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An improved bidimensional empirical mode decomposition: A mean approach for fast decomposition

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ABSTRACT

In this paper, a mean approach is proposed to accelerate bidimensional empirical mode decomposition (BEMD). In the envelope generation process, the proposed method uses a modified mean filter to approximate the interpolated envelope of the conventional BEMD, and utilizes a convolution algorithm based on singular value decomposition (SVD) to further reduce the computation time. Order statistics filter width determination, originally used in fast and adaptive bidimensional empirical mode decomposition (FABEMD), is applied to adaptively formulate an envelope. Considering the computation efficiency, the proposed method improves the algorithm for calculating distances among extrema by using Delaunay triangulation (DT). The experimental results show that the mean approach can produce intrinsic mode functions faster than FABEMD, while retaining acceptable quality.

1. Introduction

Empirical mode decomposition (EMD), first introduced in 1998, has shown its potential by the prosperity of developments in recent years [1]. This method is able to analyze non-linear and non-stationary data by obtaining local characteristics and time–frequency distribution of the data. For two-dimensional signals, bidimensional EMD (BEMD) is developed as a two-dimensional version of EMD, and it has shown potential to be a filter bank [2].

BEMD is mostly used in image analysis [2,3] and texture analysis [4,5]. The decomposition results of BEMD are two-dimensional intrinsic mode functions, which are also known as bi-dimensional intrinsic mode functions (BIMFs) and amplitude modulation/frequency modulation (AM–FM) components [4,6–8]. Conventionally, BEMD is implemented by a set of radial basis functions (RBFs). However, RBF-based BEMD suffers from boundary effects, over/under shooting problems and mode mixing problems, so it is unable to efficiently decompose a noise-contaminated image. Thus, several researches have been proposed to solve these problems. An optimization-based BEMD algorithm [9] has been proposed to overcome the over/under shooting problem. Literatures [7,8] introduce partial differentiation equations (PDEs) to model the BEMD mathematical framework. A well-defined BEMD framework helps in analyzing the decomposition result and effectiveness. The literature [10] extends BEMD into

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complex domain. Bidimensional statistical empirical mode decomposition (BSEMD) [11] replaces 2-D interpolation by a smoothing procedure in order to construct envelopes coupling with a new extrema identification method. In order to address the problem of noise-contaminated data, EEMD/MEEMD [12,13] have been proposed for removing noise effects.

In addition, another long-standing research topic is the time inefficiency problem [14]. EMD/BEMD requires an iterative sifting process for envelope generation and stopping criteria to satisfy the zero envelope mean for each IMF/BIMF. In most cases, time inefficiency problems are governed by envelope generation. This weakness is not significant in 1-D processes. However, in 2-D processes, real-time applications of BEMD are impracticable if the 2-D envelope generation methods require significantly high computation time with inefficient interpolation techniques, such as radial basis function [3] and the thin-plate splines method [2]. Most research on this problem has focused on envelope generation. Delaunay triangulation (DT) was proposed in [15] to efficiently interpolate extrema for envelope generation. [16] proposes a fast and adaptive BEMD method (FABEMD) that uses two spatial domain sliding order-statistic filters, namely, max and min filters, to approximate the running maxima and minima, and then a smoothing process is used to build the upper and lower envelopes, respectively. [17] directly forms the mean envelope with local features. These contributions have successfully improved the speed of EMD/BEMD processes, but further development is required if they become practical for real-time applications.

In this paper, we propose a fast BEMD based on [16]. The proposed method utilizes a mean-based envelope generation, fast convolution and a DT-based order statistic filter width determination to reduce computation time. Our experiments show that the proposed method consumes less computational resources and time, with similar results to FABEMD. In the following, we will describe FABEMD and the proposed method in detail. In Section 2, some EMD bases will be reviewed for our research. Section 3 describes the fast BEMD method in detail. Section 4 performs several experiments to show the effectiveness of our approach. Section 5 concludes the research in this paper.

2. BEMD revisited

The core of BEMD is a sifting process which can decompose an input signal into BIMFs without any predefined bases. Generally, BEMD acts like a filter bank. The first decomposition result contains most local features of the original signal, the later result contains less local features, and the last result contains the trend of the signal. According to [2], bidimensional intrinsic mode functions (BIMFs) are orthogonal to each other, meaning that these BIMFs can represent the basis of the input signal.

In Section 2.1, we will describe the key features of FABEMD, and Section 2.2 will list the characteristics of FABEMD.

2.1. Algorithm of FABEMD

FABEMD [16] utilizes two filters to generate upper and lower envelopes, which are faster than conventional methods such as the radial basis function and the thin-plate spline method. FABEMD can extract BIMFs from the original signal $f(x,y)$, which can be represented by the following equation:

$$f(x,y) = \sum_{n=1}^{N} I_n(x,y) + R(x,y) \tag{1}$$

where $I_n(x,y)$ represents the nth component of $f(x,y)$. $R(x,y)$ represents the residue of $f(x,y)$. A sifting process can decompose the bivariable function f into components and residue without any predefined filter. The sifting process iteratively extracts the mode of $f(x,y)$, retaining the local oscillation in the residual signal. For FABEMD, the sifting process is similar to the conventional BEMD, except for the envelope generation step. The pseudocode of the conventional BEMD is shown in Algorithm 1.

After applying the BEMD algorithm to an image, the result contains many components and one residue. In [2], the thin-plate spline interpolation method is applied for conventional BEMD to generate 2-D envelopes. Although this method produces good results, an iterative optimization approach is required to form a surface. Therefore, extremely high computation costs are required to compute the results. This drawback results in BEMD being impracticable for further application. In addition, insufficient local extrema causes erroneous surface interpolation results. FABEMD introduces a filter-based method to eliminate the need for surface interpolation results. FABEMD introduces a filter-based method to eliminate the need for surface interpolation. Experimental results in [16] show that replacing thin-plate spline method with two smoothing order-statistics filters exhibits similar approximation results. However, the filter-based method accelerates the entire process of decomposition due to its simplicity.

Algorithm 1. Conventional BEMD.

1. Set $i=1$.
2. Let $R_0(x,y)=f(x,y)$.
3. Let $h_i(x,y)=R_{i-1}(x,y)$.
4. Identify the local maxima $m_{max}(i)$ and local minima $m_{min}(j)$ of $h_i(x,y)$.
5. Generate upper envelope $e_{upper}(x,y)$ from $h(x,y)$ utilizing with local maxima $m_{max}(i)$.
6. Generate lower envelope $e_{lower}(x,y)$ from $h(x,y)$ utilizing with local minima $m_{min}(j)$.
7. Calculate the mean envelope $e_{mean}(x,y)=(e_{upper}(x,y)+e_{lower}(x,y))/2$.
8. Determine new intermittent signal $h_i'(x,y)=h_i(x,y)-m_{mean}(x,y)$.
9. Calculate stop criterion $SD=\frac{\sum_{x=1}^{W}\sum_{y=1}^{H}|h_i'(x,y)-h_i(x,y)|^2}{\sum_{x=1}^{W}\sum_{y=1}^{H}|h_i(x,y)|^2}$ for determining whether zero-mean envelope is generated.
10. If SD is a low value, such as 0.05, then $h_i'(x,y)$ is ith IMF; otherwise, assign $h_i'(x,y)$ to $h_i(x,y)$ and back to Step 3.
11. Set $R_i(x,y)=h_i'(x,y)$. If $R_i(x,y)$ is monotonic, then stop the algorithm; otherwise, set $i=i+1$ and back to Step 2.