Research on Seismic Wave Analysis Algorithm Based on HHT

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Abstract
The seismic signal is non-stationary signal, which needs to be introduced into the time frequency conversion method. EPAH is provided in this paper, which uses HHT to deal with the non-stationary seismic signal. The advantage of HHT using in processing non-stationary seismic signal is utilized in EPAH. Firstly, EMD is used to decompose the most significant information and energy of the seismic signal. Then, more low frequency information can be identified by spectrum conversion, so the relationship between time and frequency and power of seismic signal can be obtained. At last, the application of EPAH in time-frequency analyze is verified by matlab. It is shown that all kinds of feature of seismic signal can be obtained exactly.
Keywords: *seismic wave, time frequency analysis, HHT*

1 Introduction
Seismic signal analysis and processing is very important to study the geological structure and earthquake prediction. HHT time frequency analysis method, the definition of intrinsic mode function and the idea that the arbitrary signal is decomposed into intrinsic mode function are proposed, which makes the instantaneous frequency of the signal has the physical meaning. HHT is used in seismic signal analysis, and it is a hotspot in the field of signal processing.
Wu Shen et al use Hilbert spectrum to analyze the single channel seismic record, and the wavelet transform is used to do comparison [1]. Yang Peijie et al discuss that the main part of HHT is EMD (empirical mode decomposition) of signal, and complex signal can be decomposed into limited several intrinsic mode function by EMD, so the Hilbert time-frequency spectrum can be obtained [2]. The application paper is about using HHT in processing seismic data, which is provided by Huang Guangnan [3]. In these paper, the research results show that HHT has good ability of time-frequency resolving, it contributes to distinguish and verify the feature of minute structure or lithology interface in original profile at the part of extracting the seismic attribute profile, and it can get seismic profile with better SNR in part of removing noise in seismic data with noise, it is helpful for identifying the underground layer correctly.
On the basis of previous studies, this paper presents a seismic wave processing algorithm based on HHT called EPAH. It can realize the linear instant time-frequency analyze of seismic signal with physical significance, and can reflect the real seismic wave vibration characteristics.

2 Theory of Algorithm
HHT based seismic wave processing algorithm EPAH, which is divided into 2 parts: EMD solution and marginal spectrum analysis, respectively, to achieve the frequency filtering and feature extraction of the original seismic wave signal.

2.1 Emd decompositione

First of the original seismic wave signal based on the screening of EMD decomposition process, the specific steps are as follows:

The first step is to find out the local maximum and local minimum of the original seismic wave signal, and the local maximum value is used as the upper envelope through three spline interpolation, and the upper and lower envelopes should cover all the data. The local maximum and local minimum value of the envelope signal are obtained, and the average value of the envelope signal is obtained.

In the second step, the average value of the original signal is subtracted from the envelope signal, and the 1 envelope signal sequence is obtained,

$$x(t) - m_0(t) = h_1(t) \qquad (1)$$

The third step, if the condition of IMF, is the first natural mode function. Otherwise, as the original signal repeat the first step and the second step, until after the first k iteration to become a IMF,

$$c_1(t) = h_{1,k}(t) \qquad (2)$$

The iterative criterion for the steps is to make,

$$\mathrm{SD} = \frac{\sum_{t=1}^{T} | h_{1,k-1}(t) - h_{1,k}(t) |^2}{\sum_{t=0}^{T} | h_{1,k-1}(t) |^2} \qquad (3)$$

Between 0.2 and 0.3.

The fourth step is to get the first order residual signal from the original signal,

$$x(t) - c_1(t) = r_1(t) \qquad (4)$$

The fifth step, the remaining signal R1 (T) as the first signal to the first fourth steps.

Several IMF components can be obtained through the screening process, until it is too late to decompose the intrinsic mode functions so far. At this time of the cn(t) is the remainder, on behalf of the x(t) the mean or trend. x(t) can be obtained by adding the intrinsic mode function component of the cn(t). Where cn(t) as a residual function, the average trend of the signal. Each IMF component contains signals with different characteristic time scale the size of the components, the progressively larger scale. Therefore, each component is also corresponding to the composition of different frequency components from high to low, each frequency component contains the frequency components are different, and with the signal itself, the change and change.

2.2 Marginal spectrum analysis

The IMF component of the original seismic wave signal is obtained, and then the Hilbert transform for each order IMF is obtained. The Hilbert transform result can be obtained by any time series.

$$Y(t) = \frac{1}{\pi} pv \int_{-\infty}^{+\infty} \frac{X(\tau)}{t-\tau} d\tau \tag{5}$$

$$Z(t) = X(t) + iY(t) = a(t)e^{i\theta(t)} \tag{6}$$

And,

$$a(t) = \sqrt{X^2(t) + Y^2(t)} \tag{7}$$

$$\theta(t) = \arctan \frac{Y(t)}{X(t)} \tag{8}$$

Type (5): for the Cauchy Cauchy (Principal Value); for the input signal sampling time, sampling time for the output signal. Available analysis of the signal type (6). In this way, the Hilbert transform provides a unique definition of magnitude and phase function. Type (5) defines the Hilbert transform as a form of convolution, so the emphasis is on the local characteristics. Based on the Hilbert transform, the instantaneous frequency is defined as:

$$\omega(t) = \frac{d\theta(t)}{dt} \tag{9}$$

But it must satisfy some restriction conditions, can get the instantaneous frequency of the meaning. For example: the real part of the Fourier transformation must be the only positive. This restriction can be proved mathematically, but it is still a global definition. For data analysis, these conditions must be converted into the physical can be achieved by using a simple method to achieve. Therefore, the limiting conditions are based on the global change to local.
Then, the N transform of the original signal is converted to Hilbert,

$$X(t) - \mathrm{Re}\sum_{j=1}^{n} a_j(t)e^{i\phi_i(t)} = \mathrm{Re}\sum_{j=1}^{n} a_j(t)e^{i\int \omega_j(t)dt} \tag{10}$$

By means (10), the original signal can be expressed as a function of amplitude, instantaneous frequency and time, and the instantaneous amplitude is shown in the frequency of the time domain plane, which can be expressed in the three-dimensional Figure. The time-frequency distribution of the amplitude is defined as the amplitude spectrum, referred to as the Hilbert spectrum.

$$H(\omega,t) = \mathrm{Re}\sum_{j=1}^{n} a_j(t)e^{i\int \omega_j(t)dt} \tag{11}$$

Based on Hilbert spectrum, the marginal spectrum is defined as:

$$h(\omega) = \int_0^T H(\omega,t) \tag{12}$$

The marginal spectrum represents a measure of the magnitude (or energy) of each frequency on the global scale, which represents the sum of all data in the statistical sense. It can reflect the energy distribution of each frequency, but because the instantaneous frequency is defined as a function of time, the local characteristic of the signal is more accurate. Especially in the analysis of non-stationary signals, this definition can reflect the real seismic wave vibration characteristics of the signal characteristics of the time.

3 Analysis of Algorithm Performance

In this section, the performance of EPAH is verified by Matlab simulation. Fig. 1 is a seismic data section, and the horizontal coordinates represent the number of seismic traces. The seismic signal between 750~1750ms and is selected as the Hilbert Huang transform between 195th channels. Out of the seismic signal and its spectrum as shown in Fig. 2, the sampling interval is 1ms, the main frequency is concentrated between 20~40Hz.

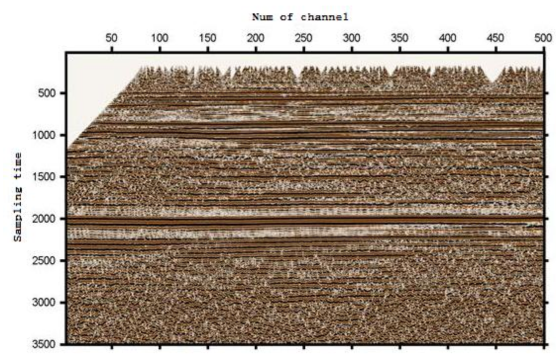


Fig. 1- Actual seismic section

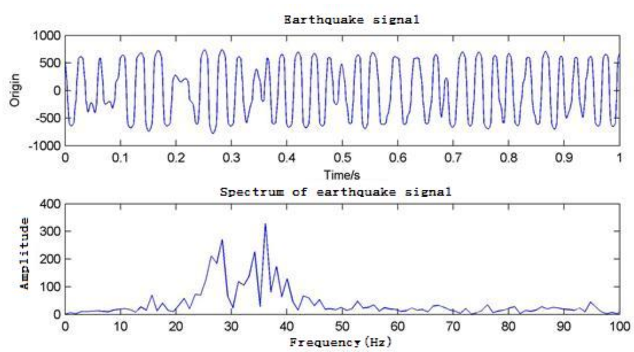


Fig. 2 - Seismic signal and its spectrum

The Fig. 3 is the EMD obtained 6 IMF component and a remainder of the seismic signal, R6 for residual function. By the decomposition diagram can be seen that the IMF component is a real reflection of the function of the signal, which is very unique.

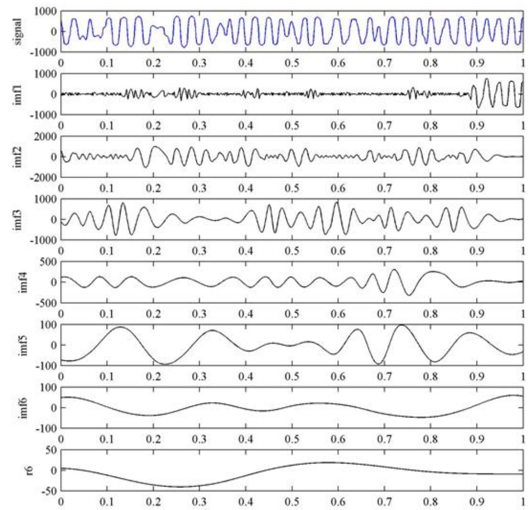
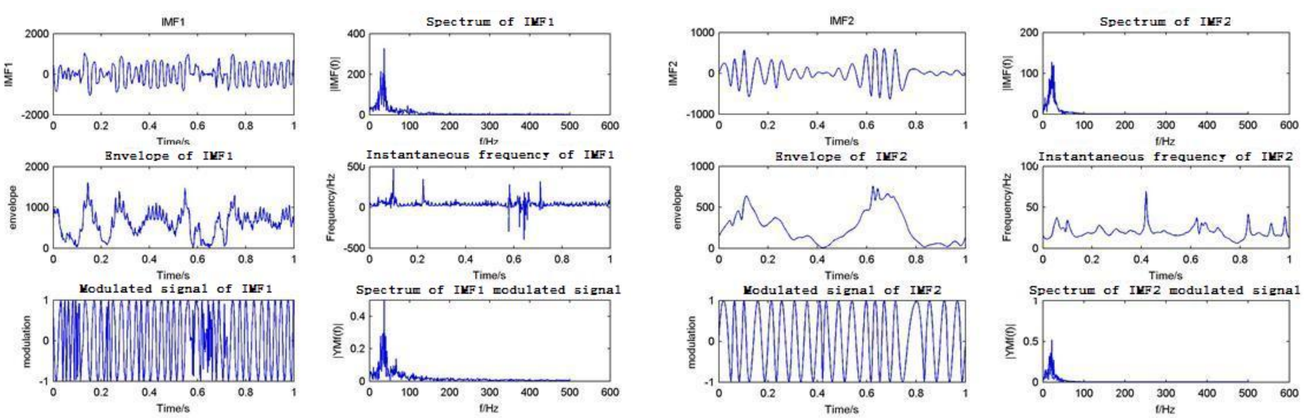


Fig. 3 - Empirical mode decomposition of seismic signal

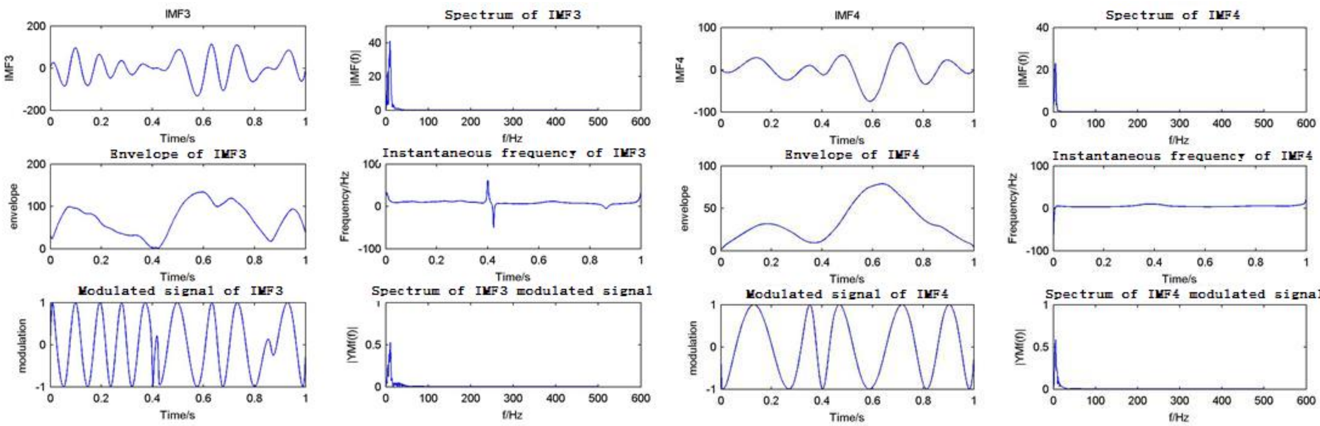
The Fig. 4～Fig. 6 is the instantaneous frequency of the 6 IMF components of the Hilbert transform and Fu Liye transform. From the instantaneous frequency of each IMF, we can see that the intrinsic mode functions of different scales and different frequencies are obtained by EMD decomposition, and the first order natural mode function has the highest amplitude, the highest frequency and the shortest wavelength. The distribution of the intrinsic mode function is determined by the nature of the intrinsic mode function. It is always the most important signal to be extracted first.

Compared with the spectrum of IMF, the instantaneous frequency of IMF can better reflect the frequency time distribution of the signal, and the energy of the signal is mainly concentrated in IMF1 and IMF2, which shows that the Hilbert spectrum has better time-frequency clustering, better time resolution and frequency resolution. So the Hilber-Huang transform of seismic signal can provide more useful information for the underground structure.



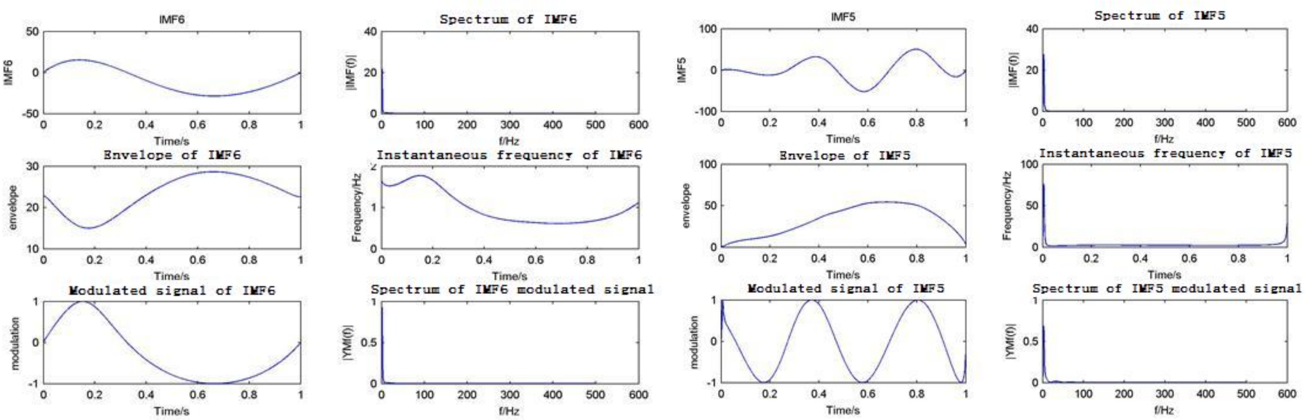
(a) IMF1 (b)IMF2

Fig. 4 - IMF1-2 time frequency chart of seismic signal



(a) IMF3 (b)IMF4

Fig. 5 - IMF3-4 time frequency chart of seismic signal

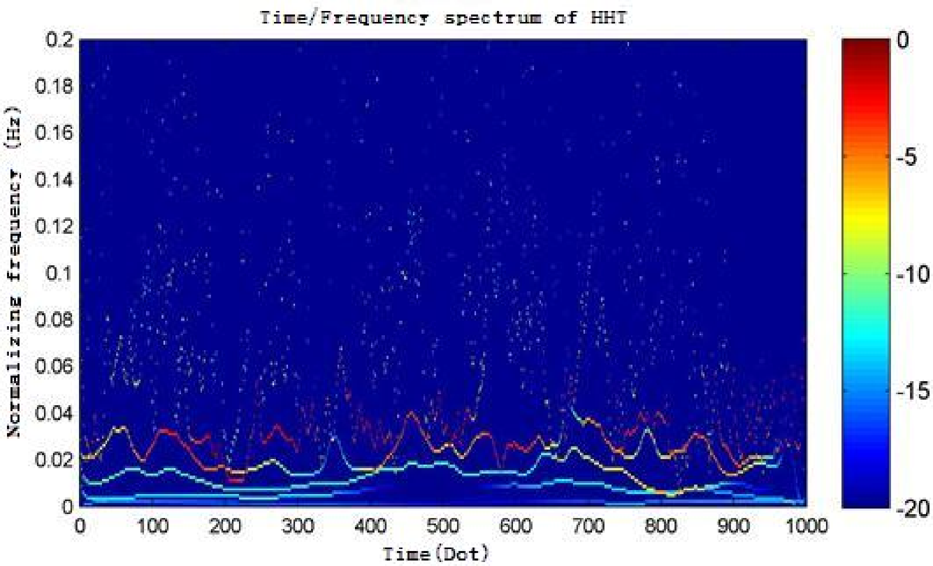


(a) IMF5 (b)IMF6

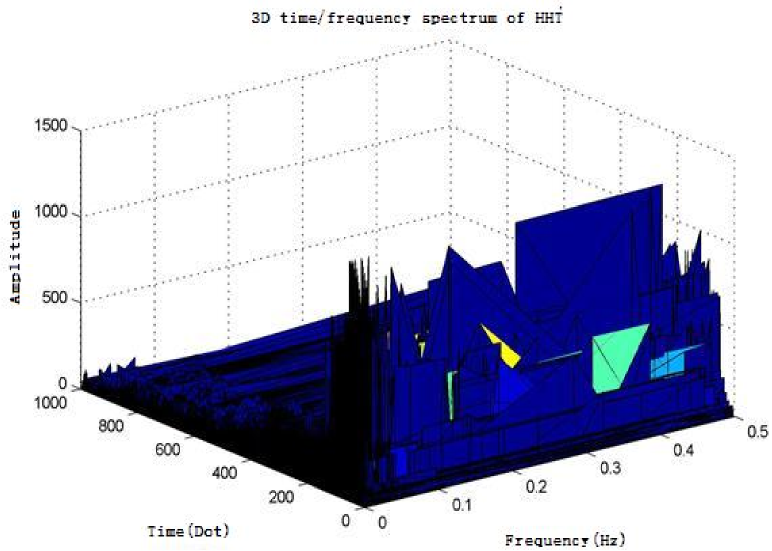
Fig. 6 - IMF5-6 time frequency chart of seismic signal

Fig. 7 (a) will each IMF signal synthesis for the seismic signal time-frequency spectrum. In the simulation took 1000 sampling points and sampling frequency of 1000Hz and the horizontal axis shows the normalized frequency is said the real frequency accounted for the percentage sampling frequency, the Figure shows the frequency is concentrated between 40Hz 20, but when spectrum can see the frequency time distribution. Fig. 7 (b) is a three-dimensional spectrum of seismic signal, you can see the signal in time - frequency energy distribution.

By the accumulation of time, the HHT method can be obtained by the marginal spectrum. Fig. 8 is the marginal spectrum of seismic signal. The marginal spectrum is non-stationary, which can reflect the instantaneous attributes, and the global distribution, that is, the statistical distribution of the instantaneous concept can be expressed.



(a) time spectrum of seismic signals



(b) 3D spectrum of seismic signal

Fig. 7 - IMF5-6 time frequency chart of seismic signal

The presentation for the Hilbert spectrum is already contains the decision all the information required for signal, time domain to complete and not redundant room for signal reconstruction and frequency domain on the marginal spectrum can reflect the signal energy distribution. And it can identify more low frequency information, which is helpful to the relationship between the time, frequency and energy of seismic signal. From this, the Hilbert spectrum obtained by HHT can obtain the optimal solution for the information in the signal analysis. The Hilbert spectrum is obtained by the direct variable (time frequency) to express the distribution of the energy of the signal itself. The algorithm itself ensures that the time frequency local variation characteristics of the signal can be reflected.

4 Conclusion

In this paper, the HHT based seismic signal processing algorithm EPAH is designed, which can establish a new time-frequency analysis method, which is based on instantaneous frequency, and can be used to analyze the linear instantaneous time-frequency analysis of seismic signal with physical meaning. The local features of the signal are more accurate, which is better than the Fourier spectrum, especially in the analysis of non-stationary signals, which can reflect the real vibration characteristics of the signal with time variation. This paper only makes a preliminary study, it needs to be further studied in the application of high resolution processing of seismic data.

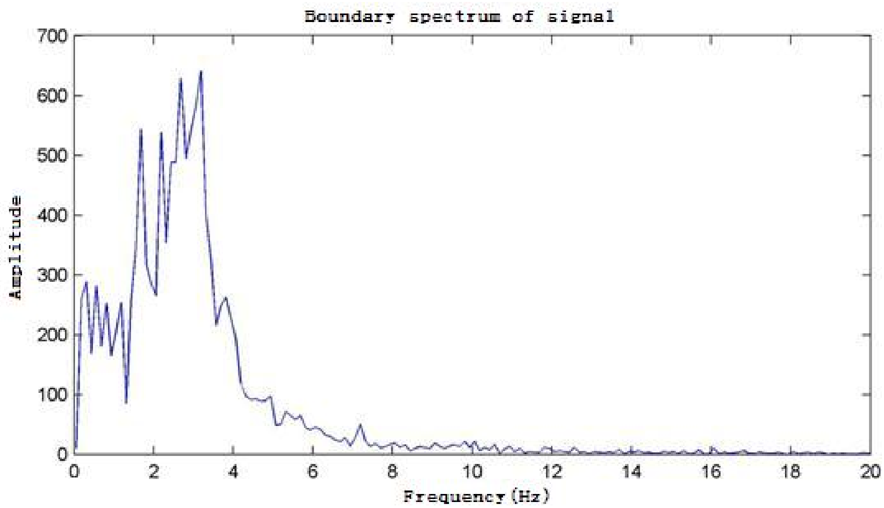


Fig. 8 - Marginal spectrum of seismic signal

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