



ELSEVIER

Contents lists available at ScienceDirect

ISA Transactions

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

Research Article

A hybrid fault diagnosis approach based on mixed-domain state features for rotating machinery

Xiaoming Xue^{a,*}, Jianzhong Zhou^b^a Faculty of Mechanical and Material Engineering, Huaiyin Institute of Technology, Huai'an, Jiangsu 223003, PR China^b College of Hydropower and Information Engineering, Huazhong University of Science and Technology, Wuhan, Hubei 430074, PR China

ARTICLE INFO

Article history:

Received 29 March 2016

Received in revised form

21 August 2016

Accepted 22 October 2016

Available online 16 November 2016

Keywords:

Rolling element bearing

Fault diagnosis

Statistical analysis

Artificial intelligence

Fast EEMD

Modified LGPCA

ABSTRACT

To make further improvement in the diagnosis accuracy and efficiency, a mixed-domain state features data based hybrid fault diagnosis approach, which systematically blends both the statistical analysis approach and the artificial intelligence technology, is proposed in this work for rolling element bearings. For simplifying the fault diagnosis problems, the execution of the proposed method is divided into three steps, i.e., fault preliminary detection, fault type recognition and fault degree identification. In the first step, a preliminary judgment about the health status of the equipment can be evaluated by the statistical analysis method based on the permutation entropy theory. If fault exists, the following two processes based on the artificial intelligence approach are performed to further recognize the fault type and then identify the fault degree. For the two subsequent steps, mixed-domain state features containing time-domain, frequency-domain and multi-scale features are extracted to represent the fault peculiarity under different working conditions. As a powerful time–frequency analysis method, the fast EEMD method was employed to obtain multi-scale features. Furthermore, due to the information redundancy and the submergence of original feature space, a novel manifold learning method (modified LGPCA) is introduced to realize the low-dimensional representations for high-dimensional feature space. Finally, two cases with 12 working conditions respectively have been employed to evaluate the performance of the proposed method, where vibration signals were measured from an experimental bench of rolling element bearing. The analysis results showed the effectiveness and the superiority of the proposed method of which the diagnosis thought is more suitable for practical application.

© 2016 ISA. Published by Elsevier Ltd. All rights reserved.

1. Introduction

Rotating machinery, as an important part in machinery system, has been widely applied in electricity, metallurgy, chemical engineering and mechanical manufacturing fields. Its health state not only affects safe and stable operations of the device itself, but also has a direct impact on later production [1,2]. More seriously, the device faults maybe lead to local damage, enormous pecuniary loss and even personal casualties. A great deal of researches concluded that the faults of bearing are responsible for 30 percent of faults in rotating machines [3]. Therefore it's significative to pitch into researching on the condition monitoring and the fault diagnosis for bearings to maintain safety of equipment and reduce maintenance cost. In recent years, with the rapid development of

signal processing, data mining and artificial intelligence technology, the data-driven methods play an important role in the fault diagnosis of rotating machine [4,5], and the procedures of these methods mainly comprise four steps, namely, signal processing, features extraction, features reduction and patterns recognition.

Throughout the entire fault diagnostic process, the first three steps are the foundation of the patterns recognition, where signal processing and features extraction can be regarded as a whole to extract the status information of the original signal. After features extraction, the features reduction is conducted to obtain the low-dimensional representations for the original features space to reduce the dimension and information redundancy. In order to enhance the accuracy and efficiency of bearing fault diagnosis, many studies in terms of features extraction and reduction have been reported in the literature. In the phase of signal processing and features extraction, the time-domain and frequency-domain analysis approaches mainly for stationary signals have essential effect on the traditional signal processing. However, due to the

* Corresponding author.

E-mail address: xue_xiaoming@foxmail.com (X. Xue).

complexity of equipment structure and variety of operation conditions, the measured signals often exhibit strong nonlinearity and non-stationarity. Recently, the development of time-frequency analysis provides an effective way for features extraction of this kind of signals. The representative and commonly used time-frequency analysis methods include short-time Fourier transform (STFT), Wigner-Ville distribution (WVD), wavelet transform (WT) and empirical mode decomposition (EMD) [6], etc.

Among these methods, the decomposition process of EMD is based on the local characteristic time scale of the original signal, which breaks the limit of basis functions and indicates remarkable self-adaptability [7]. In view of the strengths, the EMD method has got wide attentions and been applied successfully in fault diagnosis field [7–12]. In addition, a noise assisted data analysis method, namely ensemble empirical mode decomposition (EEMD) was proposed by Wu and Huang et al. to solve the mode mixing problem of EMD, which is regarded as a significant improvement and performs more stably over the original EMD method [13]. However, the added white noises produce some wretched side effects, of which the high time consumption is the most prominent and, to a great extent, has limited its development and applications in practical engineering. Fortunately, Wang and Yeh et al. has proven in theory that the time complexity of EMD/EEMD is actually equivalent to that of Fourier transform [14] and on this basis, made some improvements in terms of the algorithm structure over the original method, then a novel method named fast EEMD (FEEMD) was proposed. Compared to the original EEMD method, the time consumption of FEEMD has been much reduced, and some successful applications haven been reported in literatures [15,16].

Apart from the time-domain and frequency-domain features, the multi-scale features, such as wavelet energy feature [17], EMD based permutation entropy [18] and singular value features [19] based on time-frequency analysis methods are extracted to obtain the condition information of the original signal comprehensively. However, considering the complex mapping relations between some faults and their signs, it is often difficult to determine which attribute is worthy of reflecting the fault nature from high-dimensional feature space, thus removing the redundant features. Therefore, the high-dimensional space may easily produce the information redundancy or submergence and lead to a decline in precision and efficiency of fault diagnosis. Against this issue, many dimensionality reduction methods have been proposed which also garnered considerable attention by many researchers.

Principle component analysis (PCA), as a classical dimensionality reduction method, has been widely used for linear data, but performs ineffectively on nonlinear ones [20]. Since 2000, the presentation of manifold learning (included Laplacian eigenmaps (LE) [21], Isomap [22], locally linear embedding (LLE) [23], etc.) provides a valid solution for the dimensionality reduction of nonlinear data. As a novel manifold learning method, locality preserving projections (LPP) is a kind of linear mapping of LE by replacing the nonlinear mapping relation to achieve data reduction in essence. Owing to its sound workability and fast computation, LPP has been paid more attention in fault diagnosis domain [24,25]. But, for PCA or LPP, the representations of original signal by the obtained low-dimensional space have certain one-sidedness, where the result of PCA just preserves the global variance information of Euclidean space and that of LPP only keeps the local structure features. Based on the respective attributes of PCA and LPP, a novel data projection method, local and global principle component analysis (LGPCA), was reported in literature [26], by which both global and local information of the given data can be preserved. However, this method has the shortcomings in terms of the difficulty in adjacent relationship determination and the wasting of sample type information. Aimed at these problems, a

modified LGPCA (M-LGPCA) method is proposed in this paper, where the adjacent relationships of different samples are determined adaptively by introducing Pearson similarity index [27] and the sample type information is considered during the dimensionality reduction process.

Currently, most of the data-driven methods are in single-step mode, in other words, the diagnosed procedure is just based on one intelligent classifier which is trained through the extracted features of all given sample signals. But when faced with one complex diagnosis problem (e.g., it includes dozens of fault conditions), there is no escape from occurrence of overly complex models. On the one hand, the one-step method can introduce an increasing complexity in model training, and on the other hand, it may lead to the decrease of diagnosed accuracy and efficiency. In viewing bearing fault diagnosis methods reported in the literature, many scholars tried to put forward some improvements for complex fault diagnosis problems, but most of them are focused on the enhancement of the single method, such as the amelioration of signal processing [28,29], features extraction [30,31] or classifiers [32,33]. Unfortunately, little research about the optimization of diagnostic strategy has been reported [34,35].

The contribution of this work is the development of a mixed-domain state features based hybrid fault diagnosis approach for rolling element bearing fault diagnostics, systematically blending the statistical analysis approach with the artificial intelligence technology. And on the subject of detail, a novel features reduction method (M-LGPCA) was proposed to excavate abundant and valuable information with low dimensionality. The execution of the proposed method is divided into three steps, namely, fault preliminary detection (normal state or fault state), fault type recognition and fault degree identification. In the first step, a preliminary judgment about the health status of the equipment can be evaluated by the statistical analysis method based on the permutation entropy theory. If fault exists, the subsequent steps based on the artificial intelligence approach are performed to further identify the fault type and then recognize its degree. For the last two steps, mixed-domain state features including time-domain, frequency-domain and multi-scale features are extracted to represent the fault peculiarity under different working conditions. As a powerful time-frequency analysis technique, the fast EEMD method was employed to obtain multi-scale features. Furthermore, because of the information redundancy and low sensitivity of the original feature space, a novel manifold learning method, modified LGPCA, was proposed to realize the low-dimensional representations for high-dimensional dataset. Finally, two cases with 12 working conditions were employed separately to evaluate the performance of the proposed method, where the vibration signals were measured from an experimental bench of rolling element bearing. The analysis results showed the effectiveness and the superiority of the proposed method, and its fault diagnosis thought appears more suitable for practical applications.

The rest of this paper is organized as follows. The background knowledge about permutation entropy, fast EEMD and LGPCA is reviewed in Section 2. In Section 3, the system framework of the proposed method is simply illustrated, and then the details of the proposed method are introduced. In Section 4, the proposed method is applied to the rolling element bearing fault diagnosis. Finally, some conclusions are drawn in Section 5.

2. Background knowledge

2.1. Permutation entropy

Permutation entropy (PE) is a novel statistical measure for detecting randomness and dynamic changes of time series or

Download English Version:

<https://daneshyari.com/en/article/5004082>

Download Persian Version:

<https://daneshyari.com/article/5004082>

[Daneshyari.com](https://daneshyari.com)