Heart Sound Segmentation Algorithm Based on Instantaneous Energy of Electrocardiogram

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Abstract

This paper presents an algorithm to detect the first heart sound (S1) and second heart sound (S2). The algorithm utilizes Instantaneous Energy of electrocardiogram (ECG) to estimate the presence of S1 and S2. Thus, heart sound segmentation can be done as it is essential in the automatic diagnosis of heart sounds. The Instantaneous Energy of ECG is performed to verify the occurrence of S1 and S2 as it is widely accepted pathologically that Phonocardiogram (PCG) and Electrocardiogram (ECG) are two noninvasive source of information depicting the cardiac activity [6]. The ECG is a surface measurement of the electrical potential generated by electrical activity in cardiac tissues. Meanwhile, PCG is the graphical representation of the heart sound produced by the heart. The algorithm was tested for 210 cardiac cycles of heart sound and ECG recorded from patients from normal and abnormal simultaneously.

1. Introduction

Diagnosing heart diseases with a stethoscope and Electrocardiogram are two fundamental methods because of its efficiency, simplicity and non-invasive property. Heart sound auscultation highly depends on the hearing ability, skill and experience of a cardiologist [6]. Therefore, a computerized heart sound analysis is vital to assists the cardiologist. The heart sounds need to be segmented into it's components before any automatic analysis can be applied.

Heart sound consists of 4 components which are S1, S2, S3 and S4. The main components of heart sound are first heart sound (S1) and second heart sound (S2). S1 occurs during ventricular systole and it contributes to the 'lub' of the 'lub-dub' characteristic that can be heard from each heartbeat. It is caused by the closure of the mitral and tricuspid valves. Meanwhile, S2 occurs during ventricular diastole and it contributes to the 'dub'. It is caused by the closure of the aortic and pulmonary valves. S3 occurs just after S2 and has relatively lower energy. S4 occurs just before the S1 and has lower amplitude compared to the other heart sounds. The opening and closing of cardiac valves and the sounds they produce are mechanical events of the cardiac cycle. They are preceded by the electrical events of the cardiac cycle. Heart murmurs are noises associated with the damage of valves and improper closure of valves. The following is the relationship between the PCG and ECG in time domain. The S1 occurs 0.04s-0.06s after the onset of the QRS complex, the S2 occurs towards the end of the T wave, and the fourth heart sound S4 occurs after the P wave [6].

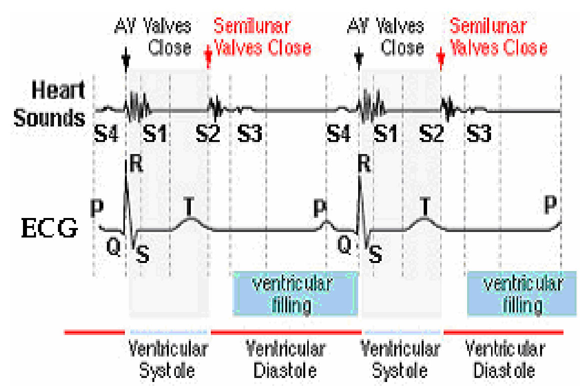

Figure1. Timing events in the cardiac cycle.

Some research has been done to segment heart sound signals. Iwata et al developed a detection algorithm for S1 and S2 based on frequency domain of PCG evaluated by Linear Prediction Method. Lehnar et. al proposed an algorithm using the ECG and carotid pulse as reference where S1 is estimated by using the onset of the R wave in ECG and the beginning of S2 by using the carotid pulse. This method fails to perform properly due to the timing between electrical and mechanical activities that vary to a larger extent [2]. The nature of these two signals in time domain may not be exactly constant but a good deal of agreement exists between them in spectral components [1]. But, the direct application of the spectrum analysis is not suitable since the spectrum can't detect the temporal variation in the heart sound and ECG. As, heart sound and ECG is time varying signal, Instantaneous Energy is applied to characterize the temporal behaviors of those signals. The purpose of this study is to develop an algorithm to detect the occurrence of S1 and S2 and thus perform heart sound segmentation based on the Instantaneous Energy of ECG.

2. Methodology

2.1. Data acquisition

A laptop was used as data acquisition for the proposed analysis. The heart sound and ECG of lead 2 were recorded simultaneously from patients of Hospital Universiti Kebangsaan Malaysia (HUKM). An ECG amplifier circuit was developed to capture and amplify the ECG of patients. Heart sound was captured using the electronic stethoscope (Super-Tone Deluxe, model FS-203). Both signals were recorded and displayed through a 2 channel Picoscope-ADC 216. A simple block diagram of this hardware system is shown in Figure 2. The data were recorded from 15 patients who consist of 5 normal patients and 10 abnormal from the group of Mitral Regurgitation, Mitral Stenosis and Ventricular Septal Defect.

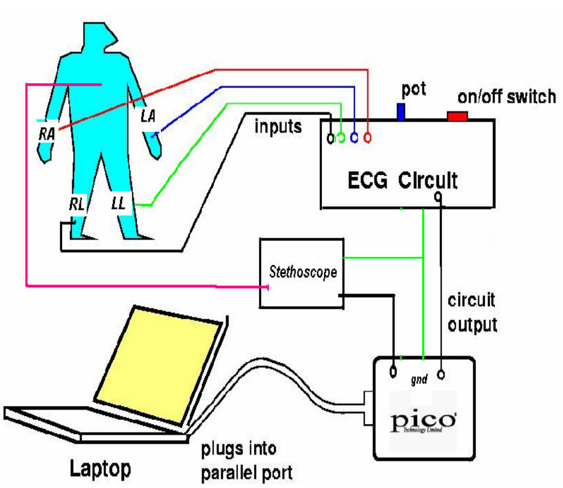

Figure2. Block Diagram of the hardware setup.

2.2. Preprocessing

The first step of signal processing is filtering the ECG and heart sound to remove the unwanted noise. ECG were filtered using a bandpass filter between 0.05HZ-100Hz to eliminate the EMG, motion artifact, baseline wander and 50Hz notch filter to eliminate power line noise. Moving-average filter proposed by Savitzky-Golay [5] were applied to both ECG and heart sound to eliminate and smooth the signals from interfering signals like speech and ambient noise captured from stethoscope.

2.3. Instantaneous energy

A time varying signal can be represented in the form of discrete analytical equation as below:

$$z(n) = x(n) + jH[x(n)] \qquad (1)$$

Where H[] is the Hilbert transform[3] of x(n) which has approximately unity gain and introduce a Π/2 phase shift with respect to the original signal. The Hilbert Transform calculation method is as follows:

$$jX_i[n] = \frac{1}{N}\sum_{m=0}^{N-1} X_R[m] \otimes V_N[n-m] \quad (2)$$

$$V_N[n] = \begin{cases} -2j \cot(\pi n/N), & n=odd. \\ 0, & n=even. \end{cases}$$

Where XR[m] is the DFS[3] of X(n) and the $\otimes$ denote the circular convolution technique. Thus, the complex form of the equation is as below:

$$z(n) = c(n)\exp\left(j2\pi\sum_{\lambda=-\infty}^{n} fi(\lambda)\right) + w(n)$$

$$0 < n < N-1 \qquad (3)$$

Characteristic of the analytical signal is the relationship between the instantaneous energy and the signal amplitude. The instantaneous energy is required to characterize the temporal behavior of the amplitude of the heart sound and ECG because the amplitude of the signal is time varying. From the signal definition in Equation (3), the instantaneous energy is

$$Ez(n) = z(n)^*z(n) = c(n)^*c(n) \qquad (4)$$

Thus, the instantaneous energy of the heart sound and ECG is the amplitude square of the signal.

3. Results

The algorithm was applied to both ECG and heart sounds and the instantaneous energy for both are presented below. It is found that the end of the first peak of the ECG signal in a cardiac signal indicates the first heart sound(S1) and the end of following peak of the ECG indicates the second heart sound(S2). This phenomenon is due to the fact that the electrical event in cardiac activities takes place before the mechanical event. Presented below is Instantaneous energy for various diseases.

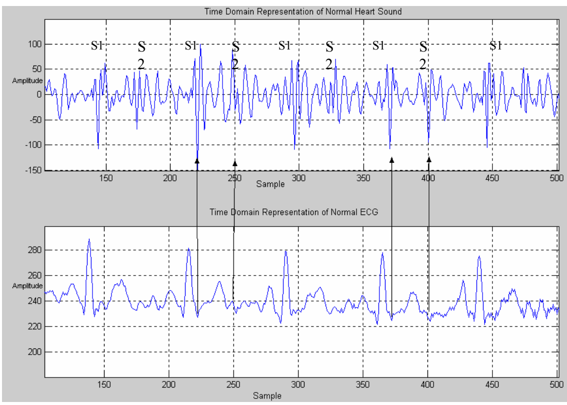

Figure3. The relationship of heart sound and ECG for Normal in time domain.

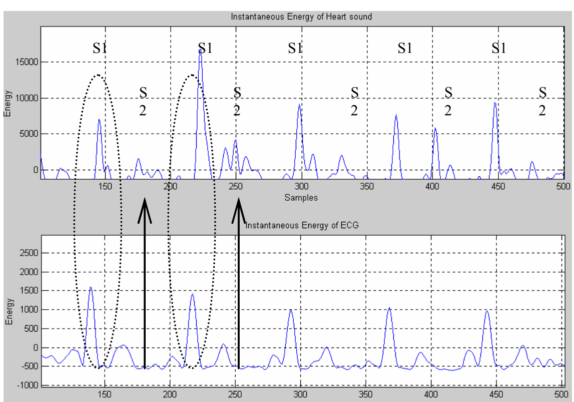

Figure4. The Instantaneous energy of heart sound (upper) and ECG (lower) for Normal.

Figure 3 shows the correlation between the heart sound and ECG for normal. It can be seen clearly that S1 occurs with a delay after the QRS complex. S2 occurs at the end of the T wave. In certain diseases, this relationship is hard to notice and thus, the proposed analysis would be beneficial. The same heart sound and ECG were transformed to Instantaneous Energy and the result is shown in Figure 4.

The first peak of the ECG signal shows the energy due to ventricular depolarization (ventricular contraction). Depolarization of the ventricles is represented by the QRS waveform on the surface ECG. The following peak indicates the ventricular repolarization.

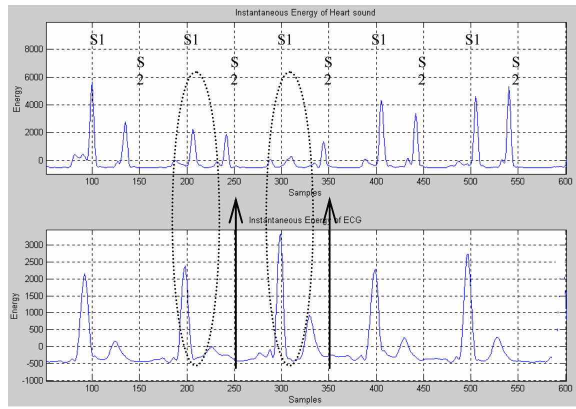

Figure5. The Instantaneous energy for Mitral Regurgitation (MR).

Figure 5 shows the Instantaneous Energy of heart sound and ECG for Mitral Regurgitation. It is well noticed that the energy of S1 and S2 for MR are almost the same. MR is due to the mitral valve which is not properly closed during ventricular systole. As a result, the intensity of S1 is diminished [6]. But with reference to ECG, the S1 and S2 can be determined.

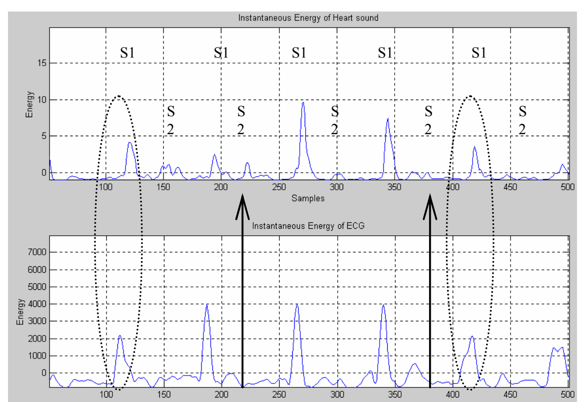

Figure6. The Instantaneous energy for Mitral Stenosis (MS).

It is also noticed that there are other components present besides S1 and S2 that makes the spectrum of heart sound not smooth. These are the murmurs that caused by the backflow of the blood due to the improper valve closure. The presence of murmurs is an obstacle to identify the S1 and S2. This could lead to erroneous in segmentation of heart sound but with the reference to the instantaneous energy of ECG, the S1 and S2 can be determined correctly. The energy of MS is shown in Figure 6. S1 and S2 can be determined using the energy of ECG although MS has accentuated S1.

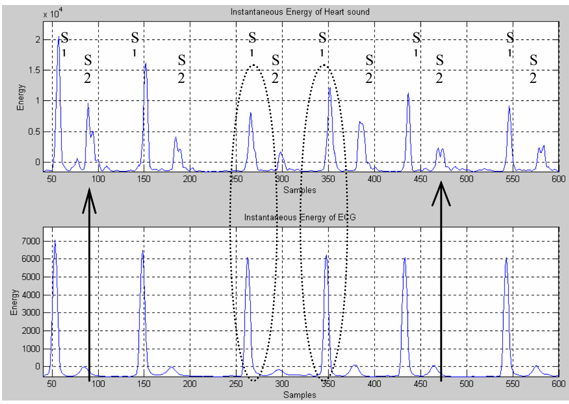

Figure 7: The Instantaneous energy for Ventricular Septal Defect (VSD).

The notch in energy of S2 lobe of Figure 7 indicates the split in the second heart sound. It is known that S2 consists of two acoustic components due to the closure of the aortic valve (A2) and pulmonary valve (P2). A2 usually closes before P2, introducing a delay called 'split'. Also noticed is the energy component contributed by murmurs.

4. Conclusions

From the results, it can be concluded that the first heart sound (S1) and the second heart sound (S2) can be determined using the Instantaneous Energy of ECG. This can assist the segmentation of heart sound before further development of automated heart diagnosis. The algorithm was tested for 210 cardiac cycles from different group of heart diseases. The proposed algorithm is found effective as it is widely accepted pathologically that Phonocardiogram (PCG) and Electrocardiogram (ECG) are two noninvasive source of information depicting the cardiac activity.

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