Research on Attribute Reduction in Hoisting Motor State Recognition of Quayside Container Crane

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Abstract. In view of too many attributes in hoisting motor state recognition of quayside container crane. Attribute reduction method based on discernibility matrix is introduced to attribute reduction of lifting motor state information table. A method of attribute reduction based on the combination of rough set and genetic algorithm is proposed to deal with the hoisting motor state decision table. Under the condition that the information system's decision-making ability is unchanged, the redundant attribute is deleted. Which reduces the complexity and computation of the recognition process of the hoisting motor. It is possible to realize the fast state recognition.

1. Introduction
As one of the important driving systems of quayside container crane, the hoisting motor directly influences the operation of quayside container crane. In order to keep abreast of the working state of the hoisting motor, the online condition monitoring system is often used to obtain the vibration signal of the hoisting motor, and then the state recognition. Mechanical equipment state recognition is essentially a pattern recognition or clustering problem, and the feature extraction of signal is one of the key elements. In order to comprehensively reflect the state of the motor, the multi-eigenvalues of the collected signals are usually extracted to form a high-dimensional characteristic parameter vector to evaluate the dynamic performance of the hoist motor comprehensively [1]. But too many characteristic parameters will take up too much storage space and affect the speed of calculation. At the same time, it will cause the problem of dimension disaster and characteristic redundancy [2]. Therefore, it is necessary to reduce the characteristic parameters of the hoisting motor to remove redundant information.

Rough set theory can remove the redundant information in the data, while maintaining the original classification ability [3]. In this paper, attribute reduction method based on rough set theory is used to attribute reduction of the high-dimensional eigenvector in the process of lifting recognition.

2. Basic definitions
Def 1. Let IS = (U, A, V, f) be an information system, where U is the set of objects, called the universe; A is the set of attributes, A = C ∪ D , C the condition attribute and D is the decision attribute; V is the set of values of attributes and f is an information function.

Def 2. For any subset, B belongs to A in the information system IS = (U, A, V, f), we can define the equivalence relation as follow.
\[ \text{IND}_A(B) = \{(x, y) \in U^2| \forall a \in B, a(x) = a(y)\}. \] (1)

Where \( a(x) \) represents the value of object \( x \) on attribute \( a \).

Def 3. Let \( R \) be a family of equivalence relations, \( r \in R \), if \( \text{IND}(R) = \text{IND}(R - \{r\}) \), then \( r \) is unnecessary in \( R \). Otherwise, \( r \) is necessary in \( R \). If each \( r \in R \) is necessary for \( R \), then \( R \) is independent.

Let \( Q \subseteq P \), if \( Q \) is independent and \( \text{IND}(Q) = \text{IND}(P) \), then \( Q \) is called a reduction of \( P \).

Def 4. The dependency of decision attribute on condition attribute is \( \gamma_C(D) \).

\[ \gamma_C(D) = |\text{POS}_C(D)|/|U| \] (2)

Where \( |U| \) is the cardinal number of universe, and \( |\text{POS}_C(D)| \) is the positive domain of the decision attribute with respect to the condition attribute.

3. Attribute reduction method of hoisting motor information table

Discernibility matrix can be used to represent knowledge [4], this method has many advantages for the attribute kernel, attribute reduction and representation in the information table [5]. The attribute reduction algorithm based on discernible matrix and attribute selection is as follows.

Input: an information table of hoisting motor \( IS = (U, A, V, f) \)
Output: an attribute reduction of the information table RED(C)

Step 1. Calculated discernibility matrix of hoisting motor information table;
Step 2. The attribute core, CORE(C), of the information system is obtained according to the discernibility matrix, let \( B = \text{CORE}(C) \);
Step 3. For any \( c_{ij} \in M(i, j = 1, 2, \cdots, n) \), if \( c_{ij} \cap B \neq \emptyset \), let \( c_{ij} = 0 \);
Step 4. If any \( c_{ij} = 0(i, j = 1, 2, \cdots, n) \), skip to step 6, otherwise execute step 5;
Step 5. The number of occurrences of each attribute in the current discernible matrix is counted, and the most frequent elements are selected, \( B \leftarrow B \cup \{\alpha\}, \) then go to the step 3;
Step 6. Output the result \( B \in \text{RED}(C) \).

4. Attribute reduction method of decision table

Solving all attribute reductions or minimal reductions of a decision table has proved to be an exponentially difficult problem [6]. Therefore, this paper uses the combination of rough set theory and genetic algorithm to reduce the redundancy condition attributes [7], and find the global optimal reduction of the decision table of the hoisting motor through the global optimization probabilistic search algorithm of genetic algorithm. Specific algorithm steps are as follows:

Input: a decision table of hoisting motor
Output: an optimal attribute reduction of the decision table

Step 1. Calculate the support degree of \( D \) with respect to \( C \).
Step 2. Set the fitness function

\[ F(r) = (l - l_r)/l + \gamma_C(D) \] (3)

Step 3. Calculate fitness of each individual in the initial population
Step 4. Generate new population according to crossover probability and mutation probability.
Step 5. Calculate fitness of each individual in the new population
Step 6. Copy the optimal individual into next generation according to the optimal preservation strategy, and save the optimal individuals.
Step 7. If the best individual fitness value of continuous \( n \) generation is no longer increased output the optimal individual, otherwise turn back Step 4.

5. Attribute reduction of hoisting motor information table

The state identification of the hoist motor is generally an unsupervised clustering process, that is, the state of the hoist motor is not known in advance [8]. Therefore, there is no decision attribute in the information table. Using the acceleration sensor mounted on the output shaft of the hoisting motor to
collect the vibration signal, and then extract the various characteristic parameters of the vibration signal to form the condition attribute set of the lifting motor information table. But not all of the condition attributes are necessary for state recognition. In order to achieve fast clustering and reduce computational cost, it is necessary to attribute reduction and delete redundant attribute of hoisting motor information table.

Taking the online condition monitoring data of the hoisting motor of 4 weeks as the study object, we take the day unit as the research object, \( U = [1, 2, \cdots, 28]' \). The daily mean value of the vibration signal, the square root amplitude, the skewness index, the waveform index, the peak value index, the pulse index and the margin index are calculated respectively [9]. A total of 8 special diagnosis parameters are taken as the condition attributes of the hoisting motor state information table. Respectively, with \( c_1, c_2, c_3, c_4, c_5, c_6, c_7, c_8 \) said. The obtained eigenvalues are discretized (using the method of equal frequency discretization in this paper) to obtain the lifting motor state information table as shown in Table 1.

### Table 1. Hoist motor status information table of hoisting motor

| U  | c1 | c2 | c3 | c4 | c5 | c6 | c7 | c8 |
|----|----|----|----|----|----|----|----|----|
| 1  | 3  | 3  | 1  | 1  | 1  | 1  | 1  | 1  |
| 2  | 3  | 3  | 1  | 1  | 2  | 1  | 1  | 2  |
| 3  | 1  | 1  | 3  | 3  | 2  | 3  | 3  | 2  |
| 4  | 2  | 3  | 1  | 1  | 1  | 1  | 1  | 1  |
| 5  | 2  | 2  | 2  | 2  | 2  | 1  | 2  | 2  |
| 6  | 1  | 1  | 3  | 3  | 3  | 3  | 3  | 3  |
| 7  | 3  | 3  | 1  | 2  | 1  | 1  | 1  | 1  |
| 8  | 3  | 2  | 2  | 2  | 2  | 2  | 2  | 2  |
| 9  | 2  | 2  | 2  | 2  | 3  | 3  | 3  | 3  |

The attribute reduction method based on discernibility matrix and attribute selection is used to attribute reduction of the hoisting motor information table. The results show that the \( \text{RED}(C) = \{c_1, c_2, c_3, c_4, c_6\} \) is the effective value, square root amplitude, skewness index, kurtosis index and peak value. After deleting the redundant attribute in the information table, the reduced feature vector has only 5 dimensions. Which is reduced by 38% compared with that before reduction, which greatly reduces the computational cost and provides a guarantee for realizing fast state identification and visualization.

To a certain extent, the motor vibration signal reflects the running status of the motor. For example, when the peak value of the vibration signal is too high, it indicates that the motor is not running smoothly or is overloaded [10]. The hoisting motor vibration signal for low-pass filter processing to remove noise and other interference signals. And then takes the peak value of the vibration signal after filtering as the decision attribute \( D \) of the state of the hoisting motor. The decision table of the hoisting motor is discretized (the method of equal frequency discretization is adopted here), and the decision table of the hoisting motor status is shown in Table 2. \( D = \{1,2,3\} \), respectively, according to the different motor vibration signal peak divided into three states of the lift motor.
Table 2. Decision table of hoisting motor

|   | $c_1$ | $c_2$ | $c_3$ | $c_4$ | $c_5$ | $c_6$ | $c_7$ | $c_8$ | D   |
|---|-------|-------|-------|-------|-------|-------|-------|-------|-----|
| 1 | 3     | 3     | 1     | 1     | 1     | 1     | 1     | 3     |     |
| 2 | 3     | 3     | 1     | 1     | 2     | 1     | 1     | 2     | 3   |
| 3 | 1     | 1     | 3     | 3     | 2     | 3     | 3     | 2     | 1   |
| 4 | 2     | 3     | 1     | 1     | 1     | 1     | 1     | 1     | 3   |
| 5 | 2     | 2     | 2     | 2     | 2     | 1     | 2     | 2     | 3   |
| 6 | 1     | 1     | 3     | 3     | 3     | 3     | 3     | 2     |     |
| 7 | 3     | 3     | 1     | 2     | 1     | 1     | 1     | 1     | 3   |
| 8 | 3     | 2     | 2     | 2     | 2     | 2     | 2     | 2     | 3   |
| 9 | 2     | 2     | 2     | 2     | 3     | 3     | 3     | 3     | 2   |

In order to find the decision rules between the condition attributes and the decision attributes of the hoist motor, the rough set theory and the genetic algorithm are used to reduce the attributes of the decision table. The dependency of decision attribute on condition attribute is added to the fitness function to ensure that the condition attribute has sufficient support for the decision attribute after reduction. The parameters of the genetic operator are set to be $P_c = 0.7$, $P_m = 0.01$ and $m = 15$. The optimal individual after reduction is $\{1\ 0\ 0\ 0\ 1\ 0\ 1\ 0\}$, i.e. the condition attribute $\{c_1\ c_4\ c_7\}$, and the results after reduction are shown in Table 3.

Table 3. Reduction result

|   | $c_1$ | $c_4$ | $c_7$ | D   |
|---|-------|-------|-------|-----|
| 3 | 1     | 1     | 1     | 3   |
| 3 | 2     | 1     | 1     | 3   |
| 1 | 2     | 3     | 1     |     |
| 2 | 1     | 1     | 1     | 3   |
| 1 | 3     | 3     | 2     |     |
| 3 | 2     | 2     | 2     | 3   |
| 2 | 3     | 3     | 2     |     |
| 1 | 1     | 2     | 1     |     |
| 2 | 2     | 2     | 2     |     |
| 1 | 1     | 1     | 1     |     |
| 3 | 1     | 2     | 3     |     |
| 2 | 3     | 2     | 3     |     |

From Table 3 can be seen to determine the state of the hoisting machine is mainly RMS, kurtosis index and pulse index. The effective value reflects the fluctuation of the signal relative to the zero value, and the effective value corresponds to the vibration energy. According to the generalization standard, it can be found that: when the effective value is relatively large, the hoisting motor vibration is relatively large; when the effective value is relatively small, the hoisting motor vibration is relatively small; RMS and hoisting motor has a similar related relationship. The kurtosis index is a dimensionless parameter,
which is independent of the structure of the lift motor and is particularly sensitive to the shock signal, and the pulse index is also a dimensionless index, which is characterized by being sufficiently sensitive to the running state of the hoist motor. When the motor running state changes caused by the vibration signal changes, the pulse index has changed significantly. And there is a stable correspondence between the pulse index and the running state of the hoisting motor, and it is insensitive to the factors other than the running state of the hoisting motor, such as the magnitude of the load.

6. Summary
In the process of state recognition of the hoisting motor of the quayside container crane, the characteristics of the feature parameter are too many and the redundant attribute affects the efficiency of state recognition. In this paper, an attribute reduction method based on rough set theory is used to deal with hoisting machine state information table. Under the premise of guaranteeing the state recognition rate and the recognition precision, the lifting machine state information table is reduced in dimension. Through attribute reduction, redundant attributes such as waveform index and margin index in hoist motor state information table are deleted. So as to achieve the purpose of reducing the complexity and the calculation amount of the lifting motor state identification process. The algorithm of attribute reduction based on the combination of genetic algorithm and rough set theory is also introduced in detail. Based on the algorithm, the attribute reduction of the decision table of the hoist motor is made, and the decision relation between the effective value, the kurtosis index and the pulse index and the hoist motor state is found.

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