Study and Design of a Shannon-Energy-Envelope based Phonocardiogram Peak Spacing Analysis for Estimating Arrhythmic Heart-Beat

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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) and a method for finding characteristics of the that signal is described. The average heart rate is calculated from the Shannon energy signal and characteristics are found using mean, variance and autocorrelation. The analysis window for calculating the instantaneous heart rate is repeated for entire signal for every one second shift. It is shown that even for normal persons there is significant variation in the heart rate. Heart rate variation shows bi-modal distribution for an abnormal case.

Index Terms- Envelope Detection, Shannon Energy Envelope, Phonocardiogram, Systole, Diastole.

I. 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 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 provides valuable information regarding the functioning of heart since the sound generated is related to the physiology of the heart valves and muscles [2]. Stethoscope is still used as the primary auscultation device for heart and lung sounds since its invention in 1817 [3]. However, analysis based on heart sounds heard using a stethoscope is subjective relying highly on the doctor's experience and hearing ability[1]. The current passive methods to check the functioning of the heart are by the use of electrocardiogram (ECG) [2]. 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 [2].

The purpose of this study is to develop an algorithm for Study and Design of a Shannon-Energy-Envelope based Phonocardiogram Peak Spacing Analysis for Estimating Arrhythmic Heart-Beat, which uses the heart sound signal as the sole source. Based on the algorithm, every cycle of the PCG signals is separated into four parts: the first heart sound, the systolic period, the second heart sound and the diastolic period. The locations and intervals of the first heart sounds and the second heart sounds are computed first. Then based on this information, the intervals of the systolic and diastolic period are obtained consequently. Then the systolic and diastolic both the periods are analysed separately as well as in combined manner. Then based on this study the heart signal are analysed whether the sound is arrhythmic or not. If it is arrhythmic then of which type whether it is overall arrhythmic or the systolic and diastolic periods are arrhythmic, which is justified using correlation between systole and diastole period. Both normal and abnormal heart sound recordings are investigated.

II. PROPOSED METHODOLOGY

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 Phonocardiogram (PCG) could be used as a simple but effective source for analysing and detecting the arrhythmic nature of heart beat pattern. The following methodology has been employed to study the effectiveness of PCG in estimating arrhythmia.

a. Pre-processing:

The recorded signals were first pre-processed before performing envelope extraction and cycle detection. Heart sound signals were normalized according to Eq. (1) as shown below:

$$x_{norm}(t) = \left(\frac{x(t)}{max(|x(t)|)}\right)^2 \quad .... \quad (1)$$

Where x(t) is the original signal and the square operation aims to make peak signal more prominent while weaken the noise.

b. Determination of Shannon Energy Envelope:

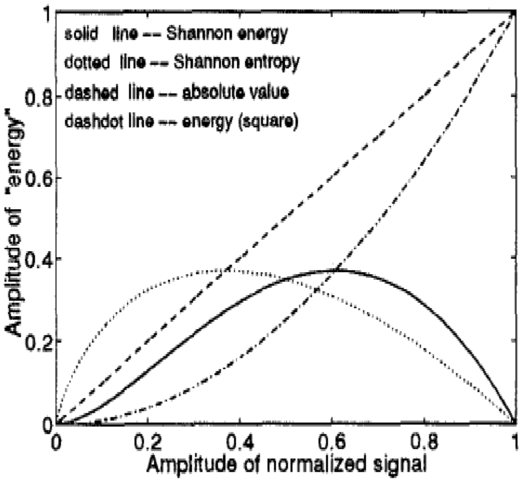

Figure 1 : Outcomes of various envelope detection methods

The envelope of the heart sound signal can be detected using different methods like absolute value of the signal, squared energy, Shannon entropy, and Shannon energy as depicted below. The normalized samples obtained through Eq. (1) makes it possible to evaluate its envelope in the temporal field. Fig. 1 plots outcome of various envelop detection methods against the normalized signal ranging from -1 to +1. The negative part is ignored in the graph due symmetry of results.

Absolute Value: $E = |x|$

Square Energy: $E = x^2$

Shannon Entropy: $E = -|x| \, log \, |x|$

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

Figure 1 provides a basic framework for comparing efficiency of various envelope detection methods. The squared energy method associates exponential weighing factors to high intensity components which will pose difficulty in isolating low intensity components. The absolute value technique associates same weighing factor to all components making it difficult to separate low from high amplitude signals. Shannon entropy method attenuates the high intensity signal since it gives more weights to low intensity signal. But it is evident from the graph that Shannon energy method emphasizes medium range amplitude components and attenuates low intensity signal more than the high intensity components. Shannon Energy can absorb the magnitude of oscillations of high intensity as well as those in low amplitudes. The square and the absolute value of the signal samples promotes oscillations of high amplitude more than those of low amplitude. To improve this beneficial effect, we can standardize or normalize this energy. The average Shannon Energy is standardized by the following relationship:

$$E_n = \frac{E - \mu}{\sigma}$$

In the above equation, E is the Shannon Energy, μ is the average value of energy E of thesignal, σ is the standard deviation of energy E of the signal and E_n is the average Shannon Energy standardized or normalized. The average Shannon energy (μ) can be calculated based on n number of normalized samples as below.

$$\mu = -\frac{1}{n}\sum_{i=1}^{n} x_i^2 \log(x_i^2)$$

Fig. 2 shows the standardized Shannon energy based envelop of a simple PCG signal which is convenient to find S1 and S2 locations.

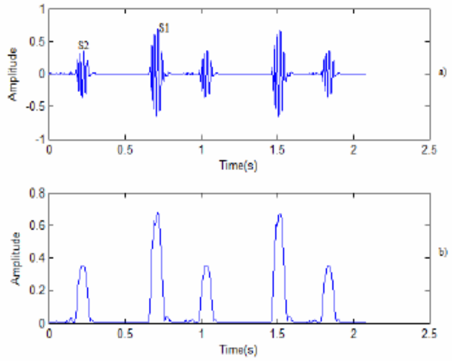

Figure 1: Shannon energy based envelop of a simple PCG signal

2.1 Identification of S1 and S2 peaks:

While it is easy to visually identify peaks in a small uni-variate time-series, there is a need to formalize the notion of a peak to avoid subjectivity and to devise algorithms to automatically detect peaks in any given time-series. A data point in a time-series is a *local peak* if (a) it is a large and locally maximum value within a window, which is neither necessarily large nor globally maximum in the entire time-series; and (b) it is isolated i.e., not too many points in the window have similar values. Not all local peaks are *true peaks*; a local peak is a true peak if it is a reasonably large value even in the global context. Let *T* =X1, X2, …,X*N* be a given univariate uniformly sampled time-series containing *N* values. Without loss of generality, the time instants are assumed to be 1, 2, …,*N* (i.e., the time-series *T* is uniformly sampled). Let *xi* be a given i^{th} point in *T*. Let *S* be a given *peak function*, which associates a score (which is a non-negative real number) *S(N, i, Xi, T)* with *i*th element X*i* of the given time-series *T*. A given point X*i* in *T* is a *peak* if *S(N, i, Xi, T)* >ϴ, where ϴ is a suitably estimated threshold value. The following algorithm finds peak position within a window of suitably chosen length. It employs binary search technique to examine whether the pivot candidate is on ascending part or on descending part or itself is a peak in the sample-sequence and based on the location of the pivot, the searching subsequence portion is determined.

2.2 Algorithm for peak finding

```
Algorithm FindPeak(X, i, j)
// Input: Sample Series (X), Starting Index (i), End Index (j)
// Output: Index of Peak Sample Value
1.    $m = \lfloor (i + j)/2 \rfloor$
2. if $(X_{m-1} \le X_m$ AND $X_m \ge X_{m+1})$
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    return m
else if ($X_{m-1} > X_m$)
    return FindPeak(X, i, m-1)
else if ($X_m < X_{m+1}$)
    return FindPeak(X, m+1, j)
```

2.3 Estimation of systole and diastole periods:

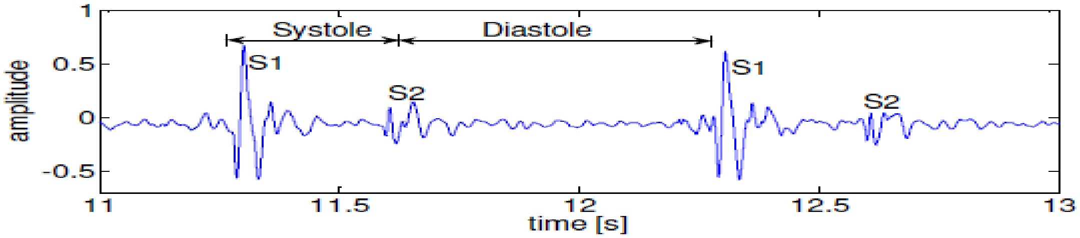

Figure2: Systole and Diastole Period with reference to S1 and S2 peaks.

The peak-locations and peak-amplitude values are analysed to identify S1 and S2 peaks in the sample sequence. Experimentally it has been observed that S1-peak values are normally larger than S2-peak values. The time-gap between consecutive S1 and S2 peaks represents systole period whereas diastole period is measured as the time-gap between consecutive S2 and S1 peaks. Every systole and diastole periods are recorded along the entire sample sequence for further analysis.

III. RESULT AND ANALYSIS

By the methodology mentioned above heart sounds are analysed. Result of analysis of ten heart sound samples is given in the Table 1 and Table 2. From Table 1 it can be concluded that the value of Systole gap is always less than the diastole gaps. Also the correlation between the Systole and Diastole gaps are shown in Table 1 that interprets the relationship between systole and diastole. In some cases the correlation between s1 and s2 sound is positive but in some cases it is negative. Positive correlation means that high scores of one signal is associated with high scores of the other, and that low scores on one are associated with low scores on the other. In our case correlation of HS_5 is positive it means high score of systole changes with high score of diastole and low score of systole changes with low score of diastole. Negative correlation, on the other hand, means that high scores on the first signal is associated with low scores of the second. Negative correlation also means that low scores on the first signal is associated with high scores on the second. In our case except HS_5,HS_7,HS_8 and HS_9 all are with negative correlation. As in these signals low scores on the systole are associated with high scores on the diastole and high scores on the systole are associated with low scores on the second.

Table 1

SOUNDs (ID)	Systole GAPS (Mean)	Diastole GAPS (Mean)	VAR_S1	VAR_S2	CORRELATION
HS_1	583.66	992.12	334.75	203.26	-0.1726
HS_2	740.90	1314.66	374.10	236	-0.3988
HS_3	481	915.83	290	184.15	-0.4911
HS_4	386.82	714.36	288.96	533.19	-0.0518
HS_5	634.76	938.25	532.69	4080.56	0.5331
HS_6	626.13	1011.14	1814.26	1759.51	-0.3347
HS_7	631.42	1304.71	385.64	7965.75	0.00010
HS_8	990.50	1696.62	1534.28	4107.12	0.0078
HS_9	502.09	863.30	410.49	91.78	0.2101
HS_10	1547	2286.16	1381	618.96	-0.3231

Table 2

SOUNDs (ID)	Actual Beat Rate (BPM)	Windowing with a window size=1 sec		On combining Systole and Diastole			Accuracy (%) (with respect to windowing)	Accuracy (%) (with respect to cardiac cycle)
		Mean (Beat_rate) (BPM)	Variance	Mean	Variance	Beat rate (BPM)		
HS_1	78.15	85.67	509.56	1579.25	372.78	77.14	90.37	98.70
HS_2	61.52	73.55	12.43	2058.33	333.75	60	80.44	98.36
HS_3	85.55	93.40	475.48	1397.16	271.60	86.66	90.81	98.71
HS_4	108.55	123.81	82.55	1100.77	791.04	110.40	85.93	98.32
HS_5	86	82.13	584.56	1571.25	6189.29	78	95.5	90.69
HS_6	73	80.89	407.67	1635.64	2474.09	75	89.18	97.33
HS_7	64	70.52	93.86	1936.14	8351.97	60	89.80	93.75
HS_8	90	86.36	898.63	2687.12	5680.69	80	95.95	89
HS_9	87	91.70	263.50	1365.60	628.93	82.50	94.59	94.82
HS_10	61	71.45	180.79	3836.83	1565.76	60	82.86	98.36

Correlation coefficients can vary numerically between 0.0 and 1.0. The closer the correlation is to 1.0, the stronger the relationship between the two variables. A correlation of 0.0 indicates the absence of a relationship. If the correlation coefficient is -0.80, then it indicates the presence of a strong relationship. It means that the taken heart sounds have the correlation as follow:
HS_5>HS_3> HS_2> HS_6> HS_10> HS_9> HS_1> HS_4> HS_8> HS_7

Here, The sign does not mean that it is having less correlation but it indicates the sign of correlation. A positive correlation coefficient means that as Systole increases, Diastole increases. And conversely, as Systole decreases, Diastole decreases. In other words, the variables move in the same direction when there is a positive correlation. A negative correlation means that as systole increases, diastole decreases and vice versa. In other words, the variables move in opposite directions when there is a negative correlation. The negative sign indicates that as class size increases, mean reading scores decrease. A correlation can only indicate the presence or absence of a relationship, not the nature of the relationship.

From the table no. 2

- The heart beat rate with sliced time of window size=one sec is taken. It is taken to analyse the signal in the interval of 1 second.
- Similarly beat rate using the measurement of complete cardiac cycle or, systole+diastole is also there.
- Finally we got our obtained beat rate with the accuracy of the beat rate is =90% in almost all the cases.
- From the above Table 2 it is clear that the measurement using cardiac cycle gives more exact result.

In both the table the mean and variance are there. In Table 1 the mean and variance of systole and diastole are there and in Table 2 the mean and variance of both overall signal with a time slice 1 sec & combination of systole and diastole or simply cardiac cycle are there.

IV. CONCLUSION

In this paper heart sounds are analysed. The analysis process includes the envelope finding using Shannon energy. Then the envelope is taken as input for the peak finding. Then we calculate the gaps between S1 and S2. After finding the peak the histogram of the gaps is calculated. Then thresholding technique is used to cluster the gaps into Systole and Diastole. Then we use the correlation to find that the signal is arrhythmic or not. In this study it is concluded that the abnormality of heart sound is not only depend on the overall cardiac cycle whereas it depends upon the individual analysis of systole and diastole period. By calculating the correlation, the clear picture of variability of systole and diastole period is found , which plays the key role for the testing of abnormality of heart sound.

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