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Automatic rule learning using roughset for fuzzy classifier in fault categorization of mono-block centrifugal pump

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ABSTRACT

Rule learning based approach to fault detection and diagnosis is becoming very popular, mainly due to their high accuracy when compared to older statistical methods. Fault detection and diagnosis of various mechanical components of centrifugal pump is essential to increase the productivity and reduce the breakdowns. This paper presents the use of rough sets to generate the rules from statistical features extracted from vibration signals under good and faulty conditions of a centrifugal pump. A fuzzy inference system (FIS) is built using rough set rules and tested using test data. The effect of different types of membership functions on the FIS performance is also presented. Finally, the performance of this classifier is compared to that of a fuzzy-antminer classifier and to multi-layer perceptron (MLP) based classifiers.

1. Introduction

Pumps are a crucial part of many industrial plants. Early detection of faults in pumps can increase their reliability, reduce energy consumption, service and maintenance costs, and increase their life-cycle and safety, thus providing a significant reduction in lifetime costs. Effective pump maintenance allows industrial plants to keep pumps operating well, detect problems in time to schedule repairs, and avoid early pump failures. Vibration is probably the most important indicator of the mechanical integrity of rotating machinery. Overall vibration levels when trended, give immediate indication of change in the condition of that machine, however, the overall vibration levels are only a numeric value and do not allow identification of any specific underlying fault type or types. Vibration spectral information allows identification of any offending frequency component(s) thus enabling the analyst to determine the fault type. As an established and proven technology with an expansive knowledge base, vibration analysis offers a comprehensive method of identifying a variety of problems. It is used for condition monitoring on multiple levels. It can be used as a simple gauge to determine if equipment is running within an acceptable vibration range with overall readings. It can also determine the cause of increased vibration with additional readings like spectrums, time waveforms, etc. Fault diagnosis is achieved by comparing the signals of centrifugal pump running under normal and under faulty conditions. The faults considered in this study are bearing fault (BF), seal fault (SF), impeller fault (IF), bearing and impeller fault (BFIF) together and cavitation (CAV). Faults in pumps can cause the breakdown of a whole system, and lead to substantial economic losses. Therefore, fault diagnosis of a pump system at an early stage is very important. Different approaches have been used for fault diagnosis of centrifugal pump. Acoustic emission for detecting incipient cavitation and determining the best efficiency point (BEP) of a centrifugal pump based on net positive suction head (NPSH) and performance tests was used in Ref. [1]. However, this method of using acoustic emission as a means of detecting cavitation is not useful in detecting other faults. A synthetic detection index with fuzzy neural network to evaluate the sensitivity of nondimensional symptom parameters for detecting faults in centrifugal pump is reported in [2]. 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)

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which could classify seven categories of faults in the centrifugal pumping system was presented in Ref. [3]. But the ANN has limitations on generalization of the results in models that can overfit the data. Fault classification with fuzzy logic as a classifier with the features extracted from the vibration signals of the pump was presented in Ref. [4]. A new combined diagnostic system for triplex pump based on wavelet transform, fuzzy logic, neural network was proposed in Ref. [5]. In the work reported by Ref. [6], the use of SVMs and Proximal Support Vector Machines (PSVMs) for classifying faults in a monoblock centrifugal pump was presented. The most serious problem with SVMs is the high algorithmic complexity and extensive memory requirements of the required quadratic programming in large-scale tasks. Ref. [7] presented the use of decision tree and rough sets to generate the rules from statistical features extracted from vibration signals under good and faulty conditions of a mono-block centrifugal pump. A fuzzy classifier is built using decision tree and rough set rules and tested using test data. Vibration based fault diagnosis of monoblock centrifugal pump using decision tree was discussed in Ref. [8]. A rule based expert system using vibration data taken from compressors, pumps and electric motors in addition to a heuristic artificial neural network system to identify useful patterns and trends in the vibration signals was presented in Ref. [9]. The intractability of the model used for identifying patterns and trends is a drawback of the neural network based method. In Ref. [10] Wigner distribution was used for analysing vibration signals and developed an expert system for vibration monitoring and diagnostics for rotating machines using back propagation neural network (BPNN). The prominent drawback of Wigner distribution is that it produces cross-terms of large magnitudes. Ref. [11] discussed principal component analysis (PCA) for feature selection, C4.5 decision tree and BPNN for classification, for fault diagnosis of rotating machinery such as turbines and compressors. This work establishes the fact that C4.5 and PCA-based diagnosis method has higher accuracy and needs less training time than BPNN.

However, to the best of our knowledge, no study involving roughset based feature selection for fuzzy logic based fault classification of a centrifugal pump has been reported so far. In this work, roughset based classifier is used to generate the rules. The rules are then used to create a fuzzy inference system (FIS) which is then used for fault classification. The effect of different types of membership functions on the FIS performance is also presented. The performance of this classifier is compared to that of a fuzzy-antminer classifier and to a MLP based classifier. The proposed technique is found to outperform all the other techniques considered. This technique is exciting because of its ability to classify the faults efficiently and in the simplicity of the rules extracted, unlike other methods. Fig. 1 shows the flow chart of centrifugal pump fault diagnosis system.

The rest of the paper is organised as follows. In Section 2, signal acquisition and feature extraction from the time domain signal is described. Roughset method is detailed in Section 3. In Section 4 ant colony based classification is discussed. The theory of fuzzy logic is presented in Section 5, followed by a description of artificial neural networks in Section 6. Section 7 presents results of the experiment. Conclusions and future direction are presented in Section 8.

2. Signal acquisition and feature extraction

2.1. Experimental setup

Fig. 2 shows the schematic diagram of the experimental test rig. The motor (2 HP) is used to drive the pump. The flow at the inlet and the outlet of the pump can be adjusted using flow control valve. The valve at the inlet of the pump is used to create pressure drop between the suction and at the eye of the impeller to simulate cavitation. An accelerometer is used to measure the vibration signals. The accelerometer location is shown in Fig. 2. It can be seen from Fig. 2 that the accelerometer is mounted at the eye of the impeller. This is due to the fact that all the mechanical components considered in the present study (seal, impeller, bearing) are located very close to the eye of the impeller. Placing the accelerometer at the eye, hence, improves the overall quality of the measured vibration signals.

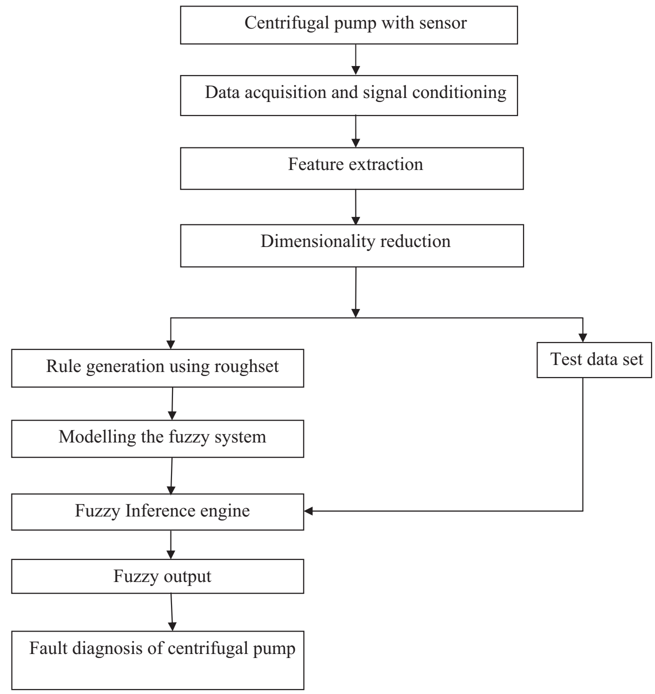

Fig. 1. Flow chart of centrifugal pump fault diagnosis system.

2.2. Experimental procedure

The vibration signals are acquired from the centrifugal pump working under normal condition at a rated speed of 2880 rpm. Centrifugal pump specification is shown in Table 1. Vibration signal from the accelerometer mounted on the eye of the impeller are measured. The sampling frequency is 24 kHz. 250 sets of readings are taken for each centrifugal pump condition.

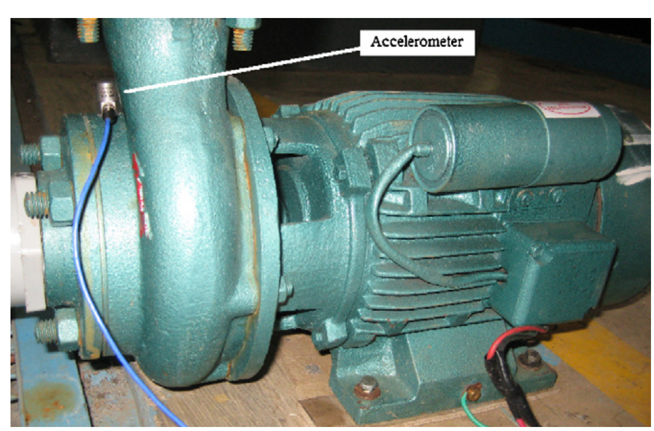

Fig. 2. Centrifugal pump setup and the location of accelerometer for condition monitoring.