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AUTOMATED R-PEAK DETECTION IN ELECTROCARDIOGRAMS: A COMPREHENSIVE STUDY

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INTRODUCTION

ECG is a diagnostic tool which helps measure the activity of the heart by recording the electrical signals within it. It is a revolutionary discovery as it can prematurely detect heart diseases, heart attacks and enlarged hearts. It can also detect irregular heart beats. To understand the working of the ECG, it is essential to understand the basic working of the heart. The heart is a muscle and it can be modelled as an electric pump. There is a rhythmic contraction and relaxation of the heart and this results in what is called a heart beat. The heart consists of four chambers, a pair of auricles that lie above a pair of ventricles. A heart beat broadly consists of the following phases that occur in tandem.

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- Auricular contraction: This corresponds to the contraction of the auricles. During this phase the inflow of blood from the rest of the body, collected in the auricles is pumped into the ventricles.
- Ventricular contraction: The blood that is collected in the ventricles in the previous phase is (purified and) subsequently pumped to the rest of the body.
- Ventricular relaxation: This is the last phase of a heart beat and corresponds to relaxation of the ventricles. This is followed by the next heart beat.

ECG consists of placing electrodes on the body on either side of the heart so as to measure the potential difference across the membrane of the heart.

How is this potential difference induced?

Sudden changes within a cell causes dramatic electrical changes, which induces electrical potential differences across the cell membrane. This potential difference occurs as a result of the interaction between fixed charges of the membrane pores in the heart with the ions Na+ and K+ diffusing in and out of the cell. The electrical membrane changes that occur during a heart beat is captured in an ECG.

A human ECG, typically shows the following characteristics that correspond to the above mentioned phases.

- P−wave: The electrical potential changes induced in the cardiac cells during auricular contraction, corresponds to a small peak in the ECG signal called the P wave.
- QRS complex: Ventricular contraction corresponds to a characteristic three pulse deflection combination in the ECG called the QRS complex. Every ECG comprises of a characteristic signal spike called the “R peak”, that occurs in the middle of the QRS complex. This is the portion of the ECG with the largest signal amplitude.
- T-wave: This small pulse succeeds the complex and is the electrical potential changes induced in the cardiac cells during ventricular relaxation.

By finding the number of R-peaks in a minute in the ECG, the number of heartbeats per minute can be estimated. This value varies from person to person and is dependent on a number of other factors. For a normal healthy adult at rest, the average number of heartbeats per minute ranges from 60 to 100. For a trained athlete, it is usually around 40 beats per minute. However, when one engages in physical activity of medium to high intensity, this value changes and the heart beat rate can range from 100-170 beats per minute. The heart beat rate also depends on age and it increases with increase in age. This is because the heart's ability to pump blood gradually deteriorates with age.

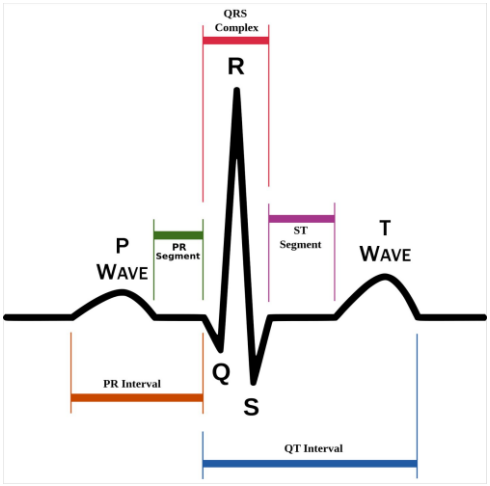


Figure 1. Waves on the ECG waveform

Source: https://en.wikipedia.org/wiki/Electrocardiography

DETECTING R - PEAKS AND FINDING AVERAGE HEARTBEAT RATE

I. Preprocessing of the ECG signal:

ECG consists of different types of noise mainly frequency interference, baseline drift, electrode contact noise and so on. Pre processing of the signal consists of two parts.

1. Getting rid of baseline wander.
2. Getting rid of the powerline interference (which consists of removing 50 - 60 Hz noise from the signal).

Baseline wander:

Baseline wander is when the base axis (X-axis) of any signal viewed on a screen appears to 'wander' or move up and down rather than be straight. This causes the entire signal to shift from its normal base. It may be caused due to improper electrodes (like rusted, or broken). The baseline wander was removed by computing a new signal y[n] = x[n] - x[n-1] (for n>=1) , y[n] = x[n] (for n=0). The frequency content of baseline wander is usually in the range below 0.5 Hz. Increased movement of the body increases the frequency content of baseline wander.

Powerline Filtering

A raw ECG signal has some AC noise added to it. The noise due to power line interference occurs at intervals of every 1/50 or 1/60 seconds (50 to 60 times per second). This can be thought of as noise having 50 - 60 hertz frequency. This noise should be removed to get a clean ECG signal. There can be different ways to remove this noise. The method we used is a band stop notch filter which removes 50 hertz frequencies. A notch filter is used when one wants to remove specific frequencies.

The transfer function for this filter is as follows

$$H(z) = b\frac{1 - 2\cos\omega_0 z^{-1} + z^{-2}}{1 - 2b\cos\omega_0 z^{-1} + (2b-1)z^{-2}}$$

Using the transfer function H(z) and the equation below, the Z transform of the filtered output is computed.

$$Y(Z) = H(Z)*X(Z)$$

The inverse transform of the above equation is computed and a difference equation for y[n] in terms of x[n] and h[n] is obtained. It is traversed in a loop to compute y[n] for each value of n and hence the filtered signal is obtained.

II. R PEAK DETECTION

Heart beat is determined by detecting R peaks in the signal. The total number of peaks averaged over the time interval gives the average heartbeat rate per unit time. For facilitating the identification of R peaks and distinguishing them from the remaining pulses in the ECG waveform, the signal is squared. This increases the amplitude of the peaks and reduces the noise strength. Squaring also eliminates the sign component of the signal.

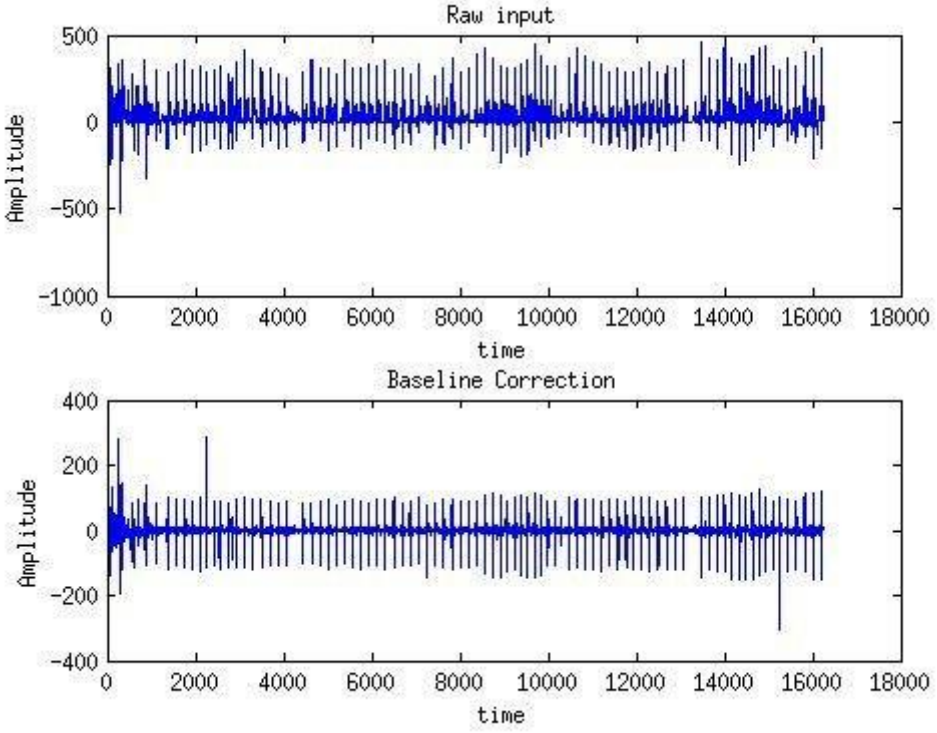
The procedure for R peak detection broadly consists of the following steps

- A threshold 't' is defined for detecting the peaks. When the signal amplitude exceeds 't' it is detected as an R peak.
- To compute 't', the squared signal is first sorted in descending order.
- A threshold is defined such that the threshold is greater than or equal to the highest five percent elements in the signal.
- Each value of the signal is traversed in the for loop.
- A time interval window (in this case it is 20 units of time) is defined in which there is no detection of peaks allowed. This time interval denotes the S-T interval in an ecg signal.

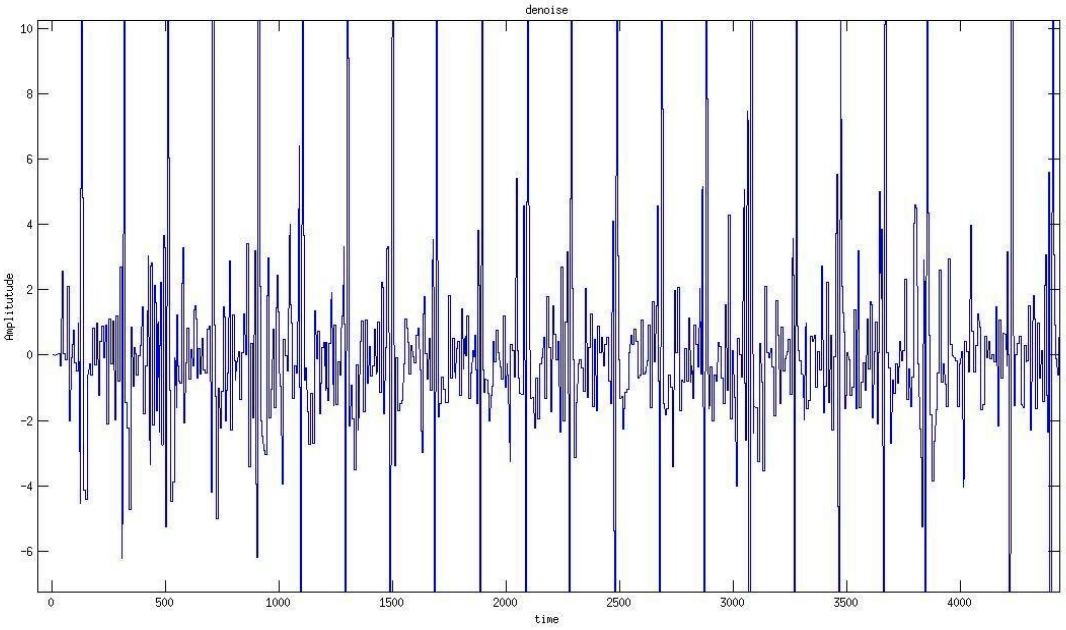
EXPERIMENTAL OBSERVATIONS

The sampling rate used in the following plots is 250 Hz. Raw input and baseline correction for the input “yateesh_DATA__raw.txt” was plotted below:

Here in the first plot (the raw input plot) it can be observed that there is baseline wander and in the second plot it can be observed that baseline is corrected. The third plot is the denoised signal that is the signal obtained after passing through the notch filter.



After removal of Powerline Noise:

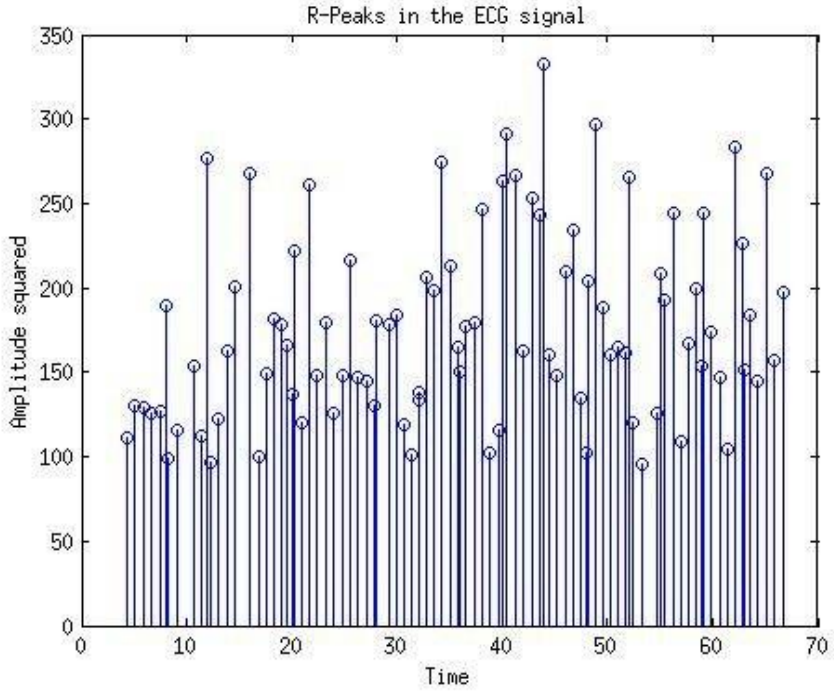


TABLE

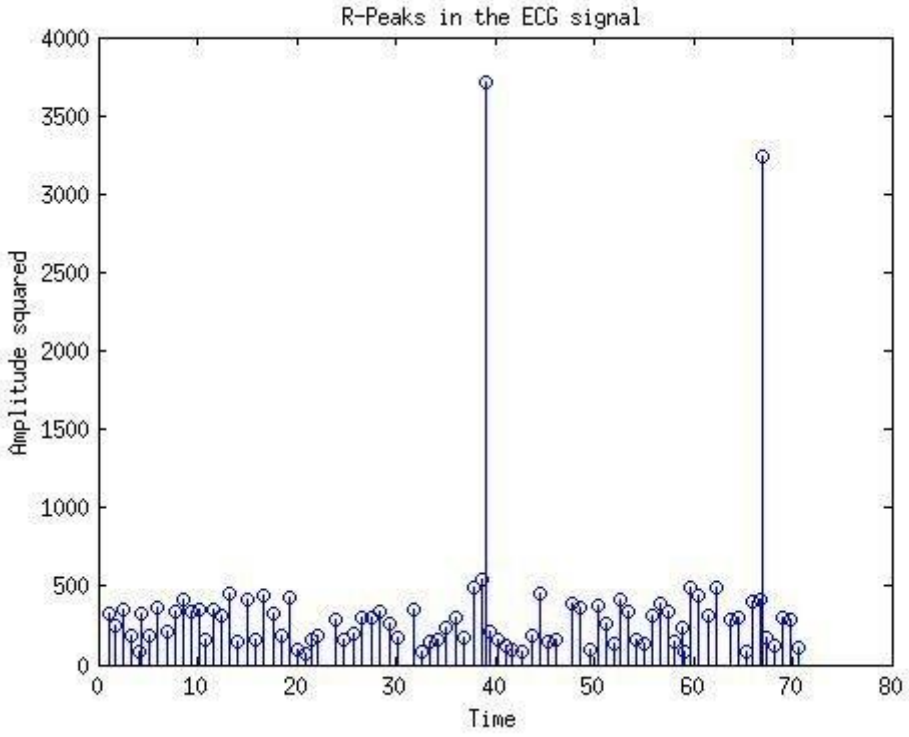
Input File	**No. of heartbeats per minute**
Karan_DATA_raw.txt	59.318184
veda_DATA__raw.txt	128.181824
sruthi_DATA__raw.txt	95
vijay_DATA_raw.txt	75.21126
vinod_DATA__raw.txt	66.3529
yateesh_DATA__raw.txt	83.076927
satwik_DATA__raw.txt	106.017
Akshit_DATA_raw.txt	85.074631
RJ_DATA_raw.txt	65.517250
samyak_DATA__raw.txt	60

R - PEAKS

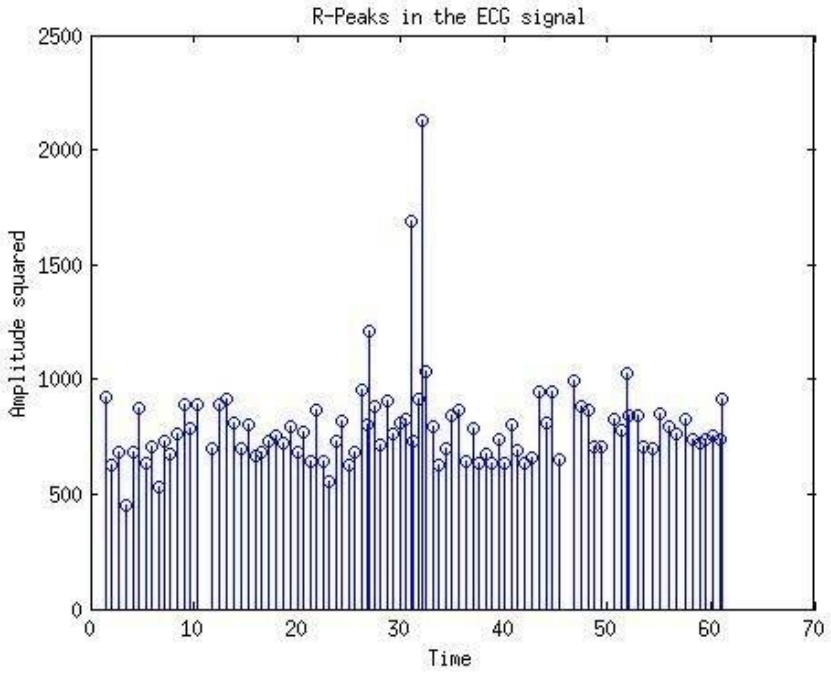
Akshit:



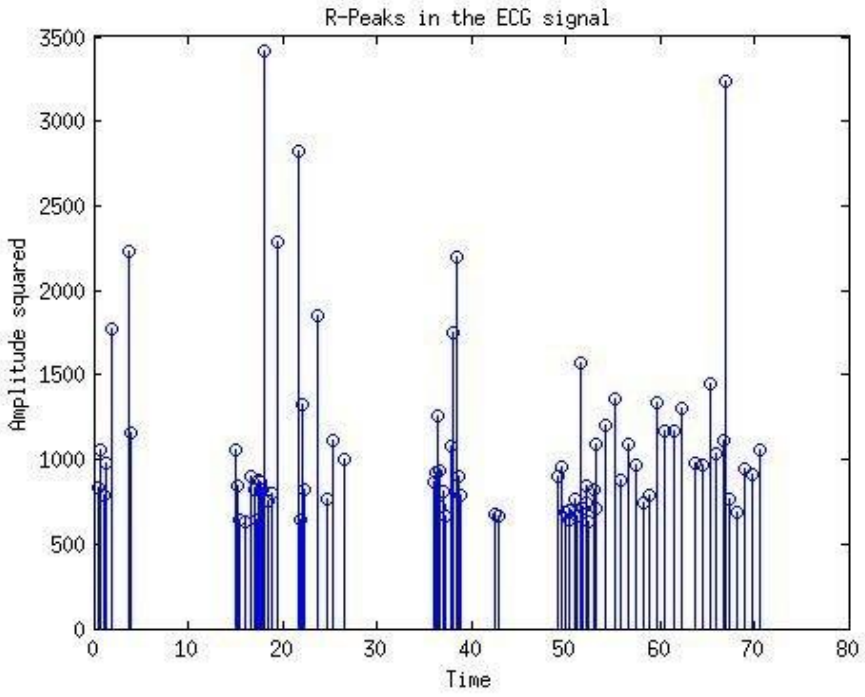
Karan:



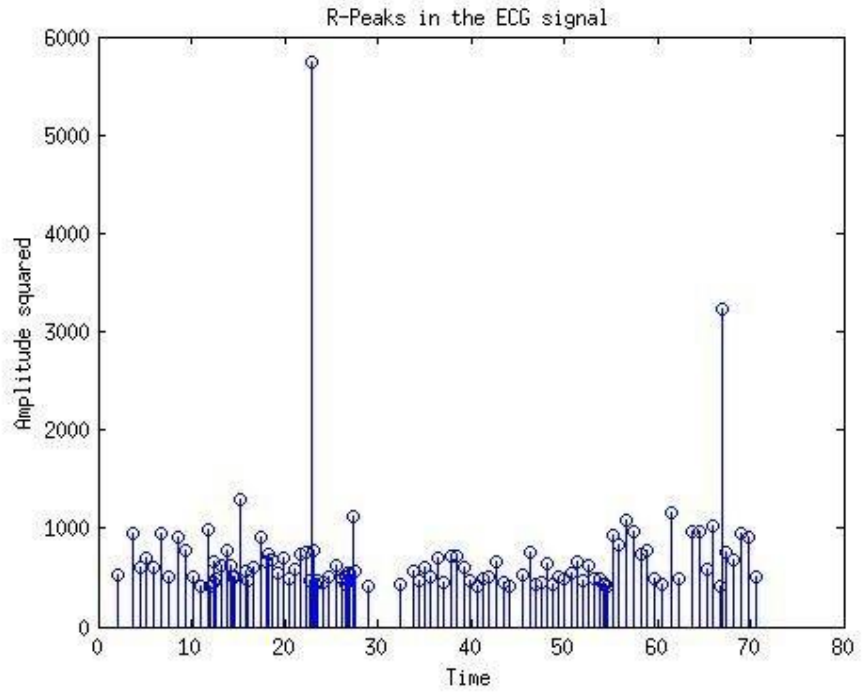
RJ:


R-Peaks in the ECG signal
Amplitude squared
Time
0
500
1000
1500
2000
2500
0
10
20
30
40
50
60
70

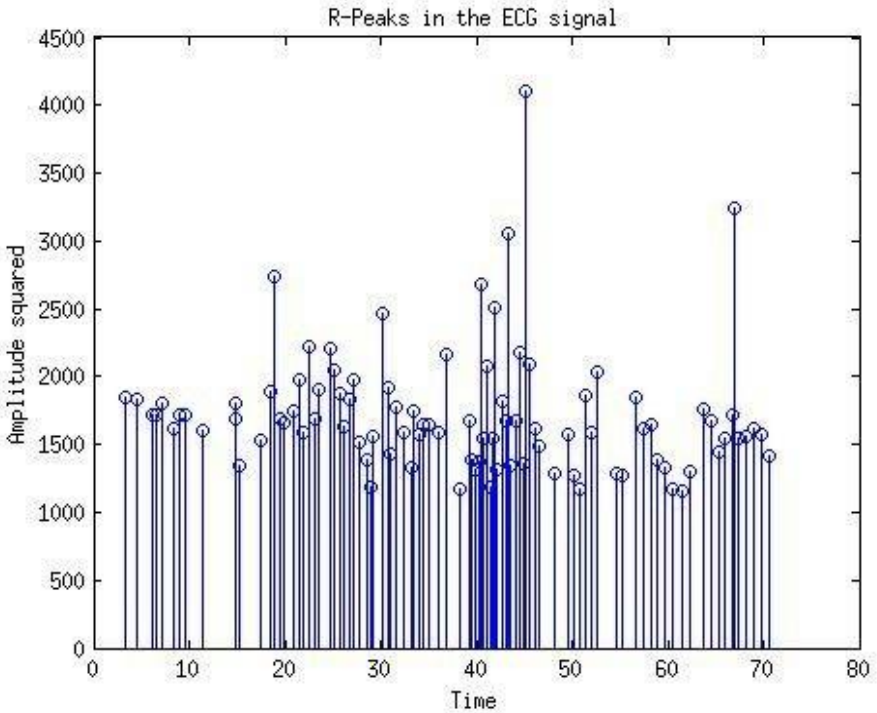
Samyak:


R-Peaks in the ECG signal
Amplitude squared
Time
0
500
1000
1500
2000
2500
3000
3500
0
10
20
30
40
50
60
70
80

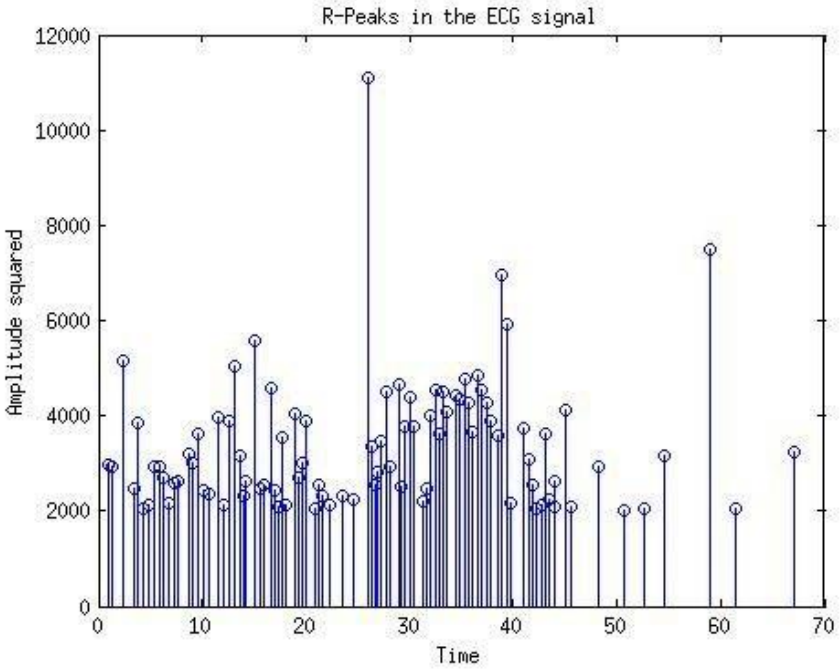
Satwik:



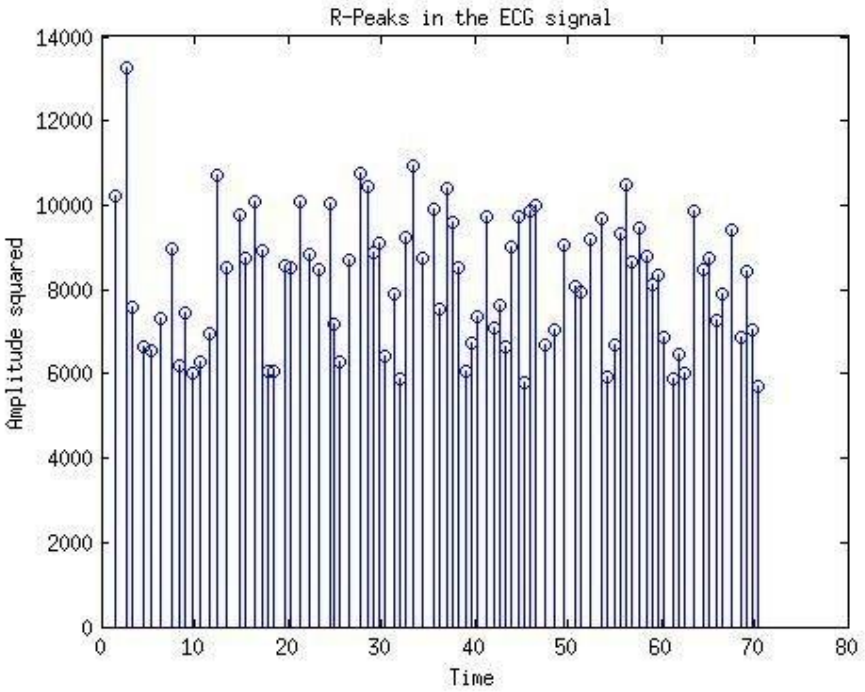
Sruthi:



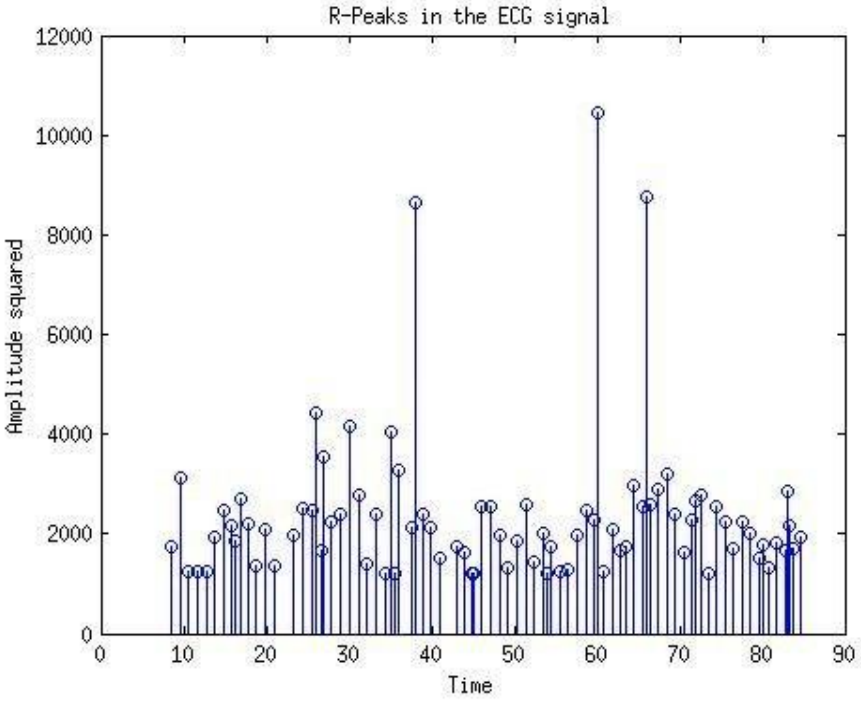
Veda:


R-Peaks in the ECG signal
Amplitude squared
Time
0
2000
4000
6000
8000
10000
12000
0
10
20
30
40
50
60
70

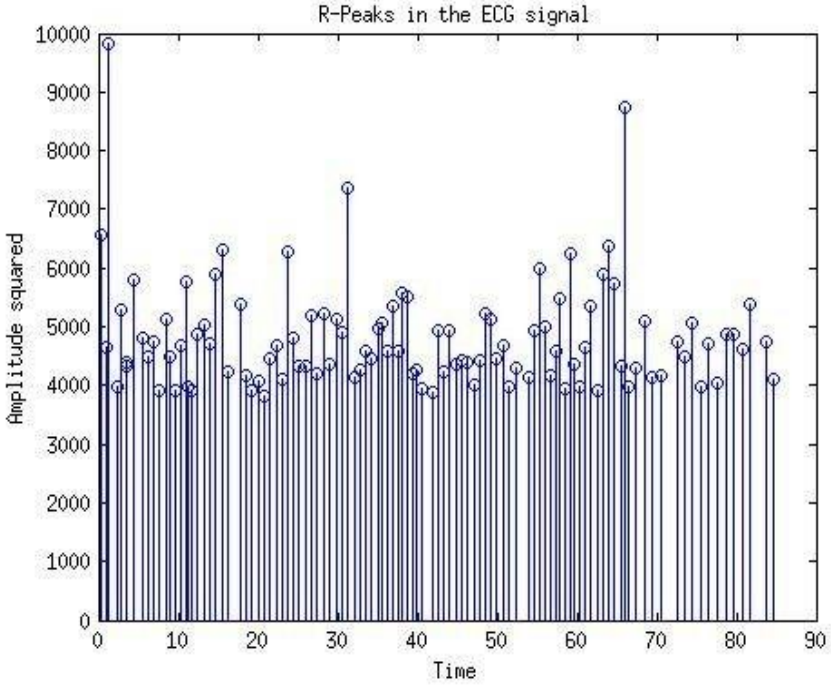
Vijay:


R-Peaks in the ECG signal
Amplitude squared
Time
0
2000
4000
6000
8000
10000
12000
14000
0
10
20
30
40
50
60
70
80

Vinod:



Yateesh:



INFERENCE

- The frequency of R peaks calculated is used to effectively estimate the heartbeat rate (beats per minute). The heart beat range calculated for the available data was between 60 – 130 bpm.
- The R peak location and amplitude varied across the available data used for different people. When the R peak values are clustered around a time interval, it indicates physical activity during that time interval.
- While small fluctuations indicates the normal variation that exists across individuals, a distinctly high (or low) heartbeat rate suggests the possibility of the person indulging in a high intensity physical activity at the time the ECG samples were recorded.
    - The number of heartbeats for veda_DATA__raw.txt for instance was estimated to be 128 bpm, while most of the other values fall between the 60-110 range. So probably Veda had indulged in high intensity physical activity at the time of recording the samples, for example say jumping, running etc.
    - The number of heartbeats for samyak_DATA__raw.txt for instance was estimated to be 60bpm, so he was probably resting or sitting idle etc., but there may be other reasons for the difference in heartbeats of different persons, it varies from person to person and also it varies with age of the person.

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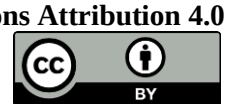

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