Digital Signal Processing Project for the Make in India National Initiative

Heart Rate Variability Analysis

Group 14

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Motivation for the project:

- Heart disease and stroke together contributed to 28.1% of total deaths in India in 2016 — compared with 15.2% in 1990.
- The delay between the first symptom of any cardiac ailment and the call for medical assistance has a large variation among different patients and can have fatal consequences.
- One critical inference drawn from epidemiological data is that deployment of resources for early detection and treatment of heart disease has a higher potential of reducing fatality associated with cardiac disease than improved care after hospitalization.
- New strategies are needed in order to reduce time before treatment. Monitoring of patients is one possible solution. For that, we require an affordable device that can be used by everyone to monitor their heart rate.
- Hence, this was chosen by us for the Make in India National Initiative

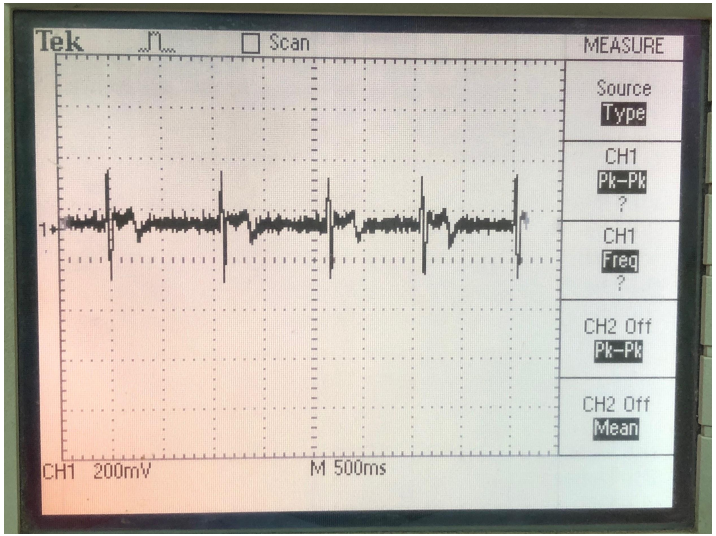
Why HRV Analysis?

- Cardiovascular heart diseases, such as Myocardial Infarction, is the number one leading cause of death in different countries around the world.
- The heart rate in human beings, which is measured by beat-to-beat intervals, is not constant and varies over time.
- This observation led to a field of studies that investigated heart rate variability (HRV) in several diseases, including coronary artery disease and myocardial infarction (MI).
- HRV can be considered as a reflection of various physiological factors modulating the normal rhythm of the heart.

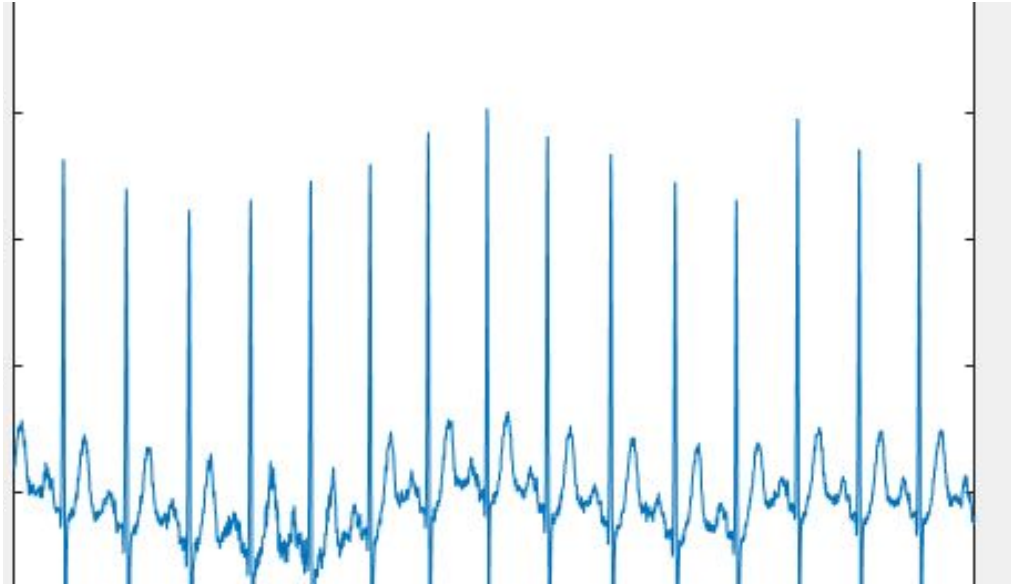
Acquiring the ECG Signal

There are many circuit designs available online to build a circuit to detect an ECG signal. The video on the right is an example of a 4 lead ECG circuit. The picture on the left is the ECG of Deep Karman.

We do not use these ECG signals for our assignment. The reason for this is that samples from modern instruments - 12 lead ECG sensors are able to reduce noise to a far greater extent. We can see the R and T waves clearly with our sensor, but we need better sensors to be able to detect the P wave, the entire QRS complex, and the T wave with much higher SNRs.



For the purpose of analysis, we took the MIT-BIH Arrhythmia Database. Here is 10 second sample from one of their many long duration signals plotted using MATLAB.

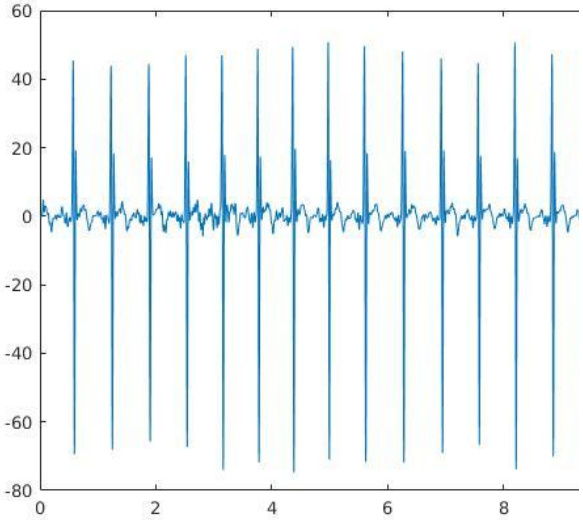


Filtering of the Signal

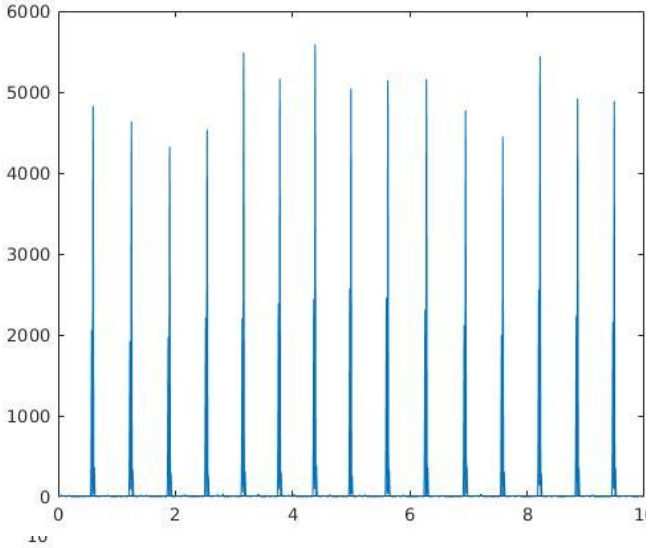
We band limit the signal to between 5 Hz and 15 Hz by passing it through a low pass filter and a high pass filter in cascade

After band pass filtering

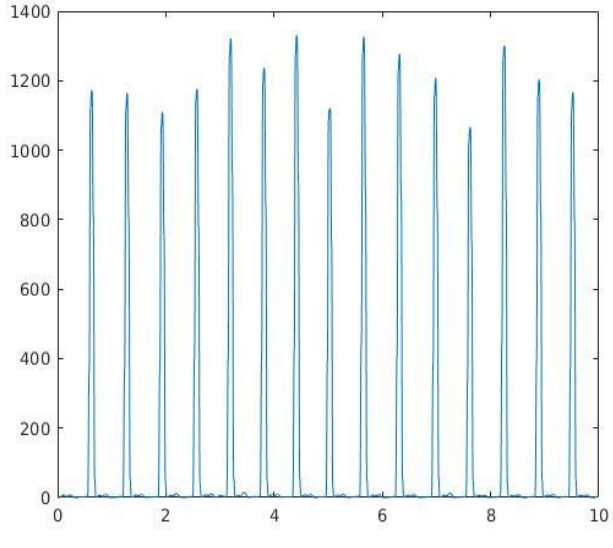
Differentiation, Squaring and Moving-Window Integration



Differentiated signal



Squared signal



Moving Window integrated signal

After the signal is filtered to remove noise, we need to identify the peaks in QRS complex and localize the R waves. We do this by passing the signal through a filter which approximates as a differentiator. This shows the points of sharp transition, corresponding to the peaks. After this we square the signal and pass it through a moving window integrator in order to localize the R waves.

RR Intervals calculation

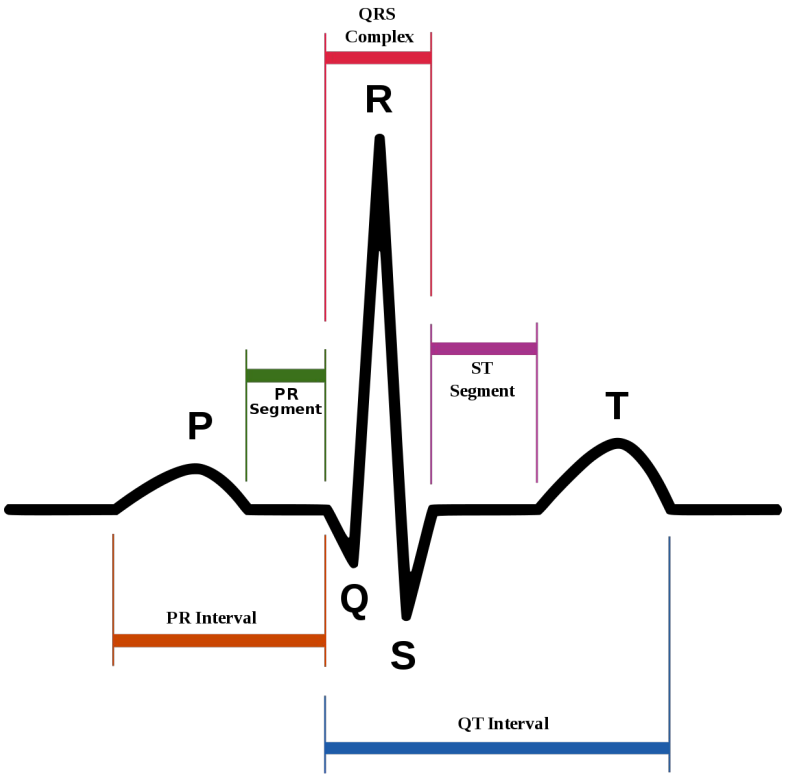


Image source: https://wikipedia.org

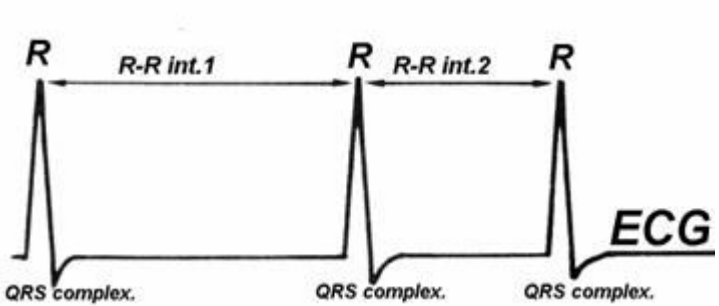


Image source: http://www.dantest.com/introduction_what_is_hrv.htm

The sequence of RR intervals (sometimes called IBI or beat-to-beat interval forms the RR interval time series. The IBI time series of an ECG segment containing N beats is given by:

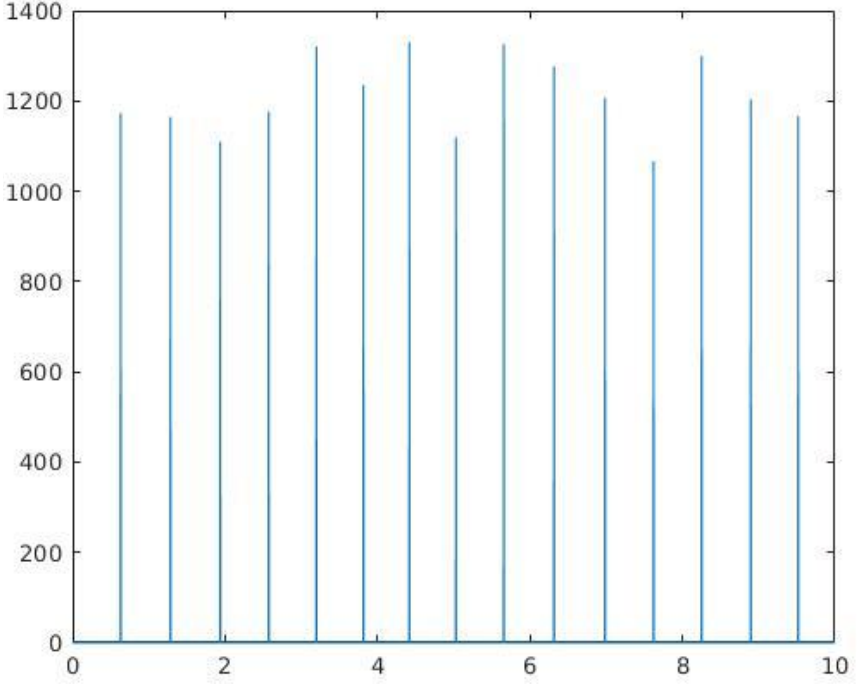
$RR_i = (t_{i+1} - t_i)*1/F_s;\ i \in \{0,2,....,N-1\}$

Where i is the sample number and Fs is the sampling frequency

Thresholding

Thresholding of the signal is absolutely essential as we need only the R peaks and for RR interval calculation and no other peaks. Hence, peak detection algorithm has to be extremely robust.

For this, we remove all values below a certain threshold and remove any additional peaks around the R sample by a margin of 40 samples. (Our sampling rate is 360 samples/second)

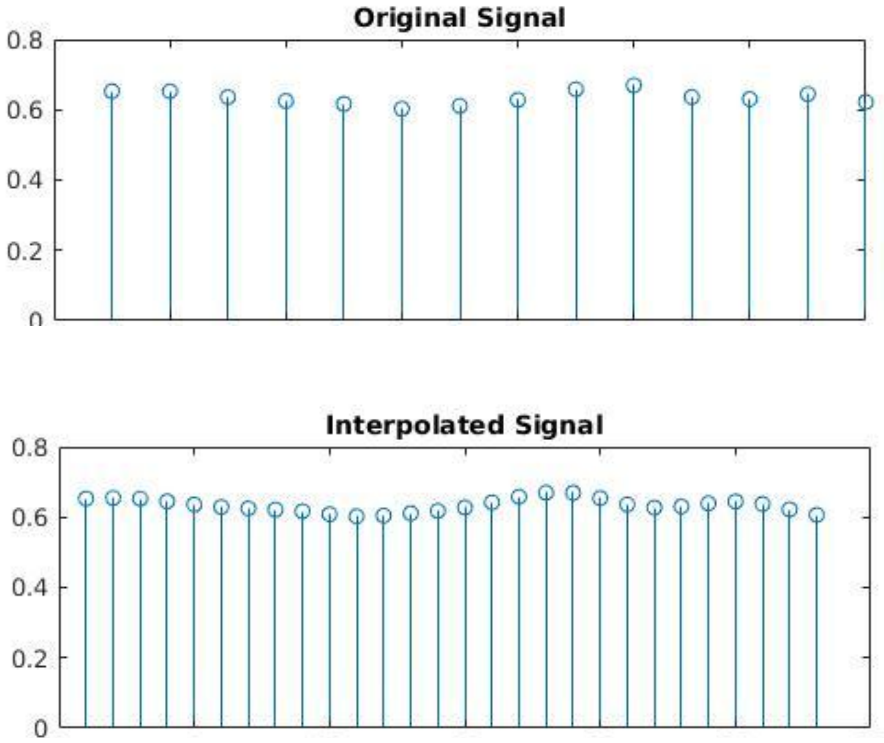


Interpolation

Interpolation editing methods replace the abnormal R-R intervals with new interpolated R-R intervals.

The RR interval time series is an irregular time-sampled signal (Since the time domain results are not standardized i.e. the beat occurrence itself is a random process.).

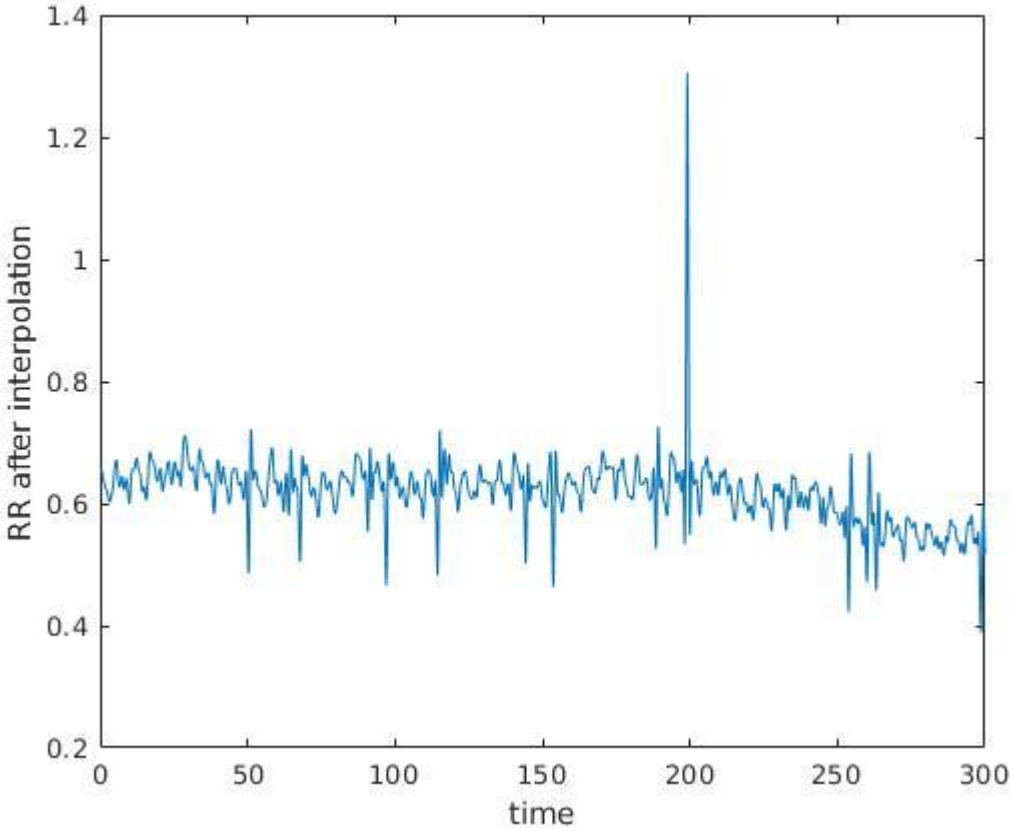
This is not an issue in time-domain, while in the frequency-domain it has to be taken into account.



Example of interpolation by 2

Generation of HRV signal

To get the heart rate variability (HRV), we interpolate the RR interval series over all samples we have (108000 over 300 seconds, sampling rate=360 samples/second) using RR interval values we have, after which we can further analyze the signal in the frequency domain.



Examples of normal and abnormal HRV signal

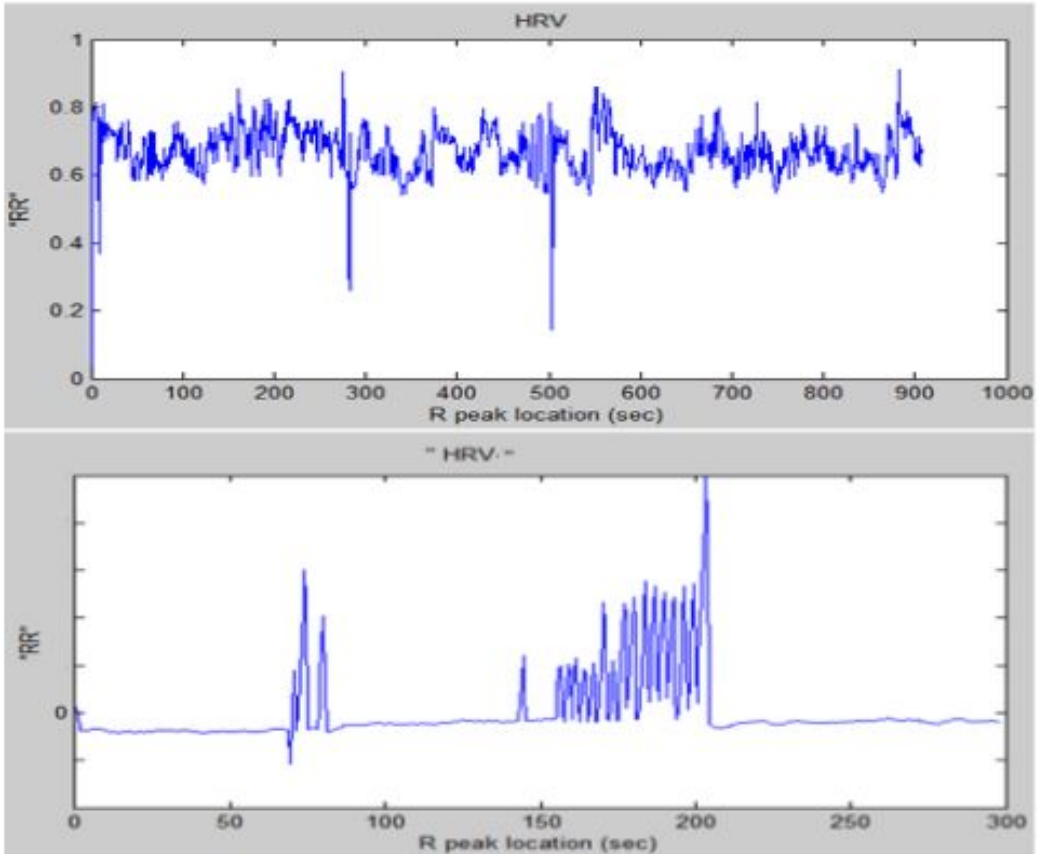


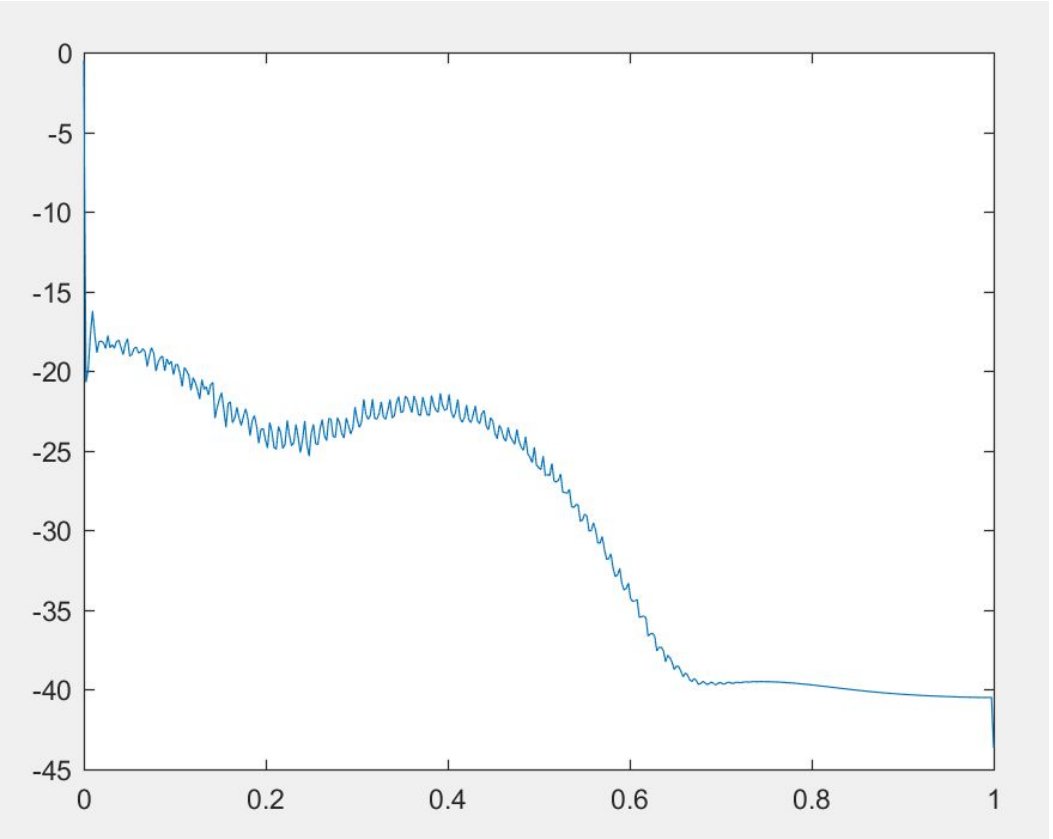
Image source: Heart Rate Variability (HRV) Analysis Using DSP For The Detection Of Myocardial Infarction

HRV Processing, Parameters Extraction and PSD Analysis

From this HRV signal, we estimate its PSD. On the left is such an estimate for a particular sample.

We use this to calculate the LFHF ratio, which simply put is the ratio of the power of the signal between frequencies of 0.04 to 0.15Hz and power between 0.15 to 0.4Hz.

A high ratio suggests greater risk of Myocardial Infarction. This is from the physiology of the heart and the correlation of the HRV with the parasympathetic nervous system.



Real Time DSP Implementation

The usage of Digital Signal Processor (DSP) for the detection and analysis of electrocardiographic signals offers a means for increased computational speed and the opportunity for design of customized architecture to address real-time requirements.

The following sub-modules will be constructed for our main algorithm:

1. R-peaks detection program that follows the same steps discussed before
2. FFT program
3. PSD analysis program

References:

1. Heart Rate Variability (HRV) Analysis Using DSP For The Detection Of Myocardial Infarction- Firas Zakaria, Mohamad Khalil
2. Quantitative Investigation of QRS Detection Rules Using the MIT/BIH Arrhythmia Database- Patrick S. Hamilton and Willis J. Tompkins,
3. https://physionet.org/physiobank/database/mitdb/
4. http://www.ijariie.com/AdminUploadPdf/Heart_Rate_and_Growth_Measurement_with_Abnormality_Detection_And_Send_Emergency_Alerts_To_Relatives_and_Ambulance_ijariie8733.pdf
5. https://www.who.int/news-room/fact-sheets/detail/cardiovascular-diseases-(cvds)
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