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ScienceDirect
Mechanical Systems and Signal Processing 21 (2007) 1197–1211
Mechanical Systems and Signal Processing
www.elsevier.com/locate/jnlabr/ymssp

Application of support vector regression machines to the processing of end effects of Hilbert–Huang transform

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Received 28 April 2005; received in revised form 6 September 2005; accepted 9 September 2005
Available online 17 October 2005

Abstract

The end effects of Hilbert–Huang transform are represented in two aspects. On the one hand, the end effects occur when the signal is decomposed by empirical mode decomposition (EMD) method. On the other hand, the end effects occur again while the Hilbert transforms are applied to the intrinsic mode functions (IMFs). To restrain the end effects of Hilbert–Huang transform, the support vector regression machines are used to predict the signals before the signal is decomposed by EMD method, thus the end effects could be restrained effectively and the IMFs with certain physical sense could be obtained. For the same purpose, the support vector regression machines are used again to predict the IMFs before the Hilbert transform of the IMFs, thus the accurate instantaneous frequencies and amplitudes could be obtained and the corresponding Hilbert spectrum with physical sense could be acquired. The analysis results from the simulation and experimental signals demonstrate that the end effects of Hilbert–Huang transform could be resolved effectively by the time series forecasting method based on support vector regression machines which is superior to that based on neural networks.

Keywords: Hilbert–Huang transform; End effects; Support vector regression machines; EMD; Hilbert transform

1. Introduction

The Hilbert–Huang transform is a new analysis method for non-stationary signals put forward by Huang [1], which contains empirical mode decomposition (EMD) and its corresponding Hilbert spectrum analysis method for signals. Firstly, EMD is applied to decompose the non-stationary signals into several intrinsic mode functions (IMFs). Secondly, Hilbert transform is carried out to each IMF component to get the instantaneous frequencies and instantaneous amplitudes. Finally, the instantaneous frequencies and amplitudes are reassembled to obtain the Hilbert spectrum. In signal analysis, time scale and the energy distribution along with the time scale are the two most important parameters to signals. The EMD method, which is based on the local characteristic time scale, can be used to decompose the complex signals into a number of IMF components. Since the decomposition is carried out according to the signals itself, the number

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0888-3270/$ - see front matter
doi:10.1016/j.ymssp.2005.09.005

of resulting IMF components are usually limited and each IMF component can reflect the intrinsic and real physical information of the signals, as a result of which the resulting Hilbert spectrum can indicate exactly the signal energy distributions in the space (or time) with diversified scales. Therefore, the Hilbert–Huang transform has been widely used in many fields, such as the analysis of the non-stationary sea wave data [2], earthquake signal and structure analysis, bridge and constructions state monitoring [3], and the fault diagnosis of machines, etc. [4,5].

Although Hilbert–Huang transform is quite suitable for non-stationary signal analysis, the end effects occur in the transform, which is represented in two aspects [1,6–11]. First of all, the two ends of time series will disperse while the signal is decomposed by EMD method and this disperse would ‘‘empoison’’ in by the whole time series gradually which makes the results to get distortion [1,6–11]. Additionally, the end effects also arise when the Hilbert transform is applied to the IMFs because of the inevitable window effects of the transform [7]. If the two end effects cannot be restrained effectively, the real characteristics of the original signals could not be reflected accurately by Hilbert spectrum. Huang et al. [1] forecast the time series by adding two characteristic waves at the ends of data, but fail to mention how to establish suitable characteristic waves. Although this method is effective some problems still exist [6]. Recently, many methods have been put forward to restrain the end effects, such as the time series forecasting based on neural networks [7], the forecasting based on AR model [8], the forecasting based on waveform matching method [9], the forecasting based on adding extreme [10], and the method by appending two parallels at the ends according to ‘‘balance place’’ of the series variety [11]. All the methods work well to a certain extent in the restraining of end effects. In EMD method, the original signals are forecast to insure that envelops are established completely by data within the ends and the distortion of envelops is limited to the least extent by discarding the end data in terms of the extremum situation during the decomposition. Also, the IMF components can be forecast before Hilbert transform and the end effects can be released out of the original signals by abandoning the end data. Hence the time series forecasting methods based on neural networks and AR model are both effective to deal with the end effects. However, the method based on AR is only suitable for stationary and simple non-stationary time series [12]. As far as the neural network is concerned, the local minimum point, over learning and the excessive dependence on experience about the choice of structures and types are its inevitable limitation [13], while support vector regression machines (SVRMs) get rid of these limitation [14] and has been applied to time series forecasting successfully [15–17]. Therefore, it is an effective method to restrain the end effects of Hilbert–Huang transform in which SVRMs are adopted to establish models and the time series are forecast. In this paper, to target the end effects, the time series forecasting method based on support vector regression machines is put forward and confirmed to be effective by analysis results from the simulation and experimental signals. It also has been found by comparison study that the method based on support vector regression machines is superior to that based on neural networks in dealing with the end effects of Hilbert–Huang transform for the forecasting results of the latter depends excessively on the choice of structure and types while the former has satisfied results for different signals based on the same parameters with small error and less time.

2. Hilbert–Huang transform

By using EMD method [1], each signal $x(t)$ can be decomposed as follows:

$$x(t) = \sum_{j=1}^{n} c_j + r_n, \tag{1}$$

where c_j is an intrinsic mode function (IMF) and r_n is the mean trend of $x(t)$.

For one IMF $c_i(t)$ in Eq. (1), we can always have its Hilbert transform as

$$H[c_i(t)] = \frac{1}{\pi}\int_{-\infty}^{\infty} \frac{c_i(t')}{t-t'}\,\mathrm{d}t'. \tag{2}$$

With this definition, we can have an analytic signal as

$$z_i(t) = c_i(t) + jH[c_i(t)] = a_i(t)\mathrm{e}^{j\Phi_i(t)} \tag{3}$$