An Technical Condition Evaluation Index Reduction Method Combining Rough Set and Genetic Algorithm

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Abstract. The evaluation of equipment technical condition involves lots of indexes and the relationship between different indexes is complex. It brings a huge workload to the collection of evaluation information, and the interference caused by the correlation between indicators also increases the uncertainty of the evaluation results. Aiming at the problems mentioned above, this paper proposes a reduction method of equipment technical condition evaluation index system based on rough set and genetic algorithm. The rough set and genetic algorithm are used to reduce the state evaluation index, the redundancy is removed, and the best indexes reflecting the change of equipment technical condition status are retained. A reduction case of a gas turbine technical condition status evaluation index system shows that this method can reduce a complex index system to a more concise and clear index system without losing its representativeness and systematicity. This method can reduce the difficulty of information collection, and improve the accuracy of the evaluation results.

1. Introduction
Technical condition assessment is a key link in equipment management[1,2]. By analyzing the changes of different indexes, the technical condition of the equipment can be determined and it is an important decision basis for the design, use and maintenance. In order to ensure that the product can meet the requirements of the specified functions, the technical specifications specify the functional characteristics in details, involving many aspects of product input, output and internal state changes[3]. Therefore, the technical condition evaluation of the equipment is a complex problem with multiple attributes, multiple levels, and multiple variables.

The commonly used comprehensive assessment methods of technical condition include analytic hierarchy process[4], D-S evidence theory[5], support vector machine[6], and Bayesian network method[7], etc. The common feature of these methods is to weight different functional characteristic indexes subjectively or objectively, and then synthesize multiple indexes to determine the technical condition of the equipment. In the era of big data, reducing attribute dimensions before data analysis is an important preprocessing task[8]. As a commonly used method of attribute reduction, rough set theory can remove some invisible attributes or the attributes which have little influence on decision-making under the premise of keeping the system classification unchanged, and it is widely used in intelligence Control[9,10], medical diagnosis[11], decision analysis[12], fault detection[13] and other fields[14,15].

For the technical condition evaluation of equipments, different indexes reflect different technical aspect of equipment, and the indexes in the technical specifications are relevant with each other.
which will also interfere with the evaluation results. Therefore, under the condition of ensuring accuracy, it is an important task to reduce the evaluation index system and retain the indexes that best reflect the changes in the technical condition of the equipment. Rough set theory was combined with D-S evidence theory in Refs. [16,17], the technical condition assessment indexes were reduced through rough set theory, and a multi-index synthesis was performed to obtain technical condition status using D-S evidence theory. This method reduces the uncertainty of evaluation and effectively improves the credibility of decision-making. Ref. [18] pointed out that the combination of rough set theory with genetic algorithms, particle swarm optimization and other heuristic algorithms can greatly improve the efficiency of attribute reduction. Based on the researches above, this paper proposes a reduction method of technical condition assessment indexes based on rough set and genetic algorithm, which has been applied to the technical condition index system reduction of a gas turbine. The results show that this method can reduce the complex index system to a more concise and clear index system without losing its representativeness and systematicity, and greatly reduce the large amount of information required for technical condition assessment.

2. Basic theory and concepts of rough set

2.1. Knowledge base theory

(1) Knowledge classification

Suppose $U$ is a non-empty set, which contains all the objects that we are interested in. We usually call $U$ as Universe. Knowledge classification is to divide each object into different categories according to the differences of knowledge contained in each object in the universe $U$. If there are any two objects in the universe $U$, and they contain the same knowledge, but the existing knowledge division rules cannot classify them, then the two objects are considered indistinguishable. This relationship is called the equivalence relationship. Several objects in the universe $U$ that have the same equivalence relationship together form an equivalence class.

Definition 1 Assuming that there is a universe $U$ and an equivalence relation set $R$, the process of knowledge classification in the universe $U$ according to the equivalence relation set $R$ is recorded as $U/R$. The Universe $U$, equivalence relation set $R$ and $U/R$ together form a knowledge base.

Based on the basic theory above, the rough set theory model divides the existing objects into the corresponding set calculation model according to the upper approximation and the lower approximation relationship.

Suppose $(U, R)$ be an approximate space, $X \subseteq U$. Then there is

\[
\begin{align*}
\bar{X} & = \bigcup \{Y \in U / R | Y \subseteq X \} \\
\overline{X} & = \bigcup \{Y \in U / R | Y \cap X \neq \emptyset \}
\end{align*}
\]  

Eqs.(1) and (2) are called the lower approximation set and the upper approximation set, respectively.

(2) Information system

Definition 2 Information system is a quadruple $S = (U, A, V, f)$, which satisfies

\[
\begin{align*}
U & = \{x_1, x_2, \ldots, x_n\} \\
U & \neq \emptyset \\
A & = C \cup D \\
C & = \{a_1, a_2, \ldots, a_n\} \\
D & = \{d\} \\
V & = V_c \cup V_d \\
f & : U \times A \rightarrow V
\end{align*}
\]

where $C$ and $D$ are the conditional attribute set and decision attribute set of the information system; $V_c$ represents the conditional attribute value of the information system, $V_d$ represents the decision
attribute value of the information system; \( f \) is the information function, the purpose of which is to assign a value to attribute.

In the information system, \( S \) is a cluster of equivalence relations on the universe \( U \). If \( B \subseteq S \) and \( B \neq \emptyset \), an indistinguishable binary relation on the universe \( U \) is defined as:

\[
IND(B) = \bigcap_{b \in B} IND(b)
\]

Obviously, \( IND(B) \) in Eq.(4) is an equivalent relationship.

2.2. Attribute reduction and attribute core

Definition 3 Suppose the attribute subsets \( P \) and \( Q \) be the equivalent relationship clusters on the universe \( U \), \( C \) and \( D \) are respectively the conditional attribute set and the decision attribute set, and \( P \subseteq C \), \( Q \subseteq D \), then the \( P \) positive domain of \( Q \) is written as:

\[
POS_P(Q) = \bigcup_{X \subseteq Q} P(X)
\]

in which, if \( a \in P \), \( POS_P(Q) = POS_{P \cup \{a\}}(Q) \) holds, the condition attribute \( a \) is said to be omissible in \( Q \), or \( a \) is obligatory in \( Q \). The set of all necessary relationships in the knowledge base \( Q \) in the attribute subset \( P \) is called the \( Q \) kernel of \( P \) and is denoted as \( CORE_Q(P) \). If all the attributes in the conditional attribute set \( C \) are necessary for the information system, the relative decision attribute set \( D \) is said to be independent; otherwise, \( C \) is dependent on the relative decision attribute set \( D \).

In the information system, if \( B \subseteq C \), the conditional attribute subset \( B \) is independent of \( D \), and \( POS_B(D) = POS_B(D) \), then the conditional attribute subset \( B \) is said to be a relative reduction of decision attribute set \( D \) of \( C \). The set formed by the reduction of all condition attribute sets \( C \) to the decision attribute set \( D \) is denoted as \( RED_Q(C) \). According to \( CORE_Q(P) = \bigcap RED_Q(P) \), the attribute core of the information system is the intersection of all reductions, which is an attribute that cannot be eliminated when performing attribute reduction of the information system.

2.3. Attribute dependency

Attribute dependency is an effective method to measure the degree of dependence between conditional attributes and decision attributes, which reflects the ability to derive decision attributes through condition attributes. The definition of attribute dependency is as follows.

Definition 4 Supposing information system \( S = (U, C \cup D, V, f) \), \( R \) is the cluster of equivalence relations of \( U \), and \( P, Q \subseteq R \):

1. If and only if \( IND(P) \subseteq IND(Q) \), knowledge \( Q \) depends on knowledge \( P \), and it is written as \( P \Rightarrow Q \).
2. If and only if \( P \Rightarrow Q \) and \( Q \Rightarrow P \), knowledge \( P \) and knowledge \( Q \) are equivalent, and it is written as \( P = Q \).
3. If and only if \( P \Rightarrow Q \) and \( Q \Rightarrow P \) are not true, knowledge \( P \) and knowledge \( Q \) are independent.

From the definition 4, we can know that if and only if \( IND(P) \subseteq IND(Q) \), then \( P \Rightarrow Q \). If and only if \( IND(P) = IND(Q) \), then \( P = Q \).

Definition 5 Supposing information system \( S = (U, C \cup D, V, f) \), \( R \) is the cluster of equivalence relations of \( U \), and \( P, Q \subseteq R \), the attribute dependency about \( Q \) to \( P \) is defined as:

\[
\gamma(P, Q) = \frac{|POS_P(Q)|}{|U|}
\]

In the formula, \( | \cdot | \) represents the basis of the set; \( POS_P(Q) \) represents \( Q \) is in the positive region of \( P \) on the universe \( U \). From Eq.(6), we can see that, \( \gamma(P, Q) = 1 \) means knowledge \( Q \) partly depends on
knowledge $P$. $\gamma_P(Q) \in (0,1)$ means knowledge $Q$ depends on knowledge $P$. $\gamma_P(Q) = 0$ means knowledge $Q$ is completely independent of knowledge $P$.

3. Index reduction algorithm based on rough set and genetic algorithm

The concept of rough set attribute reduction is introduced into technical condition evaluation. The technical condition index system is taken as the information system, each index is taken as the condition attribute of the information system, and technical condition level status level is taken as the decision attribute of the information system. Using the equidistant discretization method to discretize the index data, a decision table for index reduction is obtained. Aiming at the greater dependence of decision attributes on condition attributes and the smaller number of indicators contained in condition attributes, genetic algorithms are used to optimize and simplify the index system of technical condition evaluation.

3.1. Index data discretization method

The functional characteristic indexes of equipment are often continuous. Before the index system is reduced, the index data should be discretized. This paper uses the equidistant discretization method to discretize the index data. The equidistant discretization method is simple and fast, and its main steps are as follows:

Step 1 Determine the number of intervals $K$ for discretization of attribute values according to requirements;

Step 2 According to the number of intervals $K$, divide the attribute range $[X_{\min}, X_{\max}]$ into $K$ intervals with equal distances for each segment, and the distance for each interval is $d=(X_{\max}−X_{\min})/K$;

Step 3 Obtain the breakpoint $X_{\min}+id$ on the attribute, ($i=0,1,...,K$);

Step 4 Divide each attribute value into the corresponding interval to obtain discretization result.

3.2. Encoding method of genetic algorithm

The genetic algorithm mainly includes basic steps such as coding, initial population setting, fitness function selection, selection operation, crossover operation and mutation operation[19].

(1) Coding method

Coding refers to the transformation of the possible solution of a problem from its solution space to the search space that genetic algorithms can handle. How to encode is the first question to be solved using genetic algorithm. Different coding methods will affect the crossover and mutation process, and the coding method also has a certain effect on the genetic evolution efficiency of the population. This paper selects binary encoding method for encoding. A fixed-length binary string is used to represent individuals in the group, and the allele is composed of $\{0,1\}$. For example, the character string 01101 represents an individual, whose chromosome length is $n=5$, and each digit in the chromosome corresponds to a condition attribute. If the position of a gene is 1, it means that the condition attribute corresponding to the position is selected. If it is 0, it means that the condition attribute corresponding to the position is not selected.

(2) Fitness function

The fitness function is mainly used to calculate the adaptability of individuals in the population to the environment. The fitness function is mainly used to calculate the adaptability of individuals in the population to the environment. The fitness value of the individuals in the population is determined by the fitness function, and the individual's quality is judged by this, and the individual with the highest fitness value is selected to inherit to the next generation. According to the requirements of the evaluation index system reduction, the objective of the fitness function is to ensure the accuracy of the evaluation results while keeping the number of indexes in the index system as small as possible. Therefore, when selecting the fitness function, the attribute dependency and the number of conditional attributes are also considered.
where \( N \) is the number of conditional attributes; \( R_x \) is the number of all “1”s in chromosome \( x \), that is the number of indexes included in the technical condition evaluation index system; \( \gamma(x, D) \) is the degree of dependence of the conditional attribute included in individual \( x \) to the decision attribute \( D \), that is the degree of dependence of the technical condition status level on the evaluation index system; \( \alpha \) is the adjustment parameter, and its value range is \((0,1)\).

3.3. Algorithm flow

The main steps of the reduction algorithm of the equipment technical condition evaluation index system based on rough sets and genetic algorithms are shown in Figure 1.

**Figure 1.** Rough set and genetic algorithm index reduction steps.

Input: Information system composed of index data \( S = (U, C \cup D, V, f) \);

Output: Reduced index system of evaluation index information system \( S = (U, C \cup D, V, f) \).

Step 1: An information system composed of index data is discretized to obtain a decision table for index reduction.

Step 2: Calculate the dependence \( \gamma(C, D) \) of the decision attribute \( D \) on the condition attribute \( C \) according to Eq.(6).

Step 3: Calculate the attribute core \( \text{CORE}(C) \) of the information system. If \( \gamma(\text{CORE}(C), D) = \gamma(C, D) \), \( \text{CORE}(C) \) is the minimum reduction; otherwise, continue execution.

Step 4: Maximize the dependence \( \gamma(C, D) \) of the decision attribute \( D \) on the condition attribute \( C \) and the minimum number of condition attributes in the condition attribute \( C \) as the objective function, and use genetic algorithm to solve it.

Step 5: The initial population is composed of individuals represented by a random binary string of length \( |C| \) (the number of conditional attributes, the number of indexes included in the index system).

Step 6: Calculate the fitness value of the above-mentioned individuals according to Eq.(7).

Step 7: Perform genetic operations based on the fitness function values of individuals in the population.

Step 8: Judge whether the value of the objective function has not change for successive generations. If yes, then terminate the calculation and output the reduction result; if not, return to step 5 and continue the loop.
4. Reduction case of technical condition evaluation index system

Using the method proposed in this paper, taking a certain gas turbine as an example, the evaluation index system is reduced. According to the provisions of the technical specifications, this gas turbine has 12 functional characteristics. Among them, there are four dynamic performance indexes, output power $A_1$ (kW), low-pressure speed $A_2$ (r/min), high-pressure speed $A_3$ (r/min), moving vortex speed $A_4$ (r/min); seven operational stability indexes, Low pressure vibration $A_5$ (mm/s), high pressure vibration $A_6$ (mm/s), moving vortex vibration $A_7$ (mm/s), high pressure compressor air pressure $A_8$ (Mpa), low vortex gas pressure $A_9$ (Mpa), exhaust gas temperature $A_{10}$ ($^\circ$C), gas turbine exhaust pressure $A_{11}$ (Mpa); one economic index, fuel consumption rate $A_{12}$ (g/(kw*h)).

4.1. Discretization of functional characteristic index data

From the monitoring software and work register, 10 groups of sample data of each functional characteristic index under rated working conditions are collected and sorted out. The data after declassification is shown in Table 1. The discretization data is shown in Table 2.

### Table 1. Function quality characteristic index data.

| Sample index | $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_6$ | $X_7$ | $X_8$ | $X_9$ | $X_{10}$ |
|--------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|---------|
| $A_1$        | 1086.35 | 1086.62 | 1087.20 | 1065.65 | 1097.82 | 1084.55 | 1083.51 | 1091.75 | 1091.75 | 1089.72 |
| $A_2$        | 263.02  | 261.94  | 262.66  | 258.70  | 260.57  | 260.14  | 260.78  | 261.72  | 258.98  | 259.78  |
| $A_3$        | 336.17  | 334.80  | 335.45  | 331.63  | 334.37  | 333.72  | 334.51  | 334.30  | 332.06  | 332.35  |
| $A_4$        | 114.55  | 115.49  | 115.49  | 115.34  | 115.92  | 113.04  | 115.63  | 113.98  | 112.46  | 114.41  |
| $A_5$        | 4.86    | 6.06    | 5.94    | 6.78    | 6.30    | 4.62    | 4.68    | 4.20    | 4.38    | 5.46    |
| $A_6$        | 3.78    | 4.26    | 4.26    | 3.78    | 3.18    | 3.96    | 3.12    | 3.48    | 3.66    | 3.12    |
| $A_7$        | 4.26    | 4.44    | 4.50    | 3.90    | 3.42    | 3.96    | 3.66    | 3.90    | 3.78    | 3.24    |
| $A_8$        | 1.15    | 1.15    | 1.15    | 1.14    | 1.13    | 1.11    | 1.13    | 1.13    | 1.12    | 1.13    |
| $A_9$        | 0.29    | 0.28    | 0.28    | 0.29    | 0.29    | 0.28    | 0.29    | 0.28    | 0.29    | 0.28    |
| $A_{10}$     | 579.00  | 593.88  | 603.96  | 569.88  | 583.20  | 581.64  | 589.56  | 581.40  | 574.56  | 587.04  |
| $A_{11}$     | 307.23  | 300.66  | 233.73  | 216.57  | 300.84  | 303.39  | 233.82  | 218.16  | 205.02  | 224.91  |
| $A_{12}$     | 565.37  | 592.58  | 775.20  | 789.42  | 581.57  | 575.14  | 756.43  | 799.50  | 840.74  | 783.03  |

### Table 2. Discrete results of functional quality characteristics.

| Sample index | $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_6$ | $X_7$ | $X_8$ | $X_9$ | $X_{10}$ | Breakpoint value |
|--------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-----------|----------------|
| $A_1$        | 1     | 1     | 1     | 0     | 1     | 1     | 1     | 1     | 1     | 1         | 1081.73        |
| $A_2$        | 1     | 1     | 1     | 0     | 1     | 0     | 1     | 0     | 0     | 0         | 260.86        |
| $A_3$        | 1     | 1     | 1     | 0     | 1     | 0     | 1     | 0     | 1     | 0         | 333.90        |
| $A_4$        | 1     | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 1         | 114.19        |
| $A_5$        | 0     | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0         | 5.49          |
| $A_6$        | 1     | 1     | 1     | 1     | 0     | 1     | 0     | 0     | 0     | 0         | 3.69          |
| $A_7$        | 1     | 1     | 1     | 1     | 0     | 1     | 0     | 1     | 0     | 0         | 3.87          |
| $A_8$        | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0     | 0         | 1.14          |
| $A_9$        | 1     | 0     | 0     | 1     | 1     | 0     | 1     | 0     | 1     | 0         | 0.28          |
| $A_{10}$     | 0     | 1     | 1     | 0     | 1     | 0     | 1     | 0     | 0     | 1         | 17.61         |
| $A_{11}$     | 1     | 1     | 0     | 0     | 1     | 0     | 1     | 0     | 0     | 0         | 256.13        |
| $A_{12}$     | 0     | 0     | 1     | 1     | 0     | 0     | 1     | 1     | 1     | 1         | 703.06        |

4.2. Reduction of functional characteristics

Based on the discretization results in Table 2, a reduction decision table for the dynamic index system is established, as shown in Table 3. Use indexes $A_i, A_j, A_k, A_l$ as conditional attributes and technical condition status levels $D=[d]$ as decision attributes. $d=0$ Indicates that the status level is "poor"; $d=1$ indicates that the status level is "medium"; $d=2$ indicates that the status level is "good"; $d=3$ indicates that the status level is "excellent". According to the index system reduction steps based on rough set and genetic algorithm in Figure 1, the dynamic index decision table shown in
Table 3 is reduced, and the iterative process is shown in Figure 2. After reduction, the optimal individual \( \{0\ 1\ 0\ 1\} \) is obtained, the reduction result of the dynamic index is \( \{A_2, A_4\} \). The four attributes in the motive force index are reduced to two, namely, low-pressure speed and moving vortex speed. The calculated attribute dependence of dynamic index (decision attribute) depends on the optimal individual after reduction \( \{0\ 1\ 0\ 1\} \) (that is the reduced index system) is 1. It indicates the index obtained after reduction (the low-pressure speed \( A_2 \) and moving vortex speed \( A_4 \)) can well reflect the power of the gas turbine. Using the same method, the stability and economic indexes in Table 2 are reduced. The 8 indexes of operating stability and economy can be reduced to 3 indexes, which are Low pressure vibration \( A_5 \), low vortex gas pressure \( A_9 \), and exhaust gas temperature \( A_{10} \).

**Table 3.** Power index decision table.

| sample | index | \( A_1 \) | \( A_2 \) | \( A_3 \) | \( A_4 \) | \( d \) |
|--------|-------|----------|----------|----------|----------|------|
| \( X_1 \) | 1     | 1        | 1        | 1        | 3        |
| \( X_2 \) | 1     | 1        | 1        | 1        | 3        |
| \( X_3 \) | 1     | 1        | 1        | 1        | 3        |
| \( X_4 \) | 0     | 0        | 0        | 1        | 0        |
| \( X_5 \) | 1     | 1        | 1        | 1        | 3        |
| \( X_6 \) | 1     | 0        | 0        | 0        | 0        |
| \( X_7 \) | 1     | 0        | 1        | 1        | 0        |
| \( X_8 \) | 1     | 1        | 1        | 0        | 2        |
| \( X_9 \) | 1     | 0        | 0        | 0        | 0        |
| \( X_{10} \) | 1   | 0        | 0        | 1        | 0        |

![Figure 2. The iterative process of power index reduction.](image)

5. Conclusion

For the technical condition evaluation of equipments, different indexes reflect different technical aspect of equipment, and the indexes in the technical specifications are relevant with each other which will also interfere with the evaluation results. Therefore, under the condition of ensuring accuracy, it is an important task to reduce the evaluation index system and retain the indexes that best reflect the changes in the technical condition of the equipment. This paper proposes a reduction method of technical condition assessment indexes based on rough set and genetic algorithm, which
has been applied to the technical condition index system reduction of a gas turbine. The results show that this method can reduce the complex index system to a more concise and clear index system without losing its representativeness and systematicity, and greatly reduce the large amount of information required for technical condition assessment. This method can reduce the difficulty of information collection, and improve the accuracy of the evaluation results.

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