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Rough set based rule learning and fuzzy classification of wavelet features for fault diagnosis of monoblock centrifugal pump ☆

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ABSTRACT

The fault diagnosis problem is conceived as a classification problem. In the present study, vibration signals are used for fault diagnosis of centrifugal pumps using wavelet analysis. Rough set theory is applied to generate the rules from the vibration signals. Based on the strength of the rules the faults are identified. The different faults considered for this study are: pump at good condition, cavitation, pump with faulty impeller, pump with faulty bearing and pump with both faulty bearing and impeller. However, the classification accuracy is based on the strength and number of rules generated using rough set theory. Wavelet features are computed using Discrete Wavelet Transform (DWT) from the vibration signals and rules are generated using rough sets and classified using fuzzy logic. The results are presented in the form of confusion matrix which shows the classification capability of wavelet features with rough set and fuzzy logic for fault diagnosis of monoblock centrifugal pump.

1. Introduction

Centrifugal pump is an integral part in engineering industries and it requires continuous monitoring to increase the availability of the pump. The pumps are the key elements in food industry, waste water treatment plants, agriculture, oil and gas industry, paper and pulp industry, etc. As bearing and impeller are the critical components in a centrifugal pump that directly affects the desired pump characteristics. Hence, defect with these components have been taken for analysis. In a monoblock centrifugal pump, defective bearing, defect on the impeller and cavitation cause number of serious problems such as abnormal noise, leakage, and high vibration. Machine condition monitoring system is a decision support tool, which is capable of identifying the failure of a machine and capable of predicting failure from its symptoms [1]. Comparative study between naïve bayes and bayes net algorithms is carried out for different faults in monoblock centrifugal pump and concluded that bayes net is an effective algorithm [2]. J48 algorithm was used on monoblock centrifugal pump and attained the overall classification accuracy close to 100% [3]. Vibration and acoustic emission (AE) signals are widely used in condition monitoring of rotating machines. Fault detection is possible by comparing the signals of a machine running in normal and faulty conditions. Artificial neural network (ANN), support vector machine (SVM) and fuzzy classifier are widely used as classification tools and reported in literature. Fast Fourier Transform (FFT) is the commonly used method in conventional condition monitoring, through frequency domain. The vibration can be measured with the help of piezo electric transducers. The measured vibration is compared with the threshold value in order to understand the

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severity. Interestingly, some conventional techniques would be used to know the pattern of the individual frequencies present in the signal. This process is a very complex process and it demands domain experience and expertise. These frequencies correspond to certain malfunction. By understanding these frequencies and their patterns, the analyst can identify the location, type of problem and the root cause as well. However, the influence of machine learning in fault diagnosis is more common as an alternative to conventional methods. It is largely due to increased availability of computational resources and development in algorithms. For complex systems involving many components, it is difficult to compute characteristic fault frequencies. Even if characteristic frequencies are available the vibration signals are highly non-stationary in nature, hence FFT based methods may not be well suited for continuous monitoring. However, machine learning algorithms can be considered as an alternate for such situations. In machine learning approach, the data acquisition system is used to capture the vibration signals [4]. From the vibration signal relevant features can be extracted and classified using a classifier. Therefore, the vibration signals have been acquired from the experimental setup and classifiers such as artificial neural network and support vector machines have been used for the purpose of classification. Time domain analysis has been performed in order to get good classification accuracy [5]. Continuous wavelet features were extracted for monoblock centrifugal pump and classification was carried out with decision tree algorithms give reasonable classification accuracy [6]. A new combined diagnostic system for triplex pump based on wavelet transform, fuzzy logic, neural network was proposed [7]. An attempt has been made to establish a comparative study between neural network and support vector machines for a condition monitoring problem [8]. However, this comparative statement may not generalize the relations. A model for the fault detection of centrifugal pumping system using two different artificial neural network (ANN) approaches, namely feed forward network with back propagation algorithm and binary adaptive resonance network (ART1) which could classify seven categories of faults in the centrifugal pumping system was presented [9]. A fault diagnosis method for a centrifugal pump by using wavelet transform for feature extraction, rough sets for rule generation and fuzzy neural network for classification to detect faults and distinguish fault types at early stages have been presented [10,11]. However, the main drawback of fuzzy neural network is poor capability of creating its own structure. A synthetic detection index with fuzzy neural network to evaluate the sensitivity of non dimensional symptom parameters for detecting faults in centrifugal pump is reported [12]. A mean correlation rule is proposed to evaluate the capability of each of the principal components (PC) in characterizing machine conditions and the most representative PCs are selected to classify the machine fault patterns. Then, a procedure that uses the low-dimensional PC representations for machine condition monitoring is proposed [13]. The use of decision tree for selecting best statistical features extracted from the vibration signals of the faulty gear box was presented. A rule set is formed from the extracted features and fed to a fuzzy classifier. The author also presented the usage of decision tree to generate the rules from the feature set. A fuzzy classifier is built and tested with representative data [14]. A novel rough set-based case-based reasoner to use in text categorization (TC) is presented with four main components: feature term extractor, document representor, case selector, and case retriever. They operate first reducing the number of feature terms in the documents using the rough set technique. Then, the number of documents is reduced using a new document selection approach based on the case-based reasoning (CBR) concepts of coverage and reachability. As a result, both number of feature terms and documents are reduced with only minimal loss of information. The experimental results demonstrate its effectiveness and accuracy as it significantly reduced feature terms and documents, important for improving the accuracy of TC, while preserving and even improving classification accuracy [15]. As presented in [16], when localized fault occurs in a bearing, the periodic impulsive feature of the vibration signal appears in time domain and the corresponding bearing characteristic frequencies (BCFs) emerge in frequency domain. However, in the early stage of bearing failures, the BCFs contain very little energy and are often overwhelmed by noise and higher-level macro-structural vibrations, an effective signal processing method would be necessary to remove such corrupting noise and interference. A new hybrid method based on optimal Morlet wavelet filter and autocorrelation enhancement was presented. Moreover, the proposed method can be conducted in an almost automatic way. The results obtained from simulated and practical experiments prove that the proposed method was very effective for bearing faults diagnosis [16].

A comparative study has been made between decision tree – fuzzy and rough set – fuzzy classification algorithms for fault diagnosis of monoblock centrifugal pump using the vibration signal. The study reveals that rough-set fuzzy rules are better when compared to the other set. However, this study was carried out only for the particular data set considered at that particular speed and for the statistical features [17].

In this study, wavelet features are considered for the signal at different working conditions. A roller bearing was considered for the study and fuzzy logic was used to classify the faults in it. The application decision tree was well narrated in fault diagnosis domain and the results witness that it is good for real time applications [18,19]. However, there decision tree works based on the entropy functions. Therefore, one needs some other technique which also promises the same performance to substantiate the proposed approach. Hence, rough set based rule generation is used in this study and fuzzy logic is used to evaluate the rules and for classification.

The rest of the paper is organized as follows. In Section 2, the methodology followed is presented. The experimental setup and experimental procedure is described in Section 3. Section 4 presents feature extraction from the time domain signal. Section 5 describes the rule generation using rough set and the classification accuracy is tested and subsequently Section 6 presents the classification using fuzzy logic. Section 7 presents