Detection of Preventricular Contraction (PVC) in ECG and S1 & S2 Sounds in PCG using ECG & PPG

Project Report

Submitted by

Saurabh Chatterjee
Roll No: 22EE65R14

Abhijeet Aditya
Roll No: 22EE65R16

Satya Prakash
Roll No: 22EE65R05

Under the supervision of

Dr. Nirmalya Ghosh

Department of Electrical Engineering
Indian Institute of Technology Kharagpur,
Kharagpur, India

Abstract

The purpose of project is to detect heart premature ventricular contraction and S1 & S2 sound locations in PCG. The heart problem of a person can be noticed by examining the ECG (Electrocardiogram) signal and withdrawing the various features of the ECG signal like RR interval, width of QRS complex, P wave, R wave and heart rate. ECG signal is preprocessed and its QRS complex is detected using an algorithm, and PVC is detected using RR interval. In second part of the project, S1 and S2 sound has been detected using synchronised PCG and PPG data.

Contents

1 Introduction

This project is broken up into two parts, the first of which is identifying Premature Ventricular Contraction (PVC) in ECG, and the second of which is identifying S1 and S2 sound locations in PCG with the help of synchronized ECG and PPG data.

Signals from an electrocardiogram are frequently utilized in the process of diagnosing any heart-related issue. In an ECG signal, each cardiac cycle is made up of the P-QRS-T waves. In first part, our objective will be to find the Premature Ventricular Contraction (PVC). There are two different approaches that can be taken to detect PVC. In the first scenario, we have to detect the QRS complex and the location of the R-peaks so that we can determine whether or not there is an anomaly based on the R-R interval. And in the second scenario, we differentiate between normal beats and PVC beats with the assistance of the Form Factor.

The second part is about detection of S1 and S2 sounds in PCG. S1 is the sound that is created when the mitral valve and the tricuspid valve closes, whereas S2 is the sound that is made when the pulmonary valve and the aortic valve closes. Therefore, we have S1 when the QRS complex begins. And once the ventricle's contraction is complete, it subsequently begins to relax. Then, in order to maintain the pressure, the aortic and pulmonary valves close. This causes a slight decrease in the carotid pulse signal (the pressure at the carotid pulse), and the valve closing results in the production of the S2 sound.

2 Detection of Premature Ventricular Contraction (PVC)

2.1 What is PVC?

In normal condition, the SA node discharges the impulse that causes the heart to beat. After that, this impulse travels to the AV node, and after arriving there, it uses the bundle of his to help it spread throughout the entire heart. However, in patients with PVC, one of the ventricles contains a "abnormal firing site" known as a "ECTOPIC SITE," which causes the ventricles to become active ahead of time. So PVC complexes are not preceded by P-waves.

The signal in PVC is conducted through myosites of the heart muscles, as opposed to the normal conduction process, which is carried out through specialised cells of the conduction pathway. As a result, the QRS complexes in cases of PVC are broader than the QRS complexes that occur during normal conduction.
So we take advantage of this feature to differentiate between normal beats and PVC beats.

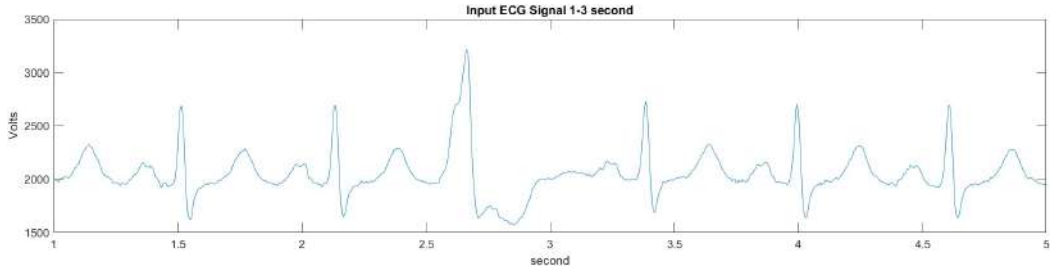


Figure 1: ECG signal with PVC beats

2.2 Proposed Method

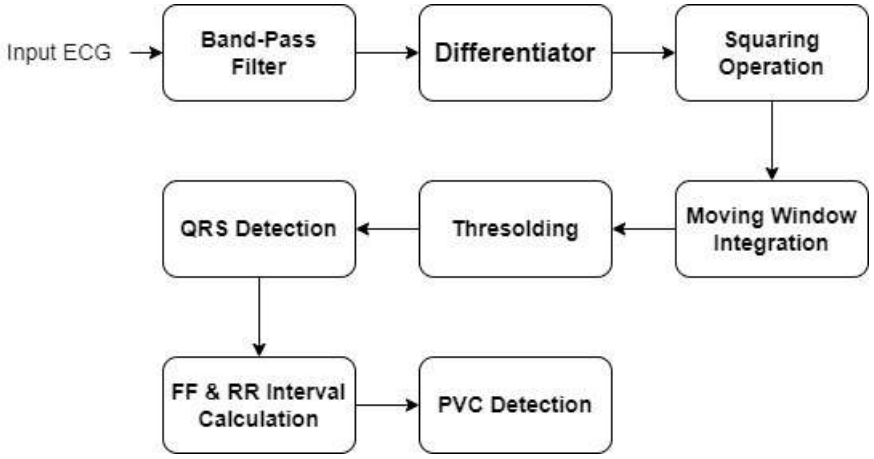


Figure 2: PVC beats detection algorithm

2.3 QRS Complex Detection Algorithm

A Finding Peaks of ECG

We are going to use the Pan Tompkins technique to locate the peaks of the ECG.

B Band Pass Filtering

In order to improve the signal-to-noise ratio, the first thing that is done is to apply a band-pass filter. It is recommended that the filter's bandwidth be set between 5 and 15 Hz in order to enhance the QRS contribution while simultaneously reducing muscle noise, baseline wander, interference from powerlines, and the P wave T wave frequency content. Pan-Tompkin introduced a low pass filter followed by a high pass filter to create a band pass filter. In case of Low pass

filter the numerator has 13 coefficients, and the denominator has 3 coefficients multiplied by 32, creating a constant scaling component termed 1 by 32. For that numerator polynomial, multiply by 32. And in case of High pass filter there are 33 coefficients in numerator and 2 in denominator.

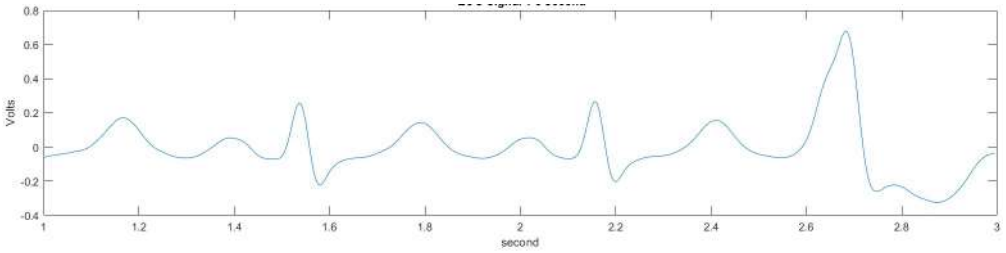
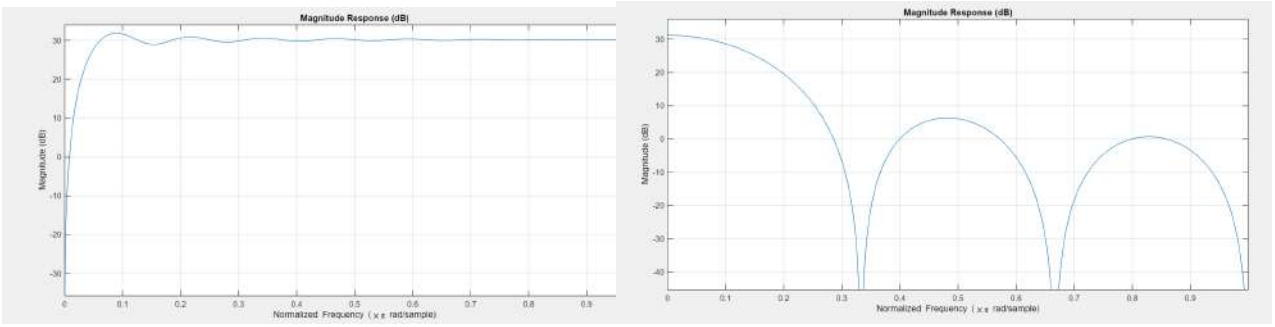


Figure 3: Output of LPF



(a) HPF Response

(b) LPF Response

Figure 4: Frequency Response of HPF and LPF

C Derivative

We use the derivative operator, which has 5 coefficients in the numerator and is not the simplest form. The 5 coefficient signifies it is a complex derivative operator, doing sum averaging along with the derivative to reduce high-frequency noise. During the derivative process, the low-frequency P and T-waves gets attenuated and the high frequency component of ECG like the QRS complex is accentuated.
Thus, the QRS complex has become more prominent and distinct from the P and T waves.

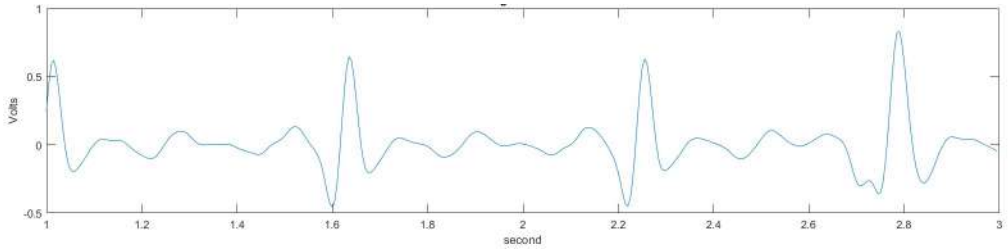


Figure 5: ECG after Derivative Filter

D Squaring

After the differentiation operation we have to use double threshold on positive and negative side of QRS to identify them, so to avoid that we will do Squaring operation
After the squaring, waveform becomes all positive, so a single threshold we will work. And, the small peaks gets subdued. So the difference between high and low peaks increases. In this, the zero points in the waveform near the bulge are the QRS peak locations.

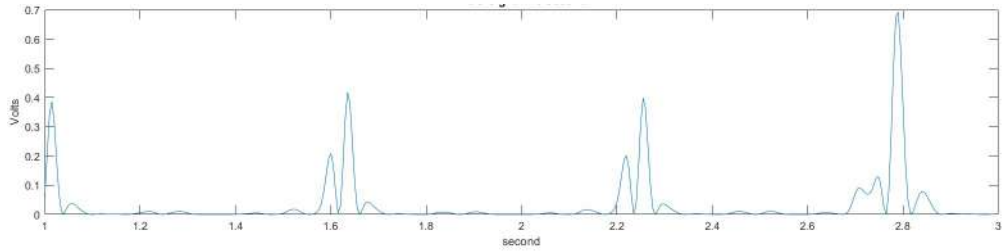


Figure 6: Squaring Output

E Moving Window Integration

From the graph, we can see that the output of the square operation has more than one peak. So, if there are more than one peak, it will be hard to find because there will be more than one value above the threshold. So, the next step is to do integration with the moving window to combine all of these peaks into a single peak that looks like a post. Here we use window of length of 30. So, we have to add 29 zeros at start and end both.

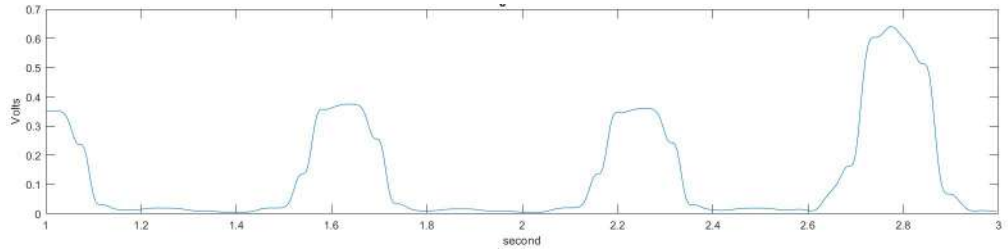


Figure 7: Moving Window Integration Output

At the top, we present the output of the squaring operation, and after MA filter, we obtain this. The ragged peaks become a post-like structure, a single post. One post per QRS complex.

F Thresholding

Next we Threshold the signal to locate the peak. We take the mean of the ECG signal. Make an array which contains '1' at only those locations where the ECG value is more than the threshold. Now identify the location on this array where the values are becoming (0 to 1) and (1 to 0), and store them in an array named "x" and "y" (represents points inside which QRS lies).

These two tell us where the post (integrated waveform) inside which QRS lies, begins and ends. Now correct the position which got changed due to the high coefficient filter applied earlier. The low pass and high pass filters gave us the band pass filter. They are substantial because the 33-tap high pass filter in the numerator produces a 16-sample delay. The low pass filter with 13 taps in the numerator introduces a 6 delay, yet the midway is the middle of a filter. Thus, the delay is the filter length minus 1 divided by 2. Thus, the "x" and "y" vectors have a 22-sample delay. To align with the QRS complex, we rectify that.

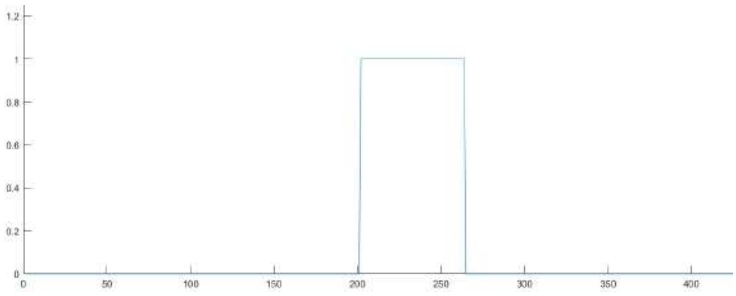


Figure 8: Thresolding

G Finding QRS Complex

The R peak is the greatest value inside the locations "x" and "y". The next step is to find Q, which we know is before R. The minimum point between R and the beginning of the QRS complex ("x" array) gives us Q, and the minimum point between R and the end ("y" array) gives us S location.

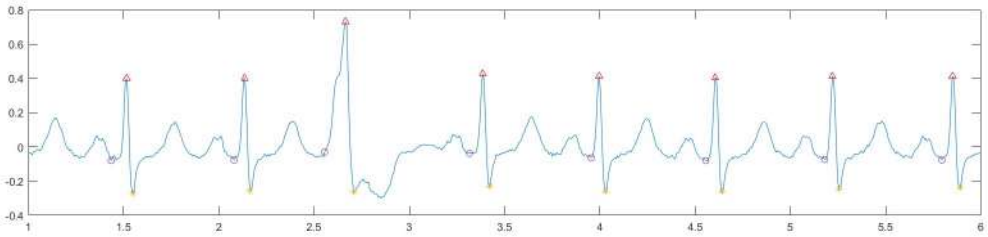


Figure 9: QRS Complex Detected

2.4 PVC Detection

A Form Factor Calculation

We can detect the PVC beats on the basis of Form Factor or R-R interval. So in first case we find the Form Factor.

Form Factor(FF) is ratio of mobility of first derivative ($M_{x'}$) of the signal to the mobility of signal (M_x) itself. Where derivative of the signal x' and corresponding standard deviation of that is a $\sigma_{x'}$; ratio of that gives us the, that mobility of the signal.

$$\boxed{M_x = \left[\frac{\sigma_{x'}^2}{\sigma_x^2}\right]^{1/2} = \frac{\sigma_{x'}}{\sigma_x}} \tag{1}$$

Form Factor(FF) is ratio of Mobility of First Derivative ($M_{X'}$) of the signal to the Mobility of Signal (M_X) itself.

$$\boxed{FF = \frac{M_{x'}}{M_x} = \frac{\sigma_{x''}\sigma_x}{\sigma_{x'}^2}} \tag{2}$$

B Result: Finding the PVC Beats

First we calculate the Form Factor and RR interval length in each cycle with the help of the QRS complex location we got earlier. Then we found that PVC beats has Larger FF and RR-Interval compared to the normal beats.
So by this way we can find the PVC beats in ECG.

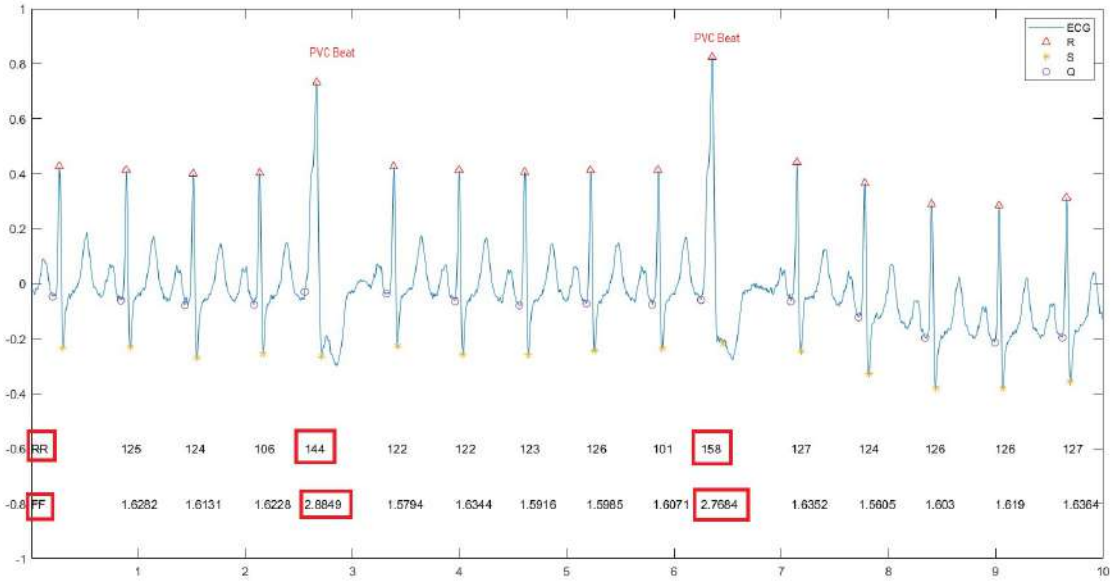


Figure 10: PVC Beats Detected

3 Detection of S1 & S2 Sound Locations in PCG by using ECG & PPG

S1 and S2 are the sounds of heart valve closure. S1 sound is produced due to closure of Mitral and Tricuspid valves, and S2 due to closure of Aortic and Pulmonary valves. Duration after S1 is called Systole during which Ventricle gets compressed, and the duration after S2 is called Diastole during which Ventricles relaxes and fills new blood.

3.1 Relating S1 & S2 in PCG to QRS of ECG and Dicrotic Notch in PPG

When QRS complex begins in ECG, ventricle starts getting compressed, just before that time Mitral and Tricuspid valves closes and produces sound S1. So from ECG we can find location of S1 in PCG.
At end of compression of ventricle it then starts to relax. Then to hold the pressure and to stop blood from getting back flowed into ventricle, the Aortic and Pulmonary valves closes and that gives rise to a small dip in the carotid pulse signal (pressure at carotid pulse) and valve closure produces S2 sound. The second small peak is called Diastolic peak which is the reflected wave that returns from the periphery of arteries.
So from PPG we can find location of S2 in PCG.

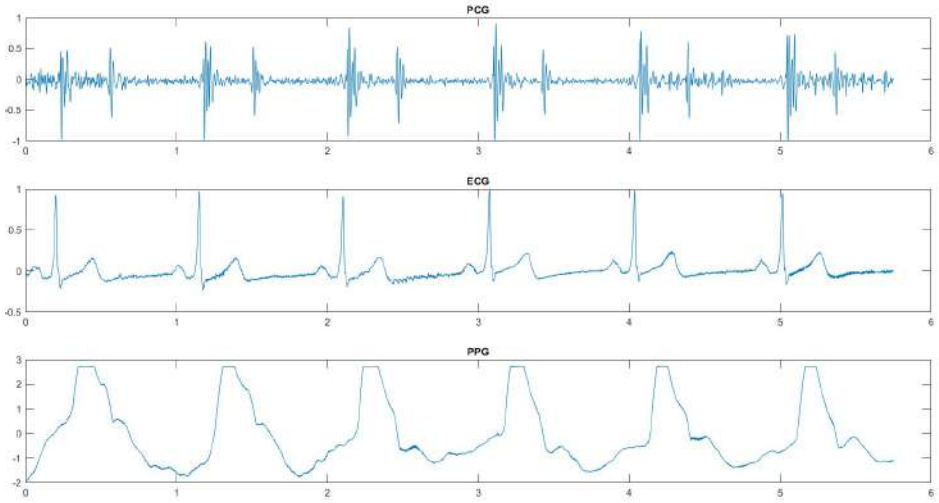


Figure 11: Synchronized 3-channel PCG, ECG and PPG data

3.2 Proposed Method

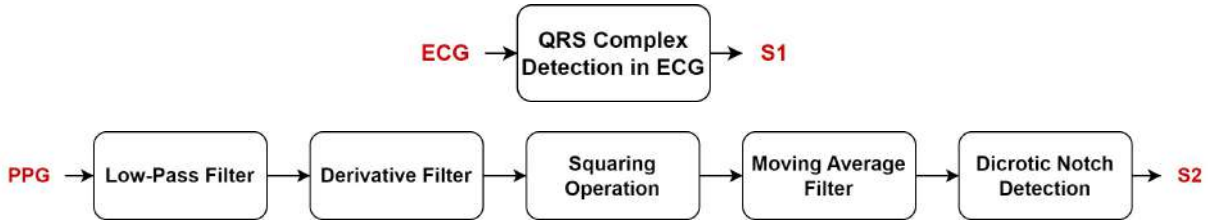


Figure 12: Detection of S1 and S2 location in PCG Algorithm

3.3 Detection of QRS Complex

We will use the same algorithm mentioned in previous section to find the location of QRS complex. This will give us the location of S1 of PCG.

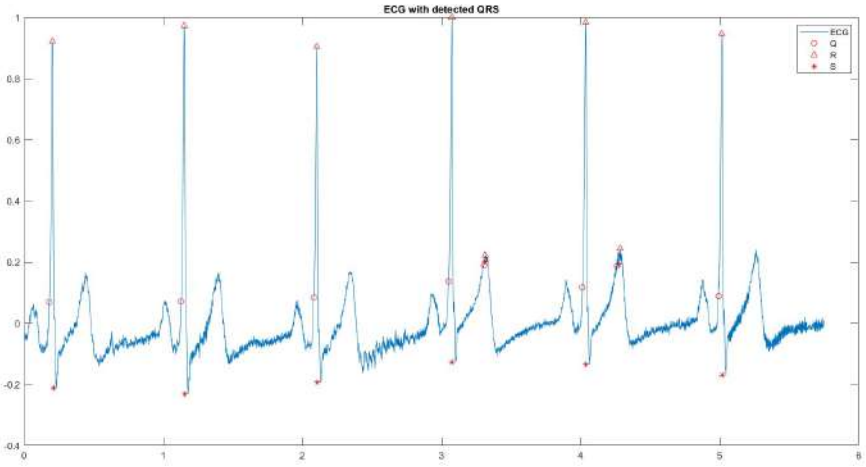


Figure 13: QRS Detected ECG

3.4 Dicrotic Notch Detection in PPG

A Low-Pass Filter

To remove the high frequency noises, We will use a 8-point low-pass Butterworth filter, the order is 8 and the cutoff frequency is 40Hz. We design the filter using the 3dB bandwidth.

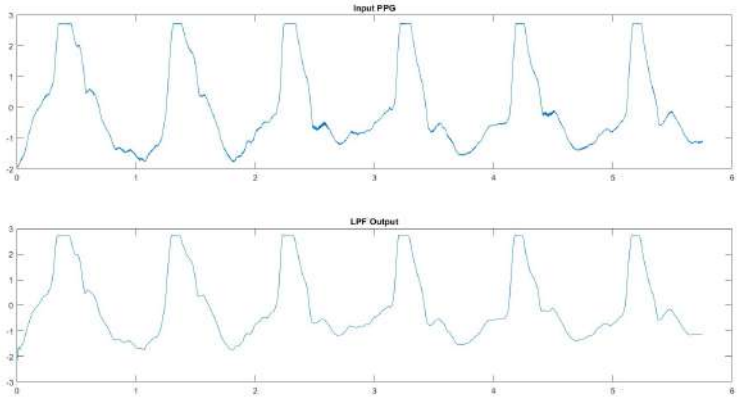


Figure 14: PCG LPF Output

B Differentiating and Squaring

It is necessary that before applying a differentiator, we need to do low pass filtering otherwise those noises could be magnified and have an impact on the accuracy of the technique. So that's why we applied low pass filter before the differentiator stage.

First, we pad the signal with reflection of front on front and reflection of end side on the end instead of zero padding because if you pad with zeros, it will unnecessarily give rise to some high frequency at that point. Now for Differentiator, we used a second order filter.
Then after squaring operation all waveform becomes positive and prominent pulses in the derivative output accentuates.

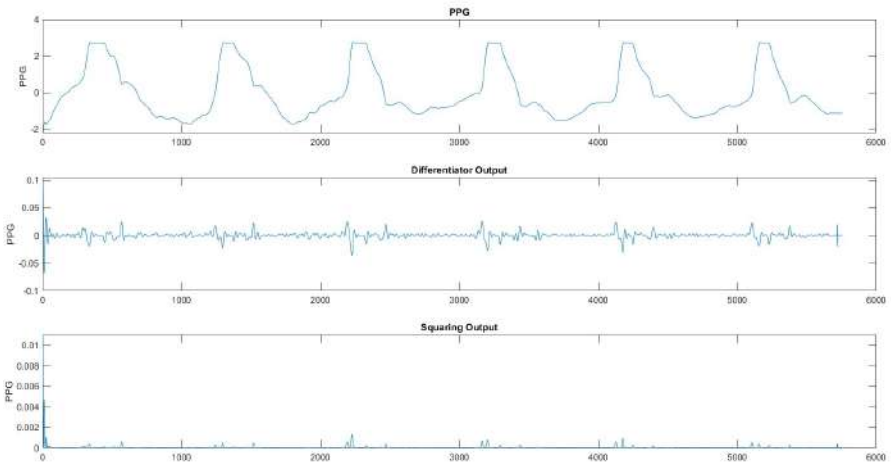


Figure 15: Differentiator Squaring Output

C Moving Average Filter

The output of moving average will give two peaks in each cycle. Location in PPG around this moving average output's 2nd peak will have the Dicrotic Notch. So first we will use a threshold to find this 2nd peak location. Then find a minima location within 20ms of this 2nd peak location in the PPG waveform, that will give us the Dicrotic notch location.
The location of this Dicrotic notch is the S2 sound location of PCG.

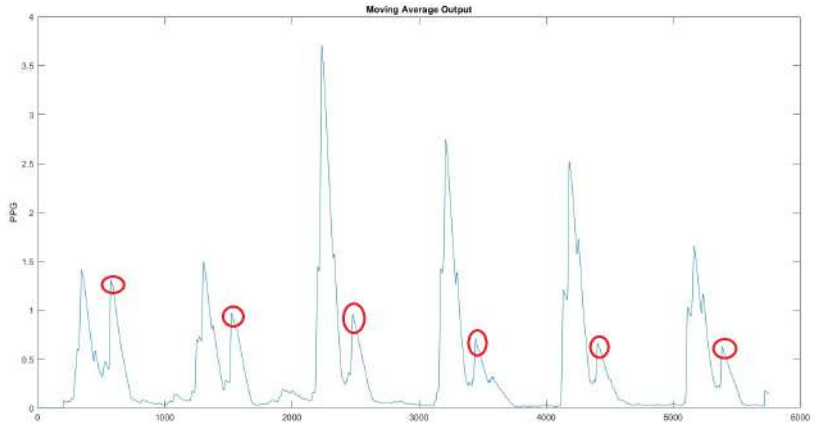


Figure 16: Moving Average Output

3.5 Result: Detection of S1 & S2 in PCG

We have determined the location of S1 and S2 in PCG by using synchronised ECG and PPG data.

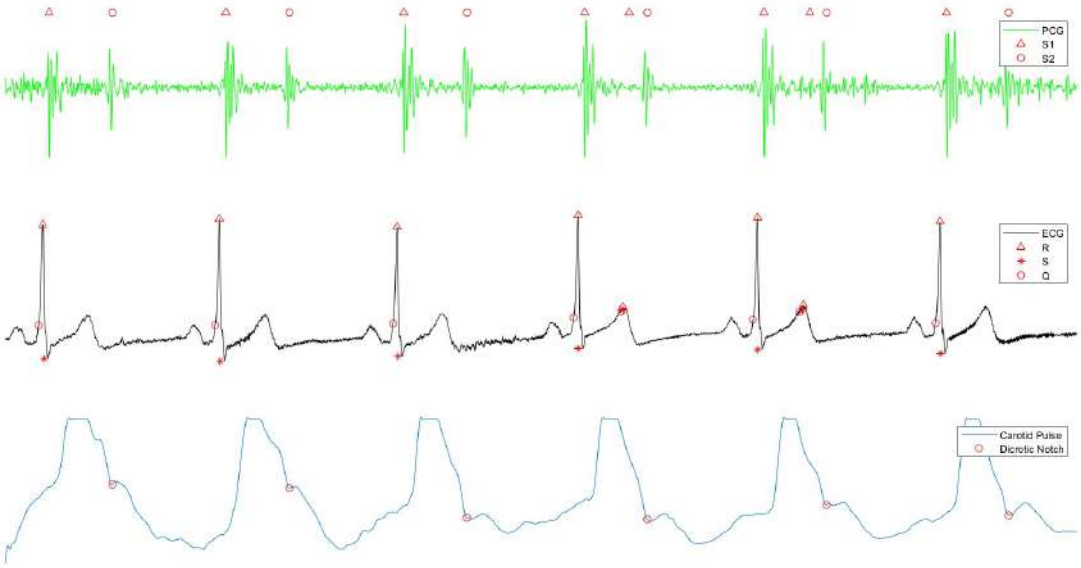


Figure 17: S1 and S2 in PCG detected using ECG and PPG

4 Related Work

Jung and Heeyoung used a computerised method to figure out PVC disease. In this paper, the statistical parameters of the ECG were taken out using the wavelet function [1]. Zarei et al. extracted morphological features of the heart, using the PAT algorithm. The ECG samples were put in a row matrix using a linear analyzer for diagnosing PVC arrhythmias [2].

Zhou FY used deep neural networks to diagnose the PVC arrhythmias, like lead convolutional neural network (LCNN) or long short-term memory (LSTM) network, and rules inference [3]. Rameshwari et al. suggested a simple and effective algorithm to extract characteristics of the ECG signal [4].

Lek-uthai et al. used several features of the ECG for diagnosing PVC. They used a state vector machine (SVM) for classifying the ECG signal [5]. Cuesta et al. used only two QRS features for detection of PVC, and was tested on the MIT-BIH Arrhythmia database [6].

5 Conclusions and Future Work

In part 1 of the project, we determined the location of QRS complex in ECG and then using that we calculated the Form Factor and RR interval through which we distinguished the PVC beats from normal beats. In part 2 of the project, we first determined the location of QRS in ECG and Dicrotic Notch in PPG and used them to locate the S1 and S2 sound locations in PCG.

In our work, we have utilised the general Pan Tompkins algorithm to detect QRS complexes, which yields a good result; however, in some circumstances, the algorithm refers some undesirable peaks as an R-peak, as in the case in our detection of QRS for S1. Other methods can be used to detect the features, like using Gabor feature extraction technique.

In the case of S1 and S2 detection, we have not made any use of PCG signal for the purpose of detection, which has its own distinct benefit; however, for the majority of the cases, we can also take the assistance of PCG signal for a better estimation of S1 and S2 and to represent in location more precisely. There are other several methods that have been offered, such as the utilisation of a zero frequency filter or the utilisation of a wavelet decomposition approach.

6 Contributions

Abhijeet Aditya implemented the Pan Tompkins algorithm step by step to detect the QRS complex in the ECG data. Satya Prakash determined the PVC beats in the ECG by estimating the Form Factor and RR interval of each cycle using the QRS location data estimated before.
Saurabh Chatterjee determined the QRS complex location in ECG and location of Dicrotic Notch in PPG from a 3-channel synchronised data of PCG, ECG and PPG, he then used them to estimate the S1 and S2 sound locations in the PCG signal.

References

[1] Jung Y, Kim H. Detection of PVC by using a wavelet-based statistical ECG monitoring procedure. Biomed Signal Process Control . 2017;36:176–82. doi: 10.1016/j.bspc.2017.03.023.

[2] Zarei R, He J, Huang G, Zhang Y. Effective and efficient detection of premature ventricular contractions based on variation of principal directions. Digit Signal Process . 2016;50:93–102. doi: 10.1016/j.dsp.2015.12.002.

[3] Mane RS, Cheeran AN, Awandekar VD, Rani P. Cardiac arrhythmia detection by ecg feature extraction. Int J Eng Res Appl . 2013;3(2):327–32.

[4] Lek-uthai A, Ittatirut S, Teeramongkonrasmee A. Algorithm development for real-time detection of premature ventricular contraction. TENCON 2014 - IEEE Region 10 Conference . Bangkok, Thailand: IEEE; 2014. pp. 1–5.

[5] Manikandan MS, Ramkumar B, Deshpande PS, Choudhary T. Robust detection of premature ventricular contractions using sparse signal decomposition and temporal features. Healthcare Technology Letters . 2015;2(6):141–8. doi: 10.1049/htl.2015.0006.

[6] Cuesta P, Lado MJ, Vila XA, Alonso R. Detection of premature ventricular contractions using the RR-interval signal: a simple algorithm for mobile devices. Technol Health Care . 2014;22(4):651–6. doi: 10.3233/THC-140818.