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# Soft computing approach to fault diagnosis of centrifugal pump

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ABSTRACT

Fault detection and isolation in rotating machinery is very important from an industrial viewpoint as it can help in maintenance activities and significantly reduce the down-time of the machine, resulting in major cost savings. Traditional methods have been found to be not very accurate. Soft computing based methods are now being increasingly employed for the purpose. The proposed method is based on a genetic programming technique which is known as gene expression programming (GEP). GEP is somewhat a new member of the genetic programming family. The main objective of this paper is to compare the classification accuracy of the proposed evolutionary computing based method with other pattern classification approaches such as support vector machine (SVM), Wavelet-GEP, and proximal support vector machine (PSVM). For this purpose, six states viz., normal, bearing fault, impeller fault, seal fault, impeller and bearing fault together, cavitation are simulated on centrifugal pump. Decision tree algorithm is used to select the features. The results obtained using GEP is compared with the performance of Wavelet-GEP, support vector machine (SVM) and proximal support vector machine (PSVM) based classifiers. It is observed that both GEP and SVM equally outperform the other two classifiers (PSVM and Wavelet-GEP) considered in the present study.



## 1. Introduction

Continuous monitoring of pump systems is the most effective technique to insure efficient operation, help prevent unexpected pump failures, reduce repair costs and downtime, and provide early warning to avoid loss of pumped fluid. Centrifugal pumps play an significant role in industries and continuous monitoring is required to increase the availability of the pump. Pumps are the key elements in food industry, waste water treatment plants, agriculture, oil and gas industry, paper and pulp industry, *etc*. In a centrifugal pump, bearing, seal and impeller are the critical components that directly affect the desired pump characteristics [1]. In a centrifugal pump, defective bearing, defective seal, defect on the impeller and cavitation cause serious problems such as abnormal noise, leakage, high vibration, *etc*. Cavitation can cause undesirable effects such as deterioration of the hydraulic performance (drop in head-capacity and efficiency), damage of the pump by pitting, erosion and structural vibration. Vibration signals are widely used in fault detection and diagnosis of centrifugal pumps. 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. Some common problems that can be detected using vibration analysis are unbalance, looseness and misalignment. Bearing, impeller, gear, and blade problems can also be determined. Cavitation readings can be collected, too. Different parts or components will be affected dependent on the magnitude of the vibration. Components that are known to fail when excessive vibration is present include mechanical seals, bearings, impellers, shafts, couplings, wear rings and bushings. Fault detection is achieved by comparing the signals of centrifugal pump running under normal and 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 of pumps can cause the breakdown of a whole system, and lead to substantial economic losses. Therefore, fault diagnosis of a pump system in an early stage is very important. Different approaches have been used for fault detection in centrifugal pump. Alfayez et al.,[2] discussed 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. However, this method of using acoustic emission as a means of detecting cavitation is not useful in detecting other faults. Peck and Burrows [3] proposed a rule

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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. The intractability of the model used for classifying patterns and trends is a drawback of the neural network based method. Wang and Chen [4] used synthetic detection index with fuzzy neural network to evaluate the sensitivity of non dimensional symptom parameters for detecting faults in centrifugal pump.

Rajakarunakaran et al. [5] developed 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. But the ANN has limitations on generalization of the results in models that can overfit the data. Wang and Hu [6] used Fuzzy logic used as classifier with the features extracted from the vibration signals of the pump. Kong and Chen [7] developed a new combined diagnostic system for triplex pump based on wavelet transform, fuzzy logic and neural network. Yuan and Chu [8] have discussed fault diagnosis of turbo rotor pump using SVM. Artificial immunisation algorithm (AIA) is used to optimise the parameters in SVM. AIA improves the fault diagnosis capability of SVM. Although SVMs have good generalization performance, they can be abysmally slow in test phase. Sheng et al., [9] reported their work using fuzzy neural network based on series of standard fault pattern pairings between fault symptoms and fault. Fuzzy neural networks were trained to memorize these standard pattern pairs. The main drawback of fuzzy neural network is poor capability of creating its own structure. Hanifi ÇanakcI et al.,[10] reported that artificial neural networks performed better than GEP and regression analysis for strength prediction of basalts. While Adil Baykasoğlu et al., [11] experimentally showed that GEP performed best overall, than neural networks and regression analysis in the context of predicting compressive strength of Portland composite cement. Data mining has been successfully applied to medical field such as dermatology, image segmentation and lymphography [12]. Some data mining algorithms have also been applied to fault diagnosis of machines. Walsh transform and SVM were used in the fault diagnosis of shaft [13]. Genetic programming was used in condition monitoring to detect the fault in rotating machinery [14]. Bayesian statistical learning theory was used to diagnose rotating machine [15], decision table has been used to diagnose boilers in thermal power [16], and a fuzzy clustering method has been used to obtain fault patterns to diagnose transformers [17]. However, there are few reports about the use of GEP for the fault diagnosis of a centrifugal pump. Therefore, GEP is employed in this paper for the fault diagnosis of centrifugal pump.

Gene expression programming (GEP) algorithm was first introduced by Cândida [18] in 1999. Gene expression programming (GEP) is, like genetic algorithms (GAs) and genetic programming (GP), a genetic algorithm as it uses populations of individuals, selects them according to fitness, and introduces genetic variation using one or more genetic operators [19]. The fundamental difference between the three algorithms resides in the nature of the individuals: in GAs the individuals are linear strings of fixed length (chromosomes); in GP the individuals are nonlinear entities of different sizes and shapes (parse trees); and in GEP the individuals are encoded as linear strings of fixed length (the genome or chromosomes) which are afterward expressed as nonlinear entities of different sizes and shapes (*i.e.*, simple diagram representations or expression trees).

The rest of the paper is organised as follows. In Section 2 experimental setup and experimental procedure is described. Section 3 presents feature extraction from the time domain signal. Feature selection using decision tree is explained in Section 4. Section 5 presents the overview of gene expression programming. In Section 6 classification of faults using GEP is discussed. Section 7 presents fault classification using SVP and PSVM. Results of the experiment are discussed in Section 8. Conclusions are presented in the final section.

## 2. Experimental studies

The main objective of the study is to find whether the centrifugal pump is in good or faulty condition. If the pump is in faulty condition then the aim is to segregate the faults into bearing fault, seal fault, impeller fault, seal and impeller fault together and cavitation. This paper focuses on the use GEP to classify the faults in the centrifugal pump.

### 2.1. Experimental setup

The motor (2HP) 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. Acrylic pipes of 1 m length each are fitted on the inlet and at the outlet of the impeller respectively, to visualize the cavitation. Moreover acrylic pipes withstand cavitation without getting badly damaged. A mono-axial piezo-electric type accelerometer is used to measure the vibration signals. Accelerometer signals are acquired using the proprietary signal processing kit Dactron and stored in the computer memory. Then the signals are processed to extract different features.

### 2.2. Experimental procedure

The vibration signals are measured from the centrifugal pump working under normal condition at a constant rotation speed of 2880 rpm. Centrifugal pump specification is shown in Table 1. The performance characteristics are studied for the pump working under normal condition. Initially priming of the pump is done. After closing the delivery valve, the pump is started and the delivery valve is slowly opened. The following parameters are measured under different operating conditions of the centrifugal pump (including faulty conditions), such as input voltage reading ($V$), input current ($A$), vacuum gauge reading ($h1$), pressure gauge reading ($h2$), speed in rpm ($N$), time ($t$) for h metre rise in the collecting tank and the time ($T$) for Nr number of revolutions in energy metre (Nr). The total head is calculated by adding the suction head and delivery head. The discharge, input power and percentage of efficiency were calculated from the tabulated values. The experiment was repeated for different delivery heads.

Vibration signal from the accelerometer mounted on the pump inlet was taken. The sampling frequency was 24 kHz and sample size was 1024 for all conditions of the pump. The sample size was chosen arbitrarily to an extent; 250 trials were taken for each centrifugal pump condition, and vibration signals were stored in the data files.

In the present study the following faults were simulated

(i) Bearing fault
(ii) Seal fault
(iii) Impeller fault

**Table 1**
Centrifugal pump specification.

| | | | |
|---|---|---|---|
| Speed: 2880 rpm | Pump size | 50 mm × 50 mm |
| Current: 11.5 A | Discharge | 392 l/s |
| Head: 20 m | Power | 2 HP |