

# Application of transient acoustic signal and rough sets in compound-fault diagnosis of bearing

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**Abstract.** Real vehicle tests for equipment cannot get steady signal, and the traditional vibration test method cannot realize noncontact, without disassembly and spoil the disadvantages of the on-line detection, using the transient acoustic signal is proposed for bearing fault diagnosis. Rough set theory is a new mathematical tool to deal with vagueness and uncertainty knowledge, attribute reduction is an important part of the study of rough sets theory, and calculates the best reduction is a NP hard problem. In order to be able to effectively obtain information system of the reduction, a new reduction algorithm is proposed. The algorithm with the worst Fisher criterion function as heuristic information to improve the efficiency of search, the Max-min ant system (MMAS) conditional attribute reduction, the use of rough set theory to fault diagnosis decision table reduction, form a clear, concise fault diagnosis rules, effectively improve the bearing fault diagnosis accuracy and efficiency.

**Keywords:** transient acoustic, rough set theory, condition attribute reduction, max-min ant system, the worst fisher criterion.

## 1 Introduction

The processing technology of gear box components such as gear, shaft and bearing is complex, and the working environment of gear box components is very poor, the bearing is one of the most easily damaged parts, its running state are directly affect the gear box. So there are extremely important engineering and economic significance to research the quick and effective bearing fault diagnosis method to prevent sudden accidents, reduce equipment maintenance costs. Based on the traditional vibration test in the fault diagnosis of sensors needed directly connected with the vibration body, even to be placed in the chamber to acquisition of various signals. While many gear box packaging equipment internally, it is difficult to install sensors, difficult to achieve on-line detection without disassembly. Acoustic probe, by contrast, as a kind of non-contact testing, time efficiency is higher, so the use of acoustic signals generated by gear box to work without disassembly for the bearing condition on-line fault diagnosis has certain advantages.

In addition, many equipment in the real vehicle running, often in speed and load of unsteady state, are unable to get steady process signal, can only obtain the transient signal to detect. Therefore, this article uses the transient acoustic signal combined with rough set for bearing fault diagnosis. In order to effectively obtain information system of reduction, the ant optimization group algorithm is

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introduced into attribute reduction, attribute reduction algorithm is put forward a new condition, in order to improve the search efficiency, with the worst Fisher discriminant standard rate as the heuristic information, considering both classification accuracy and the number of condition attributes factors, got the smallest reduction of condition attribute subsets, bearing the transient acoustic signal [1-4].

## 2 Basic knowledge of the rough set theory

Rough set theory [5] is put forward by polish mathematicians Z.P awlak in 1982, the theory is a kind of new mathematical tools for processing fuzzy and uncertain knowledge.

### 2.1 Decision table and the discretization

Knowledge system can be expressed easily to use the database table , columns represent properties, row represent record, said that the record of the information in each row, each value in the table is the corresponding row (record) in the value of the column (property), is the property value. Decision table is a kind of special and important knowledge representation system, in order to extract knowledge from a decision table with continuous quantity, first of all is to discretize the range of values of the condition attribute. Discretization methods such as spacing method, frequency spacing method, the minimum entropy method [6].

### 2.2 Simplify the decision table

In a decision system, the condition attribute for the final decision is not as important, or even redundant. The existence of the redundant attribute, on the one hand, increases the storage space, increase the difficulty of knowledge discovery; On the other hand is not conducive for people to make accurate decisions. Attribute reduction of rough set refers to the decision system ability of classification unchanged, delete redundant attributes.

Attribute reduction is one of the main content of the rough set theory, in rough set theory, the earliest attribute reduction method is a theory method given by Z.P awlak according to the definition, this method can only calculate a reduction result, but it is a complete reduction algorithm, the disadvantage is that the time complexity is higher and increase with the increase of the attribute exponentially, so the algorithm is rarely used in practical application.

## 3 Ant colony optimization algorithm

Inspired from ant group to find the shortest path foraging behavior, Italian scholars Dorigo et al. proposed a model of simulated evolutionary algorithm in 1991, which simulate ant swarm behavior in the nature, ant colony algorithm for short. Ant colony algorithm has the characteristics of a distributed computing, information positive feedback and heuristic search, the nature of evolutionary algorithm is a new heuristic optimization algorithm.

Through the study of ant colony algorithm show that the ant search behavior on the near optimal solution can improve the quality and the convergence speed of the solution, to improve the performance of the algorithm, but the search way are more likely to cause premature convergence behavior. Changing pheromone update strategy through Max - Min Ant System (MMAS) supposed by Stitzle et al in 2000 overcame the above shortcomings.

### 3.1 Condition attribute reduction

If the bearing condition attribute set  $Q = \{x | x = 1, 2, \dots, X\}$ , extract several groups of condition attribute set from each condition to establish the condition attribute sample, attribute reduction is

provided according to the bearing condition attribute sample information, from the collection  $Q$  to choose a  $x$  cardinal number for a subset of  $Q^x$ , make the corresponding condition attribute subsets samples meet some standard functions.

This paper adopts the classifier of the accuracy of test results as standard function of bearing condition attribute reduction, using MMAS algorithm search condition attribute subsets. Condition attributes reduction problem description is as follows: from the collection to select a subset  $Q^x$  whose cardinal number is  $x$ , make the corresponding condition attribute sample of the condition attributes contained in  $Q^x$  has the highest classification accuracy, its expression is as follows:

$$\begin{cases} \max R \\ |Q^x| = x, \quad 1 \leq x \leq X \end{cases} \quad (1)$$

### 3.2 The heuristic information

When using MMAS algorithm to conduct condition attribute reduction, each ant  $k$  ( $k=1, \dots, m$ ) according to the following the probability equation (2) select the next condition attribute  $j$ .

$$P_{y_p}^k = \frac{[\tau_{y_p}(t)]^\alpha [\eta_{y_p}(t)]^\beta}{\sum [\tau_j(t)]^\alpha [\eta_j(t)]^\beta} \quad (2)$$

$$P \in \{j+1, j+2, \dots, n\}$$

The  $\alpha$  and  $\beta$  on type present respectively the different role on the accumulation of pheromone in the process of movement and stimulating factor in ants selection condition attribute, according to the characteristics of this problem by using Fisher criterion function (Reference type (3)) as a class separability measure.

$$F = \frac{|\mu_1 - \mu_2|}{\sqrt{\sigma_1^2 + \sigma_2^2}} \quad (3)$$

On type,  $\mu_1, \mu_2$  are the mean of two state class in a certain condition attribute,  $\sigma_1^2, \sigma_2^2$  is variance.

The heuristic information  $\eta_j$  given by type (4)

$$\eta_j = \min_{1 \leq i \leq M-1, i+1 \leq i' \leq M} \left\{ \frac{|\mu_{ij} - \mu_{i'j}|}{\sqrt{\sigma_{ij}^2 + \sigma_{i'j}^2}} \right\} \quad (4)$$

On type,  $\mu_{ij}$  for the mean of  $i$  state class condition attribute  $j$ , is the worst Fisher criterion function as the heuristic information of condition attribute  $j$ , and prefer the bigger function of condition attribute that satisfy the worst Fisher criterion, to achieve the better effect with class separability.

### 3.3 Algorithm design

This paper uses MMAS algorithm to conduct condition attribute reduction. The main steps summarized as follows:

(1) Initialization. Set the number of iterations  $g$  to 0 and the maximum number of iterations  $N_c$ ; Set the total number of ants  $n$ ; Set the total number condition attribute  $m$  and the number needed to be

simplified to condition attribute reduction  $x$ ; Set the condition attribute information, the minimum value is  $\tau_{\min}$  and maximum value is  $\tau_{\max}$ ; Set the value of pheromone volatilization coefficient  $\rho$  and increment  $\Delta\tau$ , increment is bigger than volatilize quantity; Put the ant's current condition attribute in their current solution set  $tabu_k$ .

(2) Path selection. Start all ants, for each ant  $k$  ( $k=1, \dots, m$ ) according to the above probability equation (2) to choose the next condition attribute  $j$ , put condition attribute  $j$  into their current solution set  $tabu_k$ ;

(3) According to  $tabu_k$  to calculate the number of condition attribute in the past that ants walked. If don't need to choose the limitation of the number of condition attribute, turn to step (2), if meet the requirements of the number, to do pattern recognition, to record the current best solution;

(4) According to the pheromone update equation (5), the update belongs to the pheromone intensity in optimal condition attribute subsets;

$$\tau_i(t+1) = (1 - \rho)\tau_i(t) + \Delta\tau_i(t) \quad (5)$$

$$\Delta\tau_i(t) = \sum_{k=1}^n \Delta\tau_i^k(t) \quad (6)$$

Among them,  $\Delta\tau_i^k(t) = Q * P_i^k$  is defined as pheromone function leaved by the ant  $k$  in the condition attribute  $i$ .  $Q$  is a constant,  $P_i^k$  is the fault diagnosis accuracy after the ant  $k$  chooses the condition attribute contains the  $i$ th subset of the condition attribute; For the rest of the condition attribute, set  $\Delta\tau_i = 0$ ;  $g = g + 1$ ; Comparing the updated pheromone  $\tau_{ij}(t)$  and  $\tau_{\min}, \tau_{\max}$ , if there are  $\tau_{ij}(t) > \tau_{\max}$ , make  $\tau_{ij}(t) = \tau_{\max}$ ; If there are  $\tau_{ij}(t) < \tau_{\min}$ , make  $\tau_{ij}(t) = \tau_{\min}$ .

(5) Repeat steps (2)–(4), until  $g=N_c$ , the iteration is completed, then the  $x$  condition attributes are the highest fault classification accuracy condition attributes.

(6) Output the best solution.

## 4 Living example of bearing fault diagnosis

Gear box change speed and load testing system comprise change speed electrical machine, a two-stage load transmission gear box, coupling, magnetic powder, vibration acceleration sensor, sound intensity sensor, speed of torque sensor and LMS analyzer. The speed torque sensor measuring speed signal, sound intensity sensor measuring sound signal, test environment have simple anechoic facility, background noise is small. Trial by controlling the current size to change the size of the load, control speed regulating motor change input speed at the same time, finally get the speed and load of non-stationary signal.

In the test system, to simulate fault, processing a 0.5 mm wide, 1.5 mm deep small tank in the bearing inner ring and outer ring to simulate the bearing inner ring crack and single fault of outer ring crack, for a steel ball of the bearing in the same line method to cut a small piece from steel ball to simulate single fault, between the two steel ball cage of one side of the fracture to simulate failure of the cage. In normal, inner ring failure, steel failure, failure of outer ring and cage 5 kinds of working condition, for example, the rising process of gear box were analyzed, and the input shaft speed from zero to 1200 RPM, a variety of voice signal acquisition, respectively, in the cases of 30 sets of data, including 10 group is used as the training data, 20 groups used as test data.

First of all, for the fault signal diagnose of all measured choosing db6 wavelet layer wavelet packet decomposition, for each frequency band energy conduct normalization processing, get four feature

vector  $T' = [E_{20}/E, E_{21}/E, \dots, E_{23}/E]$ , in the four characteristic parameters as the condition attribute subsets, from low frequency to high frequency respectively with the letters a, b, c, d said. Then, for each fault signal conduct signal processing, extracting the 7 characteristic parameters of the time domain as the condition attribute subsets, including: root mean square value rms, skewness index ske, kurtosis index kur, peak index cre, pulse index imp, waveform index sha, margin index clf, for convenience, the above seven condition attributes in turn with the letter e, f, g, h, i, j, k said. The above two condition attribute subsets constitute collection of condition attributes in alphabetical order. Using MMAS algorithm to conduct the condition attribute reduction, the algorithm with Matlab programming implementation, parameter settings:  $\alpha=0.2$ ,  $\beta=1.5$ ,  $\rho=0.2$ ,  $\tau_{\max}=800$ ,  $\tau_{\min}=10$ , the number of ants  $n=11$ ,  $N_c=20$ ,  $Q=50$ . Different number of condition attributes can be comprised the different condition attributes subsets, and different condition attribute subsets can make different influence to the accuracy of the test sample, choose the condition attribute subsets with the highest accuracy in the following table 1, can get different condition attribute reduction results.

**Table 1.** The precision of condition attribute subsets.

Number of subsets	Condition attributes	Correct (%)
1	g	67.27
2	b,g	90
3	a,f,j	97.27
4	a,d,f,j	97.27
5	a,c, d,f,j	97.27
6	a,c, d,e,f,j	96.36

It can be seen from table 1: When select a condition attribute, g corresponding classification accuracy is 67.27%;As the number of the condition attribute x increasing, due to the mutual influence between condition attributes, the reduction results (condition attribute subset) corresponding to the classification accuracy of the overall master the trend of first increase after decreases, when the x is 3, 4, 5, maximum 97.27%;When x is 6, reduction results correspond to the classification accuracy decrease(96.36%). The condition attributes reduction's mission is to make the condition attribute subsets has the best classification ability, avoid the loss of information, and to avoid the loss of the sort information and the introduction of the condition attribute. Therefore, considering classification accuracy and the number of condition attributes x two factors, we made the smallest reduction of condition attribute subsets (a, f, j).

**Table 2.** Data discretization results.

U	a	f	j	D	U	a	f	j	D
1	3	1	3	1	9	5	5	1	5
2	3	1	3	1	10	5	5	1	5
3	1	2	5	2	11	4	1	3	1
4	1	2	5	2	12	2	3	5	2
5	5	2	2	3	13	5	1	2	3
6	5	2	2	3	14	5	3	2	4
7	5	4	3	4	15	5	3	1	5
8	5	4	3	4					

Making the running state of bearing as decision attribute, expressed with D, 1 for normal state, 2 for the inner ring fault, 3 for the steel ball, 4 for the outer ring fault, 5 for the maintain cage fault. Making the bearing running condition as the research object, in view of the above five kinds of working state, respectively from the group of 20 to take three groups in the training sample, forming theory of domain  $U = \{1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15\}$ . Rough set can only deal with discrete attribute values and the original fault attribute values are continuous, so have to make discretization processing to the data. In this paper, such as spacing method is used to discrete method, use the smallest reduction subsets for (a, f, j), get the data discretization results are shown in table 2.

Table 2 by attribute value reduction, can get the decision table in table 3.

**Table 3.** Decision table.

U	a	f	j	D
1	*	1	3	1
3	*	*	5	2
5	5	2	2	3
7	5	4	3	4
9	5	*	1	5
13	5	1	2	3
14	5	3	2	4

The above table \*can be omitted.

7 decision rules can be extracted from table 3.

Ruel1: IF “f=1” and “j =3” THEN1 Normal; Ruel2: IF “j=5” THEN2 Such failure; Ruel3: IF “a=5” and “f=2” and “j=2” THEN3 Such failure; Ruel4: IF “a=5” and “f=4” and “j=3” THEN4 Such failure; Ruel5: IF “a=5” and “j =1” THEN5 Such failure; Ruel6: IF “a=5” and “f=1” and “j=2” THEN3 Such failure; Ruel7: IF “a=5” and “f=3” and “j=2” THEN4 Such failure.

In this way, simple diagnosis decision rules is derived from the original bearing fault information, for the next step of fault diagnosis lay a solid foundation.

## 5 Conclusions

As a kind of non-contact, without disassembly, noninvasive diagnostic technique, using acoustic signal of gearbox fault diagnosis is feasible.

Using the worst Fisher criterion function as heuristic information, introduce the MMAS algorithm to the condition attributes reduction of rough sets, this paper proposes a new condition attribute reduction algorithm.

Considering two factors classification accuracy and the number of condition attributes, the smallest reduction of condition attribute subsets can be obtained, and then through the attribute value reduction, clear and concise diagnosis decision rules are obtained.

In this paper, the condition attributes reduction algorithm has generality, and can be used in the field of other information, this kind of method for high dimensional condition attribute and huge amounts of data more effectively; The method proposed in this paper is expected to achieve other rotating machinery fault diagnosis using acoustic signal, has the very good practical application value.

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