Heart Sounds Determination Based on Sliding Window Maximum Method

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Abstract. Determining location of heart sounds is necessary for segmentation and feature construction. Highest peak determination might be an alternative to find heart sounds location. This paper discusses the determination of the location of heart sound S1 based on the highest peak signal using Sliding Window Maximum (SWM) method. The SWM method uses a window that slide from left (old signal) to the right (new signal) of heart sounds signals and finds the signal maximum value and its position at the window. Highest peak location is classified as heart sound if its value is higher than a defined threshold and its position is at the middle of window. Signal of heart sounds is received by microphone and then the signal is filtered using resistor capacitor (R-C) circuit. The signal is amplified using non-inverted amplifier Operation Amplifier (OP AMP) circuit. Signal from the amplifier is read by analog to digital converter (ADC) of arduino nano. In arduino nano heart sounds signals are processed using digital signal processing Moving Average Filter (MA Filter) and Infinitive Impulse Response filter (IIR Filter). The signal processing result is stored in personal computer (PC). There are 838 heart beats of 5 different persons are processed. Using this method, we find the accuracy, sensitivity, and positive predictivity of 92.72%, 94.87% and 97.79%, respectively.

1. Introduction
The stethoscope was invented by René Laennec in 1816 [1]. Normal heart sounds have two recorded activities: first heart sound (S1) and second heart sound (S2). In abnormal cases, there are other sounds between S1 and S2. Abnormal heart sounds include S3, S4, murmur, snap and click [2]. The use of a stethoscope in diagnosis requires considerable experience and dependent on the sensitivity of medical hearing. The use of a digital stethoscope might be one of the solutions in the monitoring of cardiac state based on heart sounds. Heart sounds might be recorded and analyzed using hardware, computer and signal processing [3]. Automatic segmentation which includes the determination of the S1 sound component, the S2 sound component, the duration of systole and diastole required in monitoring the heart condition [4]. S1 is an important part of the heart sound that signifies the beginning of each heart cycle [5]. This paper discusses the determination of the S1 location based on the highest peak signal using Sliding Window Maximum (SWM) method in varied parameters of window’s size (k) and threshold (Th).

2. Method
In determining the location of the heart sound signal S1, data acquisition is based on the designed device. The data obtained by the designed device are analyzed.
2.1. Data Acquisition

Figure 1 shows the data acquisition system. In the data acquisition, the device is composed of chestpiece, PCG circuit, arduino and Personal Computer (PC). PCG circuit consists of a sound sensor in the form of a microphone connected to the chestpiece through a rubber tube, filter circuit and amplifier circuit. When the chestpiece is attached to the chest, the sound is transmitted to the microphone generating an electrical signal in the form of a weak voltage oscillation. Signals from microphones are amplified and filtered. The R-C circuit is used as an electrical signal filter and a non-inverted amplifier circuit is used as an amplifier. The output signal from the circuit is then received by Arduino. Arduino is an open source software and hardware single board microcontroller which has analog to digital converter (ADC). The Arduino’s ADC is used to convert the analog signal from circuit to be digital signal. There are several types of arduino. Arduino nano is used in this project. Arduino nano is based on AtMega 328 which has 10 bit of ADC. In the Arduino 260Hz of sampling rate are used. In the Arduino, signal conditioning is processed by digital filters. The digital filters used in Arduino are Moving Average Filter (MA Filter) and Infinite Impulse Response Filters (IIR Filters). The highest S1 signal lies at a frequency of 29 Hz [6]. The filter used passes the sound signal with a frequency of 20 Hz to 50 Hz. The next, digital signal from arduino nano is sent to the Personal Computer (PC). Determination of S1 in the time domain is performed by using SWM method.

2.2. Determining the location of S1

The location of S1 is determined by using SWM method with the addition of a parameter. Addition of a parameter is used to obtain the most satisfactory method work. SWM analyzes the given array using a window in the form of a subarray of size k. Each time, the window slide to the right of one data. The window slides from the left (old data) to the right (new data) and finds the maximum value of k data numbers in the window. There are two input parameters must be included, size of window (k) and threshold (Th). The parameters used are based on the difference in duration and energy accumulation. The systolic duration is shorter then diastolic duration. Accumulation of S1 energy is greater than S2. When the heart rate increases, diastolic duration decreases. The duration of systolic and diastolic is almost the same while heart rate increases. The amplitude of S1 increases while heart rate increase [4].

Algorithm 1: S1 determination using SWM method

1: Input PCG Signal $X = [x_1, x_2, x_3, \ldots, x_l]$; $i =$ index of $x$ ; $l =$ length of data
2: PCG signals are normalized by equation $x_i = \frac{x_i}{\max|x|}$
3: Set Threshold (Th) and size of window ($k$) value.
4: Initialize $n = 1$.
4: If $n - k \leq l$ then
5: Make a window $W = [x_{n-k+1}, x_{n-k+2}, x_{n-k+3}, \ldots, x_n]$
6: Find the maximum value in window $x_{\max} = \max(W)$ and index of the maximum value $i_{\max}$
7: If $x_{\max} \geq Th$ & $i_{\max} = n - k/2$ then
8: Store $x_{\max}$ as the value of highest peak S1.
9: Store $n-k/2$ as the location of S1.
10: End If
11: $n = n + 1$
12: End If
Algorithm 1 is used to determine S1. The value of the window size \( k \) goes to the number of data numbers in the window. Amount of data in the window is proportional to time signal analyzed. The determination of the \( k \) value based on the duration of the heart sound to be analyzed. The Th value is used to distinguish whether the signal is the heart sound or not. When the signal value is smaller than the Th value it is decided that the signal is not. Highest peak location is classified to be S1 if the maximum value in the window is higher than the defined threshold and its position is at the middle of window. In this paper, computational software of MATLAB is used.

3. Results and Discussion
Based on the procedure described in section 2 data acquisition was performed. Using a system that has been designed, data from 5 people are taken. Data retrieval are taken for about 2 minutes. There are about 838 heart beats are acquired and analyzed. Figure 2 shows heart sounds signal obtained by designed device.

![Figure 2. Heart sounds signal.](image1)

![Figure 3. S1 determination.](image2)

Figure 3 represents method used. The blue shows the signal being analyzed. The green line shows the specified threshold value. The black box represents the window that will shift to the right. The red dot indicates the location of the highest peak point detected.

In determining the best parameters value in detection method, analysis in the performance of the method is performed. Performance analysis of the S1 detection method, carried out using 3 parameters, there are,

\[
Acc = 1 - \left( \frac{F_p + F_n}{Total\ Beat} \right)
\]

\[
Se = \left( \frac{T_p}{T_p + F_n} \right)
\]

\[
+P = \left( \frac{T_p}{T_p + F_p} \right)
\]

Where,

\( Acc \) = Accuracy
\( Se \) = Sensitivity.
\(+P\) = Positive predictivity.
\( T_p \) = Total S1 is detected correctly.
\( F_p \) = Total not S1 detected as S1.
\( F_n \) = Number of undetectable S1.

The preceding parameters above are also used in analyzing the detection performance of QRS complexes on electrocardiogram [7].
Table 1. Methods’s performance in varied windows size

| Window size (s) | Total Beat | True Positive | False Positive | False Negative | Accuracy (%) | Sensitivity (%) | Positive Predictivity (%) |
|----------------|------------|---------------|----------------|----------------|--------------|-----------------|--------------------------|
| 0.60           | 838        | 804           | 62             | 34             | 88.54        | 95.94           | 92.84                    |
| 0.70           | 838        | 800           | 40             | 38             | 90.69        | 95.47           | 95.24                    |
| 0.80           | 838        | 800           | 40             | 38             | 90.69        | 95.47           | 95.24                    |
| 0.90           | 838        | 796           | 29             | 42             | 91.53        | 94.99           | 96.48                    |
| 1.00           | 838        | 795           | 18             | 43             | 92.72        | 94.87           | 97.79                    |
| 1.10           | 838        | 790           | 14             | 48             | 92.60        | 94.27           | 98.26                    |
| 1.20           | 838        | 789           | 15             | 49             | 92.36        | 94.15           | 98.13                    |
| 1.30           | 838        | 781           | 11             | 57             | 91.89        | 93.20           | 98.61                    |
| 1.40           | 838        | 716           | 14             | 122            | 83.77        | 85.44           | 98.08                    |
| 1.50           | 838        | 638           | 8              | 200            | 75.18        | 76.13           | 98.76                    |

Table 1 shows the performance of algorithms with threshold value of 0.32 and window size varied. In table it appears that window size increases from 0.60s until 1.00s the performance of the method begins to increase. After the window size is greater than 1.00, the performance of the method begins to decrease. The best performance occurs in the window size 1.00s and threshold 0.32, with the accuracy; Sensitivity; And the positive predictivity was 92.72%; 94.87%; And 97.79% respectively.

Table 2. Methods’s performance in varied threshold

| Threshold | Total Beat | True Positive | False Positive | False Negative | Accuracy (%) | Sensitivity (%) | Positive Predictivity (%) |
|-----------|------------|---------------|----------------|----------------|--------------|-----------------|--------------------------|
| 0.08      | 838        | 795           | 18             | 43             | 92.72        | 94.87           | 97.79                    |
| 0.16      | 838        | 795           | 18             | 43             | 92.72        | 94.87           | 97.79                    |
| 0.24      | 838        | 795           | 18             | 43             | 92.72        | 94.87           | 97.79                    |
| 0.32      | 838        | 795           | 18             | 43             | 92.72        | 94.87           | 97.79                    |
| 0.4       | 838        | 794           | 18             | 44             | 92.60        | 94.75           | 97.78                    |
| 0.48      | 838        | 788           | 17             | 50             | 92.00        | 94.03           | 97.89                    |
| 0.56      | 838        | 776           | 15             | 62             | 90.81        | 92.60           | 98.10                    |
| 0.64      | 838        | 711           | 9              | 127            | 83.77        | 84.84           | 98.75                    |
| 0.72      | 838        | 565           | 3              | 273            | 67.06        | 67.42           | 99.47                    |
| 0.8       | 838        | 439           | 3              | 399            | 52.03        | 52.39           | 99.32                    |

Table 2 shows performances analysis of the detection method, which the size of the window is set to 1.00s and the value of threshold varied. In table, it appears that, in the threshold range between 0.08 to 0.16 the performance of the algorithm does not change with accuracy; Sensitivity; And the positive predictivity was 92.72%; 94.87%; And 97.79% respectively. After the threshold value is greater than 0.32, the performance of the method begins to decrease. Due to the increased false negative, the number of false negatives indicates the number of true undrawn S1 peaks.

4. Conclusion

Studies on the use of the maximum sliding window method in the detection of the heart sound location of S1 have been performed. Using Sliding Window Maximum method the location of S1 could be detected. Using the value of Threshold (Th) and size of window (k) of 0.32 and 1.00s respectively, we get the accuracy, sensitivity, and positive predictivity are 92.72%; 94.87%; And 97.79% respectively.
References

[1] Geddes L A 2005 Birth of the stethoscope IEEE Engineering in Medicine and Biology Magazine 84

[2] Gupta C N, Palaniappan R, Swaminathan S, & Krishnan S. M. 2007. Neural network classification of homomorphic segmented heart sounds Applied Soft Computing 7(1) 286-297.

[3] Wang H, Chen J, Hu Y, Jiang Z, and Samjin C 2009 Heart sound measurement and analysis system with digital stethoscope IEEE Biomedical Engineering and Informatics 1-5.

[4] Zhong L, Guo X, Ji A, and Ding X 2011 A robust envelope extraction algorithm for cardiac sound signal segmentation IEEE Bioinformatics and Biomedical Engineering 1-5.

[5] Wang P, Kim Y, Ling L H, and Soh C B 2006 First heart sound detection for phonocardiogram segmentation IEEE Engineering in Medicine and Biology Society 5519-5522.

[6] Stein P D, Sabbah H N, Lakier J B, Magilligan D J and Goldstein D 1981 Frequency of the first heart sound in the assessment of stiffening of mitral bioprosthetic valves Circulation 63(1) 200-203.

[7] Bert-Uwe, K., Carsten, H., & Reinhold O 2002 The principle of software QRS detection-Reviewing and comparing algorithms for detecting this important ECG waveform IEEE Engineering in Medicine and Biology 42.