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Rolling bearing fault diagnosis under variable conditions using LMD-SVD and extreme learning machine

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ABSTRACT

Fault diagnosis for rolling bearings under variable conditions is a hot and relatively difficult topic, thus an intelligent fault diagnosis method based on local mean decomposition (LMD)–singular value decomposition (SVD) and extreme learning machine (ELM) is proposed in this paper. LMD, a new self-adaptive time–frequency analysis method, was applied to decompose the nonlinear and non-stationary vibration signals into a series of product functions (PFs), from which instantaneous frequencies with physical significance can be obtained. Then, the singular value vectors, as the fault feature vectors, were acquired by applying SVD to the PFs. Last, for the purpose of lessening human intervention and shortening the fault-diagnosis time, ELM was introduced for identification and classification of bearing faults. From the experimental results it was concluded that the proposed method can accurately diagnose and identify different fault types of rolling bearings under variable conditions in a relatively shorter time.

1. Introduction

Rolling bearings, an important and common component in rotating machinery, are vital to the reliable operation of the entire system. An unexpected failure of a rolling bearing may cause the sudden breakdown of rotating machinery, bringing about enormous financial losses or even personnel casualties [1,2]. However, the working environment of rolling bearings is generally tough, complex, and especially variable, which always makes the fault-diagnosis methods less effective. Nowadays, fault diagnosis of rolling bearings is the subject of intensive research [3] and many methods of fault diagnosis have been proposed, but the application of these methods under variable conditions is barely discussed [4–7]. Thus, it is of great importance to seek an efficient fault-diagnosis method applicable to variable conditions.

The faults of rolling bearings are generally accompanied by changes in vibration signals, and the fault detection of rolling bearings via vibration monitoring has been proven to be an effective method of enhancing the reliability and safety of rotating machinery [8]. The process of rolling-bearing fault diagnosis usually consists of three steps: (1) the collection of the rolling-bearing fault vibration signals, (2) the extraction of the fault features, and (3) condition identification and fault diagnosis, among which the last two are the key steps [9]. In terms of fault feature extraction of rolling bearings whose vibration signals are nonlinear and nonstationary

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due to the complexity of rotating machinery systems, several popular time-frequency analysis methods have been suggested in the literature, such as wavelet packet transform (WPT) [10], empirical mode decomposition (EMD) [2,11,12], and Hilbert Huang transform (HHT) [1].

WPT, which has the characteristic of providing local features in both time and frequency domains and distinguishing the abrupt components of the vibration signal [13], has been widely applied in fault diagnosis of rotating machinery [14]. However, WPT is essentially an adjustable window Fourier transformation, for which not all the instantaneous frequencies of each decomposed component have physical significance. In nature, WPT is not a self-adaptive signal processing method [15]. Moreover, the computing of WPT is time-consuming and large-size data analysis is difficult to realize [1].

EMD, as a self-adaptive signal processing method, was first proposed by Huang et al. [16] for the analysis of nonlinear and nonstationary signals. EMD can decompose the signal into a series of complete and almost orthogonal components named intrinsic mode functions (IMFs), which are almost mono-component. Then, by using the Hilbert transform on these IMFs, a full energy–frequency–time distribution of the signal is obtained. HHT is the combination of EMD and Hilbert transform. With the characteristic of self-adaptive decomposition, EMD and HHT have been widely applied in the fields of monitoring and fault-detection of machinery [1,9,10]. However, some problems exist with EMD, such as over-envelopment, less-envelopment, mode confusion, high time consumption, and so on. Moreover, the negative frequencies obtained by HHT are unaccountable [17,18].

Local mean decomposition (LMD), another self-adaptive signal processing method, was proposed by Smith in 2005 [17]. LMD is suitable to be applied to adaptively decompose the nonlinear and non-stationary vibration signals into a series of product functions (PFs), each of which is the product of an envelope signal and a purely frequency modulated signal from which instantaneous frequencies with physical significance can be obtained [18]. LMD is ostensibly similar to EMD; however it has been proven that LMD is better than EMD in some aspects, such as the better local characteristic and time-scale of the signal and the ability to avoid being affected by undershoot or overshoot, with more reasonable physical information and fewer decomposed components [3]. In the following case study, the superiority of LMD over EMD will be shown in detail. Based on the analysis above, in this study, LMD was employed to extract the fault features from the complex vibration signals under variable conditions. However, the PFs obtained from LMD are always too large and complex to be taken as the fault feature vectors. To solve this problem and improve the robustness of the feature vectors, singular value decomposition (SVD) was introduced in this study to compress the scale of the fault feature vectors and obtain more stable feature vectors.

Extreme learning machine (ELM), as an intelligent technology, has shown its good performance in regression applications as well as in large dataset and multi-label classification applications [19]. Moreover, ELM has been proven to require less human intervention and less running time than support vector machine (SVM) [20]. In this study, ELM was introduced to realize real-time state classification of rolling bearings under variable conditions.

This paper is organized as follows: Section 2 introduces LMD and ELM, Section 3 describes the case study performed to validate the method, and Section 4 presents the conclusions and related future works.

2. Methodology

2.1. LMD algorithm

To extract fault information from vibration signals, LMD decomposes the raw signals into a series of product functions (PFs). A PF, with a physical significance, is the product of an envelope signal and a frequency modulated signal, from which a time-varying instantaneous frequency can be derived. Based on the moving average method, LMD is accomplished by progressively smoothing the

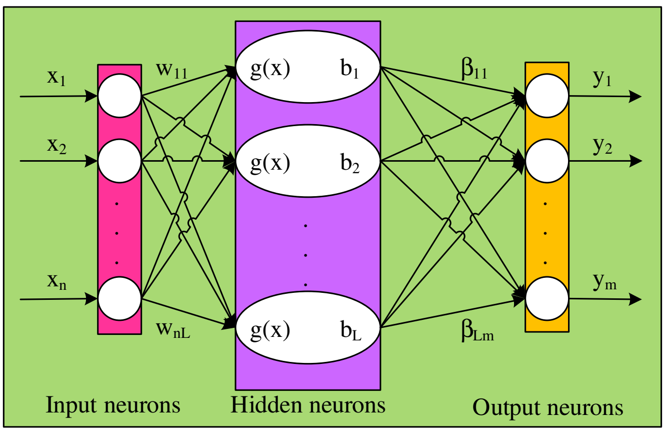

Fig. 1. Architecture of an SLFN.