

Empirical Mode Decomposition and Robust Seismic Attribute Analysis

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Summary

This paper demonstrates the suitability of empirical mode decomposition (EMD) for the seismic attribute analysis and time-frequency analysis. EMD decomposes a seismic signal into a sum of intrinsic oscillatory components, called Intrinsic Mode Functions (IMFs). Each IMF has different frequency components, potentially highlighting different geologic and stratigraphic information. Robust instantaneous frequencies can be obtained by combining EMD with the Hilbert transform. The resulting instantaneous frequencies are guaranteed to be smooth and positive with the promise of very high time-frequency resolution, and can thus be employed for robust attribute analysis of seismic data.

Introduction

The empirical mode decomposition (EMD) method developed by Huang et al. (1998) is a powerful signal analysis technique to detect non-stationary and nonlinear signal systems. Furthermore, high-resolution time-frequency analysis is possible by combining EMD with the Hilbert transform. The resulting time-frequency resolution is potentially significantly higher than that obtained using traditional time-frequency analysis tools, such as Fourier transform and wavelet transforms. Also known as the Hilbert-Huang transform, the resulting approach is known to be highly suitable for analysis of the non-stationary and nonlinear signals, such as seismic data, and holds therefore also the potential to create a step-change in seismic attribute analysis based on instantaneous frequencies or spectral decomposition.

Seismic attributes comprise all the information obtained from seismic data, either by direct measurements or by logical or experience based reasoning (Taner, 2001). They are commonly used by the oil and gas industry to facilitate interpretation of large 3D datasets and to effectively communicate subtle structural and stratigraphic features to experts and non-experts alike. In the various seismic attributes, instantaneous frequency plays a significant role. For instance, the instantaneous frequency can be used to detect and map meandering channels and to determine their thickness. Instantaneous frequency is related to channel thickness since it maps at what frequency maximum constructive interference occurs between the top and bottom channel reflection. However, instantaneous frequency has its disadvantages; it is not robust in presence of noise and fluctuates with the spatial and temporal location (Barnes, 2007).

Magrin-Chagnolleau and Barniuk (1999) were the first to explore the possibilities of the Hilbert-Huang transform for time-frequency analysis of seismic data. In this paper we revisit their work and illustrate its potential for robust attribute analysis using synthetic examples.

Empirical Mode Decomposition

EMD decomposes a data series into a finite set of signals, called intrinsic mode functions (IMFs). The IMFs represent the different oscillations embedded in the data. They are functions that satisfy two conditions: (1)

in the whole data set, the number of extrema and the number of zero crossings must either equal or differ at most by one; and (2) at any point, the mean value of the envelope defined by the local maxima and the envelope defined by the local minima is zero. These conditions are necessary to ensure that each IMF has a localised frequency content by preventing frequency spreading due to asymmetric waveforms. Unlike the Fourier transform, which decomposes the signal into a sum of single-frequency constant-amplitude harmonics, the IMFs are elementary amplitude/frequency modulated harmonics that can model the non-stationary and the nonlinearity in the data (Huang et al., 1998).

The IMFs are computed recursively, starting with the most oscillatory one. The decomposition method uses the envelopes defined by the local maxima and the local minima of the data series. Once the maxima of the original signal are identified, cubic spline is used to interpolate all the local maxima and construct the upper envelope. The same procedure is used for local minima to obtain the lower envelope. Next, one calculates the average of the upper and lower envelopes and subtracts it from the initial signal. This interpolation process is continued on the remainder. This sifting process terminates when the mean envelope is reasonably zero everywhere, and the resultant signal is designated as the first IMF. The first IMF is subtracted from the data and the difference is treated as a new signal on which the same sifting procedure is applied to obtain the next IMF. The decomposition is stopped when the last IMF has a small amplitude or becomes monotonic (Huang et al., 1998; Bekara and Van der Baan, 2008).

Examples

Seismic attributes can speed up the seismic interpretation since they are powerful tools to detect subtle changes in seismic data. However, not all attributes are robust and sometimes it is difficult to identify a physical meaning to their values; for instance, instantaneous frequencies always fluctuate rapidly with spatial and temporal location, and they can become negative which has no physical meaning.

The signal in the Figure 1 (a) is the sum of a chirp and linear trend. The instantaneous frequency of a chirp is a straight line and that of a linear trend a constant. We calculate the instantaneous frequency of their sum (Figure 1 (b)). The resulting instantaneous frequency fluctuates severely, despite the simplicity of the individual components. Figures 1 (c) and 1 (d) show the analysis results using respectively a short time Fourier and wavelet transform on the recorded signal. The short-time Fourier transform highlights both the trend as a DC component and the chirp. The wavelet transform only shows the chirp and clearly displays a varying time-frequency resolution.

We apply EMD on the composite signal to retrieve the chirp and the linear trend (Figure 2). EMD can extract the intrinsic components of original signal efficiently. After the EMD decomposition, each IMF is locally symmetric, so that the instantaneous frequency of each IMF is robust, smooth and guaranteed to be positive, thereby highlighting the inherent characteristics of each signal components.

We calculate the instantaneous frequencies of two IMFs after EMD decomposition, which are shown in Figures 3 (a) and (b), and compare these with the time-frequency analysis of short time fourier transform (Figures 3 (c) and (d)). The method of instantaneous frequency combined with EMD shows a higher time-frequency resolution. This synthetic data application demonstrates the suitability of EMD for more robust time-frequency analysis of seismic data.

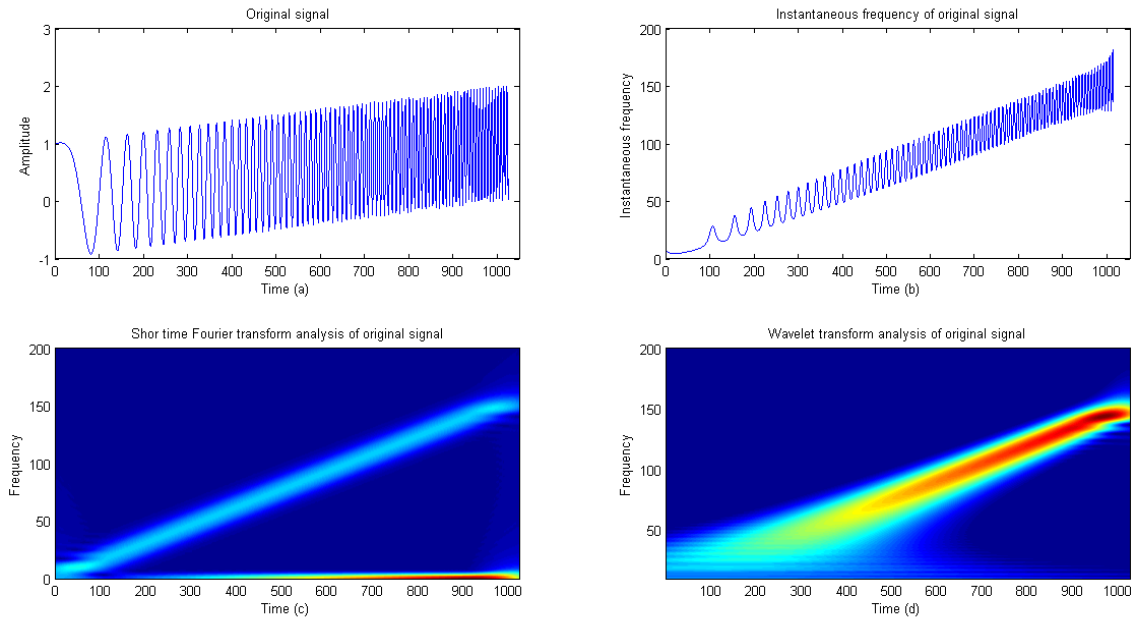


Figure 1: (a).The original signal is the sum of a chirp and linear trend. (b) The instantaneous frequency of the original signal is not robust and fluctuates severely. (c) Short time Fourier transform (STFT) analysis of original signal. (d). Wavelet transform (WT) analysis of original signal. The STFT displays a fixed time-frequency resolution whereas the WT has a varying one.

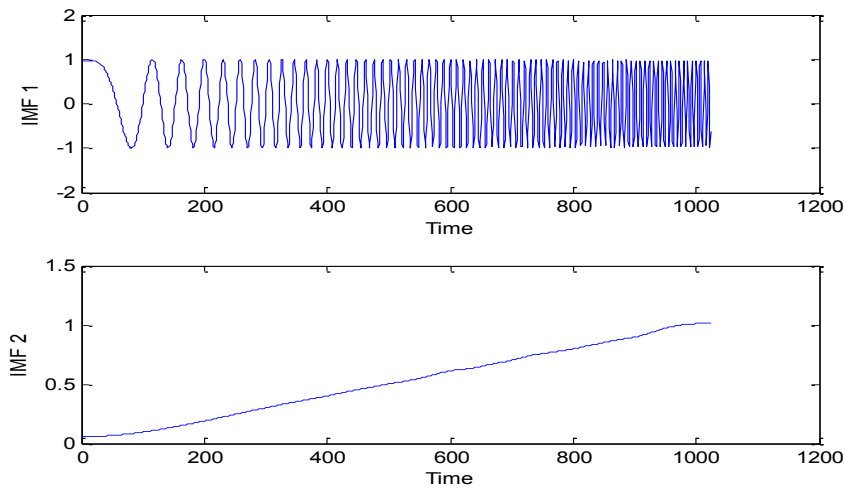


Figure 2: EMD decomposition on the original signal. IMF 1 (top signal) is a chirp, IMF 2 (below signal) is a linear trend. EMD extracts the intrinsic characteristics of the input signal efficiently.

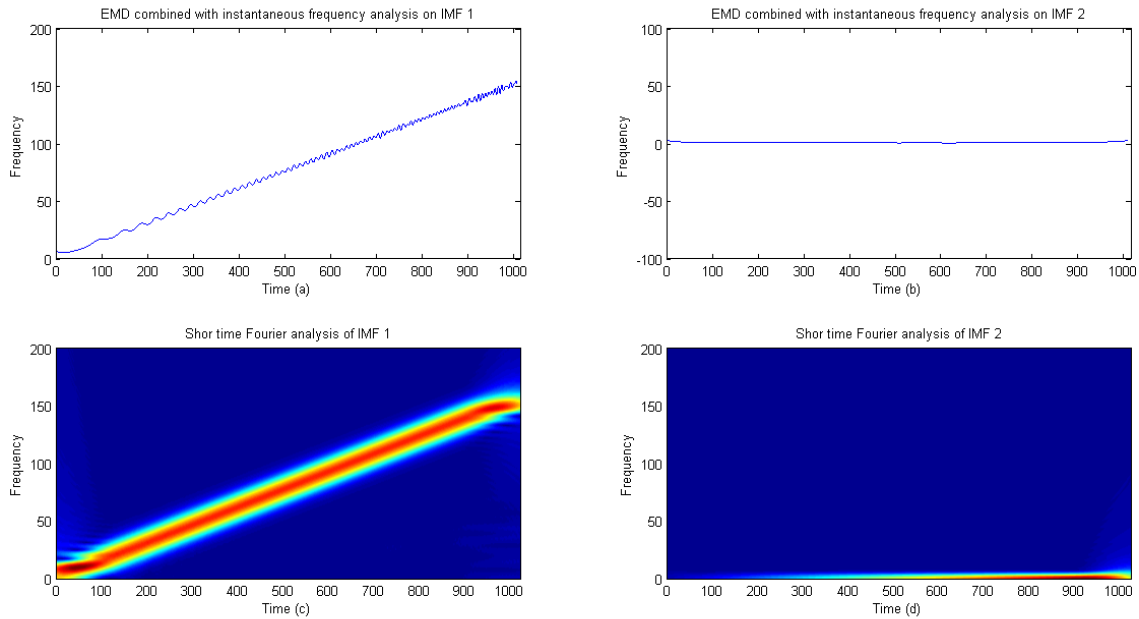


Figure 3: (a). Instantaneous frequency of IMF 1. (b). instantaneous frequency of IMF 2. (c). Short time Fourier transform analysis of IMF 1. (d). Short time fourier transform analysis of IMF 2. The instantaneous frequencies of two IMFs tend to be robust and smooth, and the method of EMD combined with instantaneous frequency has a higher time-frequency resolution than the short time Fourier transform.

Conclusions

From the synthetic data applications, the following conclusions can be drawn: first, EMD extracts the intrinsic characteristics from the non-stationary and nonlinear data adaptively and efficiently; second, the instantaneous frequency of each IMF after empirical mode decomposition tends to be robust and smooth; third, each IMF reflects different information in the input signal; fourth, EMD combined with instantaneous frequency is a possible alternative tool for high-resolution time-frequency analysis of seismic data.

Acknowledgements

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