Applied Soft Computing 10 (2010) 344–360

Contents lists available at ScienceDirect

Applied Soft Computing

journal homepage: www.elsevier.com/locate/asoc

Fault diagnosis of spur bevel gear box using artificial neural network (ANN), and proximal support vector machine (PSVM)

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ARTICLE INFO

Article history:
Received 8 July 2008
Received in revised form 6 April 2009
Accepted 2 August 2009
Available online 8 August 2009

Keywords:
Artificial neural network
Proximal support vector machine
Bevel gear box
Morlet wavelet
Statistical features
Fault detection

ABSTRACT

Vibration signals extracted from rotating parts of machineries carries lot many information with in them about the condition of the operating machine. Further processing of these raw vibration signatures measured at a convenient location of the machine unravels the condition of the component or assembly under study. This paper deals with the effectiveness of wavelet-based features for fault diagnosis of a gear box using artificial neural network (ANN) and proximal support vector machines (PSVM). The statistical feature vectors from Morlet wavelet coefficients are classified using J48 algorithm and the predominant features were fed as input for training and testing ANN and PSVM and their relative efficiency in classifying the faults in the bevel gear box was compared.

1. Introduction

Malfunctions in machinery are often sources of reduced productivity and increased maintenance costs in various industrial applications. For this reason, machine condition monitoring is being pursued to recognize incipient faults. As modern production plants are expected to run continuously for extended hours, unexpected downtime due to rotating machinery failures has become more costly than ever before. The faults arising in rotating machines are often due to damages and failures in the components of gear box assembly. Fault diagnosis is an important process in preventive maintenance of gear box, which avoids serious damage if defects occur to one of the gears during operation condition. Early detection of the defects, therefore, is crucial to prevent the system from malfunction that could cause damage or entire system halt. Diagnosing a gear system by examining vibration signals is the most commonly used method for detecting gear failures. The conventional methods for processing measured data contain the frequency domain technique, time-domain technique, and time-frequency domain technique. These methods have been widely employed to detect gear failures. The use of vibration analysis for gear fault diagnosis and monitoring has been widely investigated and its application in industry is well established [1–3]. This is particularly reflected in the aviation industry where the helicopter engine, drive trains and rotor systems are fitted with vibration sensors for component health monitoring. These methods have traditionally been applied, separately in time and frequency domains. A time-domain analysis focuses principally on statistical characteristics of vibration signal such as peak level, standard deviation, skewness, kurtosis, and crest factor. A frequency domain approach uses Fourier methods to transform the time-domain signal to the frequency domain, where further analysis is carried out, and conventionally using vibration amplitude and power spectra. It should be noted that use of either domain implicitly excludes the direct use of information present in the other. Time-frequency based energy distribution method was employed for early detection of gear failure [4]. The frequency domain refers to a display or analysis of the vibration data as a function of frequency. The time-domain vibration signal is typically processed into the frequency domain by applying a Fourier transform, usually in the form of a fast Fourier transform (FFT) algorithm [5].

The works presented in [6–9] found that, the FFT-based methods are not suitable for non-stationary signal analysis and are not able to reveal the inherent information of non-stationary signals. However, various kinds of factors, such as the change of the environment and the faults from the machine itself, often make the output signals of the running machine contain non-stationary components. Usually, these non-stationary components contain abundant information about machine faults; therefore, it is important to analyze the non-stationary signals. Most algorithms recently developed for mechanical fault detection are based on the

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doi:10.1016/j.asoc.2009.08.006

assumption of stationarity of the vibration signals. Some of these, including cepstrum, time-domain averaging, adaptive noise cancellation, demodulation analysis, etc. [10–12] are well established and have proved to be very effective in machinery diagnostics. However, in many cases these methods are not sufficient to reliably detect different types of faults. There is a need for new techniques which can cope with technological advances in machinery, and which provide satisfactory fault detection sensitivity. A relatively small amount of applied research has been done in the application of time-variant fault detection methods. It is known [13,14], that local faults in gear boxes cause impacts. As a result of this impact excitation, impulses and discontinuities may be observed in the instantaneous characteristics of the envelope and phase functions [14,15]. Due to the nature of these functions, vibration signals can be considered as non-stationary [16] and strong non-stationary events can appear in a local time period, e.g. one revolution of gear in mesh. The analysis of non-stationary signals requires specific techniques which go beyond the classical Fourier approach. There exist a lot of different time-variant methods, some are reviewed in [16–18].

In the recent past reports of fault diagnosis of critical components using machine learning algorithms like SVM, PSVM are reported [19]. In ANN, the condition-monitoring problem is treated as a generalization/classification problem based on training pattern from the samples of faulty roller bearings [20]. However, the traditional ANN approaches have limitations on generalization of results in models that can over-fit the data. Support vector machine (SVM) is used in many applications of machine learning because of its high accuracy and good generalization capabilities. SVM is based on statistical learning theory. SVM classifies better than ANN because of the principle of risk minimization. In artificial neural network (ANN) traditional Empirical Risk Minimization (ERM) is used on training data set to minimize the error. But in SVM, Structural Risk Minimization (SRM) is used to minimize an upper bound on the expected risk. SVM is modeled as an optimization problem and involves extensive computation, whereas, PSVM is modeled as a system of linear equations which involves less computation [21]. PSVM gives results very close to SVM. One of the more recent mathematical tools adopted for transient signals is the wavelet transform [22,23]. Wavelet transform (WT) has attracted many researchers' attention recently. The wavelet transform was utilized to represent all possible types of transients in vibration signals generated by faults in a gear box [24]. A neural network was used to diagnose a simple gear system after the data have been pre-processed by the wavelet transform [25]. Wavelet transform was used to analyze the vibration signal from the gear system with pitting on the gear [26]. Hence based on the literature review there exist a wide scope to explore machine learning methods like ANN, SVM and PSVM for fault diagnosis of gear box. This paper is one such attempt to apply machine learning methods like ANN and PSVM to wavelet features of the vibration signal of the gear box under investigation.

This work deals with extraction of wavelet features from the vibration data of a bevel gear box system and classification of Gear faults using artificial neural network (ANN) and proximal support vector machine (PSVM). The vibration signal from a piezoelectric transducer is captured for the following conditions: Good Bevel Gear, Bevel Gear with tooth breakage (GTB), Bevel Gear with crack at root of the tooth (GTC), and Bevel Gear with face wear of the teeth (TFW) for various loading and lubrication conditions of the gear box.

A group of statistical features like kurtosis, standard deviation, maximum value, etc. form a set of features, which are widely used in fault diagnostics, are extracted from the wavelet coefficients of the time-domain signals. Selection of good features is an important phase in pattern recognition and requires detailed domain knowledge. The Decision Tree using J48 algorithm was used for identifying the best features from a given set of samples. The selected features were fed as input to ANN and PSVM for classification.

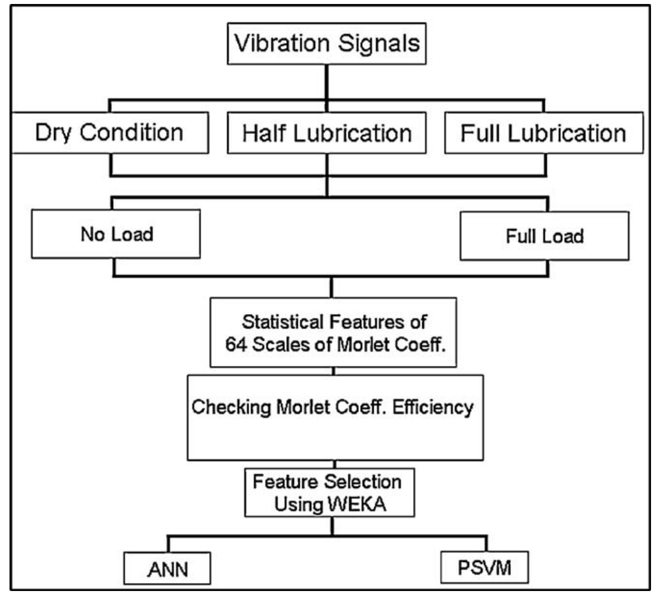

Fig. 1. Flow chart for bevel gear box condition diagnosis.

1.1. Different phases of present work

The signals obtained are processed further for machine condition diagnosis as explained in the flow chart in Fig. 1.

2. Experimental studies

The fault simulator with sensor is shown in Fig. 2 and the inner view of bevel gear box is shown in Fig. 3. A variable speed DC motor (0.5 hp) with speed up to 3000 rpm is the basic drive. A short shaft of 30 mm diameter is attached to the shaft of the motor through a flexible coupling; this is to minimize effects of misalignment and transmission of vibration from motor.

The shaft is supported at its ends through two roller bearings. From this shaft the motion is transmitted to the bevel gear box by means of a belt drive. The gear box is of dimension

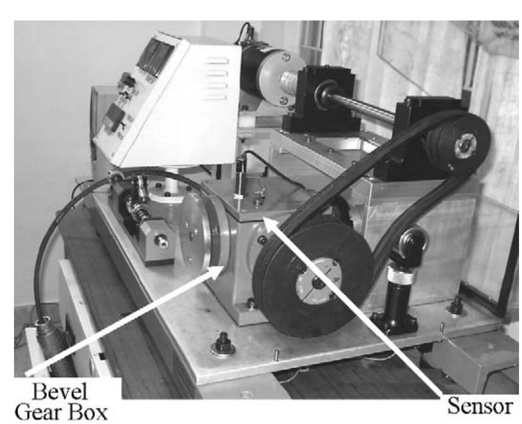

Fig. 2. Fault simulator setup.