Mechanical Systems and Signal Processing 85 (2017) 56–70

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

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

Diagnosis of combined faults in Rotary Machinery by Non-Naive Bayesian approach

Mahsa Yazdanian Asr [a], Mir Mohammad Ettefagh [a,*], Reza Hassannejad [a], Seyed Naser Razavi [b]

[a] Faculty of Mechanical Engineering, University of Tabriz, Tabriz 51666-16471, Iran
[b] Faculty of Electrical and Computer Engineering, University of Tabriz, Tabriz 51666-16471, Iran

ARTICLE INFO

Article history:
Received 10 March 2016
Received in revised form 19 June 2016
Accepted 2 August 2016

Keywords:
Rotary Machinery
Fault diagnosis
Combined faults
Feature extraction
Naive Bayesian Classifier

ABSTRACT

When combined faults happen in different parts of the rotating machines, their features are profoundly dependent. Experts are completely familiar with individuals faults characteristics and enough data are available from single faults but the problem arises, when the faults combined and the separation of characteristics becomes complex. Therefore, the experts cannot declare exact information about the symptoms of combined fault and its quality. In this paper to overcome this drawback, a novel method is proposed. The core idea of the method is about declaring combined fault without using combined fault features as training data set and just individual fault features are applied in training step. For this purpose, after data acquisition and resampling the obtained vibration signals, Empirical Mode Decomposition (EMD) is utilized to decompose multi component signals to Intrinsic Mode Functions (IMFs). With the use of correlation coefficient, proper IMFs for feature extraction are selected. In feature extraction step, Shannon energy entropy of IMFs was extracted as well as statistical features. It is obvious that most of extracted features are strongly dependent. To consider this matter, Non-Naive Bayesian Classifier (NNBC) is appointed, which release the fundamental assumption of Naive Bayesian, i.e., the independence among features. To demonstrate the superiority of NNBC, other counterpart methods, include Normal Naive Bayesian classifier, Kernel Naive Bayesian classifier and Back Propagation Neural Networks were applied and the classification results are compared. An experimental vibration signals, collected from automobile gearbox, were used to verify the effectiveness of the proposed method. During the classification process, only the features, related individually to healthy state, bearing failure and gear failures, were assigned for training the classifier. But, combined fault features (combined gear and bearing failures) were examined as test data. The achieved probabilities for the test data show that the combined fault can be identified with high success rate.

1. Introduction

The concept of diagnostics originally was inspired by the medical field. Nowadays, sophisticated diagnostics methodologies are available to identify the root causes and the type of machine failures. However, diagnostic is a reactive action, which is performed when the fault has already happened. In fact, fault diagnosis is the problem of detecting the probable

* Corresponding author.
E-mail address: ettefagh@tabrizu.ac.ir (M.M. Ettefagh).

http://dx.doi.org/10.1016/j.ymssp.2016.08.005
0888-3270/

faults characteristics hidden in the observed dataset that are related to specific machine conditions. Besides, vibration condition monitoring of rotating machines is used as a suitable tool for detection of variety faults. General framework for fault diagnosis systems, comprises of data acquisition, signal processing, feature extraction and also feature reduction step if needed, and finally proper classification procedure using knowledge base of faults, which may be derived from expert knowledge, historical data and physical models [1].

There are two types of fault diagnosis i.e. single and combined. In single fault diagnosis, only one failure maybe observed throughout the system, while in combined fault diagnosis, multiple failures may become apparent and that is very common observation especially in modern complex equipment. However, it is too difficult to carry out combined fault diagnosis accurately and effectively due to the dependence and combination of features that indicate the single failure. In fact, failure features, related to the single faults of the system, are strongly dependent and they should not be considered independent of each other. On the other hand, the specifications that would be indicative of combined faults, cannot be detected and characterized effortlessly. The specialist cannot declare obvious information about combined faults and also there is usually no appropriate historical database for them. Therefore, the information about combined fault characteristics are infrequent, while the intensity of each failure are not clarified accurately. As an example to explain the matter, a professional physician is a person who can recognize the symptoms of each single illness and declare the combined diseases as well. So a key characteristic of combined fault diagnosis is the requirement to recognize individuals meticulously.

As an available prototype for presenting the idea, gearbox is selected to study. Because gearbox is remarkably operated in various industrial equipment and is one of the core components in rotating machinery, so it can be a good representative for the complex rotating machine, containing simple rotary segments with non-stationary vibration signals such as bearings and gears. It is obvious that, the whole idea can be applied in large scale such as gas turbines, steam turbines, etc. which contain huge rotary parts and also there could be a certain possibility of combined faults. This dilemma is happened frequently in the industry and due to the severity of one damage to comparison with others, specialists at the time of their maintenance decisions, are unaware of existence of other multiple devastations in the complex system and by that reason, hidden weaker failures remain trackless and unknown. Therefore, after repairing the severe damage, installation and restarting the system, symptoms of hidden failures are observed again and weaker damages show up themselves. It leads to spend more time and cost and it causes economical loss.

In recent years, because of the complexity and difficulty of this problem, researchers have little attention to combined faults issue and this subject requires more attentions and needs to have a broader view. In the past few decades, most researches focus on single segment faults or different types of defects in just one significant segment such as bearing or gear. Several studies conducted in the field of bearing failure. Kankar et al. [2] studied different failures of ball bearings. In mentioned research, Support Vector Machine (SVM) and Artificial Neural Network (ANN) were applied to classify statistical features which were extracted from time domain vibration signals. The ANN method was demonstrated superiority compared to the SVM. Zhang et al. [3,4] decomposed the vibration signal into a set of Intrinsic Mode Functions (IMFs) by EMD as a signal processing method. In both of their studies, entropy of the vibration signal was introduced as a good feature to detect healthy or faulty bearing. Wang et al. [5] also decomposed the original signal of rolling bearing' early weak fault by Ensemble Empirical Mode Decomposition (EEMD) and several IMFs are obtained. Then the IMF with biggest kurtosis index value is selected and kurtosis factor was found as an efficient feature that can be extracted from IMFs. Su et al. [6] and Fei et al. [7] did research on bearing's fault detection too. In these researches, EMD was selected as the preprocessing method before feature extraction, because EMD doesn't need base function and is completely based on the local characteristic time scale of the signal. In fact EMD is a self-adaptive signal processing method that is applicable to non-stationary and non-linear vibration signals. Besides, they admitted that entropy, especially Shannon entropy and Kurtosis factor, are adequate features that can be extracted from IMFs. Li et al. [8] also conducted similar research on the failure of the bearings. Statistical features used as a good criterion to detect the failures despite an efficient method for processing the signal. Hajnayeb et al. [9] recommended statistical features as practical implements which can evoke both gear and bearing's defects characteristics as well. In their research, a system based on Artificial Neural Networks (ANNs) was applied to diagnosis different types of fault in a gearbox. Rajeswari et al. [10] and Bordoloi et al. [11] conducted investigations in gear failures and used wavelet transform as a signal processing tool. On the other hand, Zamanian et al. [12] indicated that wavelet transform provides redundant data, so it makes process of feature extraction more complicated. Although wavelet transform shows efficiency but it has some drawbacks such as selection of scale in the case of multi component signals. They also applied EMD methods to decompose vibration signals of gears into IMFs. Consequently, it was implied that finding a procedure to select appropriate IMFs for feature extraction is still being investigated. Lu et al. [13] studied about two kinds of failures in rotary machines i.e. rotor damage and bearing's defect separately. They also implemented EMD method as a powerful signal processing tool to extract inherent segments of the signal in different frequency ranges. Statistical features were also utilized to extract effective characteristics of failures. Hernandez-Vargas et al. [14] investigated multiple combined faults on induction motors. In their research, combined fault features were used as training data set. This works introduced entropy criterion as a proper feature for multiple fault detection and ANN as a classification method. He et al. [15] proposed a new model of Bayesian classifier named Non-Naive Bayesian classifier in a non-technical example which removes the fundamental assumption of Naive Bayesian, i.e., the independence among features. Superiority of this method compared with other Bayesian methods was shown especially in the case of detecting combined faults without using its related features as a training data set.

In this paper, as shown in Fig. 1, after data acquisition, angular resampling technique is applied to have same sample number of signal digits in each revolution of shaft as will be explained in Section 2. For signal processing step, EMD is elected according to the above mentioned research literature and correlation coefficients are computed to select appropriate