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Fault diagnosis of automobile hydraulic brake system using statistical features and support vector machines

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ABSTRACT

Hydraulic brakes in automobiles are important components for the safety of passengers; therefore, the brakes are a good subject for condition monitoring. The condition of the brake components can be monitored by using the vibration characteristics. On-line condition monitoring by using machine learning approach is proposed in this paper as a possible solution to such problems. The vibration signals for both good as well as faulty conditions of brakes were acquired from a hydraulic brake test setup with the help of a piezoelectric transducer and a data acquisition system. Descriptive statistical features were extracted from the acquired vibration signals and the feature selection was carried out using the C4.5 decision tree algorithm. There is no specific method to find the right number of features required for classification for a given problem. Hence an extensive study is needed to find the optimum number of features. The effect of the number of features was also studied, by using the decision tree as well as Support Vector Machines (SVM). The selected features were classified using the C-SVM and Nu-SVM with different kernel functions. The results are discussed and the conclusion of the study is presented.

1. Introduction

The brake system is a safety critical component necessary for the safe operation of the vehicle. Brake failure is crucial not only for the driver and passengers but also for automobile manufacturers. In April 2007, BMW, an automobile manufacturing company recalled over 160,000 SUVs, because of a problem that could cause a potential loss of brake fluid or even the brake circuit to fail completely. Chrysler recalled 60,000 vehicles, due to an issue with potential brake failure in May 2007 [1]. There may be no sure way to prevent the possibility of a brake failure accident, but one can do their own part to prevent failure. The faults in a hydraulic brake system of an automobile are not fairly noticeable. Some warning signs that there is something wrong with brakes include a grinding or squeaking noise. If faulty brakes are used, the vehicle cannot be stopped within a reasonable distance. This causes the vehicle to veer to one side.

Fault diagnosis is an important process in the preventive maintenance of many components such as, the gear box and bearings. This can avoid serious damage if defects occur in one of the components during operation. Prevention is better than cure. Early detection of a defect, therefore, is crucial to prevent the system from malfunction that could cause damage to the entire system or an accident. It can predict the condition of the system at any time and avoid unexpected failures.

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Nomenclatures

A	$m \times n$ matrix whose elements belong to real space R
D	$m \times 1$ matrix representing class label ($+1$ and -1)
e	a vector of ones
ν	a control parameter that defines the weight of error minimization
R	real space
w	orientation parameter
γ	location parameter (location relative to origin) of separating hyper-plane

This is not only capable of identifying the failure of a machine component or system, but also predicts failure from its symptoms [2]. Therefore, a machine condition monitoring system can be effectively used as a decision support tool. Vibration and acoustic emission (AE) signals are widely used in the condition monitoring of rotating machines. By comparing the signals of a machine running in normal and faulty conditions, the detection of faults is possible. Frequency domain based spectral comparison was used dominantly for stationary signals. Due to wear and tear, the vibration signals from an automobile will be non-stationary. Data modeling using the machine learning approach can be used to solve such problems. Machine learning involves three main steps, viz, feature extraction, feature selection, and feature classification. Features can be statistical features [3], auto regressive moving average (ARMA) features [4], histogram features [4] and wavelet features [5]. In the present study statistical features were used.

There are many techniques available for feature selection. The commonly used techniques for the selection of features are the principal component analysis (PCA) [5], genetic algorithm (GA) [6,7] and decision tree (DT) [8]. The principal component analysis is a method that reduces the dimensionality of data by performing a covariance analysis between factors. As such, it is suitable for data sets in multiple dimensions, such as a large experiment. It is one of the pattern identification techniques in the data of high dimensions. It maps data from a higher dimension space to lower dimension space. In a study by Sugumaran et al., the use of a decision tree to identify the best feature selection from a given set of samples for classification was illustrated [3]. The most important feature will be placed on top of the decision tree and others will follow. Based on this, the most important features were identified. This paper makes use of the decision tree for feature selection, i.e., for the identification of good features in the order of importance and eliminating the non-contributing features. Decision trees are simple to understand and interpret. A decision tree can be represented more compactly as an influence diagram, focusing attention on the issues and relationships between events. A decision tree has value even with little hard data.

For feature classification a number of classifiers are available, namely, artificial neural network (ANN), Naïve Bayes (NB) and Bayes Net (BN), decision tree, support vector machine (SVM), proximal support vector machine (PSVM), etc.

Naïve Bayes (NB) and Bayes Net (BN) were successfully applied for the fault classification monoblok centrifugal pump [4]. NB and BN often fail to produce a good estimate of the correct class probabilities; this may not be a requirement for many applications. PSVM was also studied for the fault classification of bearings [9]. As the size of the patterns increases, the training time and also the computational complexity increases for the PSVM.

The use of vibration analysis for gear fault diagnosis and monitoring has been widely investigated and its application in industry is well established. Even visual inspection can identify the faults; industry needs an automated procedure for the identification of the faults. One commonly used technique is artificial neural network (ANN) [4]. The condition monitoring problem is treated as generalization/classification problem based on the training pattern from the samples. However, the traditional ANN approaches have limitations on the generalization of results in models that can over-fit the data [5].

A work was reported on condition monitoring of rotating machinery which combines wavelet transforms and auto associative neural networks to extract features from the vibration data sets in an unsupervised mode [10]. The fuzzy neural network was used to memorize the standard fault pattern pairings, between fault symptoms and faults [11–13]. The main drawback of the fuzzy and neural networks is poor capability of creating its own structure. The Winger distribution was used for analyzing the vibration signals, and an expert system was developed for vibration monitoring and diagnostics for rotating machines using the back propagation neural network (BPNN) [14]. The prominent drawback of Wigner distribution is that it produces cross-terms of large magnitudes. The principal component analysis (PCA) was used for feature selection and feature classification using the C4.5 decision tree and BPNN for the fault diagnosis of rotating machinery, such as turbines and compressors [15]. PCA models have trouble with high dimensional data or large numbers of data points, and it is not clear how to deal properly with an incomplete data set, in which some of the data points are missing.

To overcome the above drawbacks, researchers are constantly on the lookout for a classifier, which will give very high classification accuracy with a simple operation. SVM seems to be an algorithm which satisfies these requirements. Support vector machine (SVM) is used in many applications of machine learning, because of its high accuracy and good generalization capabilities [16,17]. SVM is based on the statistical learning theory. SVM classifies better than the ANN because of the principle of risk minimization. In ANN traditional empirical risk minimization (ERM) is used on training data set to minimize the error. In contrast, structural risk minimization (SRM) is used to minimize an upper bound on the expected risk, in SVM.

In the recent past, fault diagnosis of critical components using machine learning algorithm like the SVM was reported [18]. Recent work [19] reports the use of SVM for on-line condition monitoring and its comparison with the ANN. The SVM