Heart Rate Variability using Shannon Energy

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Abstract
The heart rhythm is directly related to the electrical activity of the heart. Electrocardiogram (ECG) is generally used for obtaining information about the heart rhythm. In this paper, a method for calculating heart rhythm variation using the Phonocardiogram (PCG) is described. The average heart rate is calculated from the Shannon energy signal and this is used as the input for selecting the time window for local analysis. The analysis window for calculating the instantaneous heart rate is taken as thrice the calculated average heart rate. This is repeated for the entire signal for every half a second shift. It is shown that even for normal persons there is significant variation in the heart rate. Heart rate variation for an abnormal case shows bi-modal distribution.

Keywords: Phonocardiogram, Shannon energy, Electrocardiogram, Heart rate variability

1. INTRODUCTION

Heart is one of the critical organs in our body pumping blood continuously throughout the entire life-time. The blood carries the nutrients and the oxygen for the proper functioning of the cells. Heart is made up of a strong muscle called myocardium, and has four valves for regulating the blood circulation. It beats at almost regular intervals and is controlled by the electrical pulses generated from the sinus node near the heart. The rhythmic beating of heart produces a characteristic sound commonly referred to as "Lub-Dub" due to the closing of the atrio-ventricular valves and the aortic-pulmonic valves. Moreover, there are other sounds, which are generated due to the structural and functional defects of the heart, called as murmurs. Analysis of heart sounds provides valuable information regarding the functioning of the heart since the sound generation is related to the physiology of the heart valves and muscles. Stethoscope is still used as the primary auscultation device for heart and lung sounds since its invention in 1817. However, analysis based on heart sounds heard using a stethoscope is subjective relying highly on the doctor's experience and hearing ability.

The current passive methods to check the functioning of the heart are by the use of electrocardiogram (ECG). ECG provides information on the electrical functioning of the heart system, but does not provide much information regarding the valve functioning or other structural or functional defect of the heart.

The objective measurement on heart sounds is achieved by the transduction and digitization of heart sounds resulting in phonocardiogram signal, which is then processed using signal processing algorithms. The analysis of the phonocardiogram (PCG) provides the information on the valvular defects, if any, and also the rhythmic variation of the heart beats.

2. OBJECTIVE

This paper reports a method for extracting heart rate variation using Shannon Energy of PCG signal. The normal heart sounds are obtained using indigenously developed DSP based stethoscope called KilaScope by Kila Medical Systems, Bangalore. The signals of heart defect cases are obtained from the internet [2] [3]. The signal is then down sampled to 2000 Hz by the use of a digital anti-aliasing filter of cutoff 800 Hz. This down sampled version of the signal is used as the input for envelope detection.

Sec.3.1 describes the Shannon energy computation. Sec.3.2 describes the method for finding the average period. Sec.3.3 presents heart rate variability on normal and pathological heart sounds. Conclusion is presented in Sec.4.

3. METHOD

3.1. Shannon Energy

The envelope of the heart sound signal is detected using different methods like absolute value of the signal, squared energy, and Shannon energy etc. In [4], Liang Lukkarinen, and Hartimo clearly pointed out the advantage of the Shannon envelope detection of the heart sounds over the other methods. Autocorrelation of the Shannon energy envelope is computed to detect the average period over the entire analysis interval. Using the estimated average period, an analysis of window of 3 cycles is selected and once again the autocorrelation is computed to estimate the average period within this shorter interval of 3 cycles. Successive frames are selected with 0.5 sec shift to compute the heart rate variability.

The equations of the common envelope detection methods are given below.

Shannon Energy: $E = -x^2 \log x^2$

Shannon Entropy: $E = -|x| \ln |x|$

Absolute Value: $E = |x|$

Squared Value: $E = x^2$

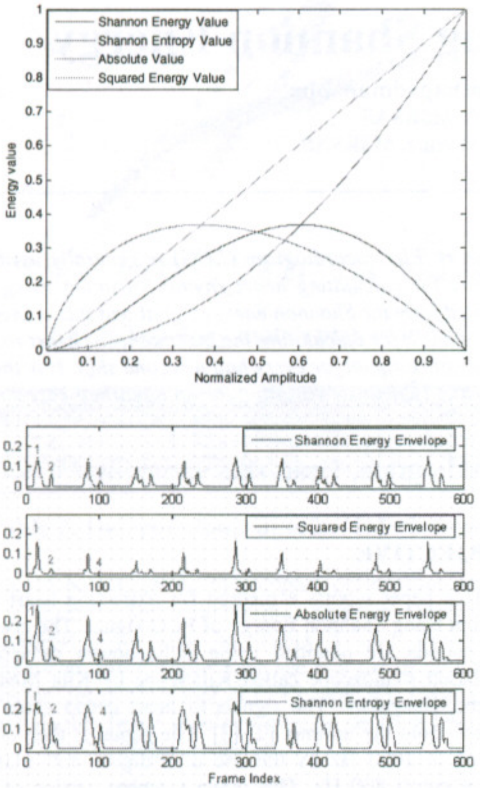


Fig 1: (a) Comparison of energy value for different envelope methods using normalized amplitude (b) Envelope Vs Frame Index of normal heart sound computed by various methods

Fig 1 shows that the absolute value method gives the same weight to all input amplitudes. The Shannon entropy method attenuates the high intensity signal and gives more weight to the low intensity signal. The squared energy method gives exponential weightage to high intensity signals, which will make it difficult to identify low intensity signals. The Shannon energy method gives more emphasis on medium intensity signal and attenuates low intensity signal more than the high intensity signal. This reduces the gap between the low intensity and high intensity sounds and thereby increasing the chance to detect the medium intensity sounds. In figure 1(b), the peak 4 is missed in squared energy envelope case, and it is more accentuated in Shannon entropy method.

The Shannon energy calculated with 50milli-second window duration is the empirically determined optimum for the envelope detection. The signal is windowed using Hanning window of 50 millisecond width before computing the Shannon energy. The windowing will smooth the edges and reduce the effect of a large signal in adjacent time segments. In addition, it helps to separate the closely spaced sub-components of S1 or S2. The signal is normalized to absolute maximum over the entire duration of the signal being analyzed. The Shannon energy is calculated with 10 millisecond shift. The equation for the average Shannon energy for a single frame is

$$E_{avg} = (-1/N)\sum_{i=0}^{N-1} x^2(i)\ln[x^2(i)]$$

Where N is the length of the window

The envelope of normal heart sounds is computed with different definitions given above. The results are shown in Fig.1 Shannon energy envelope has a clear advantage over other formulae and hence is used for further processing.

3.2 Average Heart Rate using Autocorrelation

The autocorrelation $r_{xx}(l)$, of an infinite sequence x(n) is defined as

$$r_{xx}(l) = \sum_{n=-\infty}^{\infty} x(n)x(n-l)$$

The autocorrelation is useful for detecting the underlying periodicity of the signal [5]. For a windowed signal, the summation extends over the windowed duration. Further, using the property that autocorrelation is the Fourier inverse of the magnitude squared spectrum, the computation can be made very efficient. The autocorrelation function of the Shannon energy signal is calculated. The distance between the peak at lag=0 and the first peak is noted. This gives the average period of the heart signal. The heart beat per minute is calculated from the heart rate as

Beats per Minute (BPM) = 60/ (Period in second)

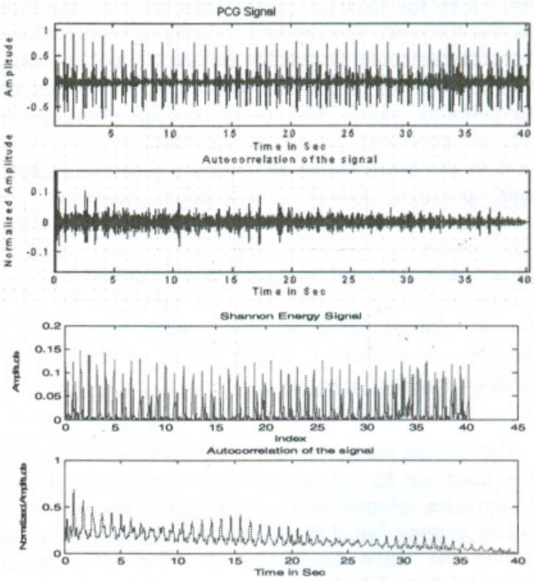
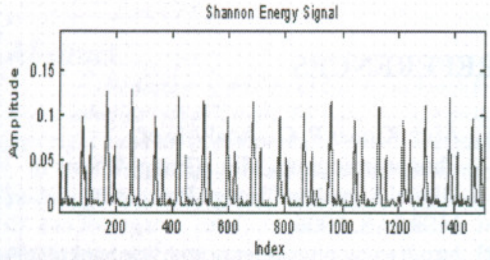


Fig 2: (a) Autocorrelation of the input heart signal; (b) Autocorrelation of the Shannon energy signal

Fig 2 shows the autocorrelation sequence of the input heart sound and Shannon energy signal. It is evident from these figures that autocorrelation of the Shannon energy signal is better suited for calculating the period of the signal. This is due to the rapid variation of the heart sound signal and the background noise.

Fig 3 shows the zoomed autocorrelation sequence of the Shannon energy signal and the detected period location is marked with a red line.



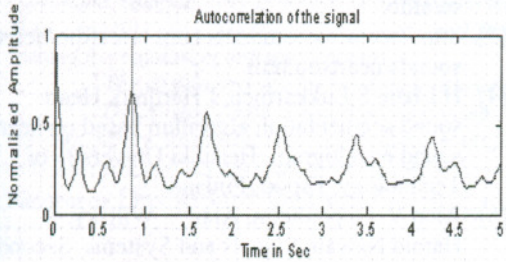
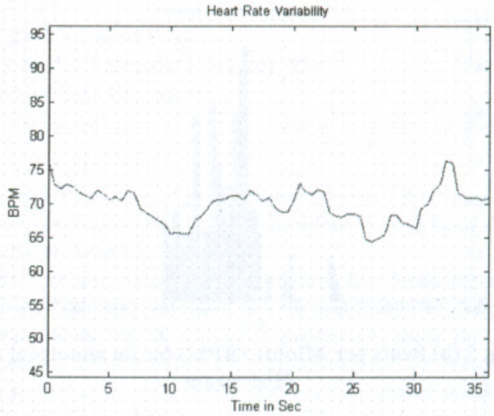


Fig 3: (a) Shannon energy (b) Autocorrelation with detected period location

3.3. Heart Rate Variability

The heart rhythm is very complex in nature. It varies from person to person and even varies rapidly for a single person depending upon his/her physical and mental condition. The heart rate and its variations are very important in clinical cardiology. The doctor usually calculates the heart rate roughly by noting the wrist pulse or the carotid pulse. The heart rhythm is directly related to the electrical activity of the heart as well as its valve movements. The Electrocardiogram (ECG) gives the most accurate information about the heart rhythm. The Phonocardiogram (PCG) is also useful for extracting the heart rate variation. The average heart rate is calculated from the Shannon energy signal and this is used as the input for selecting the time window for local analysis. The analysis window for calculating the instantaneous heart rate is taken as thrice the calculated average heart rate. This is repeated for the entire signal for every half a second shift. Figure 4 shows the heart rate variability of a normal patient and the histogram of the beats per minute.

Fig 5 shows the heart rate variability of a simulated case of patient having Atrial Fibrillation (a kind of arrhythmia) [2] [6] and the histogram of the beats per minute. It is evident from Figures 4 and 5 that the heart rate variation can be calculated from the heart sounds.



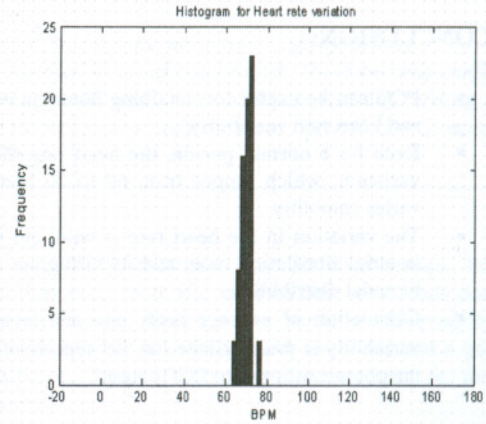


Fig 4: (a) Heart Rate Variability – Normal Patient (b) Beats per Minute (BPM) for a normal case- Histogram

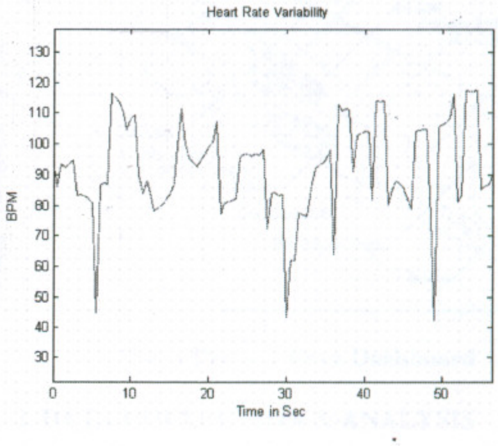


Fig. 5 (a) Heart Rate Variability – Arrhythmia patient

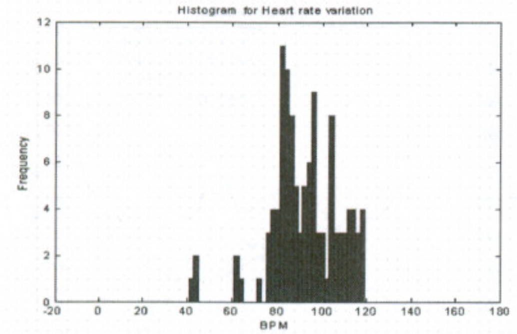


Fig. 5 (b) Beats per Minute (BPM) for an abnormal case-Histogram

4.CONCLUSION:

- PCG can be useful for obtaining Shannon energy, and heart rate variability.
- Even for a normal person, the heart rate shows a variation; which ranges from 60 to 80 bpm, and varies smoothly
- The variation in the heart rate is wild and erratic in atrial fibrillation case; and its histogram shows bimodal distribution.
- Calculation of average heart rate and heart rate variability is pre-requisite for the segmentation of the phonocardiogram (PCG) signal.
- Envelope of PCG gives more reliable results compared to heart rate variability calculated directly from PCG.

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