A Wavelet-based Factor for Classification of Heart Sounds with Mitral Regurgitation

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ABSTRACT

Heart sound analysis has been shown to provide an assessment of heart diseases. In this research, two groups of patients: patients with normal heart sounds and those with mitral regurgitation, were studied. The application of wavelet transform analysis to the heart sound signals is investigated for both groups. High frequency components of heart sounds with mitral regurgitation can be observed at the smaller scales of the Continuous Wavelet Transform (CWT). It shows that the patients with mitral regurgitation exhibit more nonuniformity of energy distribution than those with normal heart sounds in the time-scale representation. In order to quantify the degree of nonuniformity, a new concept of a Local Intermittency Factor computed from the CWT is introduced for patient classification. It is shown that the heart sounds of patients with mitral regurgitation tend to have higher Local Intermittency Factor than those with normal heart sounds.

Keywords: continuous wavelet transform; local intermittency; mitral regurgitation; murmur

1. INTRODUCTION

The mechanical function of the heart, blood flow and valve movements produce the heart sound during heart contraction and relaxation. The heart sound signal is an important clinical information in the diagnostic process of heart malfunctions. Traditionally, heart auscultation is a screening method for early diagnosis of heart diseases but it has a limitation of human hearing. Thus, it requires the skilled cardiologists to diagnose heart sounds more accurately. Therefore, phonocardiography has been developed to record the heart sound signal with a conventional sound sensor on the chest. It shows a recording of the heart sound signal. The heart sound is considered as a nonstationary signal. It is very difficult to analyze this signal in the time domain. It is thus necessary to obtain both time and frequency characteristics of the heart sound signals. The advanced signal processing techniques for analysis of heart sounds have been introduced. Theses techniques have included the Short Time Fourier transform (STFT), Wigner-Ville distribution (WVD), and Wavelet Transform (WT) [1-8]. The limitations of the STFT and WVD are the proper choice of the window length and the cross-term interference, respectively. The localization property of the WT has been proven a useful tool for the detection and characterization of nonstationary signals. In addition, the WT has been widely used for time-scale analysis of electrocardiogram (ECG) signals with nonstationary properties [9] [10]. The meaningful features extracted from heart sounds with wavelet analysis are of great interest for clinical interpretation of heart diseases. Hence, the objective of this study is to investigate the application of WT and local turbulence analysis for detection of normal heart sounds and murmurs. In this research, a new algorithm based on the CWT is proposed for classification between the normal heart sounds and abnormal heart sounds with mitral regurgitation.

2. METHODOLOGY

The WT has currently become a widely used technique in signal processing. It can be viewed as a decomposition of a signal into a set of basis functions called wavelets. A family of wavelets $\psi_{a,b}$ is generated from the mother wavelet ψ by using the scaling parameter a and translation parameter b. It is defined as:

$$\psi_{a,b}(t) = \frac{1}{\sqrt{a}}\psi\left(\frac{t-b}{a}\right) \quad (1)$$

The CWT of a signal is defined as:

$$CWT\,(a,b) = \int_{-\infty}^{\infty} s\,(t)\,\psi^{*}_{a,b}(t)dt \quad (2)$$

where *s(t)* is the signal, $\psi(t)$ is the mother wavelet, a and b are the scaling and translation parameters, respectively, and t is the time. In the wavelet technique, the mother wavelet is applied to the given signal through a scaling parameter which dilates or contracts and translates the mother wavelet. As a result, the signal is analyzed in the time and scale domain. In the CWT, the terms of scale is proposed as an alternative to frequency and it is inversely proportional to frequency, therefore the CWT of a signal

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is described in a so-called time-scale representation. High frequency resolution is achieved at low frequencies, whereas high time resolution is obtained at high frequencies. The selection of the mother wavelet type must be considered to give a well-performed decomposition of the signal. Many researchers have reported that the Morlet wavelet provides satisfactory results for analysis of heart sounds [2] [4] [5]. The Morlet wavelet is therefore used as the mother wavelet in this investigation.

2.1 Data Acquisition

The heart sounds were recorded and saved in a hard disk of a computer for later analysis. They are obtained from subjects with normal heart and those with mitral regurgitation. Sampling rate of 4096 Hz with 12 bit resolution was set for heart sound data collection.

2.2 Data Analysis

The heart sound signals were preprocessed by performing a digital high pass filter. High pass filter of 30 Hz cutoff frequency was designed to remove low frequency noise from muscle or chest movements. The heart sound signals and ECG signals were recorded simultaneously. The first heart sound S1 occurs at the onset of ventricular contraction which corresponds to the R wave of the ECG signal. The R wave was utilized to locate the start point of S1. The recorded heart sounds then were segmented into each complete heart sound cycle consisting of S1 and S2. One segment was used and contained 3,900 samples of heart sound data for each patient. The CWT with scales from 10 to 200 was applied to one heart sound cycle for each patient group.

2.3 Local Intermittency

One notable utility of the CWT is that it is highly localized in the time-scale domain, making it very efficient for local feature extraction in nonstationary data sets and the characterization of sharp discontinuities. A new concept of local intermittency is utilized to investigate nonuniformity of the energy distribution [11]. It is defined as follows:

$$I_L\left(a,t\right) = \frac{E_c\left(a,t\right)}{\bar{E}_c(a)} \tag{3}$$

where $I_L\left(a,t\right)$ and $E_c\left(a,t\right)$ are the local intermittency and signal energy at scale a and time b, respectively.

$$E_c\left(a,t\right) = CWT^2\left(a,t\right) \tag{4}$$

$CWT\left(a,t\right)$ is the coefficients computed from the CWT.

$\bar{E}_c\left(a\right)$ is the mean value of $E_c\left(a,t\right)$ at scale a over all time. If the local intermittency is 1 for all a and t, it means that the energy distribution of a signal is very uniform. The Local Intermittency Factor *(LIF)* is defined as follows:

$$LIF = \frac{1}{MN}\sum_{j=1}^{M}\sum_{i=1}^{N}\left|I_{ij}-1\right| \tag{5}$$

$$\text{where} \quad I_{ij} = \frac{\left|CWT_{ij}\right|}{\bar{E}_i} \tag{6}$$

$$\bar{E}_i = \frac{1}{M}\sum_{j=1}^{M}\left|CWT_{ij}\right| \tag{7}$$

CWT_{ij} is the matrix of the CWT coefficients. N is the number of scales. M is the number of elements in each scale. $\bar{E}_i$ is the mean value of the absolute coefficients CWT_{ij} for each scale.

3. RESULTS

Three consecutive heart sound cycles of one patient with normal heart and those of one patient with mitral regurgitation are shown in figure 1a and b, respectively. It clearly identifies between the S1 and S2 of heart sounds for each cycle, as shown in figure 1a, but it is not quite clear for the abnormal heart sounds, as shown in figure 1b. Additional information was observed in the interval between S1 and S2.

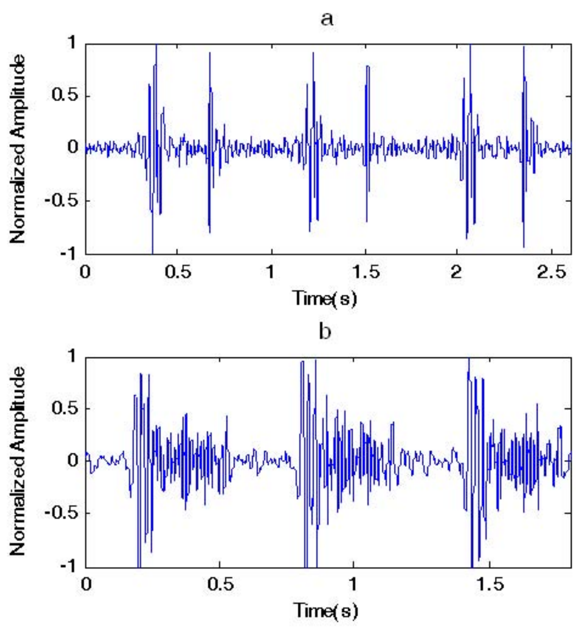

Fig.1: *Three consecutive heart sound cycles for the patient with normal heart (a) and the patient with mitral regurgitation (b).*

The CWT with scales from 10 to 200 was applied to the heart sounds of figure 1a and b. The CWT contour plots are then illustrated in figure 2a and b, respectively. Moreover, the three dimensional (3D) time-scale plots of figure 1a and 1b are shown in figure 3a and 3b, respectively. In figure 2a, it clearly separates the S1 from S2. In figure 2b and 3b, the presence of high frequency contents, as shown within the dotted circles, can be seen between the S1 and S2 at the smaller scales. In general, the high frequency components of murmurs have a smaller intensity than the low frequency components of the normal heart sounds. The diagnostic information of clinical interest is contained in the high frequency murmurs. Therefore, the digital band pass filter with cutoff frequency between 500 and 2,000 Hz was used to separate the low frequency components from the interesting high frequency murmurs and also remove the unwanted frequency above 2,000 Hz.

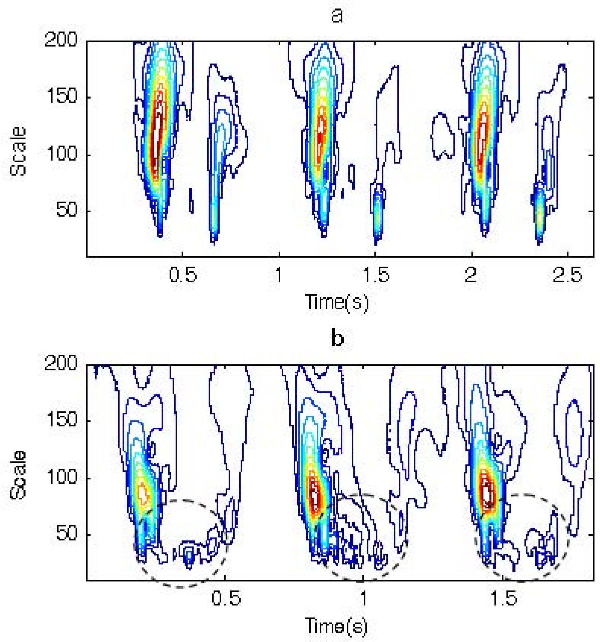

Fig.2: *The CWT contour plots for the normal patient (a) and the patient with mitral regurgitation (b).*

The band pass-filtered heart sounds are shown in figure 4. Then the CWT was applied to the band pass-filtered heart sounds, as shown in figure 5. The high frequency contents of heart sounds with mitral regurgitation can be clearly observed at the smaller scales, as shown in figure 5b. In addition, the abnormal heart sounds display more nonuniformity of the CWT energy distribution (figure 5b), in particular at the smaller scales.

In order to quantify the energy nonuniformity due to high frequency parts, the CWT was applied to the band pass-filtered heart sounds and then the LIF was computed for the two patient groups at the CWT scales between 10 and 50 in steps of 5. The result of the LIF is plotted in figure 6. It clearly shows that a significant difference between the two patient groups can be found. The patients with mitral regurgitation would appear to have larger LIF than those with normal heart sound. The Wilcoxon Rank Sum test was applied to the LIF results. A statistically significant difference between the two patient groups was confirmed at the 99.9% level of confidence ($p<0.0005$).

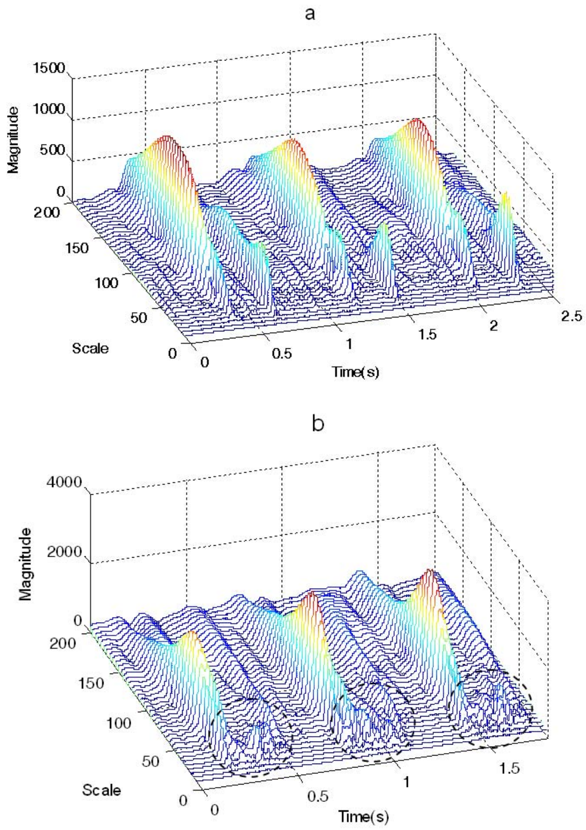

Fig.3: *The 3D Continuous Wavelet Transform plots for the patient with normal heart (a) and the patient with mitral regurgitation (b).*

4. DISCUSSION AND CONCLUSION

The heart sound detection is essential in the evaluation of heart diseases. The heart sound signals often present nonstationary properties. The wavelet transform is a powerful tool for data characterization of nonstationary signals. In this study, the detection algorithm of heart sounds with mitral regurgitation based on the Continuous Wavelet Transform was introduced and then the Local Intermittency Factor was proposed for patient classification between normal heart sounds and heart sounds with mitral regurgitation. This factor is expected that it would be sensitive to changes in the local disturbance of heart sounds due to murmurs of mitral regurgitation. It is assumed that the heart murmurs would not be the continuous signals.

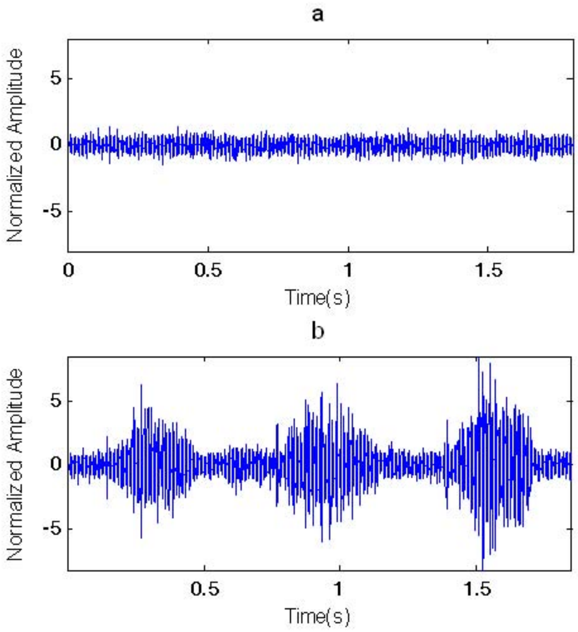

Fig.4: *Three successive cycles of band pass-filtered heart sounds for the patient with normal heart (a) and the patient with mitral regurgitation (b).*

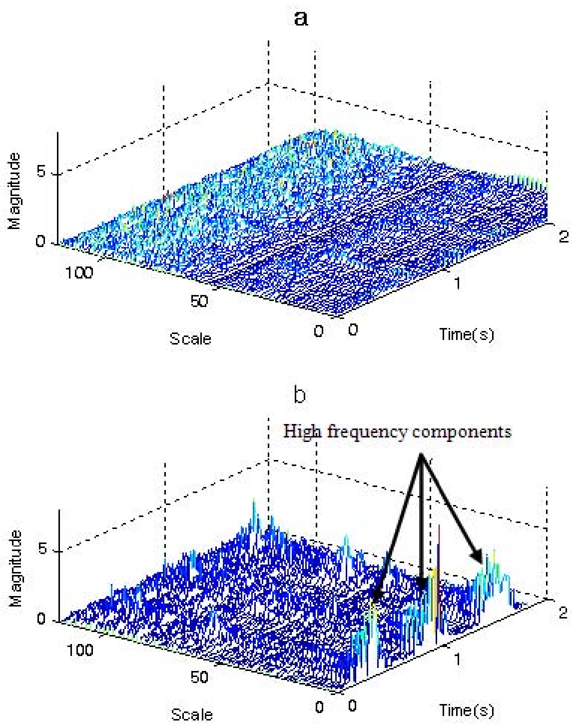

Fig.5: *The 3D Continuous Wavelet Transform plots of figure 4 for the patient with normal heart (a) and the patient with mitral regurgitation (b).*

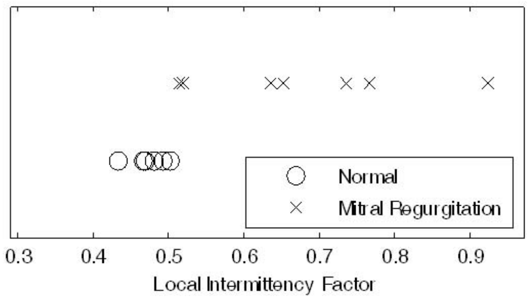

Fig.6: *The Local Intermittency Factor for patients with normal heart sound and those with mitral regurgitation.*

The LIF may reveal subtle variability of heart sound disturbance of murmurs. The presence of high frequency murmurs would be characterized as an occurrence of mitral regurgitation events. The results show that this approach can successfully detect the heart sounds with mitral regurgitation, however, a large number of patients with mitral regurgitation are needed to validate this algorithm. In addition, the heart sound data should be preprocessed by the band pass filter in the frequency range of 500 - 2,000 Hz before the LIF is applied.

In this study, the LIF was computed between the R wave and the next R wave, using the R wave as a reference for heart sound segmentation. Typically, the presence of murmurs, as a result of mitral regurgitation, starts from the S1 and lasts up to the S2. Thus, it would be sufficient to detect mitral regurgitation in the interval between S1 and S2 for each cardiac cycle and it will be further investigated for future research.

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