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Demodulation for hydraulic pump fault signals based on local mean decomposition and improved adaptive multiscale morphology analysis

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ABSTRACT

Scales of IAMMA are adaptively determined by morphological features of signal, thus fault features of a hydraulic pump fault signal presented in multi-scales can be adaptively demodulated. In some coefficient range, IAMMA outperforms AMMA in demodulation ability based on the same SE, and it is less susceptible to noises than AMMA. The best performance of IAMMA with triangle SE is stronger than that of IAMMA with plat and semi-circle SE when they demodulate the same fault signal of hydraulic pump. Compared with traditional demodulation methods of HT and TKEO, IAMMA is adaptive and has stronger demodulation ability. An evaluation method based on kurtosis, power and standard deviation is proposed, by which some PFs which are rich in fault features can be selected as data source.

1. Introduction

When rotating machinery, such as rotor, bearings or gear, becomes fault, the impact vibration of high-frequency is generated and impulses are brought about, as a result, the amplitudes of the vibration signal are modulated by the impact, and the fault features are concealed. Thus demodulation has attracted some attention and been implemented in the fields of mechanical fault monitor and diagnosis. A fault signal of rotor is decomposed by ensemble empirical mode decomposition (EEMD), and Hilbert transform (HT) is applied to intrinsic mode function (IMF) to get demodulation results [1]. A fault signal of roller bearings is decomposed by local mean decomposition (LMD), and then HT is applied to product function (PF) to get demodulation results [2]. After the decomposition of a fault signal of gear by empirical mode decomposition (EMD), IMF is demodulated by HT [3]. A fault signal of ball bearings is decomposed by EEMD, then HT is used to demodulate IMF [4]. The decomposition of rotor fault signal can be got by EMD, and then demodulation results are acquired by applying HT to IMF [5]. The decomposition of rolling bearings fault signal can be got by EMD, and IMF is demodulated by Teager–Kaiser energy operator (TKEO) [6]. A fault signal of gear is decomposed by LMD, then TKEO is applied to PF to obtain demodulation results [7].

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Hydraulic system is an important control and transmission part, and it has been applied in many important industrial fields of aeronautics, astronautics, metallurgy, petrochemical engineering and engineering machinery. As rotating machinery, hydraulic pump is a crucial part in the system, whose running state has a great influence on equipment even the working conditions of whole unit, thus it is of great significance that working condition of hydraulic pump is monitored and diagnosed. The methods of monitor and diagnosis are mainly based on a vibration signal [8,9], but the vibration signal is demodulated and fault features are concealed when hydraulic pump becomes fault.

Because of the demodulation problems of hydraulic pump fault vibration signals, the method is proposed based on LMD and improved adaptive multiscale morphology analysis (IAMMA). Both LMD and IAMMA work according to the morphological features of signal, therefore the proposed method is highly adaptive.

LMD, developed based on EMD, is a new adaptive time-frequency analysis, and it was proposed by Smith and firstly applied to the electroencephalogram signal in 2005 [10], furthermore it also has got applied widely in the field of mechanical fault diagnosis [11–13]. The multi-component signal is decomposed adaptively by LMD based on time intervals of extreme points, then some mono-components called PFs can be got, and the PFs have physical meanings. Each of the PFs is the product of an envelope signal and a purely frequency modulated signal. The instantaneous amplitude of the PF can be got from an envelope signal, and the well-defined instantaneous frequency can be calculated from a purely frequency modulated signal. In essence, each PF component is an amplitude-modulated and frequency-modulated signal (AM–FM signal). In addition, LMD is better than EMD at inhibiting mode mixing, end effect, computation cost and retaining original signal information of frequency and envelope [14,15].

Mathematical morphology was put forward based on integral geometry and stochastic set theory by Serra [16,17]. And then it was introduced to the field of signal processing [18], its goal is to modify the geometry of signal by its interaction with structure element (SE), therefore only the morphological features of the signal which are matched with those of SE can be extracted [19,20].

Feature information is presented in multiscale, therefore the important comprehensive morphological features cannot be extracted only by the signal-scale morphological analysis. Aiming at the problems, the multiscale morphological analysis was proposed by Maragos [21,22]. According to the multiscale morphological analysis, the adaptive multiscale morphology analysis (AMMA) was proposed by Zhang et al. [23], and it has been used in the signal processing of gear and rolling bearing [24,25]. Based on AMMA, the improved adaptive multiscale morphology analysis (IAMMA) is proposed for the demodulation in this study, and it is much less prone to the influence of noises, therefore its demodulation ability is stronger than that of AMMA.

In this study, firstly, the fault signal of hydraulic pump is decomposed by LMD, and then a series of PFs are acquired. Secondly, in order to select some PFs, data source, which are rich in fault features, an evaluation method is proposed based on kurtosis, power and standard deviation. The algorithm is described as follows. The three indices are extracted from the original signal and PFs respectively, then a vector of original signal is constituted by the three indices, so is the vector of each PF. The Euclidean distance between vector of original signal and that of every PF is computed, and then the three PFs corresponding to the three minimum values of Euclidean distances are selected to be reconstructed, thus the reconstruct signal is adopted as data source. Lastly, the reconstruct signal is demodulated by IAMMA with plat SE, semi-circle SE and triangle SE, thus most of fault features can be extracted. Furthermore, the signal is also demodulated by AMMA with the three types of SEs, HT and TKEO to demonstrate the good performance of IAMMA. The result illustrates that IAMMA can well demodulate the fault signals of hydraulic pump, and IAMMA in some adaptively selected scales performs best, especially the one with triangle SE compared with the other three demodulation methods.

The rest of the paper is organized as follows. In Section 2, the algorithm of LMD is presented. In Section 3, multiscale morphology analysis is briefly introduced, and then IAMMA is detailed based on AMMA. In Section 4, the evaluation method which can select PF as the data source and feature energy ratio which can assess the demodulation ability are presented. In Section 5, the experimental results are demonstrated by applying the fusion method of LMD and IAMMA to demodulate the fault signals of hydraulic pump. In Section 6, the conclusions of this investigation are summarized.

2. Algorithm of LMD

LMD is a new self-adaptive analysis method in time-frequency domain. A multi-component signal of nonlinear and non-stationary can be decomposed into a set of mono-component AM–FM signals (PFs) by LMD. In essence, each PF is the product of a purely frequency modulated signal and an envelope signal. The algorithm is described as follows [2]:

(1) Given signal $x(t)$, and generate all local extrema $\{n_i\}$, therefore the mean value m_i of the two successive extrema n_i and n_{i+1} is computed by

$$m_i = \frac{n_i + n_{i+1}}{2} \tag{1}$$

All mean values m_i of two successive extrema are connected by straight line, and the line is smoothed by the moving average method, then local mean function $m_{11}(t)$ can be obtained.