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A Reservoir Information Extraction Method Based on Improved Hilbert-Huang Transform

Qingmi Yang
School of Communication Engineering, Chengdu University of Information Technology, Chengdu, China

ABSTRACT

Hilbert-Huang transform (HHT) is a nonlinear non-stationary signal processing technique, which is more effective than traditional time-frequency analysis methods in complex seismic signal processing. However, this method has problems such as modal aliasing and end effect. The problem causes the accuracy of signal processing to drop. Therefore, this paper introduces the method of combining the Ensemble Empirical Mode Decomposition (EEMD) and the Normalized Hilbert transform (NHT) to extract the instantaneous properties. The specific process is as follows: First, the EEMD method is used to decompose the seismic signal to a series of Intrinsic Mode Functions (IMF), and then The IMFs is screened by using the relevant properties, and finally the NHT is performed on the IMF to obtain the instantaneous properties.

Keywords : Hilbert-Huang Transform, Seismic Signal, Instantaneous Property, Reservoir

I. INTRODUCTION

The seismic signal belongs to a non-stationary, nonlinear signal. The instantaneous frequency obtained by directly using the Hilbert transform is only an approximation. The HHT is a new signal processing technique consisting of Empirical Mode Decomposition (EMD) and Hilbert Transform (HT)[1]. The IMF obtained by EMD decomposition belongs to the narrow-band single-component signal, which satisfies the requirements of Hilbert transform. In reservoirs with unsatisfactory seismic response characteristics, EMD can eliminate the interference of noise and other formation information, and reconstruct the seismic sub-signals for oil and gas detection by reflecting the characteristic components of oil and gas information [2]. The method is based on the characteristics of the signal, and does not need to preset any basis functions. The decomposition result is better than Fourier transform, wavelet transform and some other time-frequency methods [3,4,5]. However, not all single-component signals can obtain meaningful instantaneous frequencies through Hilbert transform, and EMD has modal aliasing problems. In this paper, the EEMD method is used to extract the instantaneous properties of seismic signals with clear physical meaning, which overcomes the modal aliasing by adding Gaussian white noise. HHT is limited by the Bedrosian principle and the Nuttall principle when performing the Hilbert transform, resulting in insufficient transient properties of the acquired seismic signals [6]. In view of the existing problems, this paper uses AM-FM demodulation and normalization method to improve it, which make it more suitable for seismic signal decomposition.

II. METHODS AND MATERIAL

2.1 EEMD Method

Huang et al. believe that EMD can be decomposed according to the time scale of the signal itself, without setting any basis functions. It can decompose nonlinear, non-stationary signals into a series of high-to-low frequency IMFs. An IMF must meet the following two conditions:

1) In the entire data set, the number of extreme points and the number of zero crossings are equal, or at most one difference
2) At any point in time, the mean of the lower envelope consisting of the upper envelope and the local minimum formed by the local maxima must be zero.

But EMD will have a very serious problem - modal aliasing [7]. Studies have shown that modal aliasing is mainly caused by intermittent phenomena, and intermittent phenomena are often abnormal events, such as intermittent signals, pulse interference and noise [8]. By introducing noise-assisted analysis, the EEMD method can better suppress the modal aliasing phenomenon generated in EMD, and make the obtained IMF component more physically meaningful.

The main steps for EEMD decomposition of the original seismic signal are as follows:

1) The Gaussian white noise $n_i(t)$ is added multiple times in the seismic signal $x(t)$, where the amplitude standard deviation of $n_i(t)$ is constant,
$$x_i(t) = x(t) + n_i(t) \qquad (1)$$
2) According to the EMD decomposition process, EMD decomposition is performed on $x_i(t)$, and IMF is obtained as $c_{ij}(t)$, where $c_{ij}(t)$ is the jth IMF decomposed after adding noise to the ith time.
3) Perform the overall average calculation on the IMF calculated above, and the result is the final result. The formula is as follows:
$$c_j(t) = \frac{1}{I}\sum_{i=1}^{I} c_{ij}(t) \qquad (2)$$

Where $c_j(t)$ is the jth IMF obtained after EEMD decomposition of the original seismic signal. x(t) is a continuous signal in the time domain, and its Hilbert transform is as follows:

$$h(t) = \frac{1}{\pi}\int_{-\infty}^{\infty} \frac{x(\tau)}{t-\tau} d\tau \qquad (3)$$

Analyze the signal to the following formula:

$$A[x(t)] = x(t) + jh(t) = a(t)e^{j\theta(t)} \quad (4)$$

The instantaneous amplitude and instantaneous phase are as follows:

$$a(t) = \sqrt{x^2(t) + h^2(t)} \qquad (5)$$

$$\theta(t) = \arctan\frac{h(t)}{x(t)} \qquad (6)$$

The instantaneous frequency is as follows:

$$f(t) = \frac{1}{2\pi}\frac{d\theta(t)}{dt} \qquad (7)$$

2.2 Improved Hilbert transform method

The IMF signal obtained from the original signal is decomposed into an envelope signal

$E_i(t)$ and a carrier signal $\cos\theta(t)$ of amplitude 1 and normalized at the same time. The instantaneous amplitude, instantaneous phase and instantaneous frequency of the signal are then obtained by Hilbert transform. By such improvement, the instantaneous frequency of the signal in the Bedrosian theorem can be compensated for by the noise, the frequency will have periodic intermittent interference, and the transient frequency has a negative value.

The specific steps of the improved HHT algorithm are briefly described as follows.

1) Calculate the absolute value $|x(t)|$ of an IMF component $x(t)$ and find the local maximum of $|x(t)|$
2) These cubic maxima are fitted using a cubic spline to obtain the empirical envelope signal $E_i(t)$
3) Normalize $x(t)$ with $E_i(t)$

$$y_i(t) = \frac{x(t)}{E_i(t)} \tag{8}$$

4) Test $y_i(t)$, when $|y_i(t)| \leq 1$, the normalization process ends. Otherwise, steps (1) through (3) are repeated until the final result $|y_n(t)| \leq 1$ satisfies the condition.

$$\begin{cases} y_2(t) = \dfrac{y_1(t)}{E_2(t)} \\ \vdots \\ y_n(t) = \dfrac{y_{n-1}(t)}{E_n(t)} \end{cases} \tag{9}$$

5) Calculate the instantaneous properties of the seismic signal, and the instantaneous amplitude of the IMF component x(t) is

$$E_{Amp}(t) = E_1(t)E_2(t)E_3(t)\cdots E_n(t) \tag{10}$$

Instantaneous frequency and instantaneous phase can be obtained by performing the Hilbert transform on the obtained $y_n(t)$

III. EXPERIMENTAL

IMPLEMENTATION

In order to verify the anti-modal aliasing effect of EEMD, EMD and EEMD decomposition are performed on the simulated signal synthesized by a low-frequency sinusoidal signal $y_1(t)$ and a high-frequency discontinuous signal $y_2(t)$.

$$y_1(t) = 5 * \sin(10\pi t) \quad 0 \leq t \leq 1 \tag{11}$$

$$y_2(t) = \begin{cases} 0 & 0 \leq t < 0.3 \\ 0 & 0.4 \leq t < 0.7 \\ & 0.8 \leq t \leq 1 \\ 3 * \sin(80\pi t) & 0.3 \leq t < 0.4 \\ & 0.7 \leq t < 0.8 \end{cases} \tag{12}$$

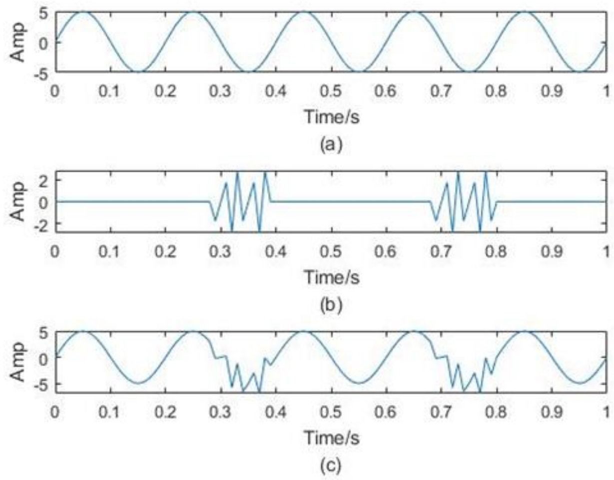


Figure 1 Synthetic signal comparison result ((a) low-frequency sinusoidal signal
(b) high-frequency discontinuous signal (c) Composite signal)

After the synthesized signal is decomposed by EMD, the result is shown in Fig. 2. As can be seen from the figure, the IMF1 component contains both a low frequency sinusoidal signal and a high frequency discontinuous signal, resulting in component modal aliasing. At the same time, the distortion and physical meaning of the remaining components are also unclear. The result of the simulation signal decomposed by EEMD is shown in Fig. 3. The IMF1 is mainly a high-frequency discontinuous signal, and the IMF2 is mainly a low-frequency sinusoidal signal. Comparing Fig. 2 and Fig. 3, it can be seen that for nonlinear and non-stationary signals, EEMD can greatly suppress the influence of modal aliasing caused by discontinuous signals.

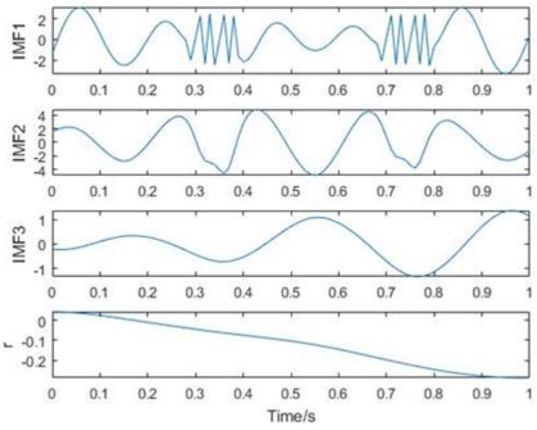


Figure 2 EMD decomposition result

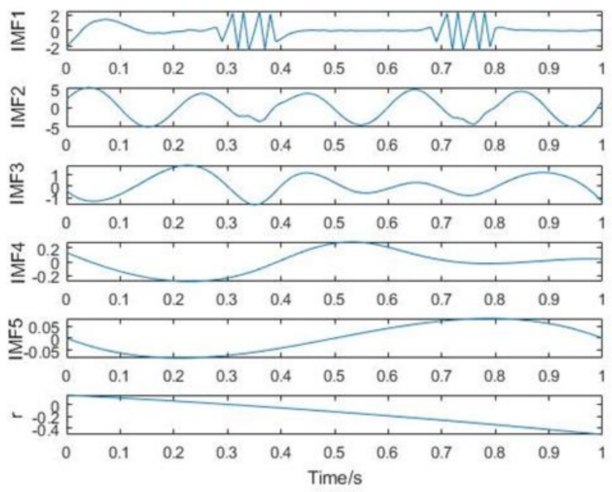


Figure 3. EEMD decomposition result

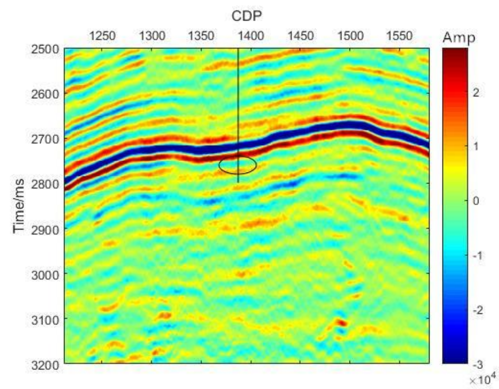
Taking a certain area of China as an example, according to the drilling data, there are three wells in the target area, the reservoir depth is about 5,000 m, and the seismic response characteristics of the target layer are weak. EEMD is performed on the B well seismic signal, and all IMF components are obtained. Then, correlation analysis is performed on each obtained IMF component and B well data, and the results are shown in Table 1.

Table 1. Correlation coefficient between each IMF component and B well data

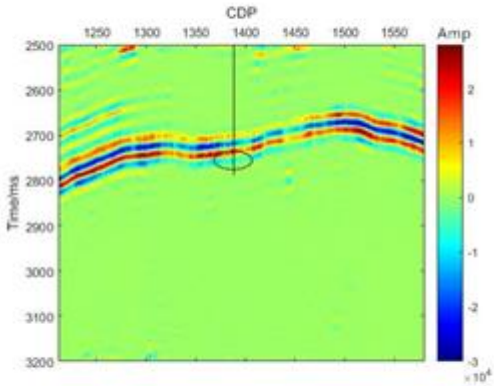
Parameter	IMF1	IMF2	IMF3	IMF4	IMF5	IMF6	IMF7	r
B well	0.7712	0.7656	0.5592	0.3892	0.0702	0.0116	0.0018	0.0203

Fig. 4(a) shows the original section of well B. It can be seen from the figure that the difference between the amplitude of the elliptical target area and the surrounding area of the original section is not obvious, and it is difficult to identify the gas content of the reservoir. It can be seen from Table 1 that the first three IMF components contain the main features of the original signal, and then the original profile of the B well is processed by EEMD one by one. The obtained IMF component profile is shown in Figures 4(b)-(d). As can be seen from the figure, the IMF1 component profile contains Gaussian noise because it is the highest frequency profile. The IMF2 profile highlights the primary reflector of the original profile, with less interference, clear target areas and significant differences in amplitude and surrounding amplitude. The IMF3 profile reflection energy is weakened and the reflective layer becomes blurred. At the same time, the same result can be obtained by performing EEMD processing on the A and C well data. So, we believe that the IMF2 profile can better characterize the distribution of the reservoir and the gas-bearing information.

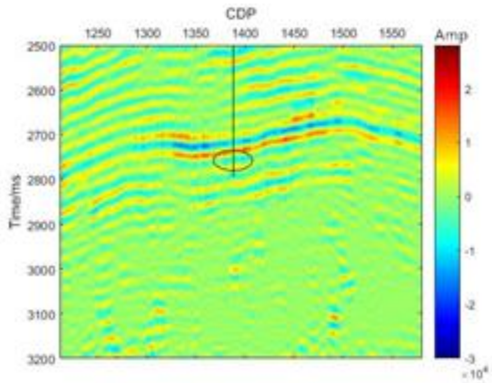
Therefore, for the extraction of gas-containing properties, this paper only considers the IMF2 component.



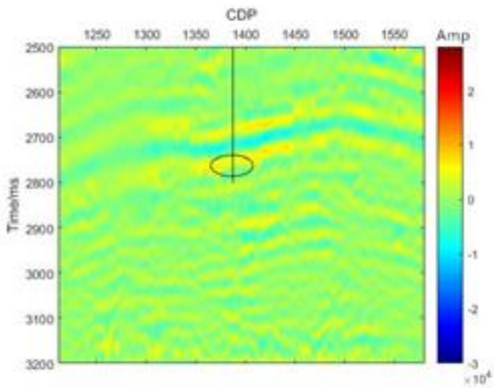
(a) B well original section



(b) IMF1 profile



(c) IMF2 profile



(d) IMF3 profile

Figure 4. Profile Comparison

The seismic signal of Well B is selected, and the IMF2 component obtained by EEMD is processed by HT and improved NHT method respectively. The instantaneous parameter comparison diagram is shown in Figure 5. The dotted line in Figure 5(a) is the original waveform of IMF1, The blue curve is the result of the HT process and the red curve is the result of the NHT process. It can be seen from the figure that the instantaneous amplitude obtained by the NHT is smoother than that of the HT, and at the extreme point of the original seismic signal IMF1, the result of the NHT is more suitable for the original signal, the result of HT is largely offset from the original signal at the end. In Figure 5(b), at the front end of the signal, the instantaneous frequency curves of NHT and HT are basically coincident, but there is no physical negative value at the tail end HT, and the NHT curve is smooth without negative values.

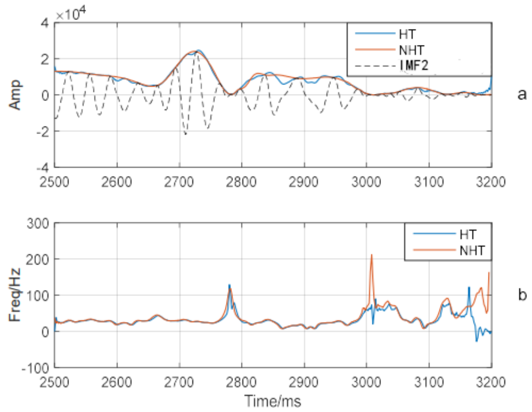


Figure 5 Comparison of HT and NHT for instantaneous parameter results

IV.CONCLUSION

This paper analyzes the shortcomings of the HHT method, and improves the details of HHT in response to these shortcomings, and finally forms an improved HHT method. First, EMD cannot effectively separate local burst high-frequency signals, causing aliasing and interference between sub-components. EEMD adds Gaussian white noise to the signal to be decomposed, so that each frequency component is continuous on the time scale. Secondly, the result of EMD decomposition is not satisfied by the conditions of Bedrosian theory and Nuttall theory. The instantaneous parameters obtained by Hilbert transform may contain singular values, and the improved algorithm normalizes the Hilbert transform to The original signal is decomposed into a frequency modulation portion and an amplitude modulation portion such that the instantaneous parameters of the solution have a clear meaning.

V. REFERENCES

[1]. HUANG N E, SHEN Z, LONG S R, et al. The empirical mode decomposition and the Hilbert spectrum for nonlinear and non-stationary time series analysis [J]. Proceedings of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences, 1998, 454(1971): 903-995.

[2]. XUE Y J, CAO J X. Seismic signal attenuation analysis using ensemble empirical mode decomposition and wavelet transform [J]. Oil Geophysical Prospecting, 2016, 51(6): 1148-1155. (in Chinese)

[3]. Huang Y P, Geng J H, Zhong G F, et al. Seismic attribute extraction based on HHT and its application in a marine carbonate area[J]. Applied Geophysics, 2011, 8(2): 125-133.

[4]. Xue Y J, Cao J X, Tian R. A comparative study on hydrocarbon detection using three EMD-based time–frequency analysis methods [J]. Journal of Applied Geophysics, 2013, 89: 108-115.

[5]. Chen C S, Jeng Y. Natural logarithm transformed EEMD instantaneous attributes of reflection data[J]. Journal of Applied Geophysics, 2013, 95: 53-65.

[6]. Nuttall A H, Bedrosian E. On the quadrature approximation to the Hilbert transform of modulated signals [J]. Proceedings of the IEEE, 1966, 54(10): 1458-1459.

[7]. Huang N E, Shen Z, Long S R. A new view of nonlinear water waves: the Hilbert spectrum [J]. Annual review of fluid mechanics, 1999, 31(1): 417-457.

[8]. Huang N E, Wu M L C, Long S R, et al. A confidence limit for the empirical mode decomposition and Hilbert spectral analysis [J]. Proceedings of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences, 2003, 459(2037): 2317-2345.

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