INSTANTANEOUS FREQUENCY ESTIMATION AND ITS APPLICATION TO HEART SOUND SIGNALS

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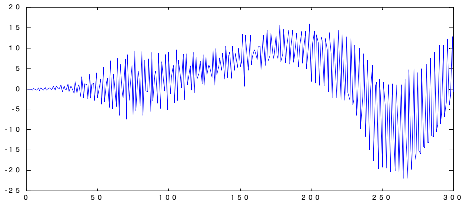
Stationary process analysis has long been dominated by FFT with its end products in the form of power spectra. Various significant results have been routinely obtained for the signals that satisfy both stationarity and periodicity in time domain. However, in practical application, the FFT-based power spectral analysis fail to deal with the medical signals since many kinds of practical signals such as heart sound signals, EEG, EMG and ECG turn to be extremely non-stationary and nonlinear time series. Alternatives for these medical signals are thus needed so that we can investigate how a signal's frequency changes with time at a high resolution in both time and frequency domains. There have been different time-frequency representations, such as short time Fourier transform (STFT), Wigner-Ville distribution (WVD) and wavelet transform, for this purpose. Nevertheless, there exist more or less significant disadvantages for these methods. The heart sound signals are the acoustic measurements caused by the vibration on opening and closing of cardiac valves and other surrounding structures. The understanding of the heart vibration mechanism and the inherent complexity of the sounds are still limited since the sounds measured on the surface of the chest are related to their generation mechanism and the diagnosis in a very complex manner. The high resolution time-frequency distribution of the heart sounds can provide us useful information regarding the heart.

To provide a more efficient way for the analysis of non-stationary and nonlinear signals with high time-frequency resolution and extract more information about the acoustic frequency features involved in the HS signals, a new method is developed in this paper to investigate the instantaneous frequency distribution of the practical heart sound signals. The aim of this contribution is to explore the role that both empirical mode decomposition and Hilbert transform can be used to play in such practical signals. The novel decomposition analysis for a non-stationary time series consists of a procedure of decomposing a time series into a finite set of functions, known as the intrinsic mode functions (IMF), based on a sifting procedure. Then the Hilbert transform is applied to the intrinsic mode functions to construct the global time-frequency distribution of the underlying signal with a point of view of instantaneous frequency. To avoid the waver phenomena of the instantaneous frequency due to the estimation of the time-varying phase of the signal, a new method is also developed to smooth each instantaneous frequency estimation of IMF such that a more accurate and sharper instantaneous frequency distribution can be obtained. The novel time-frequency technique provides a sharp identification of embedded structures of the signals, by comparing with other time-frequency distribution like WVD or wavelet transform.

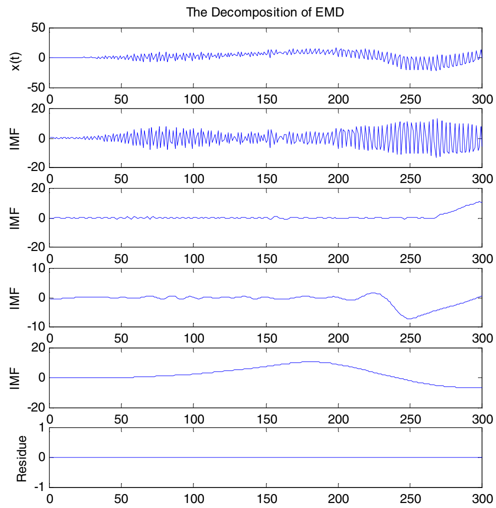
Both simulation and experimental results were presented and analyzed to demonstrate the power and effectiveness of the proposed new time-frequency distribution. As an example, Fig. 1 (a) shows a record of non-stationary signal. Its corresponding empirical mode decomposition is also presented in Fig. 1 (b). The signal is decomposed into 4 basic IMF components. The time-frequency distribution of the signal was shown and compared with the result by using Morlet wavelet transform in Fig. 2. Clearly, the time-frequency distribution by using Hilbert spectrum is much better than the results by employing the Morlet wavelet transform. With Hilbert-based spectral analysis, two kinds of clinical heart sound signals with normal and abnormal cardiac functions recorded from the surface of the chest were studied. These instantaneous frequency distributions of the heart sound signals were also compared with the results by using the Morlet wavelet transform. Fig. 3 shows an example of the time-frequency distribution of the normal and abnormal heart sounds by using both Hilbert spectra and wavelet transform. Fig. 3 (a) and (d) show two records of normal and abnormal heart sound signals. With the new time-frequency technique discussed in this paper, the time-varying frequency components of the heart sound signals can be clearly identified, as shown in Fig. 3 (b) and (e).

The results indicate that the time-frequency structures of heart sound series are too vague to identify the individual frequency component when using the wavelet analysis since the wavelet transform is a mathematical decomposition and the energy in high frequency will be spread. However, the sharper time-frequency distribution of heart sound signals can be obtained for clinical purpose by using the instantaneous frequency estimation due to the novel decomposition is a physical decomposition process. The Hilbert spectrum is regarded as a local and adaptive method in time-frequency analysis. This novel method provides us a new physical insight in understanding the non-stationary and nonlinear phenomena of heart sounds and other practical signals. The instantaneous frequency estimation, including the proper decomposition and smoothing, also provides a new way to effectively deal with the time-varying spectral characteristics of the non-stationary medical signals in a wide range of practical applications.

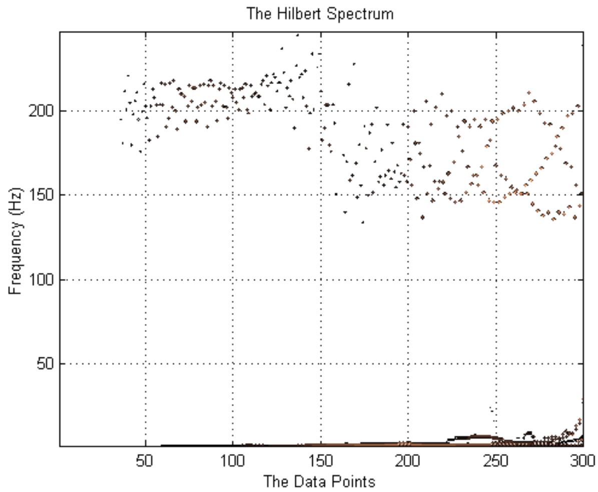


(a)

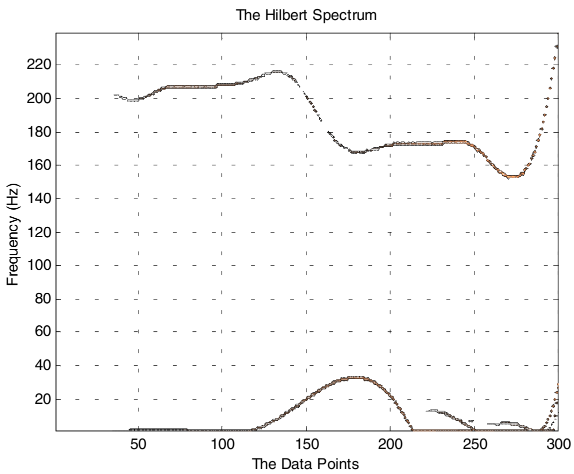
Fig. 1 A non-stationary process (a) and its corresponding empirical mode decomposition. The original signal was decompounded into 4 basic components.



(b)



(a)



(c)

Fig. 2 (a) The instantaneous frequency estimation of the signal before smoothing. (b) The smoothed instantaneous frequency distribution of the signal via a specified smoothing method. (c) The Morlet wavelet transform of the signal.

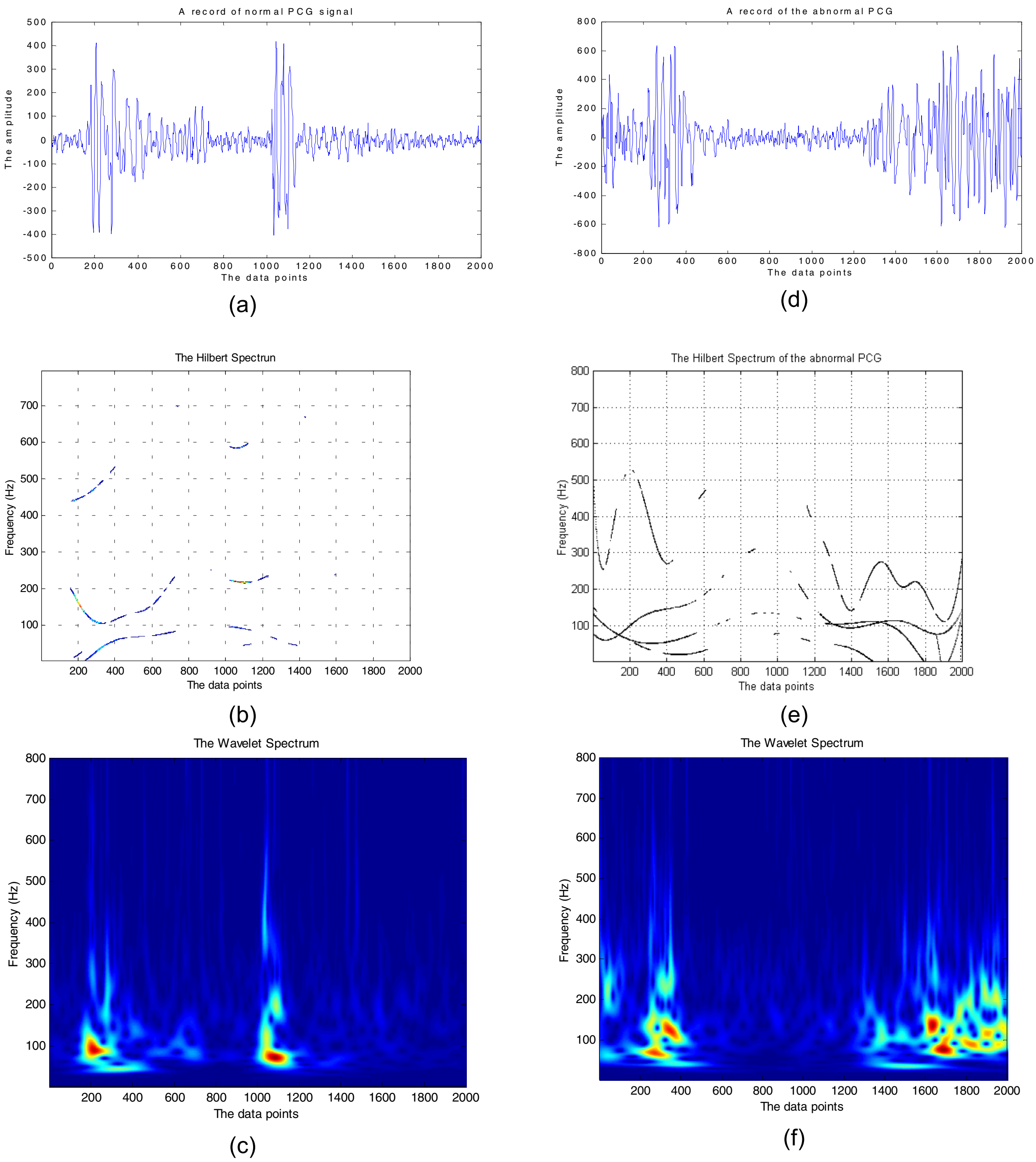


Fig.3 (a) and (d): Two records of heart sound signals with normal and abnormal cardiac function. (b) and (e): The corresponding Hilbert spectral estimations of the signals in (a) and (d). (c) and (f): The corresponding wavelet spectra of the signals in (a) and (d), as the results compared with the Hilbert spectra