An Effective Method on Reducing Measurement Noise Based on Hilbert-Huang Transform

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Abstract: For non-stationary signal in ultrasonic inspection, an effective denoising method based on Hilbert-Huang transform (HHT) is presented and a few key questions using the HHT method are discussed. The overall scheme of HHT includes two parts which are empirical mode decomposition (EMD) algorithm and a sum of intrinsic mode functions (IMF). Through the EMD process, individual IMF can be found. The IMF coefficients are preceded in useful signal dominative layers using a soft threshold method and finally those IMF coefficients are reconstructed. The results show that the usage of HHT method is reasonable at removing the measurement noise than the wavelet transform.

Key-Words: - Ultrasonic inspection, Hilbert-Huang Transform, Wavelet Transform, denoising scheme.

1 Introduction

Ultrasonic inspection techniques are commonly used to characterize welds in a variety of applications such as chemical and nuclear plants, and gas transmission. Due to the imperfections introduced into the material during the welding process, welding regions are often susceptible to various kinds of defects. In ultrasonic inspection of submarine hull welding, the detection of flaws is often rendered difficult by the clutter introduced due to the grain structure of the material. The scattering of ultrasonic waves from grain boundaries can interfere and introduce artifacts in the received signal that can sometimes mask indications of a small flaw. Hence, denoising the signal will enhance the ability of the automatic signal processing (ASP) system to detect flaws. In order to reduce noise in the detected signal, researchers provided many different kinds of signal processing methods, such as Short Time Fourier transform (STFT), two-dimensional fast Fourier transform, Wavelet transform and Wigner-Ville Transform [1,2]. Since STFT only analyzes stationary signals, the window width must be restricted in time and frequency domain. Wavelet transform has advantages such as being able to change adaptively to the time and frequency resolution according to the different frequency band, but the performance depends on the selection of wavelet basis.

Hilbert-Huang Transform (HHT) is a time-frequency analysis technique introduced by Huang to process non-stationary signals. It combines the Hilbert transform and the Empirical Mode Decomposition (EMD). According to time scale characteristics, a signal is decomposed into a sum of a mono-contribution function called Intrinsic Mode Function (IMF), which emphasizes local feature. Through the decomposition, these IMF coefficients are transformed and processed by Hilbert transform. The HHT has two advantages: First, the signals with variable amplitudes and frequencies are obtained based on the EMD process. This process shows the advantage of breaking down the restriction of the Fourier transform with fixed amplitudes and frequencies. Second, EMD belongs to adaptive decomposition whose basis functions are sine and cosine functions, which has a series of variable amplitudes and frequencies. For non-stationary signals, this paper applied to the HHT method for reducing the noise.

In this paper, we first explain the Hilbert-Huang Transform in the next section. The denoising method with wavelet transformation and modified HHT will be discussed and followed by conclusion.

2 The HHT method

The Hilbert Huang Transform (HHT) consists of two processes. First, it performs the Empirical Mode Decomposition (EMD) of the signal. Second, it calculates the Hilbert Spectrum of the EMD output IMFs. From these spectrums, an amplitude and frequency-time representation of the signal can be determined. Fig 1 describes the general flow of HHT. EMD algorithm plays role in HHT method to remove the measurement noise. The main interest of the EMD is to consider the features of the analyzed signal, which are oscillations on determining the IMFs by using an iterative process. This explains that the time-scale of the decomposition will automatically be adapted to the dynamic of the analyzed signal. The individual IMF is the result of the sifting process, which attempts to satisfy the following two criteria [3-6].

(1) The number of zero crossings and the number of local extrema must be the same or off by at most one.

(2) The mean defined by the average of the local maxima envelop and local minimum envelop must be zero.

The following describes the general procedures for the sifting process of EMD.

Step 1: Calculate the upper and lower envelopes of the signal $x(t)$ and their mean value $m_1(t)$.

Step 2: Calculate $h_1(t)=x(t)-m_1(t)$

Step 3: Check if $h_1(t)$ satisfies the IMF properties.

Step 4: If not, use $h_2(t)= h_1(t)-m_2(t)$ to obtain new h, where $m_2(t)$ is found from $h_1(t)$ as in Step 1.

Step 5: Continue until an $h_k(t)$ satisfies the IMF properties. When done, $c_1(t)=h_k(t)$ is the first IMF.

Step 6: Considering the $r(t)=x(t)-c_1(t)$ as the new signal, continue from Step 1 to get the higher IMFs, upto $c_n(t)$. The process is continued until the residue becomes a monotonous function.

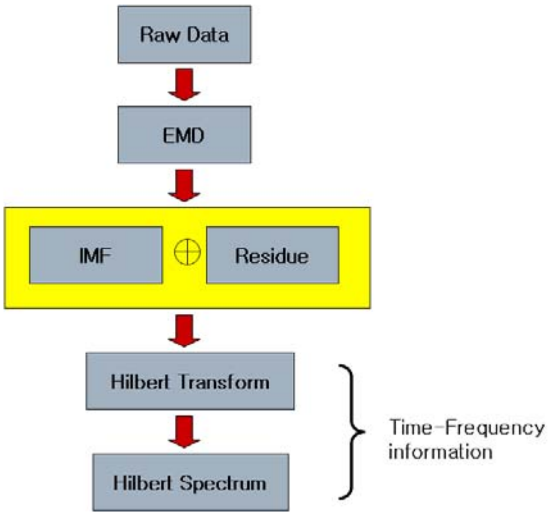


Fig. 1. The overall process of HHT

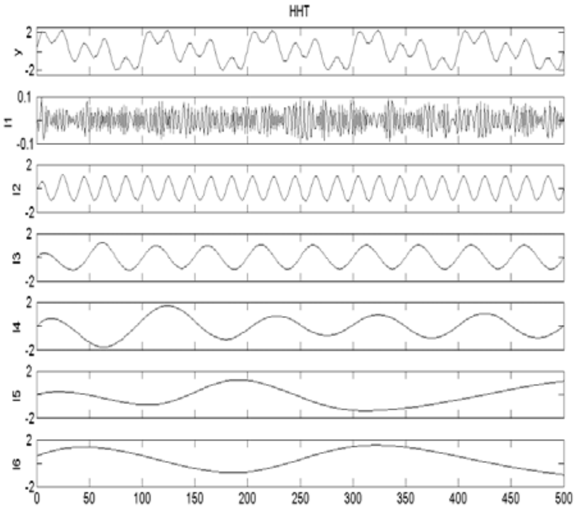
Fig. 2 shows the EMD decomposition and corresponding frequency spectrum on different scales with a signal,

$$x(t) = \sin(2*\pi*50*t) + \sin(2*\pi*100*t) + \sin(2*\pi*150*t) + 0.2*rand.$$

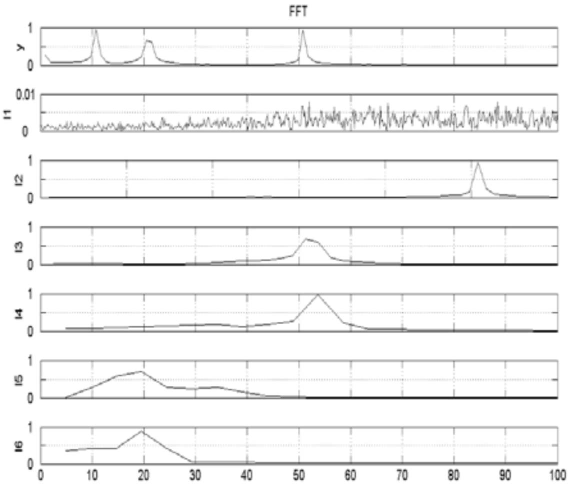
From Fig.1, it can be seen that EMD is a new principal component analysis method, which extracts IMFs from high to low frequency, and those IMF coefficients focus on the most significant information of the original signal. Generally, noises are mainly concentrated on the first several scales. In Figure 1, IMF1 mainly includes high-frequency noise on the first scale, IMF2 on second scale of 150Hz, IMF3 of 100Hz, and IMF4 of 50Hz respectably. Through this process, the useful information can be extracted from EMD algorithm.

3 The denoising method by Wavelet transform

A typical weld geometry of the ultrasonic hull inspection is shown in Fig. 3. Using the piezoelectric sensor, the exciting frequency of ultrasonic is 5MHz, and the sample frequency is 25MHz. Fig. 4 shows the measured signal and corresponding frequency spectrum.



(a)



(b)

Fig. 2. EMD decomposition and frequency spectrum analysis: (a) EMD decomposition and (b) Frequency spectrum on different scales.

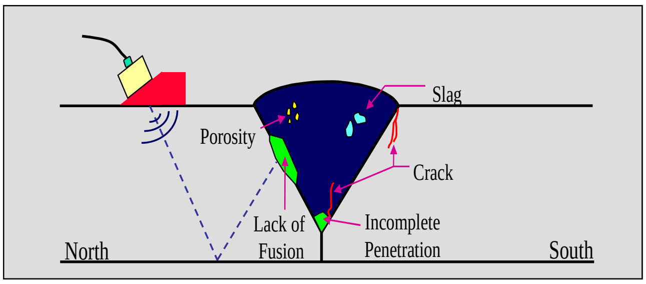
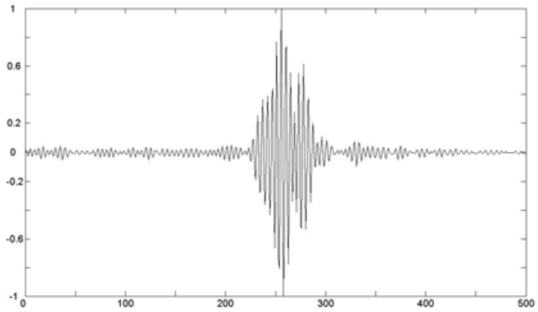
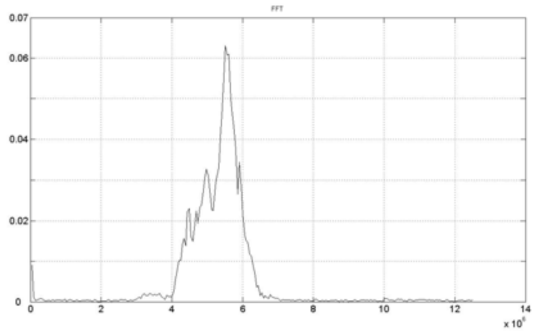


Fig. 3. Weld inspection geometry.



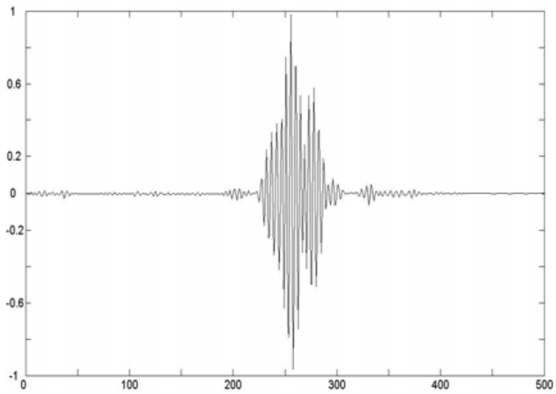
(a)



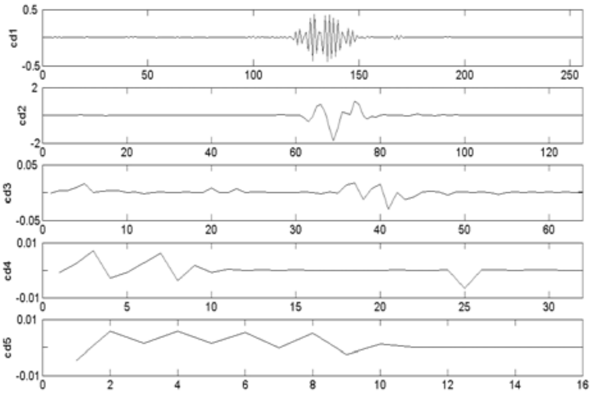
(b)

Fig. 4. The original signal and its spectrum.

The principle of denoising method using Wavelet transform is that the wavelet coefficients belonging to the noise at each scale must be removed while keeping the valuable signal. Finally, the reconstruction of the decomposed and denoised signal can be processed by reciprocity property. Fig. 5 shows the denoised signal and decomposition process by the Daubechies Wavelet threshold method.



(a)



(b)

Fig. 5. The results from (a) a denoised signal and (b) its decomposition by Wavelet Transform

4 The denoising method based on HHT

In Fig. 5-(a), we can see that the denoising effect is not very well compared to that of the Wavelet transform. Fig. 5-(b) shows the decomposition on different scales and the decomposition shows that measurement noise still exists on different scales. This paper uses the HHT method to remove the measurement noise. Fig. 6 is the decomposed signal by HHT, which shows that noise and useful signal mainly focus on the first several scales (such as 1^{st},2^{nd}, 3^{rd}). In other words, the rest of IMFs can be ignored since the scales of the intrinsic mode amplitude are very small.

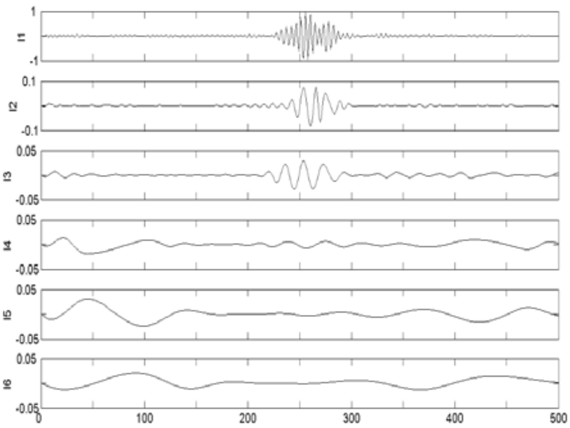
The denoising procedure by HHT is as follows:

(1) The signal with the noise is decomposed by EMD.

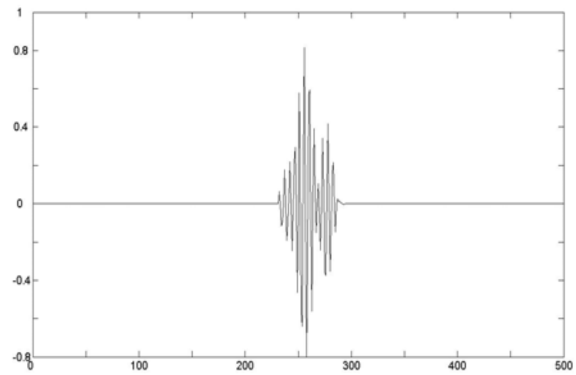
(2) From the scale with the valuable information, for example, 1^{st}, 2^{nd} or 3^{rd} scale, choose appropriate threshold at every scale [7] and remove high frequency noises using Eq. (1).

$$imf^{'}(j,k) = \begin{cases} 0, & if\left|imf(j,k) < C_j\right| \\ sgn(imf(j,k))(\left|imf(j,k)\right| - C_j) & if\left|imf(j,k) \geq C_j\right| \end{cases} \quad (1)$$

where $\{C_j\}$ are thresholds. The proceeded IMF coefficients from those scales (mainly the first 3 scales) are reconstructed and the filtered signal can be obtained from the reconstruction process. Fig.6-(b) shows the filtered signal by the method above. Comparing to Fig.5-(a), we could figure out that the result of the HHT method is better than that of the Wavelet transform.



(a)



(b)

Fig. 6. The results from (a) decomposition by HHT and (b) the denoised signal.

5 Conclusion

This paper introduced a method that is used to remove the measurement noise in welding by HHT. After analyzing its characteristics, the HHT method showed the capability to remove the measurement noise. The results showed that IMF coefficients by EMD include the local attribute information of the signal, which can reflect the signal's non-stationarity. Compared to the Wavelet transform, the HHT method has a better improvement.

Using the HHT method, several problems should be resolved for the future works. First, boundary treatment: Due to the limited length of the signal, both its two endpoints are not sure to be the extrema, therefore, the upper and lower envelop by cubic spline interpolation could be distorted seriously near the signal's each endpoint. Therefore the method of symmetric extension, endpoints value extension or a method selecting a starting point of the spline interpolation near the endpoint according to the change trends should be considered. Second, soft thresholding method: For the denoising purpose, it always comes up as a main issue for thresholding. We need to more study for the optimal thresholding value selection.

References:

[1] HE Cunfu, LI Ying, WANG Xiuyan, WU Bin, LI Longtao, "Ultrasonic Guided Wave Signal Analysis Based on Wavelet and Wigner-Ville Transform Processing", *Journal of Experimental Mechanics*, Vol. 20(4), 2005, pp. 584-588.

[2] D. H. Zou, Y.Cui, V. Madena, C. Zhan, "Effects of frequency and grouted length on the behavior of guided ultrasonic waves in rock bolts", *International Journal of Rock Mechanics and Mining Sciences*, Vol. 44, 2007, pp. 813-819.

[3] N.E Huang, "The empirical mode decomposition and Hilbert spectrum for nonlinear and Hilbert spectrum for nonlinear and nonstationary time series analysis", *Pro. R. Soc*. London, Vol. 454, 1998, pp. 903-995.

[4] Hassan Sharabaty, Bruno Jammes, Daniel Esteve, "EEG analysis using HHT: One step toward automatic drowsiness scoring", *22nd International Conference on Advanced Information Networking and Applications*, 2008, pp. 826-831.

[5] Gabriel Rilling and Patrick Flandrin, "One or Two Frequencies? The Empirical Mode Decomposition Answers", *IEEE Tran. on Signal Processing*, Vol. 56(1), 2008, pp. 85-95.

[6] Sun Liying, Li Yibo, Qu Zhigang, etal, "Study On Acoustic Emission Detection For Pipeline leakage Based On EMD Signal Analysis Method", *Journal of Vibration and Shock*, Vol. 26(10), 2007, pp. 161-164.

[7] Donoho D L, "De-Noising by Soft-Thresholding", *IEEE Trans. Inform. Theory*, Vol. 41(3), 1995, pp. 613-627.