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EMPIRICAL MODE DECOMPOSITION: A METHOD FOR ANALYZING NON-STATIONARY SIGNALS

Shweta A. Fulambarkar*, Dr. D. V. Jadhav
* TSSM's BSCOER, Pune
Project Guide E & TC Department

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ABSTRACT

This paper described the non-linear Technique called Empirical Mode Decomposition (EMD), a method to analyze non-stationary signal and representing them as a mono component called Intrinsic mode Function (IMF). Decomposition of a signal is done by using sifting process & the analyzed with Hilbert Transform. It gives the instantaneous frequency& instantaneous amplitude variation.

KEYWORDS: Empirical mode decomposition, Hilbert transform.

INTRODUCTION

In the field of signal processing, signal has an extreme importance. There are abundant kinds of signals ranging from simple to complex. Hence, it is necessary to analyze them with the help of diverse techniques. The conventional signal analyzing methods are used on the basis of the signal classification which has much importance. The signals are deterministic, non-deterministic, stationary and non-stationary. The methods like Fourier analysis, short time Fourier analysis, Wavelet analysis failed for non-stationary events and detecting trends in signal. So the emphasis is on non-stationary signal analysis which is burden to handle. These signal having the changing statistics varied with time, defined as non-stationary signal.Each kind of signal has its own feature and this feature extraction involves simplifying the amount of resources required to accurately describe a large set of data. If extracted features are distinct enough; even a simple classifier can accurately and efficiently classify the data.

Hence, Empirical mode decomposition (EMD) method has proposed by N. E.Huang et al in 1998 for analyzing non-stationary, nonlinear signal. In this iterative method of finding intrinsic mode functions (IMF) from a non-stationary signal bysifting procedure is explained. The Sifting procedure is nothing but removal of lowest frequency from a signal until highest frequency remains in the signal and this is termed as IMF.These IMFs could be easily analyzed for their instantaneous frequencies and bandwidths by simple application of Hilbert
Transform on these IMFs. After removal of first IMF same procedure is repeated until residue becomes monotonic signal i.e. lowest frequency signal.

The EMD method described here proved useful in a variety of applications such as diverse as climate variability, biomedical engineering, etc.

METHODOLOGY

A signal which has changing amplitude and frequency with respect to time is a Non-stationary signal. To represent these non-stationary signals as a combination of various sinusoidal signals will not be accurate and single frequency cannot define. Now, it is necessary to a flexible process to detect the frequency change with time. This gives rise to an idea of Instantaneous frequency (IF). The EMD method is Empirical because the local characteristic time scales of the data itself are used to decompose the time series. Previously, Fourier analysisor wavelet transform is used as a general tool for examining timeseries. There are some crucial restrictions of Fourier analysis: the system must be linear and the data must be periodic or stationary. Wavelet transform decomposes the signal into family of scaled and translated functions.

Here, shown in fig 1 the EMD process, it is an iterative procedure for separating oscillations by simple sifting process.

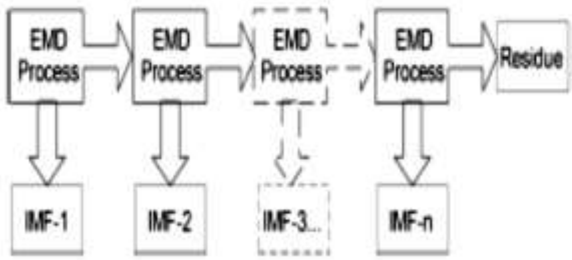

Fig1 EMD process

The method extracts mono component and symmetric components from non-linear &non-stationary signals. Sifting indicates removing of lowest frequency information until only the highest frequency remains. The decomposed signals are intrinsic mode function, is a zero mean oscillatorywaveform, possibly modulated in both amplitude and frequency. They satisfy the following two conditions:

1) For a data set, the number of extreme and
Zero crossings must either be equal or differ at most by one.
2) At any point, the mean value of the envelope defined by the local maxima and a local minimum is zero.

Computational algorithm to find IMF
The hung et. al. algorithm for extracting an IMF by sifting process is as given below:

Step1: The upper and the lower envelopes are constructed by connecting all the maxima and all the minima of signal $x(t)$ with cubic splines, respectively.

Step 2: Take the mean of the two envelopes and let it be defined as

$$m(t) = \frac{xmax(t) + xmin(t)}{2}$$

Subtract the mean $m(t)$ from the original signal $x(t)$ to get a component $h_1(t)$ where

$$h_1(t) = x(t) - m(t)$$

These steps has shown in Fig 2 in it envelops of maxima minima are given.

Step 3: If $h_1(t)$ satisfies the two conditions of IMF, given above then $h1(t)$ is the first IMF else it is treated as the original function and steps 1-3 repeated to get component $h_{11}(t)$such that : $h_{11}(t)=h_1(t)-m_1(t)$

Step 4: The above sifting process is repeated k times and $h_1k(t)$ become first IMF known as IMF1, it is stored in $C_1(t)$
Separate IMF 1 from $x(t)$ and let it be $r_1(t)$, such that

$$r1(t) = x(t) - h_{1k}(t)$$

after nine iterations the First IMF, IMF-1 found.

Step 5: Now taking the signal $r_1(t)$ as the original signal andrepeating the steps 1-4 second IMF is obtained.The aboveprocedure is repeated for n times and such n IMFs are obtained.When $r_1(t)$ becomes monotonic function no further IMF can be
extracted.At the end we have residue $r(t)$and collection of IMFs $C1$ to$Cn(t)$ Such that

$$x(t)=\sum_{i=1}^{n} Ci(t)+ri(t)$$

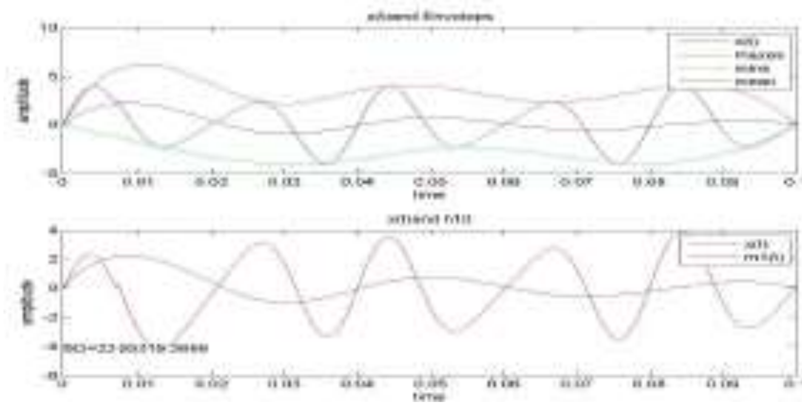

Fig 2 Data upper and lower envelope defined by local extreme & means value of two envelopes

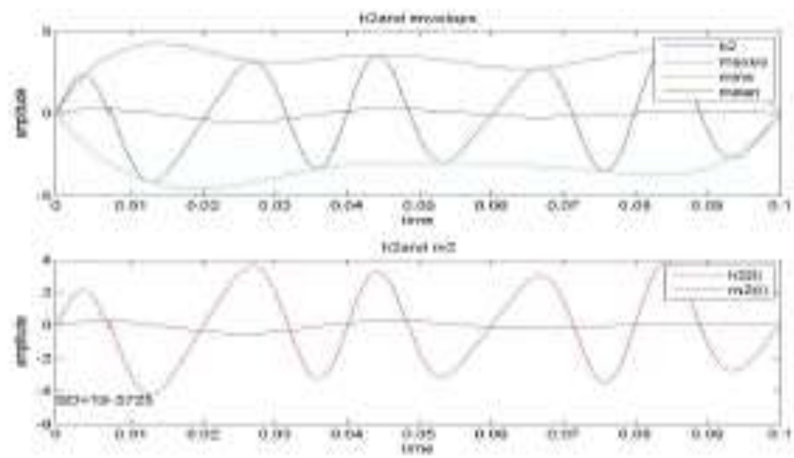

Fig 3 data and mean of signal for iteration 2

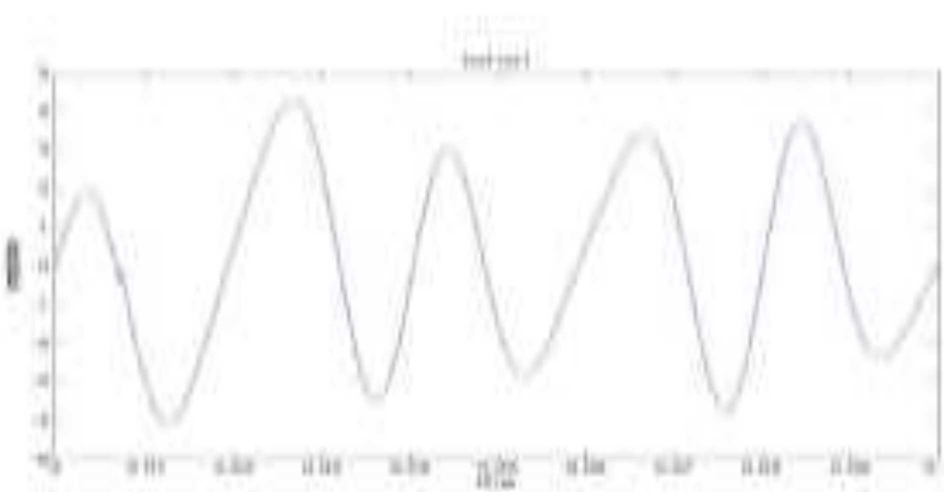

Fig 4 IMF First (IMF 1)

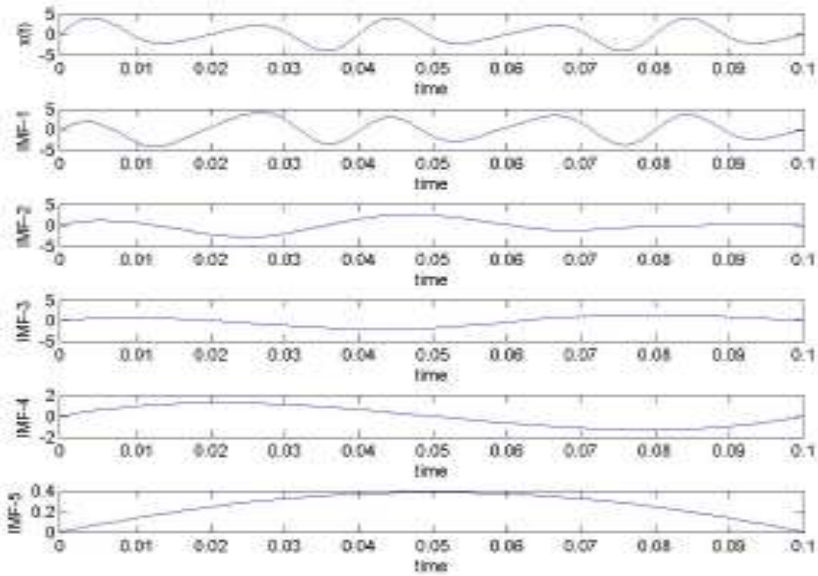

Fig 5 IMFs obtained by sifting process on sample signal

Hilbert Transform

Generally, any non-linear distorted waveform can be regarded as harmonic distortions. Harmonic distortions are a mathematic artificial consequence of imposing a linear structure on a nonlinear system. They may not have mathematical meanings but physical meanings. Hence the physically meaningful way to describe a non-linear system is instantaneous frequency, which will reveal the intrawave frequency modulations. The Hilbert transform relates real and imaginary parts of a complex function on real line. In this Hilbert transform has been used to find real and imaginary part of signal $x(t)$ which further used for calculating instantaneous phase and frequency of signal.

Hilbert Hung spectral analysis

Hilbert spectrum shows instantaneous frequencies consisted in each IMF separately with respect to time. Hilbert spectrum of test signal is shown in Fig 6.The instantaneous frequency can be considered as average of all the frequencies that exist at a given moment, while the instantaneous bandwidth can be considered as the deviation from that average. This obtained instantaneous amplitude, frequency used for classification and selecting features of signal by analyzing statistical properties of IMFs

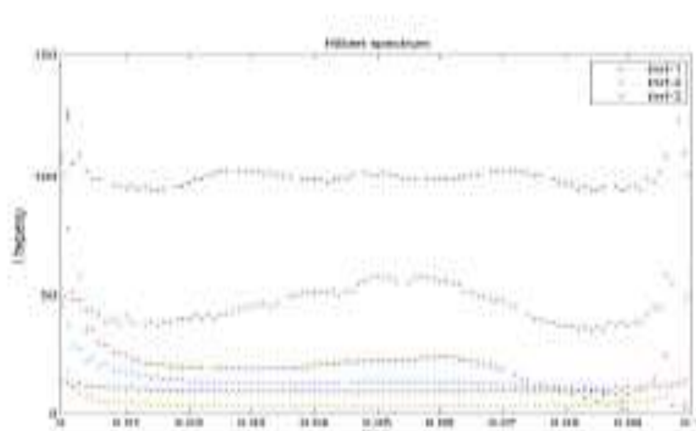

Fig 6 Hilbert transform of the test signal

CONCLUSION

The Empirical Mode Decomposition and Hilbert spectral analysis, comprising the Hilbert Huang transform, can be applied with great success for nonlinear and non-stationary signal analysis in various areas. It can be used as faster algorithm and will be helpful for predicting weather conditions.

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