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Study on Condition Monitoring of Hydraulic Excavator Based on Data Mining Technology

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Abstract

In order to monitor working conditions of the hydraulic excavator correctly, the data mining technology is applied in it. Firstly, the basic theory of hydraulic excavation is studied; Secondly, the basic theory of data mining is summarized; Thirdly, the application of rough set is analyzed; then design of status monitoring system for hydraulic excavator is carried out; finally, a case study of excavator monitoring system is carried out, and results show that the data mining technology is an effective method for monitoring the condition of hydraulic excavator.

Keywords*: working conditions; hydraulic excavator; data mining technology*

1. Introduction

The hydraulic excavator is a big system with complex mechanical-electrical integration, which has been developing to the direction of high speed, big power, high reliability, and large scale; therefore it is difficult to monitor the conditions of the hydraulic excavator. The monitoring system of the hydraulic excavator is a multi tasks information processing system integrating the signal collection, condition analysis, and situation display. The condition monitoring system of the hydraulic excavator can monitor the condition of it in real-time. In order to monitor the condition of the hydraulic excavator correctly, an advanced technology should be found out. The data mining technology is also named as knowledge discovery, which can analyze the mass data in the analysis database, and make inductive reasoning. And hidden mode can be mined, which can be applied in the prediction. The useful information combining with database, artificial intelligence, data statistics and visualization technology can improve the correctness of condition monitoring for the hydraulic excavation [1].

2. Basic Theory of Hydraulic Excavation

The simplified model and energy conversion process of component of engine and hydraulic system for the excavator is shown in Figure 1.

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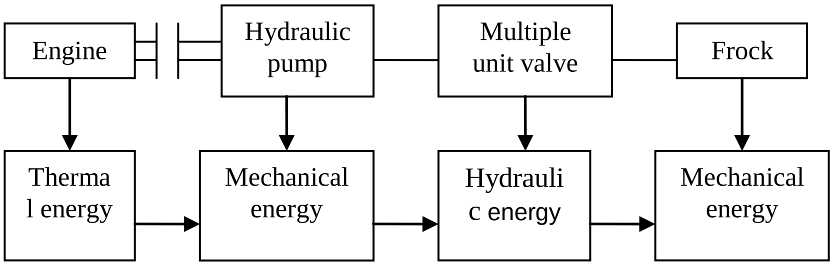

Figure 1. Simplified Model and Energy Conversion Process of Component of Engine and Hydraulic System for the Excavator

The output power of engine is expressed as follows [2]:

$$P_e = M_e n_e \tag{1}$$

where M_e denotes the torsion of the engine, n_e denotes the rotating speed of the engine.

The absorbing power of the pump is expressed as follows:

$$P_p = p_p(t) q_{V_p} = p_p(t) V_p(t) n_p = M_p n_p \tag{2}$$

where $p_p(t)$ denotes the outlet pressure of the pump, $V_p(t)$ denotes the output volume of pump, n_p denotes the rotating speed of the pump, M_p denotes the torsion of the pump, q_{V_p} denotes the flow of the pump.

The load absorbed power P_a is calculated by the following expression:

$$P_a = F v_c = F \frac{q_{v_c}}{A_c} = p_c q_{V_c} \tag{3}$$

where F denotes the load force, v_c running speed of the actuating element, q_{v_c} denotes the flow of the actuating element, p_c denotes the pressure of the actuating element, A_c denotes the area of the actuating element. .

3. Basic Theory of Data Mining

Data mining comes from statistics firstly, which denotes the blindness of the activity. The development of data mining is the procession promoted by the gradually evolved requirement. When the research of people on knowledge acquisition has experienced three stages concluding machine learning, expert system and artificial network, the term “knowledge discovery in database” is put forward. Data mining is a creative procession relating a lot of different technologies and knowledge. Before data mining is carried out, the steps used and the aim achieved should confirmed, a good plan can ensure the methodical implementation of data mining and obtain the success. The prototype of data mining is put forward firstly by Frawley J and Piatetsky, The procession model centered client is put forward by Branchman and others in 1996. So far, the procession models of data mining have been induced and summarized by many people.

In the meantime, many software suppliers and consultant companies of data mining also put forward a lot of data mining procession models, which can guide their clients to carry out standard data mining work. The famous model is Cross industry standard process for data mining, which is verified through actual project. In addition, there are other models., which concluding 5A model of SPSS, SEMMA model of SAS, PMML model, Microsoft OLE DB model, and professional data mining model [3].

The data mining technology is introduced into the condition monitoring of device, the four main stages of data mining procession model should be understood and described from the angle of the status monitoring.

(1) Objective understanding and definition: data mining is best for changes of data in weak level that can not be found out by normal human expert. For example, in the field of device monitoring, equipment operator can understand the whole characteristics of the device system well, however changes of monitoring data because of the update of device part and change of manufacturing abject is difficult to be obtained.

(2) Establishing the mining data collection: this stage is divided into four parts, which are data collection, data clear, data transformation, and data reduction. Because data from monitoring system has diversity, complexity and massive character, the corresponding data collection should be collected from monitoring and history database according to object of data mining, and the clear, transformation and reduction should be carried out.

(3) Data mining (model discovery): this is an iterative process which can use all kinds of statistical and machine learning techniques, such as principle learning, decision tree and cluster. In order to ensure precision and robustness, the mining data collection can be divided into two parts, one is applied in mining, and the other is applied into evaluation.

(4) Application of model: because real application data is different, the model can be updated continuously during the procession of learning under the driving of massive data, activity status and fault model of the device should be found out, and the high monitoring correctness can be ensured.

4. Application of Rough Set

Condition monitoring can be achieved based on rough set, and this procession concludes relative reduction, rule generation and rule matching. The function of condition monitoring can predict the status of device according to the history and knowledge database [4].

Pre-procession of data: data pre-procession can carry out clearance of original data, and remove the noise, and delete redundancy and incomplete information.

Quantization: quantization is an important step during the procession of processing rough set, the good and bad of quantization can affect the precision of final results directly, but fine quantization can affect the efficiency of monitoring system.

Relative reduction: reduction concludes reduction of objective and property, the algorithm of reduction can affect the correctness of results directly. There are many algorithms of relative reduction, and the rough set theory can carry out reduction based on core and equivalence relation. The best algorithm of reduction facing the client is listed as follows:

Input:

(1) The increasing identification of R' in task relating whole relationship is defined by TAG, and the relationship R is obtained, where the TAG value of the vague group is set as F, and other TAG values are set as T, tuple of F is boundary tuple.

(2) The generalization relationship attribute set of the relationship R' is made up of condition attribute C and decide attribute D, where the condition attribute concludes knowledge database and past data of device fault, the decide attribute is the current device data.

(3) The core CO of AR is calculated based on the difference matrix R'.

(4) The client appoints a attribute collection UA.

Output: a group of property collection REDU after reduction

The corresponding algorithm is listed as follows [5]:

Step 1; calculate REDU=CO YUA

Step 2: let $Q = m_{ij} : m_{ij} \ I \ REDU \neq \Phi$, $i \neq j$, $i, j = 1, 2, \cdots, n$,

$$M = M - Q \tag{4}$$

$$B = C - REDU \tag{5}$$

Step 2: Calculate the effective value for all attribute with $aK \in B$, $i, j = 1, 2, \cdots, n$, the corresponding expression is listed as follows:

$$SGFSGF(a, R, D) = K(R, \{a\}, D) - K(R, D) \tag{6}$$

where $K(R, D) = \frac{Card(PosR(D))}{Card(U)}$, $Card$ is the basis of collection, Pos is the positive region of D under R. A attribute a_j in B is selected according to the maximum effective value.

Step 4: $REDU = REDU \ Y\{a_j\}$

Step 5: repeat the steps above until $M = \Phi$

Rule generation: information system is a rule database after relative reduction, and the rules in the rule database may led to conflicts. Therefore the rules with conflicts should be deleted from database, and the corresponding algorithm is listed as follows:

Step 1 investigate the condition attribute in the information table column by column, delete this column, if the conflicting record generates, the original attribute of the conflicting record is saved. If the there is no conflict but concludes repeated records, and this attribute values of repeated records can be signed by "*"; for other records, the attribute value is signed by "?".

Step 2: delete the possible repeated records, and investigate every record with signal "?". If the decision can be made based on the attribute value without signal, then "?" can be changed to "*". Otherwise, the original attribute value is revised; if all attribute values of a record are signed, then the attribute with signal "?" can be changed to value of original value of attribute.

Step 3: delete all records that the condition attribute is signed as "*" and the possible repeated records.

Step 4: if the two records have only one different record, and the attribute of a record is signed as "*", then attribute value without signal can make decision for this record, then the other record is deleted, otherwise, this record is deleted.

Rule matching: extract the rules from the rule database, and predict the attribute value of decision through comparing the known condition attribute value.

5. Design of Status Monitoring System for Hydraulic Excavator

The monitoring system can monitor the working status of the hydraulic excavator in real time, and the process the data accepted in real time [6].

(1) Start of system

The Socket technology in C# is used to open the port, which can accept the data information. The user datagram protocol is a protocol without connection. When the computer transfers data based on the user datagram protocol, the sender only know the IP address and port number of the other side to send information without data connection. The user datagram protocol can be achieved based on Visual C#, the most critical class is UdpClient, which locates name space System.Net.Scokets, Visual C# can send, accept database package of UDP through UdpClient class.

The "Receive" method in UdpClient is used to accept the UDP data package, and the calling syntax is listed as follows:

Public byte [ ] Receive (


```
ref IPEndPiont remoteRe
);
```

The parameter remoteRe is a living example of IPEndPoint Class, which denotes the node of data package sent by network. And the data acquisition can be achieved through intercepting local port number, and the information code can be obtained through intercepting the local port number "8080" as follows [7]:

```
UdpClient server = new UdpClient ( );
receivePoint = new IPEndPoint (new IPAddress ("127.0.0.1"), 8080);
byte [ ] receiveData = server.Receive (ref receivePiont); // accept the transmitting data
ASCIIEncoding encode = new ASCIIEncoding ( ); // obtain the require data of client
string ReceiveString = encode.GetString (receiveData); // extract information of client, which is stored in the character string array.
```

ReceivString stores the accepting data, which concludes working status and position information of hydraulic excavator. then the accepting data is analyzed, and the needed information is transferred to the database.

(2) Achievement of the monitoring function

Monitoring of single excavator and all excavators are conformed to monitor every excavator, when a single excavator is monitored, the working status of excavator can be found out through number from database. Therefore the page can achieved through control or component in .ASPX file, the operation of database can be achieved in the corresponding .CS file, and the conditions of the hydraulic excavator searched can be transferred to the page and show.

A transferred button is added in the monitoring page of the single excavator mode, hitting this button can switch to global monitoring mode of excavator, the following codes are applied:

```
protected void Change_Click (object sender, EventArgs e)
{
Response.Redirect ("AllCurrentinfo.aspx"); // switch to global monitoring mode
  }
```

In the mode of global monitoring mode of excavator, the Datagrid control is used to show status information of all excavators. The Datagrid control can carry out binding operations with database, the timely update of data can be achieved.

```
string sql = "select * from GrabStatus"; //search database
DataTable dt = link.SelectAlltDataBase (sql); // execute search and return to DataTable
if (dt ! = null)
{
  This.DataGrid.DataSource = dt; // set data source
  DataGrid1.DataBind ( ); // binding data
}
```

In like manner, a switch button should be added on the page of global monitoring mode of excavator, and hitting the button can switch to the single machine monitoring mode of excavator.

(3) Management of data

The current data information of system can be saved, which can be used when the future data damages or data is transplanted [8].

SQLDMO is provided by own SQLDMO.dll of Microsoft SQL Server, because SQLDMO.dll is a object of COM, and the adduction is added to .NET before using, and the backup procession is listed as follows:

```
SQLDMO.Backup Backup1= new SQLDMO.BackupClass ( );
SQLDMO.SQLSever SQLSever = new SQLDMO. SQLSeverClass ( );
SQLSever.Connect ("server name", "client name", "password"'); // connect server
Backup1.Action= SQLDMO.SQLDMO_BACKUP_TYPE.SQLD
MOBackup_Database;
```



```
Backup1.Database = "audelo";
Backup1.Files = @"e:\"+time+".bak"// save file name as current time
Backup1. initialization = true;
SQLBackup (SQLSever);
```

Manage of data concludes two aspects, one it the search of data, the other is the generation of data table.

The search of data is achieved based on Data Grid control blinding the database. The generation of data table is a method of data collection that blinding the Crystal Report and ReportViewer1 controls.

(4) Client interface

The client interface concludes the following modes:

(a) Procession simulation display

The industrial product procession is simulated based on the monitoring system based on data mining, and a lot of actions of excavator in the display are the decision instructions after the data obtaining from field is analyzed, and the field data can be shown in the display in real time.

(b) Trending figure display

According to the data display time, the trending figure can be divided into real time trending figure and history trending figure. The former is applied in displaying the changing status of field data, and only displaying the history data in relative close period. The latter can display continuous running data for the past long time.

(c) Report interface

The report can show data in the form of table, which is an important form of recording the data for the monitoring system of hydraulic excavator. It can reflect the working status of the system in real time, and the can count, analyze and conduct the future production for the long product procession, the report display interface concludes real time data report and history data report.

6. Case Study of Excavator Monitoring System

The monitoring system of hydraulic excavator is test for a kind of hydraulic excavator, an the condition parameters of it has been monitored in real time, the testing results are shown in Figure 2 and Figure 3.

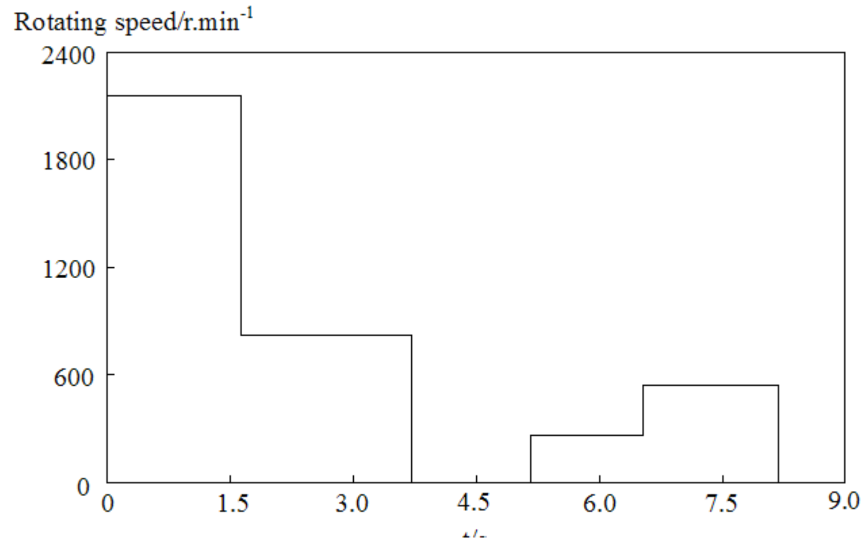

Figure 2. Pressure Changing Curves of Hydraulic Pump of Excavation

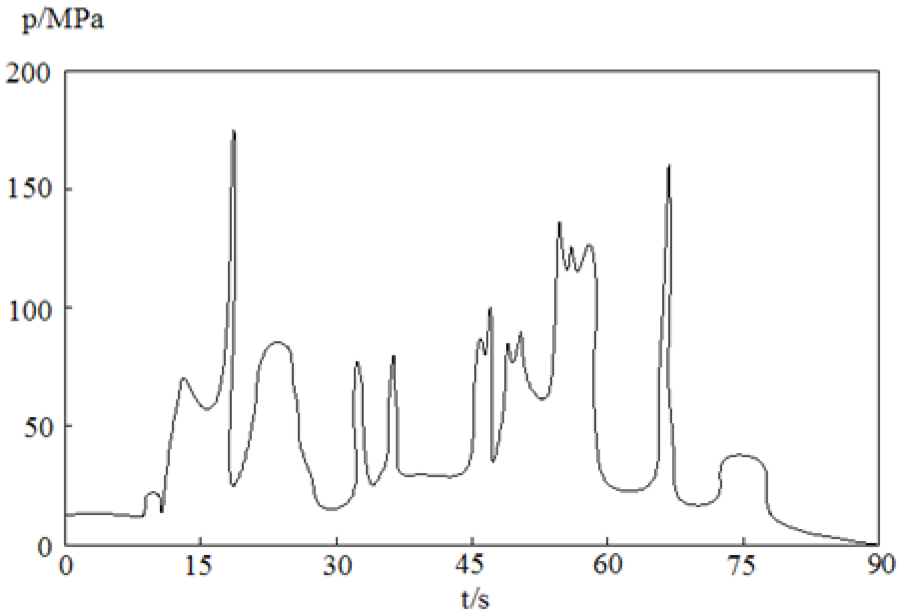

Figure 3. Rotating Speed Changing Curves of Hydraulic Excavation

Figure 2 shows the changing rules of pressure of hydraulic pump of the excavator from 0 to 90s, and Figure 3 shows the changing rules of rotating speed of hydraulic excavation from 0 to 9s. As seen from the monitoring results,

7. Conclusions

With the development of the information technology, the hydraulic excavator should work under safe and reliable conditions, and therefore it is necessary to monitor the working status of the hydraulic excavator correctly. The data mining technology is introduced into the monitoring system of hydraulic excavator, and simulation results show that this kind of technology has a wide developing view.

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