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Brake fault diagnosis using Clonal Selection Classification Algorithm (CSCA) – A statistical learning approach

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ABSTRACT

In automobile, brake system is an essential part responsible for control of the vehicle. Any failure in the brake system impacts the vehicle's motion. It will generate frequent catastrophic effects on the vehicle cum passenger's safety. Thus the brake system plays a vital role in an automobile and hence condition monitoring of the brake system is essential. Vibration based condition monitoring using machine learning techniques are gaining momentum. This study is one such attempt to perform the condition monitoring of a hydraulic brake system through vibration analysis. In this research, the performance of a Clonal Selection Classification Algorithm (CSCA) for brake fault diagnosis has been reported. A hydraulic brake system test rig was fabricated. Under good and faulty conditions of a brake system, the vibration signals were acquired using a piezoelectric transducer. The statistical parameters were extracted from the vibration signal. The best feature set was identified for classification using attribute evaluator. The selected features were then classified using CSCA. The classification accuracy of such artificial intelligence technique has been compared with other machine learning approaches and discussed. The Clonal Selection Classification Algorithm performs better and gives the maximum classification accuracy (96%) for the fault diagnosis of a hydraulic brake system.

1. Introduction

Brakes are the most important control components in automobile. Every automobile shall be equipped with an efficient brake system which ensures the stability of the vehicle. An efficient brake system should bring the vehicle to rest within a reasonable distance. It is also desirable that the rate of retardation should be proportional to the pedal effort. The brake system must promote the highest degree of safety on the road not alone for the person driving but also for the others moving on the road. Since there are moving components involved, they are bound to get faulty due to various reasons, viz. wearing, air leak, fade, etc. When such things occur, the effectiveness of the brake system reduces resulting in accidents. It is essential that the brake system and brake components should be monitored all the time and diagnosed when faults occur. Hence maintenance of the brake system plays a vital role in terms of safety. The malfunction of the brake system can be identified through its symptoms or some warning sign; since the faults in the brake system are not fairly noticeable. A patented method was proposed for monitoring the applications of the brakes in automobiles. This device which consists of a chart recorder with traces driven by a transducer was used to measure the brake force [1]. An apparatus was developed for measuring and regulating a braking force using sensors [2]. In both the cases, the sensors have been used to measure some parameters like brake temperature, friction force and braking force etc. No such system has been proposed to measure brake pad wear, mechanical fade, reservoir leak, etc. Hence a vibration based fault diagnosis approach has been reported in the present study to monitor the condition of a brake system.

Monitoring of a brake system is not an easy job. This can be performed using intelligent techniques called fault diagnosis through machine learning. Machine fault diagnosis is a field of mechanical engineering deals with finding faults arising in machines. Many methods like vibration analysis [3], acoustic emissions [4], thermal imaging [5], etc. were used to identify the most probable faults leading to failure. Most commonly used method is vibration analysis. The vibration signals are analyzed by using methods like spectral analysis, wavelet analysis, waveform analysis, etc. Such analysis will provide the information required to make a decision about when intervention is required for maintenance. The

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results of such analysis are used for failure analysis in order to determine the original cause of the fault. This failure analysis can be done using machine learning approach. Machine learning approach consists three steps. (i) feature extraction, (ii) feature selection, and (iii) feature classification.

There are many features available in literature, namely, histogram features [6,7], statistical features [7], and wavelet features [8,9]. In the present study statistical features were used for the fault diagnosis study. The statistical features were extracted from the vibration signals which were acquired from the brake system setup, under various fault conditions. All the statistical features may not be required for classification. Hence, the most important features which contain the necessary information required for classification are to be identified. This was achieved by using feature selection. There are many techniques available for feature selection namely principal component analysis (PCA) [10], and decision tree (DT) [11]. Principal component analysis is suitable for data sets in multiple dimensions and it is not suitable for incomplete data set. In a study, the best feature sets were identified using decision tree (DT) from the given samples [11]. However, it may not be preferable due to its noise and over sensitivity property to irrelevant attributes. Hence a new technique called attribute evaluator has been used for feature selection.

Many classifier algorithms have been reported for feature classification. Algorithms like SVM and PSVM have been reported for fault diagnosis of various machine elements such as bearing, impeller of a centrifugal pump, etc [11–13]. The computational complexity of such classifiers is usually intensive, since it involves a quadratic programming. A report illustrated a fuzzy and neural network based fault diagnosis system for a centrifugal pump to classify faults at early stages [14]. The effectiveness of fuzzy classifier depends on the rules suggested by the experts or algorithms. A system was developed using artificial neural network approaches (feed forward network and binary adaptive resonance network (ART1)), for the fault classification of centrifugal pump [15]. However, training of an artificial neural network classifier is complex and time consuming one. The convergence of the training is not always guaranteed. Naïve Bayes and Bayes net algorithms were effectively used for monitoring the condition of a single point cutting tool [16]. The main drawback is that it assumes independence of features. In a study, Best First tree was used for the fault categorization [17]. It gave encouraging results when compared to decision tree. The problem with the Best first decision tree is the selection of splitting criteria to measure the impurity which requires more computation time. A classifier which will give very high classification accuracy with simple operation should be used for feature selection and feature classification. C4.5 decision tree algorithm satisfies these conditions and it has been used in many applications [18]. However, decision tree algorithm is more sensitive for irrelevant data.

The immune system is a robust and powerful information process system that demonstrates features such as parallel processing, adaptation and learning via experience. Artificial Immune Systems (AIS) are machine-learning algorithms that exemplify some of the principles and attempt to take advantages of the benefits of natural immune systems for use in tackling complex problem domains [19]. The Clonal Selection Classification Algorithm (CSCA) is one such system inspired by the clonal selection theory of acquired immunity, which has shown success on broad range of engineering problem domains [20]. From the literature one can understand that many classification algorithms have been used for classifying the faults in various machine elements. In order to suggest strongly that a particular algorithm is better, a detailed study needs to be conducted. This study mainly focuses on the performance of the Clonal selection classification algorithm in the brake fault diagnosis. However, classification of faults in automobile hydraulic brake system using CSCA has not been attempted. Hence an effort has been initiated in the present study to classify the faults in the hydraulic brake using CSCA. The flow chart of the fault diagnostic system is shown in Fig. 1.

The paper is structured as follows:

The experimental setup, experimental procedure and fault simulation procedure have been described in Section 2. Vibration signal acquisition, feature extraction process has been discussed in Section 3. Feature selection process has been described in Section 4. The theory about CSCA algorithm has been discussed in Section5. The classification accuracy of CSCA algorithm have been evaluated and discussed in Section 6. Section 7 summarizes the main findings of this paper. The Clonal Selection Classification Algorithm (CSCA) classifier with statistical features has been proposed as a suitable classifier for the brake fault diagnosis.

2. Experimental studies

The experimental study was conducted on a static hydraulic brake test setup. A commercial passenger car's (Model: Maruti Suzuki-Swift) hydraulic brake system was fabricated as the brake test rig as shown in Fig. 2. The vibration signals were acquired by using a piezoelectric type accelerometer (an uni-axial type, 50 g range, 100 mV/g sensitivity and 40 kHz resonant frequency). Since accelerometer has high-frequency sensitivity for detecting faults, it can be used to detect very small amplitude vibrations without

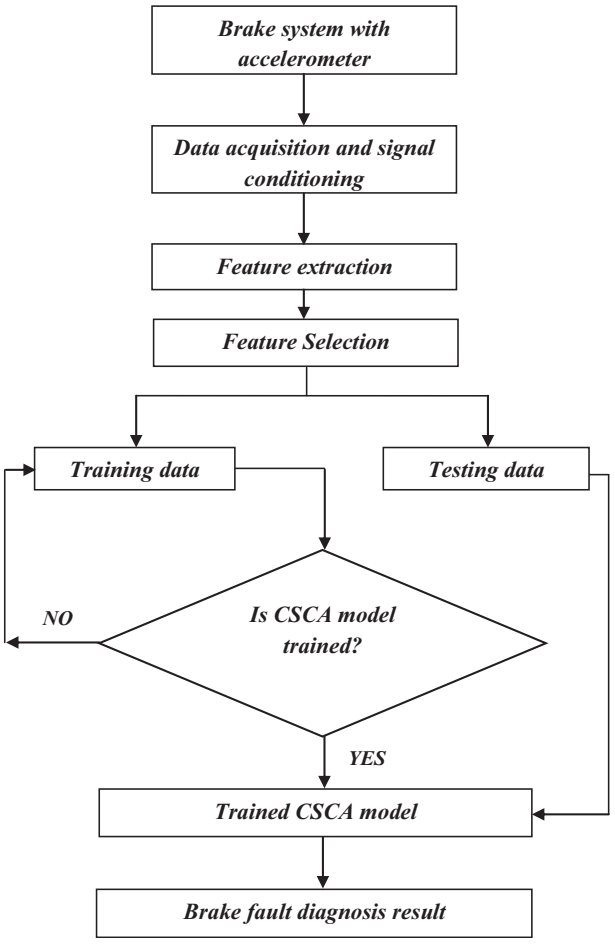

Fig. 1. Flow chart of brake fault diagnosis using CSC algorithm.