Project 1B: Analysis of ECG signals – Heart Rate Variability

1-3: RR Interval

Task 1-

In this part, the task was to design the FIR filter and complete the code. The parameters of the filter have been defined in detail in the relevant matlab file examplerr_task1.m. A causal filter was selected since we want to take into account both past and future values of the EGC trace during our filtering process.

Figures 1-4 show the ECG signal and the R peaks for all data sets.

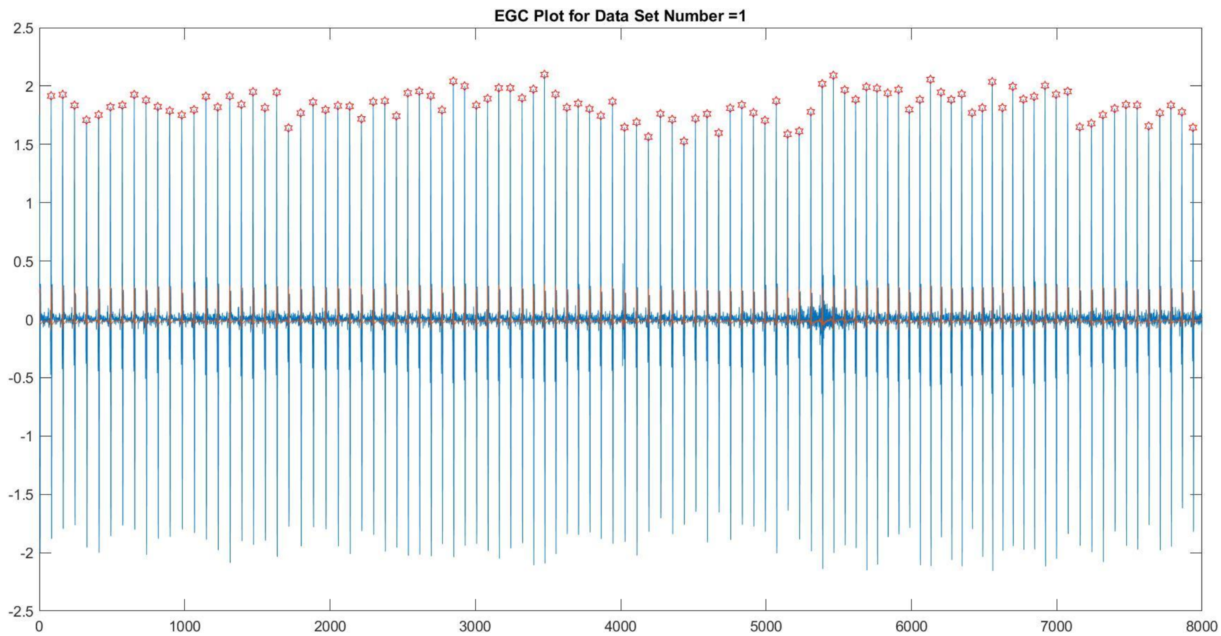

Figure 1: Plot of ECG Signal and the R peaks for the first data set

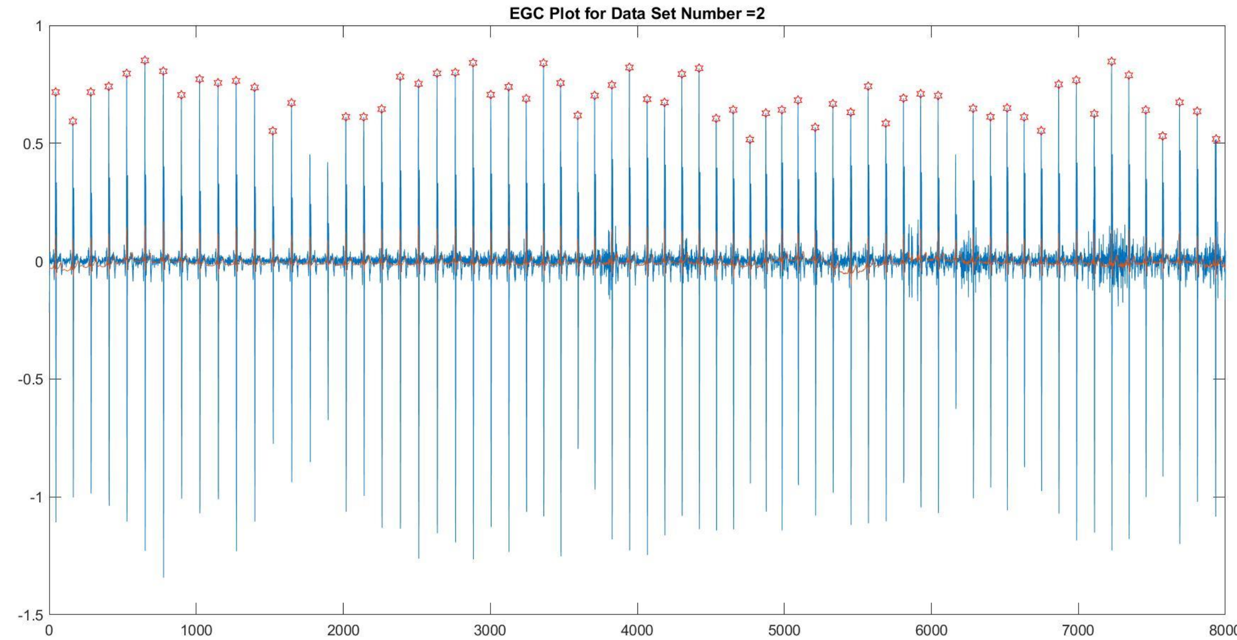

Figure 2: Plot of ECG Signal and the R peaks for the second data set

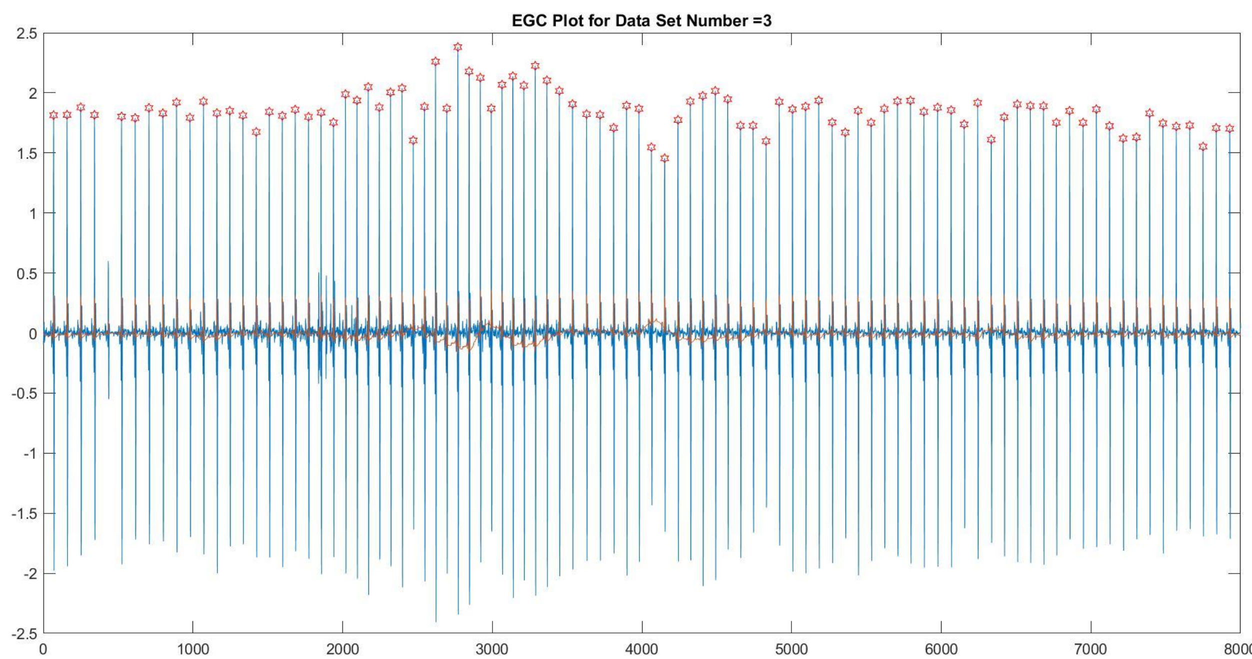

Figure 3: Plot of ECG Signal and the R peaks for the third data set

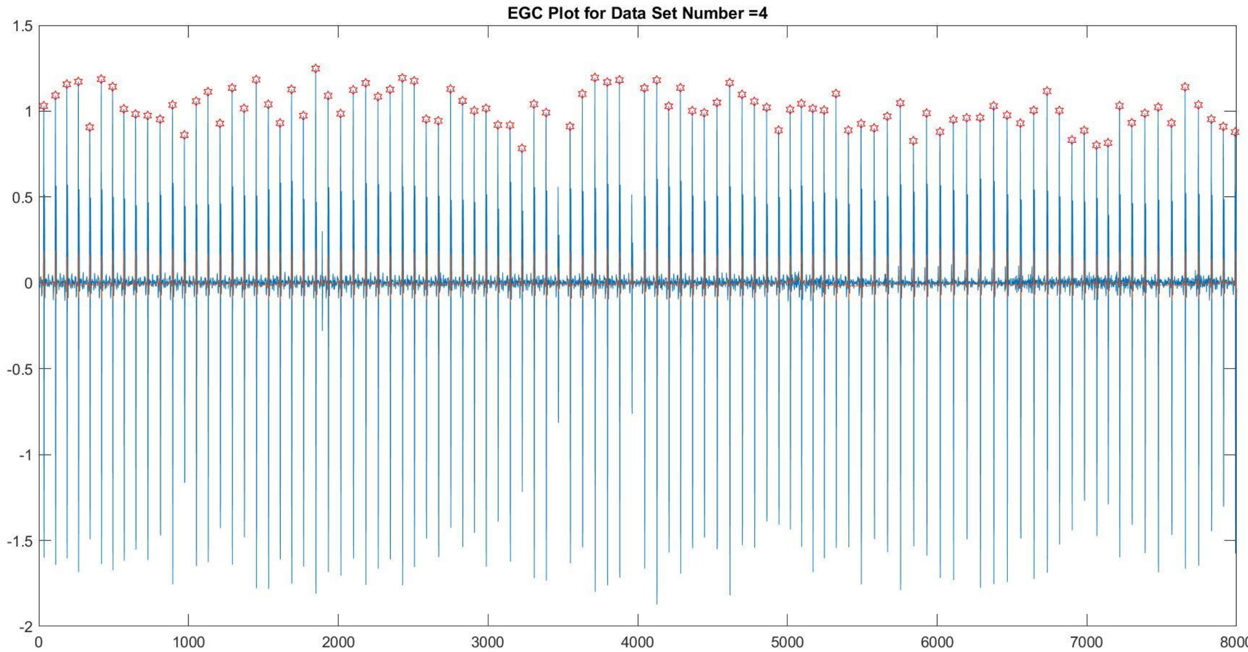

Figure 4: Plot of ECG Signal and the R peaks for the fourth data set

Task 2-

Since the electrodes that sense and record the heart signals are connected to the chest, it is expected that the ECG signal is affected by the respiration. The Respiratory Activity is a low frequency phenomenon which mostly affects the amplitude of the ECG signal and the length of the RR-intervals, as well as the IHR which is directly affected by the RR-intervals.

We can see that for a given athlete the RR-intervals are not constant over time and that there is a small changing difference between the length of a given RR-interval and its neighbouring RR-intervals. This could be attributed to the Respiratory Activity.

In addition to the above, the peaks of the EGC signal are not constant over time. Based on the visulizations of the R-peaks of the ECG, a low frequency sinosoidal wave can be observed which can be attributed to the Respiratory Activity. In order to determine the repiratory rate, we can find the distance between two local maximum peaks of the ECG signal and this distance shall give us the value of the period of the low frequency sinosoidal wave . A closer view of the ECG signal of three data sets is demonstrated in figures 5-7. We should also keep in mind that a normal respiratory rate is 12 to 20 respirations / breaths per minute.

The calculations of the respiration rate are presented below:

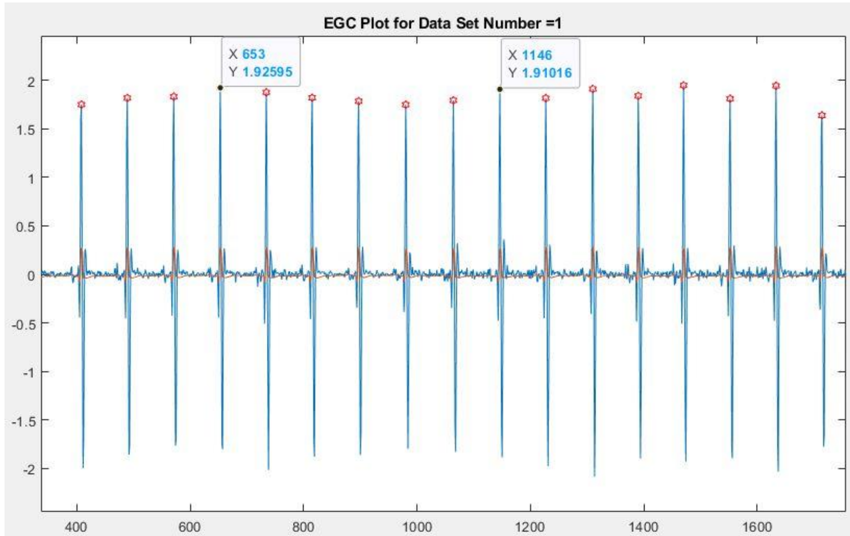

Figure 5: Plot of the ECG signal and R-peaks for the first data set, Two selected peaks

As it is specified in figure 5, The differences of the number of samples in the above signal is: $\Delta n = 1146 - 653 = 493\ samples$

Since the sampling frequency is 128 Hz, so the period of the sinosoidal wave would be $T = \frac{493}{128} = 3.85\ s$

To calculate the respiration rate, we need the number of respirations per second. So the relevant respiratory frequency will be : $F = \frac{1}{T} = 0.26\ Hz$

Finally, based on the definition of the respiration rate which is per minute we can caculate it as:

$resptration\ rate = F * 60 = 15.57\ (respiration\ per\ minute)$

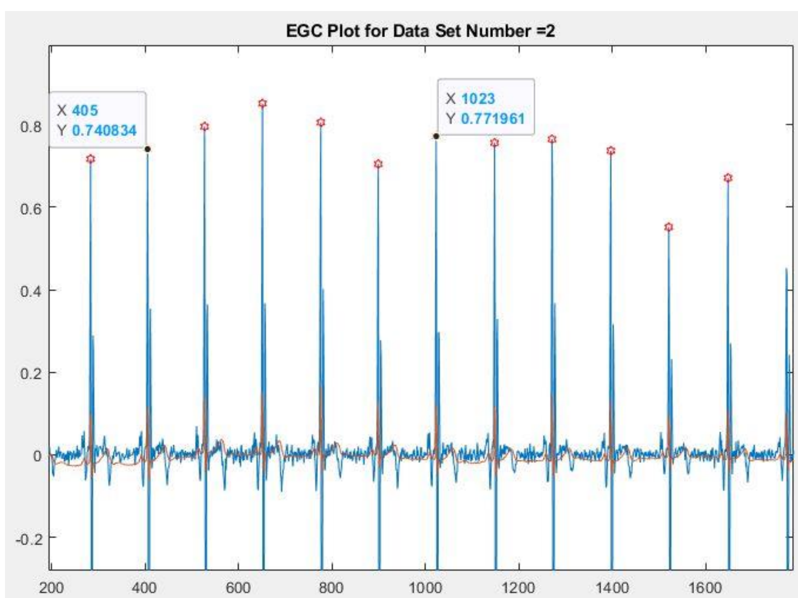

Figure 6: Plot of the ECG signal and R-peaks for the second data set, selected points of the signal(start and end of a period)

With similar calculation, the respiration rate for this data set would be:

$$resptration\ rate = F * 60 = 12.43\ (respiration\ per\ minute)$$

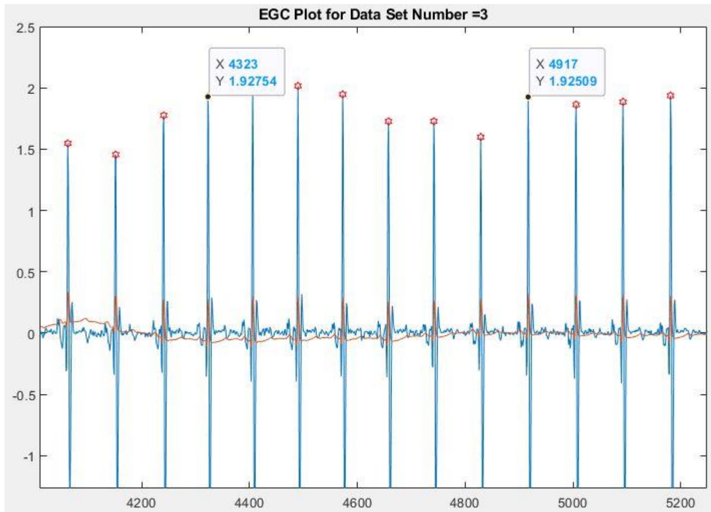

Figure 7: Plot of the ECG signal and R-peaks for the third data set, selected points of the signal(start and end of a period)

$$resptration\ rate = F * 60 = 12.98\ \ (respiration\ per\ minute)$$

Based on a normal respiratory rate of 12 to 20 respirations / breaths per minute our above calculations are logical.

Task 3-

As far as the issue of outliers is concerned, an outlier should be replaced by neighbouring data. If the outliers were removed the neighbouring R-peaks would become more distant and the RR-intervals would get bigger which is unwanted behaviour.

As can be observed in figures 1-4, in all data sets there are some R-peaks that are not detected by the peak function because of their very small amplitude. This phenomenon will affect the RR interval and the IHR since the interval increases if an R wave is not detected. The task is to implement a function to replace these low amplitude R-peaks with representative ones. Below is the solution that we came up with to solve this issue:

We set a lower value for MPH. Thus, the peakfinder function will find all the outlier peaks that are lower than our initial MPH. But then we set an if loop with a larger value threshold for MPH such that if the amplitude of an R-peak is smaller that the newly defined threshold, the same amplitude shall be replaced with the average of the next and previous R-peak values. Our relevant matlab code is examplerr_task3.m.

Figures 8- 11 illustrate the result of this solution:

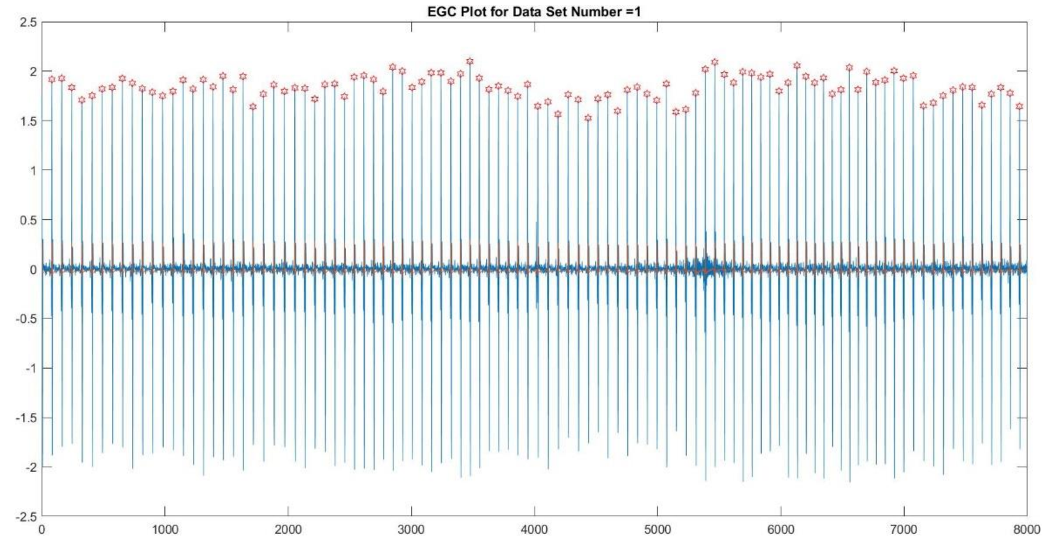

Figure 8: Plot of the ECG signal and R-peaks for the first data set- After replacing outliers

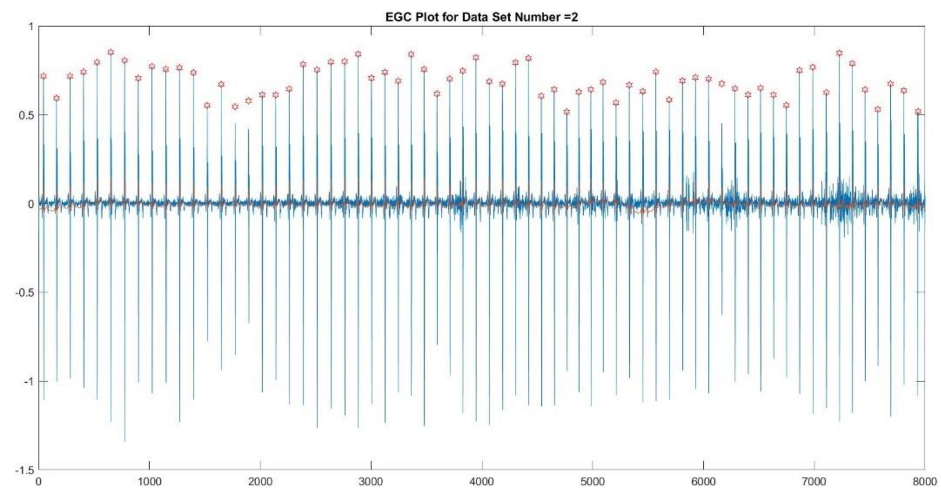

Figure 9: Plot of the ECG signal and R-peaks for the second data set- After replacing outliers

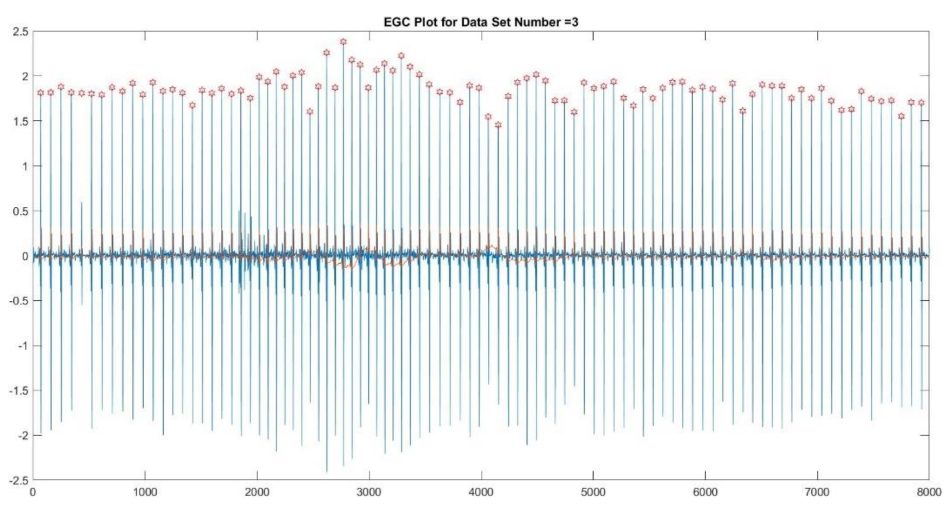

Figure 10: Plot of the ECG signal and R-peaks for the third data set- After replacing outliers

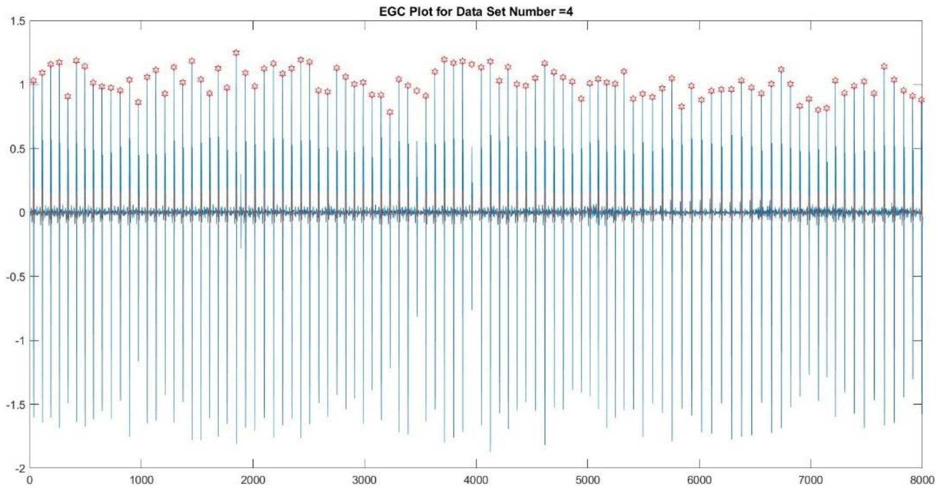

Figure 11: Plot of the ECG signal and R-peaks for the first data set- After replacing outliers

Task 4-

If we consider that the RR interval is q samples long, we can calculate the period of the RR-interval as: ($T = \frac{q}{fs}$).

Then, we calculate the number of heart rates per second which is the definition of frequency. So, by inversing the calculated period, we have the frequency in Hz. ($F = \frac{1}{T}$)

And Finally, Heart rate is defined as Heart Beats per minute which can be calculated as: $HR = F * 60$

In general, for a given value of q the heart rate would be : $HR(bpm) = \frac{f_s}{q} * 60$

Figures 12-15 demonstrate the IHR values for each data set.

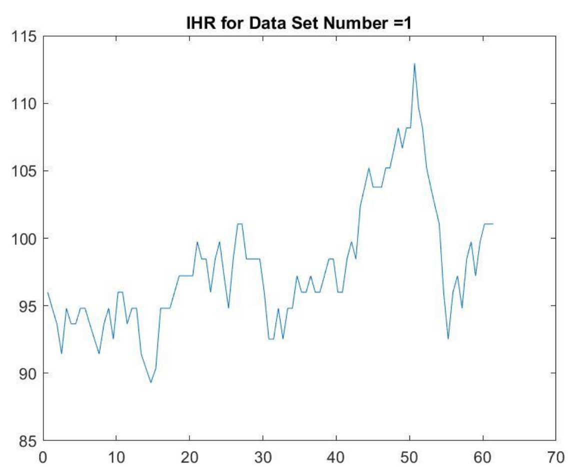

Figure 12: IHR for the first data set

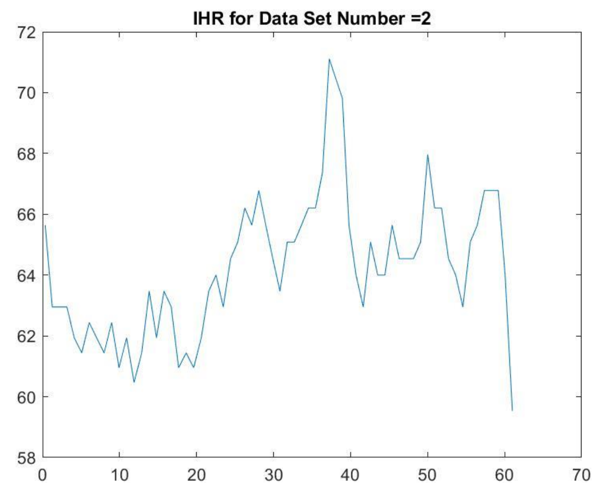

Figure 13: IHR for the second data set

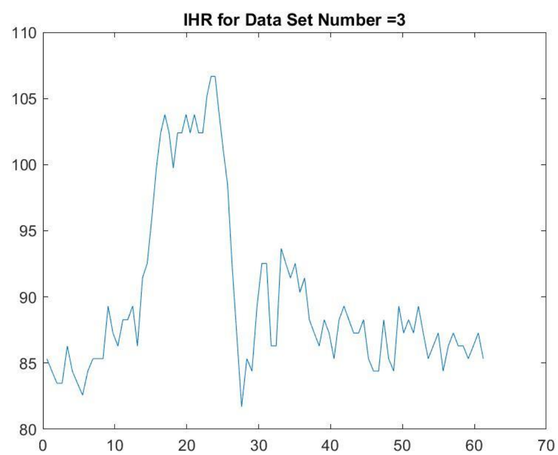

Figure 14: IHR for the third data set

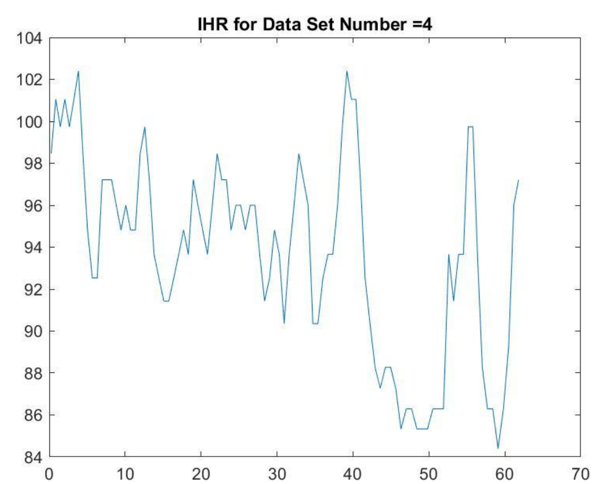

Figure 15: IHR for the fourth data set

Task 5-

The task in this section was to plot the IHR in a way, that it would be easy for analyzing the data. We consider that the histogram would be a good choise, since it represents the distribution of the data. If we study the graph, we can easily observe the more repeated RR interval. Figures 16-19 show the histogram of RR interval for all data sets. Since the histogram shows the RR-interval distribution for a given data set, a doctor could observe the fluctuations of the RR-interval and could determine the dominant RR-interval. From the above analysis a doctor could conclude if a heart rate is regular or irregular and if a patient is arrhythmic or not.

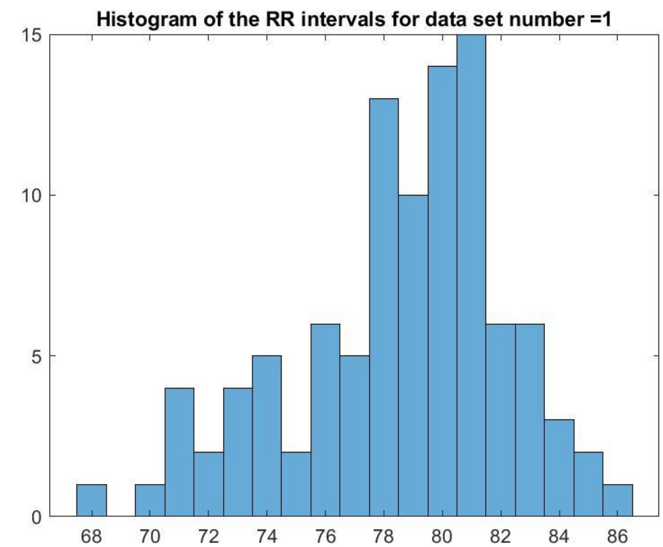

Figure 16: Histogram of the RR interval for first data set

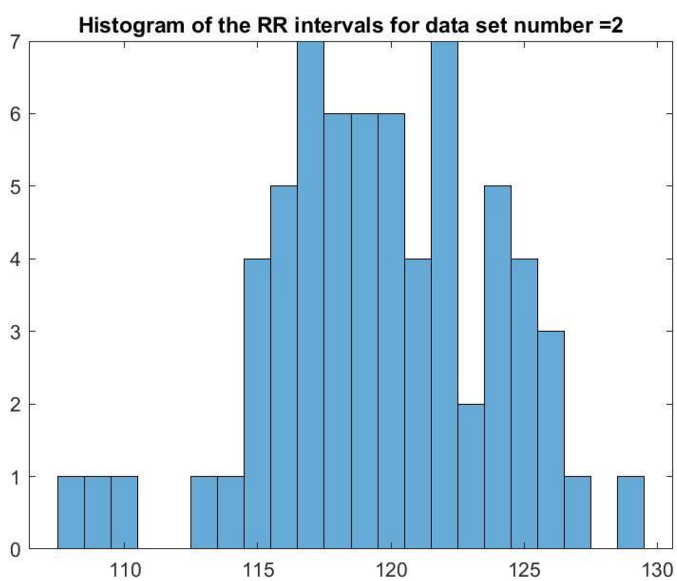

Figure 17: Histogram of the RR interval for the 2nd data set

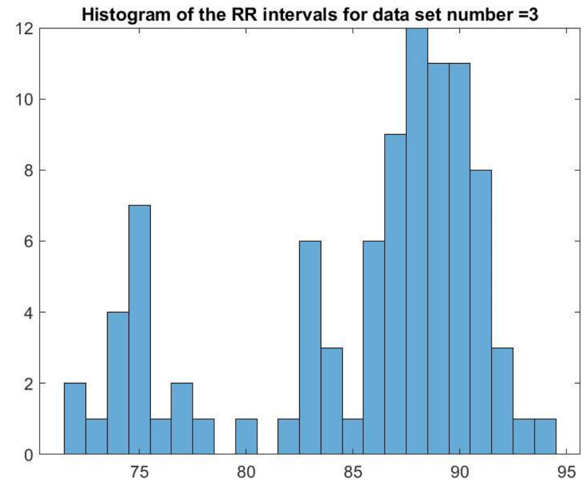

Figure 18: Histogram of the RR interval for the 3rd data set

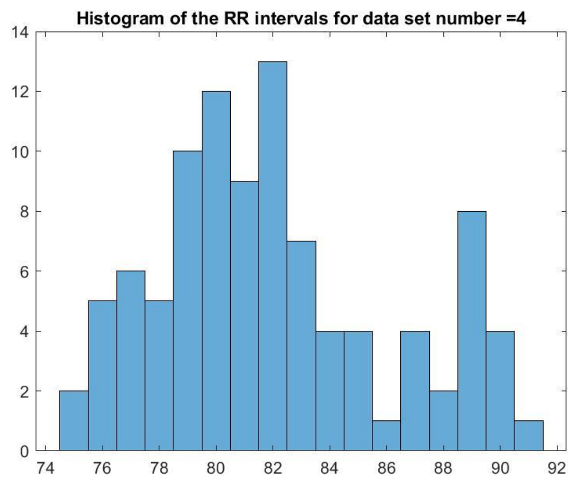

Figure 19: Histogram of the RR interval for the 4th data set

1-5: Analysing the long term HRV

Heart rate variability (HRV), that can be defined as fluctuations of the heart rate around the average value, is a valuable tool to investigate the condition of the cardiovascular system. Thus, There are different approaches that can be used for this analysis. In this task we look into two methods, average (mean) and standard deviation of RR intervals for one minute segmentations of the data.

Figures 20-27 illustrate the plot of Average and standard deviation of RR-intervals during the given 24 hours data for all data sets. (relevant matlab file: examplerr_task5.m)

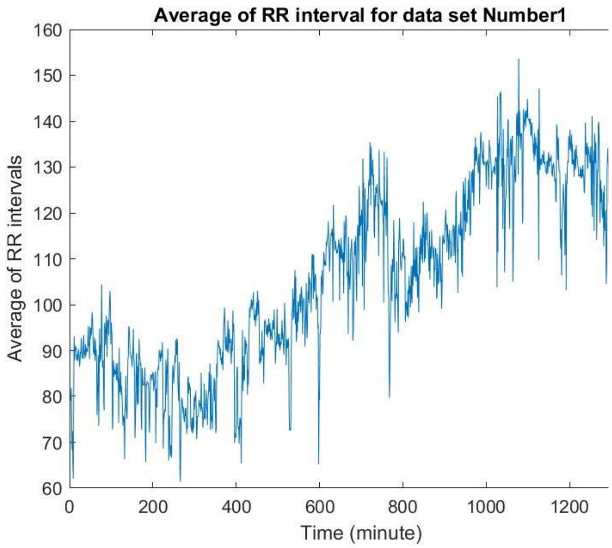

Figure 20: Average of RR-intervals for 1st data set in 24 hours

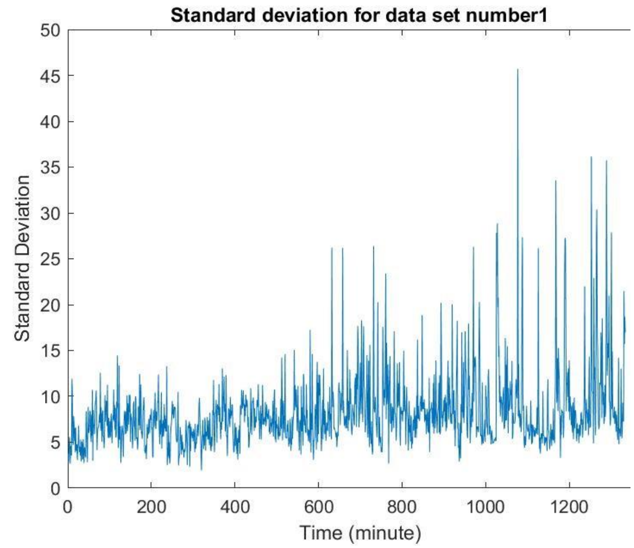

Figure 21: Standard Deviation of RR-intervals- 1st data set in 24 hours

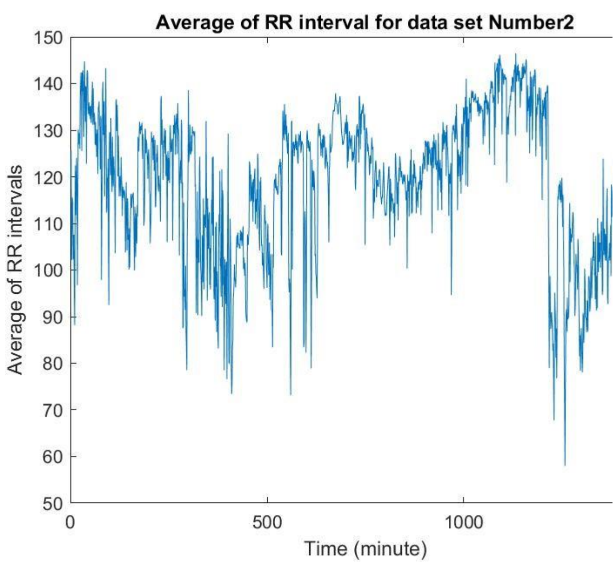

Figure 22: Average of RR-intervals for 2nd data set in 24 hours

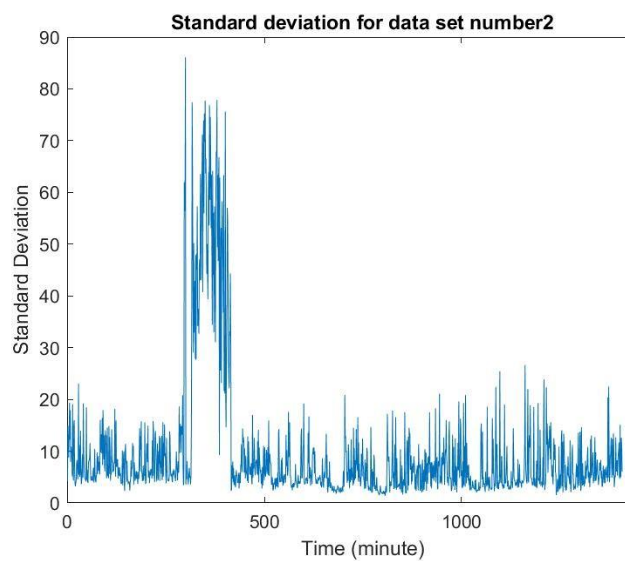

Figure 23: Standard Deviation of RR-intervals- 2nd data set in 24 hours

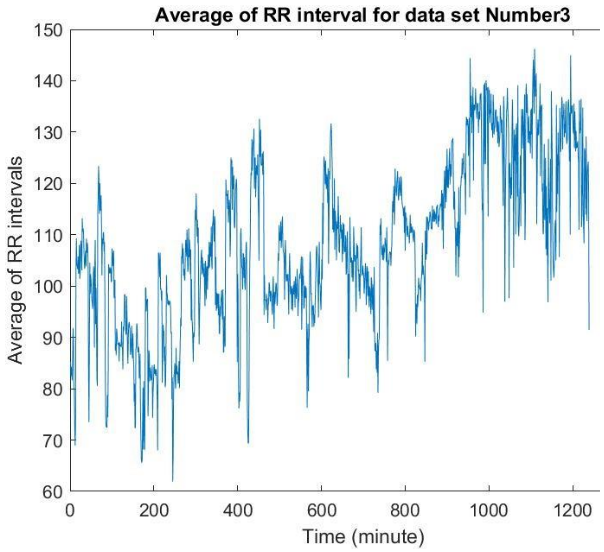

Figure 24: Average of RR-intervals for 3rd data set in 24 hours

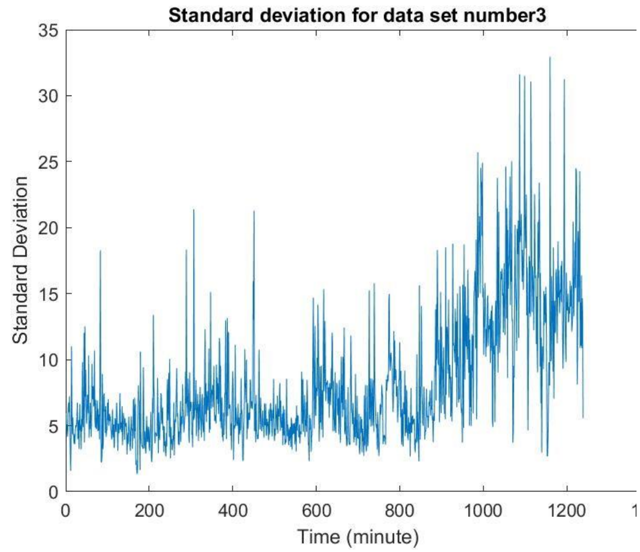

Figure 25: Standard Deviation of RR-intervals- 3rd data set in 24 hours

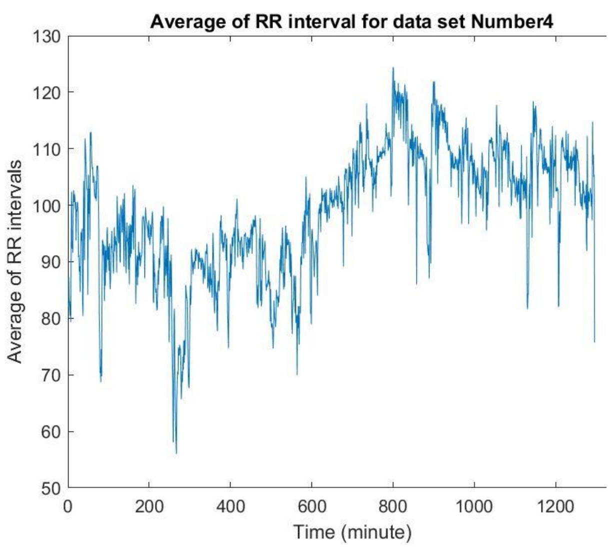

Figure 26: Average of RR-intervals for 4th data set in 24 hours

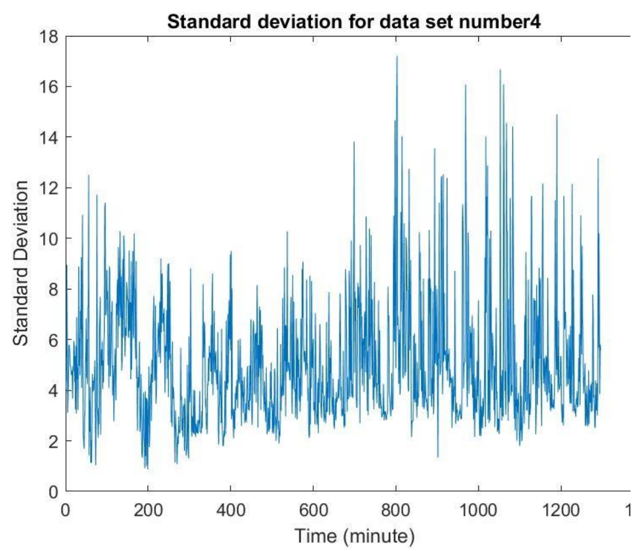

Figure 27: Standard Deviation of RR-intervals- 4th data set in 24 hours