0.0387 | 0.0478 | 0.0455 | 0.1904 | 0.1817 |
|               | 0.0011 | 0.0013 | 0.0018 | 0.0046 | 0.0026 | 0.0      | 0.0    | 0.0    |
| Decision attribute | 0.3534 | 0.2876 | 0.1387 | 0.3183 | 0.4056 | 0.5296 | 1      | 1      |
|               | 0.0526 | 0.0468 | 0.0018 | 0.0123 | 0.0206 | 0.0423 | 0.0158 |       |
|               | 0.0258 | 0.0160 | 0.0018 | 0.0146 | 0.0107 | 0.0017 | 0.0071 |       |

Table 2. Reduction results

| Number of conditional attributes after reduction | Approximate simplicity/% | Reduction accuracy/% |
|--------------------------------------------------|--------------------------|----------------------|
| 5                                                | 37.5                     | 99.12                |

4.3 Analysis of Fault Diagnosis Result of Mine Fan Bearing

The reduced 400 groups of data are divided into 320 groups and 80 groups. 320 groups of data are
used as training samples and 80 groups of data are used as test samples to verify the model. Figure 5 is the training fitness curve of BAS-BPNN. It can be seen from the graph that the objective function value has been stabilized and converged faster when iteration is 23 times, which achieves the ideal effect. Figure 6 is the diagnosis result chart. In 80 test data sets, there are 8 groups of classification errors, the accuracy rate is 90%. After many tests, the results are stable, which proves that the method has good reliability for fault diagnosis of mine ventilators. Table 3 lists the performance of these algorithms for fault diagnosis of mine ventilators.

![Figure 5. BAS-BPNN Fitness curve.](image1)

![Figure 6. Diagnostic results of BAS-BPNN.](image2)

| Table 3. Comparison of Diagnostic Performance of Different Intelligent Algorithms |
|---------------------------|----------------|----------------|----------------|----------------|----------------|
|                          | BAS-BPNN | GA-BPNN   | PSO-BPNN   | ICA-BPNN   | ALO-BPNN   |
| Accuracy                 | 90%      | 86.25%    | 87.5%      | 83.75%      | 87.5%      |
| Training time            | 42s      | 106s      | 64s        | 122s        | 96s        |

Through repeated experiments, BAS takes less time than the other four algorithms, and its accuracy is higher than the other four intelligent algorithms. It can be concluded that BAS has good diagnostic ability for bearing fault of mine ventilator.

5. Conclusion and prospect

After attribute reduction of rough set from original data, this paper uses BAS optimized BP neural network to diagnose the bearing fault of mine ventilator, and compares it with other optimization algorithms. It is concluded that this method has higher accuracy, shorter time and faster convergence speed for fault diagnosis.

BAS has a good effect on optimizing neural network to solve fault diagnosis of mine fan bearing, so this method can be applied to other fault diagnosis, so as to solve the problem more quickly and accurately.

There are some areas in the paper that need further research and improvement. The following are listed:

- A good parameter can further improve the efficiency of the algorithm, so the selection of parameters needs to be fine-tuned.
There is still room for further optimization of mine fan fault data discretization and attribute reduction.
Perhaps the network model trained in the end is not necessarily the optimal solution, which needs further study.

Acknowledgments
Foundation item: Scientific research start-up funds of Guangdong Ocean University.

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