Two Channel Data Acquisition System for Heart Sound Segmentation Algorithm Based on Instantaneous Energy of Electrocardiogram

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Abstract

This paper presents the hardware design of 2-channel data acquisition system for heart sound and Electrocardiogram (ECG) to capture the heart sound and ECG simultaneously from patients; and software algorithm to detect the first heart sound (S1) and second heart sound(S2). The algorithm utilizes Instantaneous Energy of 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 hardware consists of instrumentation amplifier, filter, isolation amplifier for each channel, multiplexer, Analogue to Digital Converter (ADC) and microcontroller 68HC11 *to control and handle communication protocols with PC. The algorithm was tested for 210 cardiac cycles of heart sound and ECG recorded from patients from normal and abnormal simultaneously.*

1. Introduction

Telemedicine applications are inclusive of monitoring and real-time diagnosing systems. Data acquisition and signal conditioning are two important aspect of electronic environment for real-time monitoring before computer-aided medical diagnosing systems developed. Diagnosing heart diseases with a stethoscope and ECG are two fundamental methods because of its efficiency, simplicity and non-invasive property. 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. 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].

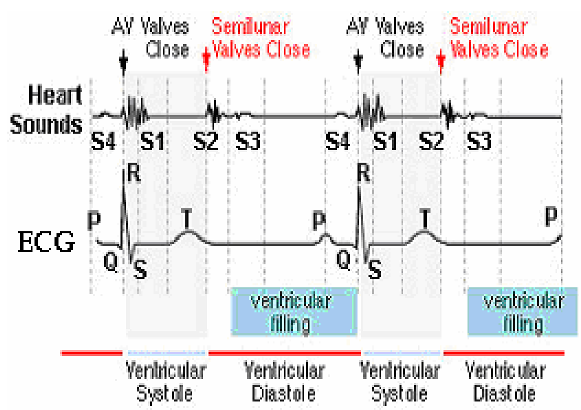

Figure 1. Timing of events in the cardiac cycle.

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 to perform heart sound segmentation based on the Instantaneous Energy of ECG. Thus, 2-channel heart sound and ECG data acquisition system is developed to acquire the signal from patients

2. Methodology

2.1. Hardware Design

It consists of two channel; time division multiplexed data acquisition where one channel is for the heart sound and another for the ECG. The design is divided into 2 parts. First is the analog signal conditioning. Figure 2 shows the block diagram of signal conditioning for the channel of heart sound and ECG.

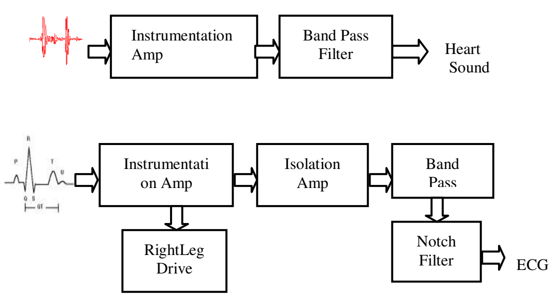

Figure2. Analog Signal Conditioning.

The main function is to take the weak signal of biological origin and increase its amplitude so that it may further process, recorded and displayed. Filtering is done to eliminate the EMG, motion artifact, baseline wander for ECG and smooth the signals from interfering signals like speech and ambient noise captured from stethoscope [7].

The transducer used to capture the heart sound is an electronic stethoscope (Super-Tone Deluxe, model FS-203) and electrodes are used to capture the ECG signal. The electrodes are located on the patient, the cables attached to the electrodes. Both the signals are passed through the low noise and low power instrumentation amplifier, INA121. The instrumentation amplifier consists of a high-input impedance amplifier and a differential amplifier.

The heart sound is amplified with an approximate gain of 30 and filtered using a low noise dual op-amp LM833. A 4^{th} order Butterworth band pass filter which consists of a high pass active filter with a cutoff frequency of 20Hz and a low pass active filter at cutoff frequency of 1000 Hz were implemented to match the frequency range of heart sound . Refer to Appendix 1 for the schematic diagram of the circuit. Whilst for the ECG, there are 3 basic inputs for this circuit which is Right Arm (RA), Left Arm (LA) and Left Leg (LL). These inputs contribute to the bipolar leads (lead 1, 11 and 111) [7]. Table 1 shows the proper electrode connection for the three bipolar limb leads.

Lead	Positive Electrode (+)	Negative Electrode (-)
1	Left Arm	Right Arm
11	Left Leg	Right Arm
111	Left Leg	Left Arm

Table1 Electrode connections for bipolar leads.

The ECG is amplified with a gain of 1000 and filtered using a 2nd order Butterworth band pass filter which consists of a high pass active filter with a cutoff frequency of 0.05Hz and a low pass active filter at cutoff frequency of 100 Hz to match the frequency characteristic of ECG. This is achieved by using LF412 op-amp. The isolation amplifier, AD210 provides protection to the patient from cardiac shock, and circuits and equipment from damage besides eliminating ground loop effect and attenuating the 50 Hz ac power line noise with a gain of 1. A notch filter with the twin-t configuration with current feedback is applied to the signal to eliminate the 50 Hz ac power line noise. The right leg drive is the inversion of the common-mode interference. The common-mode signal will be inverted into the right leg drive (RL). The gain of the RL drive is usually set at high voltage but must not be too high so that RL drive will not be saturated. Refer to Appendix 2 for the schematic diagram of the circuit.

The second part of the hardware design is the signal routing, analog to digital converting and interfacing with the software for display. The process is shown in figure 3. The conditioned analog signal is multiplexed using the MPC508 analog multiplexer from Burr Brown. The multiplexer guarantees the break-before-make switching to ensure the signal from previous selected channel does not mix together with the signal from the currently selected channel. The ADC, AD976 is from the successive approximation type with 16-bit resolution and maximum throughput of 100 kHz. It is configured for bipolar input of ±10V. The sampling rate for this system is controlled by the microcontroller at 2019Hz. The sampling rate of ADC is achieved by calculating the clock cycles executed by the microcontroller multiplexing, sampling, transferring rate through the parallel port, and applying appropriate delay in the firmware.

The MC68HC11 microcontroller controls multiplexing, sampling rate and data transfer to the parallel port via the 74LS244 octal tri-state buffer. The transfer rate is programmed so that it does not exceed the maximum transfer rate of the parallel port. The PC retrieves these digitized data from the parallel port to display the heart sound and ECG signals accordingly. A GUI based software using Visual C++ is developed to plot the signal instantaneously.

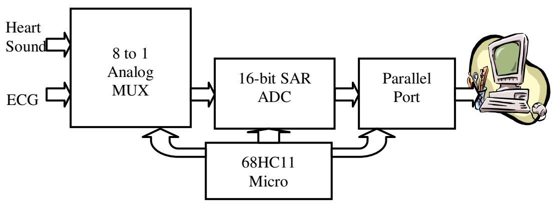

Figure3 Signal Routing, A/D Converting & Transfer

The heart sound and ECG of lead 11 were recorded simultaneously from patients of Hospital Universiti Kebangsaan Malaysia (HUKM). Lead 11 were selected among the 3 bipolar leads because it carries the most important and accurate information. 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.

2.2. 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 $\Pi/2$ phase shift with respect to the original signal. The Hilbert Transform calculation method is as follows:

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

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

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.

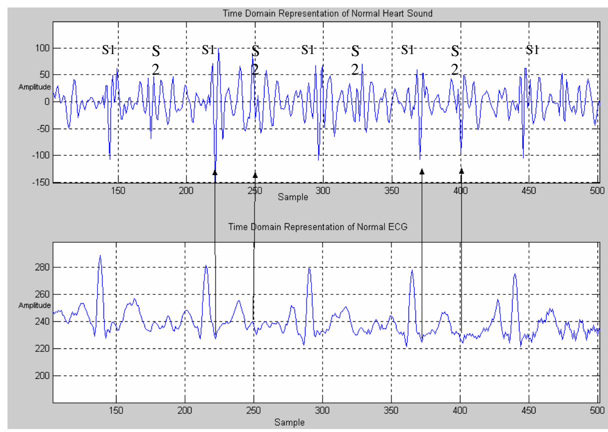

Figure4. The relationship of heart sound and ECG for Normal in time domain.

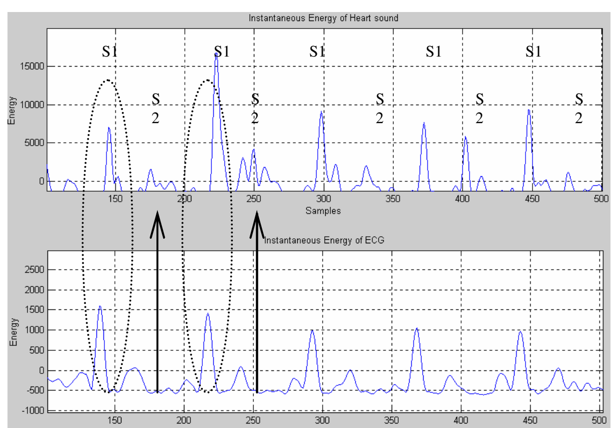

Figure5. The Instantaneous energy of heart sound (upper) and ECG (lower) for Normal.

Figure 4 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 5. 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.

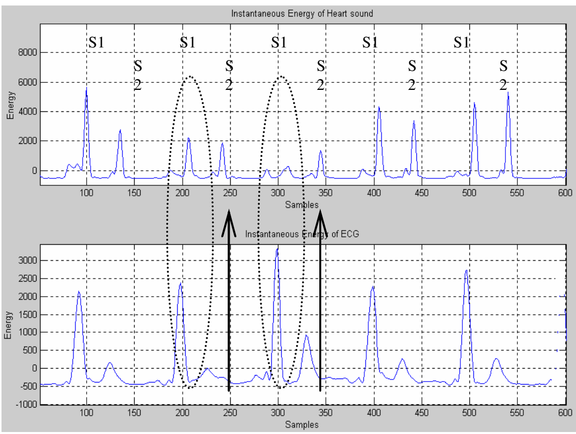

Figure6. The Instantaneous energy for Mitral Regurgitation (MR).

Figure 6 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.

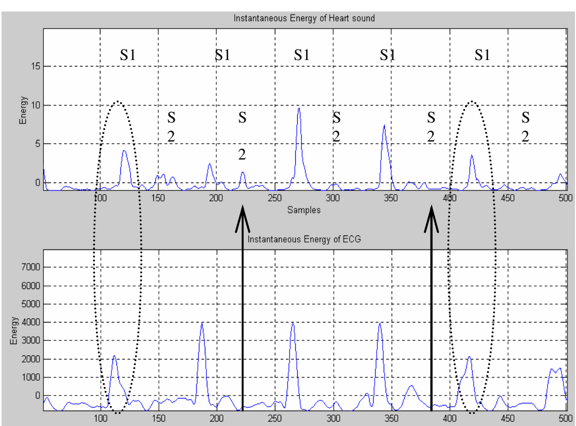

Figure7. The Instantaneous energy for Mitral Stenosis (MS).

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 7. S1 and S2 can be determined using the energy of ECG although MS has accentuated S1.

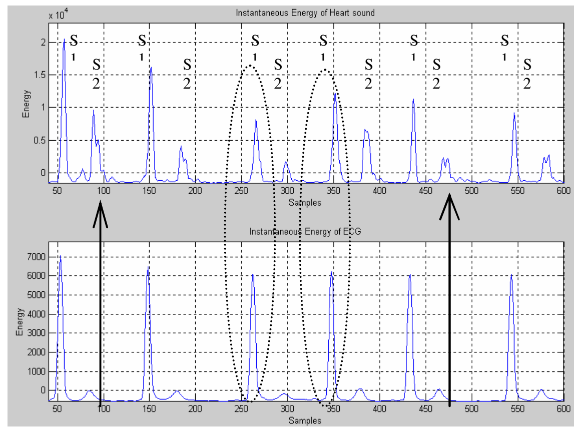

Figure8. The Instantaneous energy for Ventricular Septal Defect (VSD).

The notch in energy of S2 lobe of Figure 8 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.

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. The constructed two channel heart sound and ECG data acquisition system is capable of acquiring a satisfactory reading of rest ECG signal and heart sound. It can be expanded to be a multi-channel ECG amplifier capable of recording the standard 12-Lead system.

Acknowledgement

Authors would like to express gratitude to Dr. Mohd Daud Sulaiman (M.D) for his assistance and guidance in acquiring the ECG and heart sounds. This project is supported by the IRPA Grant 74153: Development of a Prototype Intelligent diagnostic Systems of Heart Diseases Based on the ECG waveform.

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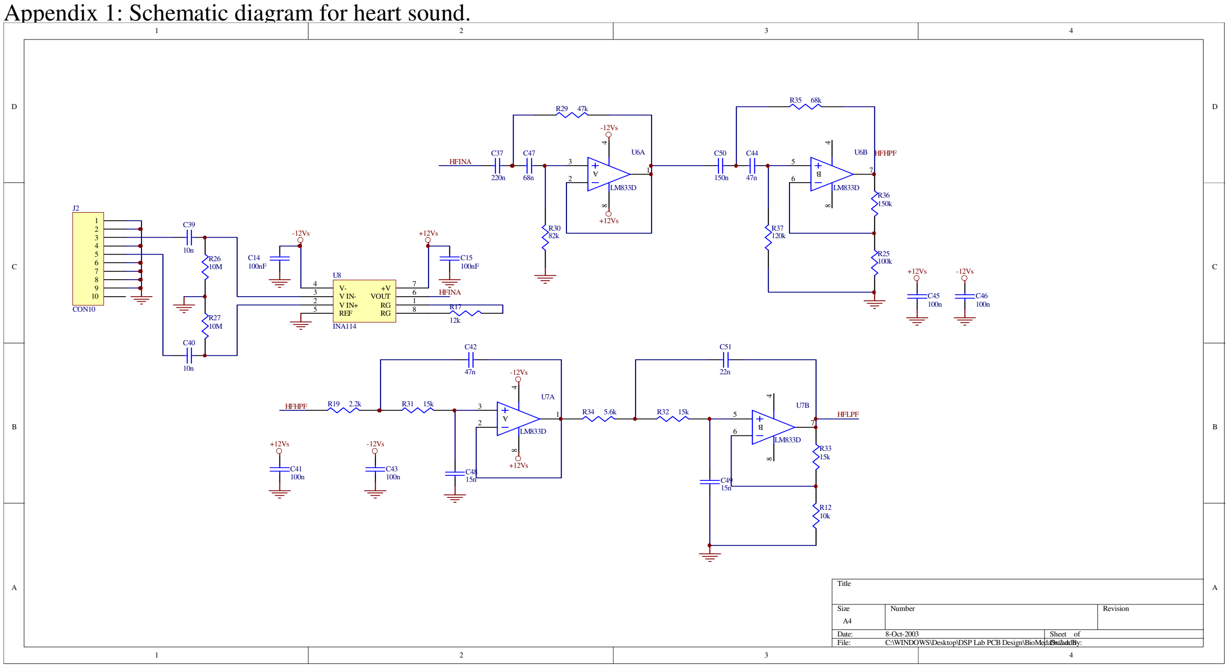
Appendix 1: Schematic diagram for heart sound.



Appendix 2: Schematic diagram for ECG.