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A comparative study between Empirical Wavelet Transforms and Empirical Mode Decomposition Methods: Application to bearing defect diagnosis

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A B S T R A C T

The Ensemble Empirical Mode Decomposition (EEMD) is a noise assisted method that may sometimes provide a significant improvement on Empirical Mode Decomposition (EMD). However, the amplitude and number of added noise need to be selected when applying the EEMD method. Furthermore, the computation time which depends on the number of ensemble trails is very high compared to the EMD. In this paper, a new way for choosing the appropriate added noise is presented. Conversely, a recently-developed method called the Empirical Wavelet Transform (EWT) is investigated. A comparative study between the EMD and EWT methods is conducted. The results show that the EWT is better than the EEMD and EMD on mode estimates and computation time is significantly reduced. An experimental study on bearing diagnosis is conducted. The EWT is applied to experimental data coming from damaged bearings. In the paper, an index selection is introduced that allows for the automatic selection of the Intrinsic Mode Functions (IMF) that should be used to perform the envelope spectrum. It is shown that choosing all the IMF selected by the index is more efficient than only choosing the best one. The envelope of the sum of the selected IMF clearly reveals the bearing frequencies and its harmonics which are excited by the defect. This approach seems to be an effective and efficient method for processing bearing fault signals.

1. Introduction

The bearing may be considered one of the most stressed parts in rotating machines. Early stage bearing defects first excite the resonance frequencies which manifest in the high frequency domain. The traditional fault diagnosis techniques mainly contain demodulations and envelope-based methods due to their ability to identify defect-induced frequency in the bearing. However, the major challenge in the application of this technique is the proper selection of the center frequency and bandwidth to perform the envelope spectrum.

Recently, signal processing techniques for non-stationary and noisy signals has attracted considerable attention. One of them is the Empirical Mode Decomposition (EMD). EMD is a self-adaptive algorithm and is suitable for analyzing the non-stationary and nonlinear phenomena, since it can adaptively decompose the signal into Intrinsic Mode Functions (IMFs) [1,2]. The basic idea is to decompose the signal into multiple IMFs and then select the appropriate IMF to construct the envelope spectrum using the Hilbert transform. Lei et al. [3] present a good review of EMD applied to a fault diagnosis in

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rotating machinery. However, it is well known that EMD suffers from a major drawback which is mode mixing [4]. To overcome this drawback, an Ensemble EMD (EEMD) is proposed [5]. The method proposed is to add some white noise with limited amplitude to the researched signals. Therefore, the EEMD method is considered as a significant improvement over the EMD method, and is recommended as a substitute for the EMD method. Indeed, the EEMD method has shown its superiority over the EMD method in many applications, and EEMD has been widely applied in fault diagnosis of rotating machinery, such as in gear fault diagnosis [6,7], rolling bearing fault diagnosis [8–10,13] and rotor fault diagnosis [11]. However, there is a lack on how to choose the appropriate amplitude of the added noise and its computation efficiency is fairly low.

Recently, a new method called “Empirical Wavelet Transform” (EWT) was developed by Gilles [12]. The concept is based on wavelet decomposition. The main idea is to extract the modes of a signal by designing an appropriate wavelet filter bank. EWT is used in this paper to diagnose bearing defects and its effectiveness is compared to that of EMD. EWT decomposition is based on segmentation of the Fourier spectrum. With bearing defects, unfortunately, segmentation can be affected by interference components, and substantial noise and modulation effects. Thirumala [36] applied EWT to the electrical signal and proposed another way to estimate the support boundaries of the filter bank. He used a threshold magnitude set to 3% of the fundamental magnitude to recognize the significant frequencies; whereas, the threshold for frequency distance was 8 Hz to avoid overestimation of false frequencies. In this paper, in order to overcome this drawback, a new methodology for spectrum segmentation is proposed. First, the performance of the proposed method is compared to the EMD and EEMD method. Secondly, an automatic selection of the component excited by the defect is proposed to perform the envelope spectrum.

In this paper, the authors propose to use the Empirical Wavelet Transform to diagnose bearing defects and compare its efficiency with an improved EEMD. This paper is organized as follows. Section 2 provides a theoretical background of EMD, EEMD and EWT. In this section, an improvement of EEMD is proposed. In Section 3, a comparison between the improved EEMD, EMD and EWT is presented through simulated signals from bearing defect. An application of EWT to experimental data acquired from damaged bearings via acoustic emission is presented. A new way to select the IMF related to the defect to accomplish a good diagnosis will take place. Finally, conclusions are drawn in Section 4.

2. Theoretical background

2.1. Empirical Mode Decomposition (EMD)

The EMD method can self-adaptively decompose a non-stationary signal into a set of intrinsic mode functions (IMFs) from high frequencies to low frequencies. The decomposed signal may be written as:

$$x(t) = \sum_{i=1}^{N} C_i(t) + r_N(t) \quad (1)$$

Where $C_i(t)$ indicates the i^{th} IMFand $r_N(t)$ represents the residual of the signal $x(t)$.

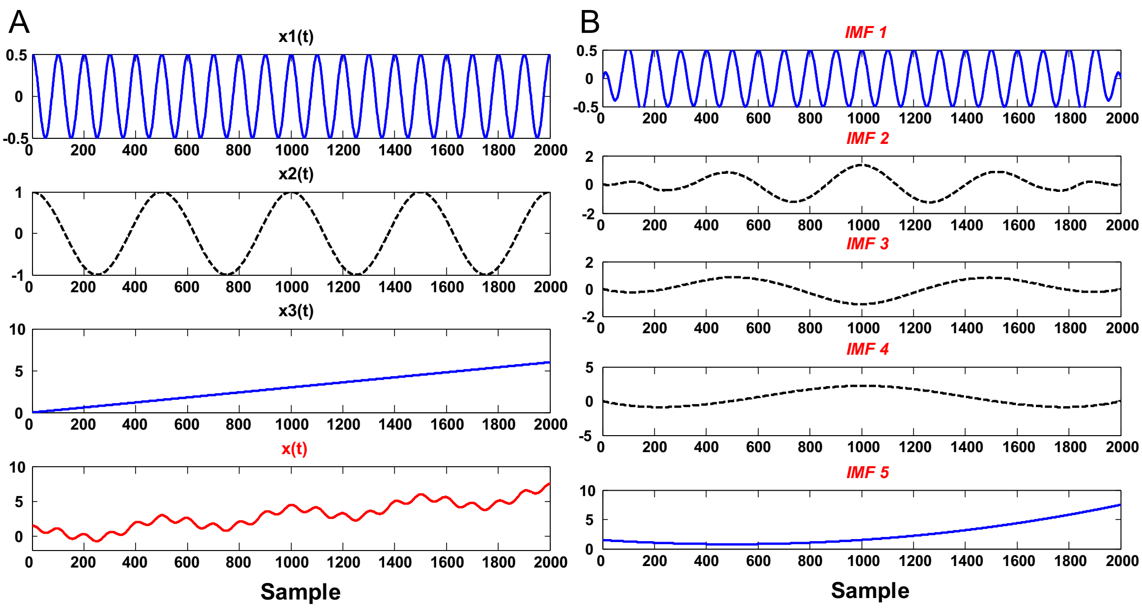

Fig. 1. (A) The simulated signal $x(t)$ (red color) and its components (blue and black color) and (B) the EMD decomposition of the signal $x(t)$.(For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)