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Condition Monitoring of the Starter Motor Using Sound Signals and Fuzzy Logic

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ABSTRACT

Today, with technology advances, machinery and industrial equipment are getting more complicated day by day, and parallel to this complexity, they become more sensitive and require more attention, subsequently; since damage to them and their downtime may cost a lot. This study attempts to help increase the accuracy of predicting the defects of the starter motor using various data mining techniques, and finally introduce the best data mining technique which leads to the highest accuracy. To this end, firstly, a system was designed to gather data, then using a small microphone, vibration data have been received, and finally, the data were processed. According to this research the overall results can be summarized as: Detecting the condition of the starter motor is possible through comparing the change domain in the graphs which present different conditions of the starter motor using sound signals in the frequency domain, also the use of the statistical parameters of the sound spectra, is a simple and practical method for extracting the features of the spectrum and the overall classification compliance degree was 91/6 percent which is acceptable from the engineering perspective.

KEYWORDS

Condition Monitoring, Starter Motor, Sound Signals,Fuzzy Logic

INTRODUCTION

Today, with technology advances, machinery and industrial equipment are getting more complicated day by day, and parallel to this complexity, they become more sensitive and require more attention, subsequently; since damage to them and their downtime may cost a lot.

The existing strategies and viewpoints in the industry about maintenance have experienced a rise and fall process in the last century, and there have been many changes in this area. In summary, the prevailing view in the field of maintenance has changed from a passive attitude in the early 20th century to an active one in the beginning of the 21st century. Many of these changes have happened in the last 30 years (since 1970s). In this regard, John Moubray stated that "In recent years, more than any other management perspectives, attitudes toward maintenance management have changed and experienced dramatic developments. The main driving force behind these developments is the change in the expectation levels regarding maintenance. "[9, 10]

Nowadays, with the advent of a new branch of knowledge known as Physical Asset Management, a wide variety of activities are taking place with regard to this subject in universities and research centers and a new area has been devoted for developing maintenance knowledge as well as a completely scientific view to this issue.

A review of the related literature shows that the best method of maintenance is monitoring the condition or predicting the defects of the machinery relying on symptoms such as sound and vibration signals. Condition monitoring will save time and costs. Therefore, the present study is conducted to monitor the conditions and predict the defects of the starter motor, one of the key components of car, using sound signals. This study attempts to help increase the accuracy of predicting the defects of the starter motor using various data mining techniques, and finally introduce the best data mining technique which leads to the highest accuracy.

Overall, the objectives of the present study include:

a. taking the sound produced by the starter motor in its various conditions and transferring sound data from the time domain to the frequency domain.
b. extracting statistical features of frequency domain data (such as mean, standard deviation, variance, dispersion coefficient, the third to sixth central moment, kurtosis, etc.)
c. using statistical features to make classifier and predict defects

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MATERIALS AND METHODS

As mentioned above, the aim of the present study was to identify the defects and determine the condition of the starter motor using the obtained sound signals and fuzzy logic. To this end, firstly, a system was designed to gather data, then using a small microphone, vibration data have been received, and finally, the data were processed. In the following parts, each of the mentioned stages will be fully described.

To better obtain the vibration data, the researchers designed and built the test bed, one of the most important parts of the data gathering system. Eight rubber fenders were used under electromotor and metal plate. These fenders were used to transfer the vibration which is less than electromotor to other parts of the system, particularly, to the starter motor. Figure 1 shows the system built for data gathering.

Fig. 1. The system built for data gathering

Vibration data were collected using a condenser microphone. Data regarding this microphone are presented in Table 1 and Figure 2. According to research carried out in this area, the most common starter motor defects that are detectable by sound include: a) rotor unbalance and b) bearing wear. Hence, in the present study, these defects were exerted on the starter motor. This means that data gathering was done in each of the following conditions: a) normal, b) rotor unbalance, c) bearing wear, and d) rotor unbalance and bearing wear. For each condition of the starter motor, 100 data spectra were collected.

Tab.1. The characteristics of the condenser microphone used in this study

model	AKG-c417
type	Pre-polarized condenser
Frequency range	20Hz-20KHz
Sensitivity	10Mv/Pa
The electrical resistance	200 Ω

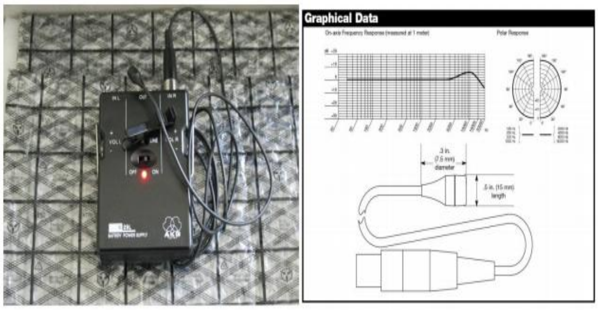

Fig.2. AKG-C417 microphone

Each data spectrum contained 16,000 data. All the resultant sound spectra were in time domain; as mentioned, these spectra are not capable of providing enough information, thus they should be transferred to other areas.

After transferring data from the time domain to frequency domain, the statistical features of the data were extracted; they were used as input for fuzzy classifier. Overall, 23 statistical features were extracted from each data spectrum.

In order to reduce the size of the input data, the researchers selected the top features from among the extracted features. This can be done using different methods; however, in this study, it was done using Correlation-Based Feature Selection (CFS) method. This method has been used in many articles and resources; it is proved to be an effective method. Weka software was employed to select top features based on CFS method. This software is written in the Java programming language in the University of Waikato, New Zealand. Weka is a set of machine learning algorithms and data preprocessing tools. Weka supports all aspects of data mining process (i.e., preparation of input data, statistical analysis of learning, and graphing input and output data).

Decision trees, as an important part of data mining systems, are considered a powerful tool for classification. In this piece of research work, Weka and J48 algorithm were used to classify the defects of the starter motor relying on the selected features of sound signals. In classifying the defects of the starter motor, the labels presented in Table 2 were considered for each condition of the starter motor.

Tab. 2. Labels used for the classification of defects

Worn bearing and unbalance drive shaft	Unbalanced drive shaft	Worn bearing	healthy
UDS & WB	UDS	WB	H

After creating decision trees, fuzzy rules were extracted. To extract rules, we should move from the highest node to the tree leaves. In building a fuzzy model, care should be taken to define the rules verbally and prevent entering the numbers. Therefore, in the present study, the numbers were

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used on the branches of the tree to determine the threshold values of membership and all the rules were defined verbally.

After determining the threshold values of the membership functions based on the decision tree, and extracting fuzzy rules for each condition of the starter motor, MATLAB R2010a software was used to create fuzzy inference engine. It is possible to determine the accuracy of the classifier by entering the selected statistical features into the fuzzy inference engine section. In fact, 30 percent of the data that had been excluded for evaluating the performance of the classifier were used in this section.

RESULTS

Figures 3, 4, 5, and 6 relate to a graph of wave spectrum of the sound obtained from starter motor in different conditions and in frequency domain.

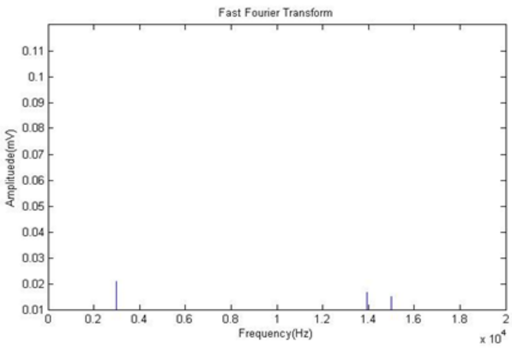

Fig. 3. The sound signals obtained in healthy state in the frequency domain

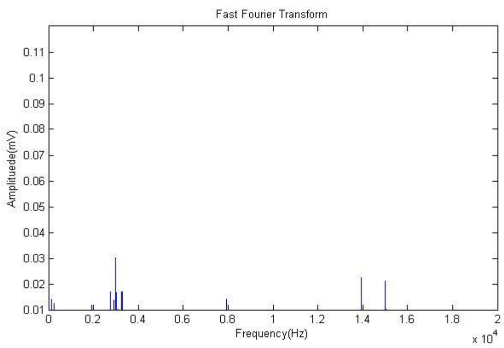

Fig. 4. The sound signals obtained in the case of worn bearing in the frequency domain

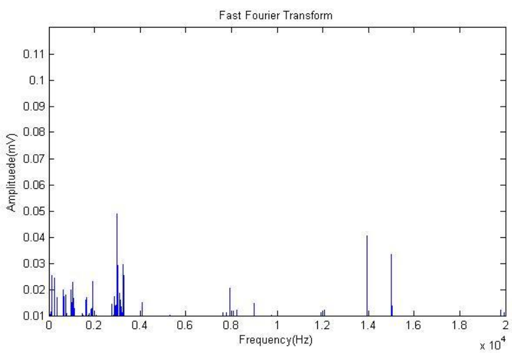

Fig.5. The sound signals obtained in the case of unbalanced drive shaft in the frequency domain

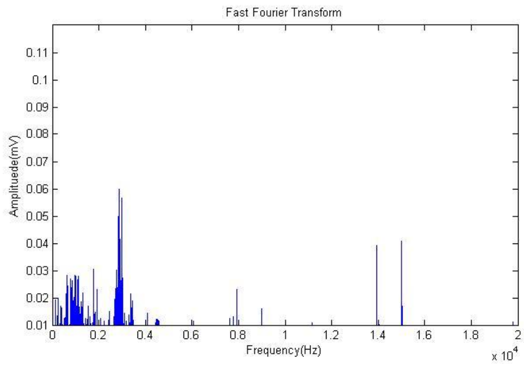

Fig. 6. The sound signals obtained in case of worn bearing and unbalanced drive shaft in the frequency domain.

As is evident from the Figures, defects appeared in various frequencies. As a result, by analyzing the received sound, the changes are detectable and the defects are recognizable.

As mentioned above, from the obtained data, 23 features were extracted and, in turn, top features were selected from them. The extracted top features include: T12, T15, T2, T6, T3, T10, and T19. These features related to the third central moment, the result of dividing root mean square by the mean signal value, the square root mean of the signal value, the result of dividing the third central moment by the cubic mean, standard deviation, mean deviation from the mean, and variance, respectively. After extracting top features, the decision tree was created and using this tree the fuzzy rules were set. Figure 7 shows the created decision tree.

After creating the decision tree, fuzzy rules were extracted. Fuzzy rules obtained from the created decision tree are:

As previously mentioned, 30% of the data were used to evaluate classifier. After setting the rules, the fuzzy inference engine was created and then the top features of evaluation data were entered into the fuzzy inference engine to determine the accuracy of the system.

Tab.3. The confusion matrix of the decision tree developed by Fourier analysis

Classification label	B-F	B-C	B-P	H
WB	28	1	2	0
USD	1	28	1	0
USD &WB	2	0	26	2
H	0	1	0	29

As previously mentioned, 30% of the data were used to evaluate the classifier. The data were entered into fuzzy inference engine and the response of the classifier was received. The results of the evaluation suggest the overall accuracy of 91/6 percent for the designed system.

CONCLUSION AND RECOMMENDATIONS

The overall results of this study can be summarized as:

- Detecting the condition of the starter motor is possible through comparing the change domain in the graphs which present different conditions of the starter motor using sound signals in the frequency domain.

- The use of the statistical parameters of the sound spectra, is a simple and practical method for extracting the features of the spectrum.
- Selection of top features reduces the input space and sometimes (due to the elimination of noisy data) increases the accuracy of the classifier.
- The overall classification compliance degree was 91/6 percent which is acceptable from the engineering perspective.

The following suggestions are offered for future research:

- Defining the different levels of wearing and breakage to make the monitoring of the system condition more effective
- Simultaneous use of vibration data, oil or temperature along with sound data using data fusion method
- Using more statistical features and other methods of feature selection
- Using other classification methods such as neural network, neuro-fuzzy method, nearest neighbor method, and support vector machine

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