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Wavelet leaders multifractal features based fault diagnosis of rotating mechanism

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ABSTRACT

A novel method based on wavelet leaders multifractal features for rolling element bearing fault diagnosis is proposed. The multifractal features, combined with scaling exponents, multifractal spectrum, and log cumulants, are utilized to classify various fault types and severities of rolling element bearing, and the classification performance of each type features and their combinations are evaluated by using SVMs. Eight wavelet packet energy features are introduced to train the SVMs together with multifractal features. Experiments on 11 fault data sets indicate that a promising classification performance is achieved. Meanwhile, the experimental results demonstrate that the classification performance of the SVMs trained with eight wavelet packet energy features in tandem with multifractal features outperforms that of the SVMs trained only with wavelet packet energy features, time domain features, or multifractal features, and it is also superior to that of wavelet packet energy features in tandem with time domain features, or multifractal features combined with time domain features. The feature selection method based on distance evaluation technique is exploited to select the most relevant features and discard the redundant features, and therefore the reliability of the diagnosis performance is further improved.

1. Introduction

With the rapid development of science and technology, modern mechanical equipment is controlled automatically and with high precision. Dealing with the equipment breakdown promptly and accurately is very helpful in terms of enhancing its reliability and decreasing downtime. Rolling element bearings constitute the key parts in rotating machinery, and their fault detection and diagnosis are of great importance. To this end, researches focused on extracting the features relevant to the bearing conditions from mechanical vibration signals which contain abundant running information [1–3].

Mechanical vibration signal is a typical non-linear signal. The traditional feature extraction methods based on linear system cannot work effectively. In the last few years, fractal theory has been employed to depict the complex non-linear dynamic behavior of the mechanical fault signal. In Logan and Mathew's seminal papers [4,5], the correlation dimension of vibration signal was used for rolling element bearing fault diagnosis. Then, the application of capacity dimension and fractal dimension were discussed in the fault diagnosis [6–9]. Furthermore, Yang et al. proposed a fault diagnosis method using all

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of the three fractal dimensions for rolling element bearing [10]. All of the above methods utilize single fractal features, which only reflect the overall irregularity of signals; but fail to describe the local scaling properties. However, different local conditions and fluctuations of features are important indicators of mechanical faults [11]. Multifractal features can fully display the distribution of signal's singularities, while the geometric characters and the local scaling behaviors are described more precisely [12,13]. As an effective tool for unstable and non-linear signals, wavelet transform is widely used. The wavelet coefficients are utilized to calculate multifractal spectrum directly in some situations. But wavelet decompositions necessarily yield a large number of coefficients closing to 0, which implies that the computation of structure functions for negative orders qs will be numerically instable [14]. The wavelet transform modulus maxima (WTMM) method, which is based on continuous wavelet transform (CWT), is an alternative approach for multifractal analysis [15–21]. It overcomes the shortcoming of the origin wavelet coefficients method and some progress is made in fault diagnosis [11,20,21]. But no mathematical results have been proved to hold in a sense for this technique even now, such as the Legendre transform of the scaling function yields an upper bound for the spectrum of singularities is not available, and the continuous transform implies more computational complexity [22]. Therefore, the WTMM method is hardly applied to online real time diagnosis.

Recently, a new multifractal analysis method based on wavelet leaders was proposed by Lashermes et al. [23–25]. Based on discrete wavelet transform (DWT), the new approach not only describes the characters of spectrum on a full domain (for the negative orders qs and positive orders qs), but also has a solid theoretical mathematical supports. Furthermore, the complicated calculation is avoided. So, the wavelet leaders based method is an effective tool for extracting multifractal features, which has been successfully used in texture classification [26–28], analysis of heart rate variability [29], turbulent velocity [30], fMRI time series [31], and ECG signal [32], etc.

Essentially, fault diagnosis can be considered as a pattern recognition problem. Some intelligent classification technologies, such as artificial neural networks (ANNs) and support vector machines (SVMs) have been successfully applied to the fault diagnosis of rotating machinery [33–35]. The most difference between them is the rule of risk control. The former only implements the experience risk minimization (ERM) principle, and it leads to poor generalization ability; however, SVMs, a universal learning algorithm, is established on the theory of the structural risk minimization (SRM) principle, and seems to prevail in the field of intelligence fault diagnosis for its favorable generalization ability. In many practical applications, the classification performance of SVMs outperforms many traditional classification technologies [10,34].

In this study, the classification performance of multifractal features, including scaling exponents, multifractal spectrum, log cumulants and their combinations, on various fault data sets is studied, and the intelligent classification technology of SVMs is adopted [33–35]. In order to improve the performance of the classifier, eight wavelet packet energy (WPE) features [35] are introduced to train the SVMs together with multifractal features, and the classification performance of multifractal features in tandem with eight WPE features is investigated. The schematic diagram of fault diagnosis is shown in Fig. 1.

This paper is organized as follows. The experimental system and data sets are introduced in Section 2. Section 3 displays a brief description of extracting multifractal features. In Section 4, the multifractal analysis for simulation and real vibration

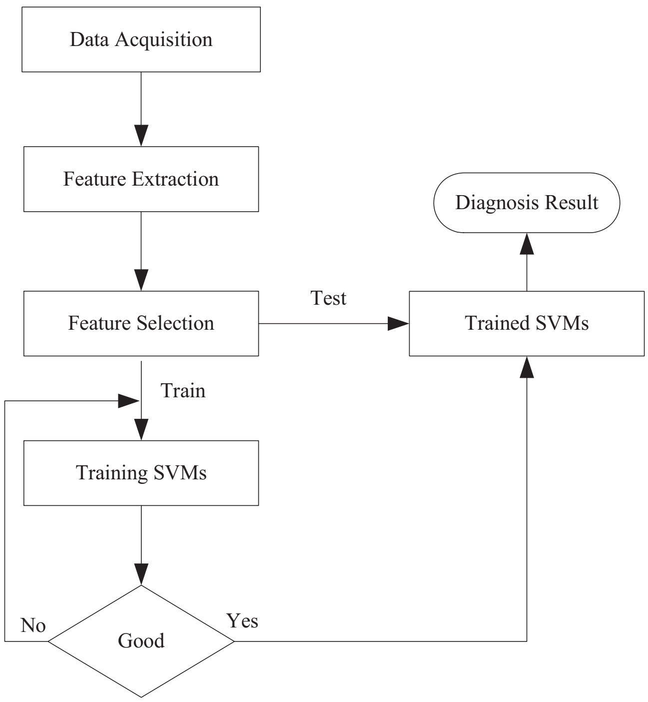

Fig. 1. Flowchart of fault diagnosis system.