Report

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Problem Statement:

Electrocardiogram (ECG) is a vital signal and is used for diagnosis purposes for major cardiovascular diseases. A standard ECG waveform is shown in Figure.1. It can be seen that an ECG is annotated with PQRST complex. Each annotation represents a significant information about the heart performance. QRS is one of the most important complexes out of this and is being used extensively to evaluate heart performance and to diagnose different diseases such as heart arrythmias. Conventionally, QRS complex is annotated manually by medical practitioners which is not only cumbersome but also required train physician and therefore an automatic detection of QRS complex is desired. This paper will highlight implementations of two such ways to automatically detect QRS complex.

Introduction:

Electrocardiogram (ECG) is an important bio-signal for diagnosis and prognosis purposes of different diseases particularly for cardiovascular diseases. It is an electrical representation of functions of different parts of heart. A standard and normal sinus ECG is shown in Figure.1 and different annotations on it represents the electrical activity of different parts of the heart. A heart is composed of two upper chambers known as atria and lower two chambers, known as ventricles. A P-wave represents the depolarization (activation) of the atria whereas QRS represents the depolarization (activation) of ventricles. A short QRS complex indicates rapid depolarization of ventricles whereas a prolong QRS indicates slow ventricular depolarization which may imply dysfunction in conduction system. Therefore, QRS complex is important complex for diagnosing problems related to the ventricles of heart. Moreover, the T wave reflects

the rapid repolarization of contractile cells and this cycle goes on with contraction and relaxation of heart.

An ECG has a frequency range of 0.05-150 Hz with P wave having frequency range of 5-30 Hz whereas the frequency response of QRS complex lies in the 0-20 Hz and T wave has a frequency range in 0-10 Hz. An ECG is also susceptible to a number of noises such as baseline wander, having frequency range of 05-0.6 Hz, Powerline frequency 50 or 60 Hz and motion artifacts having frequency range lower than 20 Hz.

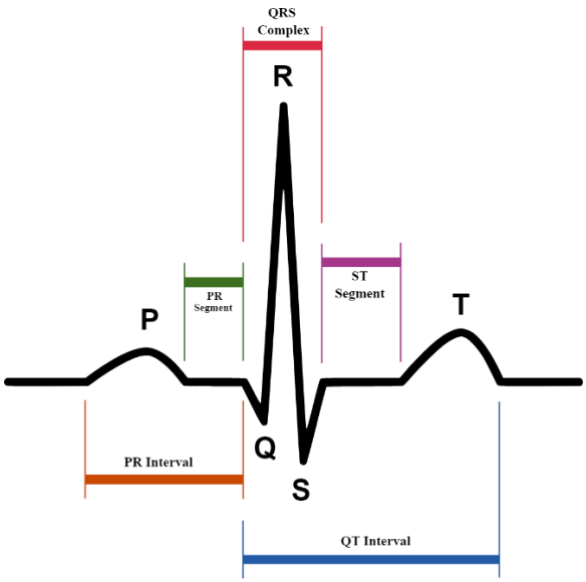

Figure.1 Electrocardiogram (ECG)

QRS Complex

As discussed QRS complex has a frequency range of 0-20 Hz and its normal duration lies in the 80- 100 milliseconds. Detection of QRS complex leads to vital information about the overall performance of the heart in general and of ventricles in particular. An abnormal QRS complex

indicate heart arrythmias for example, a shortened QRS preceded by normal P wave may be indicative of sinus tachycardia. Similarly, a narrow QRS complex may also be indicative of Supraventricular Tachycardia. A prolonged QRS having duration greater than 120 milliseconds may occur in heart failure patients. Moreover, VF is a serious and terminal cardiac rhythm characterized by irregular, wide bizarre shaped QRS complexes. It needs urgent treatment with unsynchronized DC cardioversion and Ventricular tachycardia is a rapid, wide QRS-complex tachycardia with a heart rate 150-250 beat/min. It is a serious condition that may result from drug toxicity (digoxin), myocarditis or severe metabolic derangement.[i]. Therefore, it is essential to accurately detect QRS complex. Conventionally QRS is being detected manually by trained physicians however, it is not suitable for realizing the use of ECG for continuous and real time monitoring of heart performance. Therefore, an automatic detection of QRS complex is required and for this purpose, this report will highlight the use of two ways to accurately detect the QRS complex automatically along with their comparison. First way is using wavelet and second is by using Pan-Tompkins algorithm. Subsequent paragraphs will highlight the details and results of these two methods.

Data:

MIT-BIH arrythmia dataset has been used from the physionet for the implementation of aforementioned methods. The recordings were digitized at 360 samples per second.

Methods:

Two different methods have been adopted to automatically detect the QRS complex. These methods are automatic detection of QRS complex using wavelet and the automatic detection of QRS using Pan-Tompkins algorithm. Details of these methods have been explained in the subsequent paragraphs.

Automatic detection of QRS complex using wavelet:

This method has been implemented as an example in the Mathworks and it shows how to use wavelets to analyze ECG. For this purpose, the *sym4* wavelet has been used to decompose the given ECG to 5 levels and then reconstruct using wavelet coefficient having the frequency range relevant to the QRS complex. The frequency range of the reconstructed signal is as follows:

Scale 4 -- [11.25, 22.5) Hz

Scale 5 -- [5.625, 11.25) Hz.

The reconstructed signal is then squared and a peak finding function *findpeaks()* is used to find the peaks of the squared signal. These peaks correspond to the R peaks of the QRS complex of the original ECG signals. The R peaks found is then compared with the original annotations of the ECG and are found to be the same.

The above method can be summarized in following steps:

Step 1: Decomposition of ECG using sym4 wavelet.

Step 2: Reconstruction using relevant coefficients.

Step 3: Squaring the reconstructing signal.

Step 4: Finding peaks of the squared signal.

I have used the same method to find the Q and S points along with the R points. For this purpose, I have used the same reconstructed signal but instead of using just the reconstructed signal I have implemented the findpeak function on the negative of the reconstructed signal. This is because, Q and S are negative peaks therefore if we take the negative of the reconstructed signal and apply findpeaks function on it, the findpeaks function will find the peaks of the negative of the reconstructed signal which in this case now be Q and S peaks. The result of this method is shown in Figure. 2

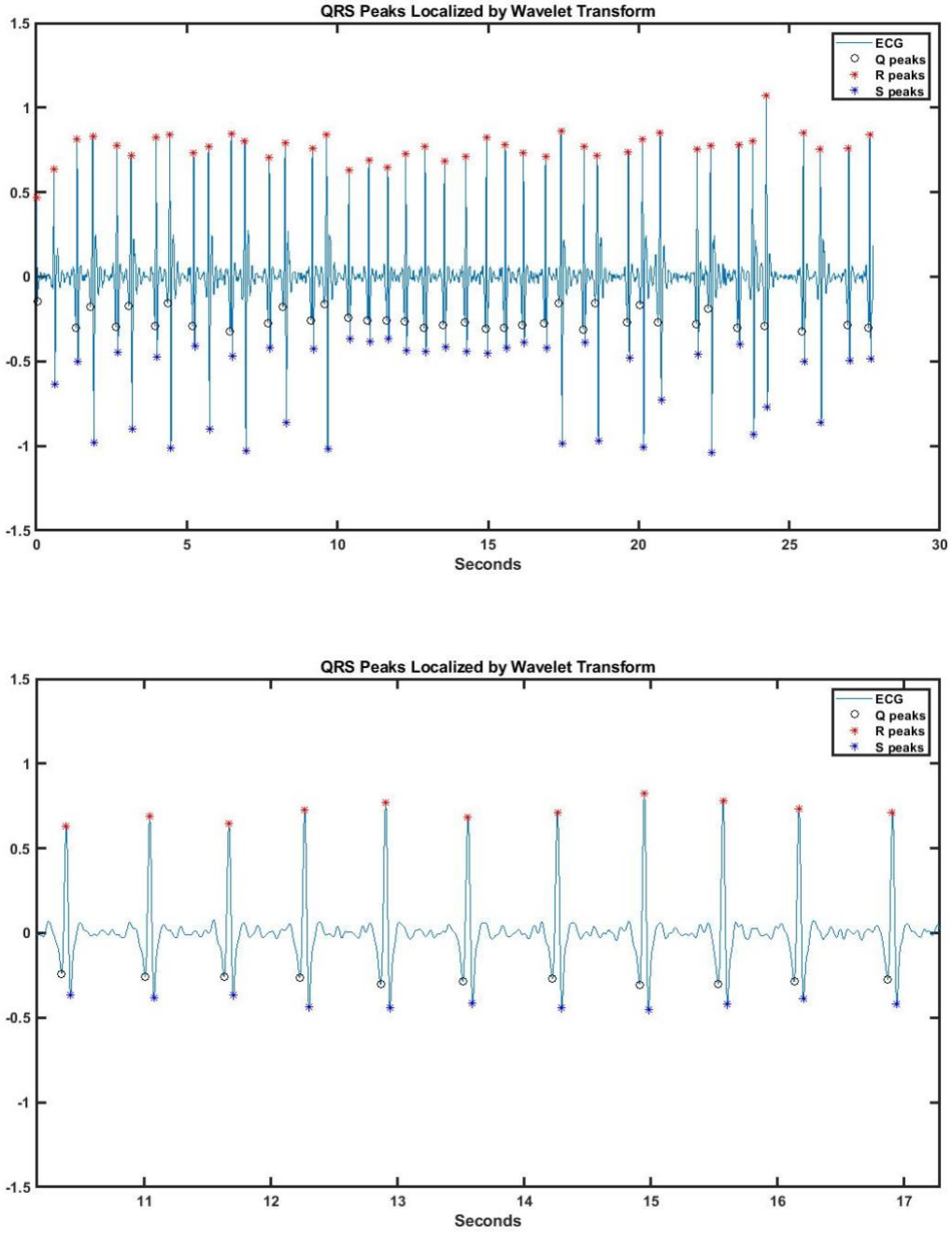

Figure 2 QRS complex detected using the wavelet decomposition.

Pan-Tompkins Algorithm:

The Pan-Tompkins algorithm is the widely used algorithm to detect the QRS complex of ECG. It was proposed by Jiapu Pan and Willis J. Tompkins in 1985, in the journal IEEE Transactions on Biomedical Engineering. Th flow diagram of the algorithm is shown in the Figure. 3. In Pan-Tompkins algorithm the signal is pre-processed and cleaned by passing through a bandpass filter to allow frequency 5-15 Hz range, relevant only to the QRS complex, as previously discussed. The bandpass filtered signal is shown in Figure.4.

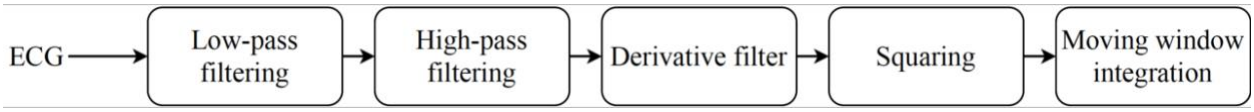

Figure:3 Pan-Tompkins Algorithm flow diagram

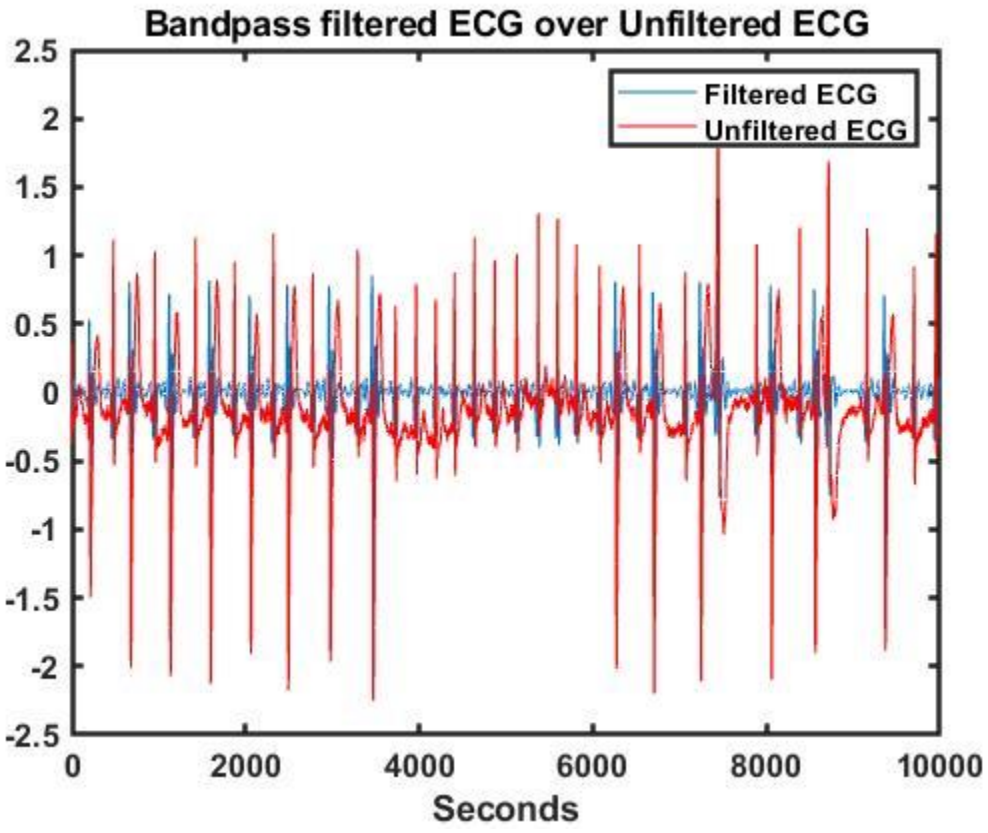

Figure: 4 A bandpass filtered signal

The filtered signal is then passed through a derivative filter such that to provide information about the slope of the QRS. The proposed derivative filter is a 5-point derivative filter and has following transfer function.

$$H(z) = 0.1(-2z^{-2} - z^{-1} + z^{1} + 2z^{2})$$

Information about the slope of the QRS is obtained in the derivative stage. The filtered signal is then squared. Figure. 5 shows the filtered after a derivative filter. The squaring process intensifies the slope of the frequency response curve of the derivative and helps restrict false positives caused by T waves. Figure. 6 shows a squared signal. The squared signal is then passed through a moving-average filter, which produces a signal that includes information about both the slope and the width of the QRS complex. This signal has been termed as integrated signal in the Pan-Tompkins algorithm. An integrated signal is shown in Figure.7.

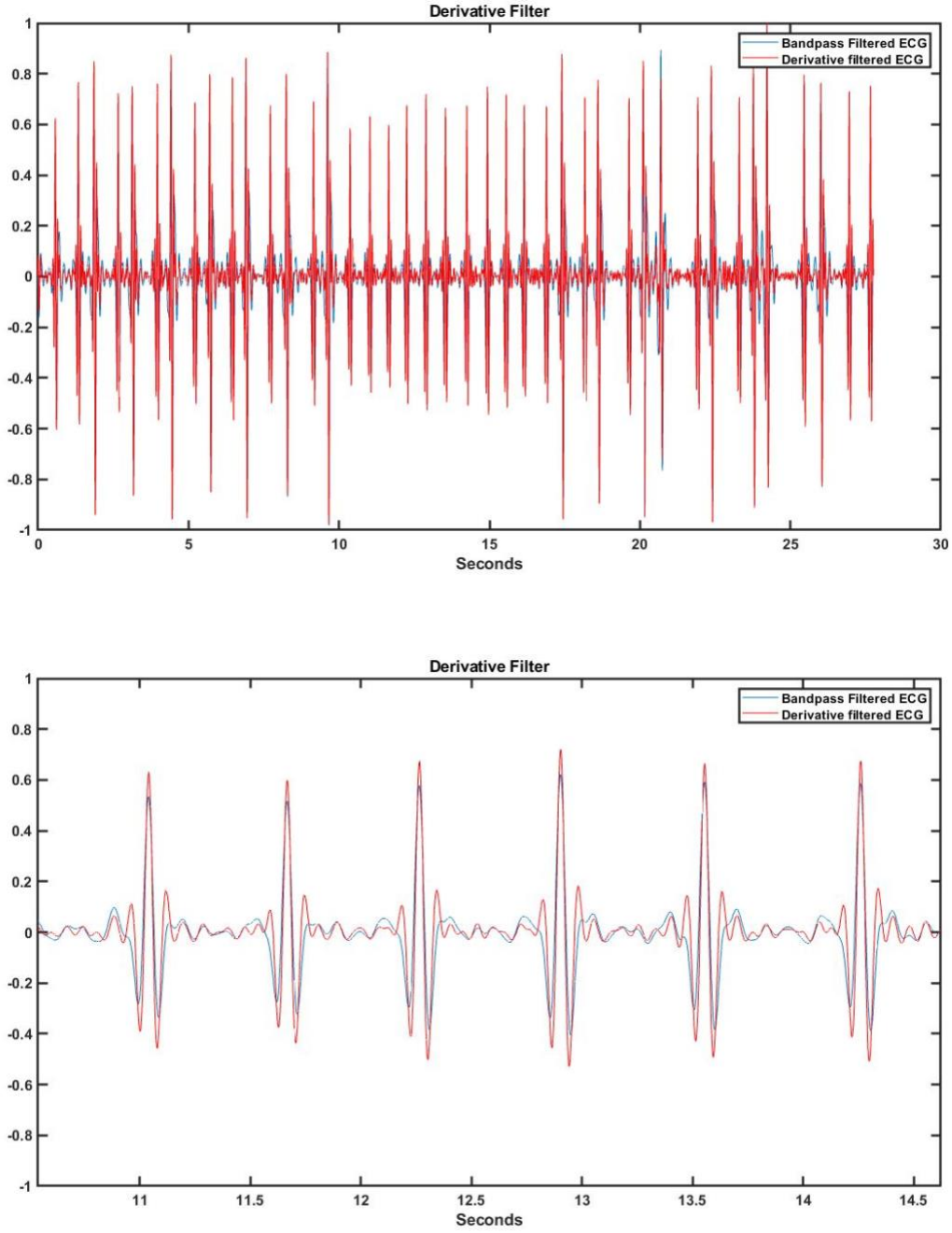

Figure. 5 A derivative filtered signal b. A zoomed version of the derivative filtered signal.

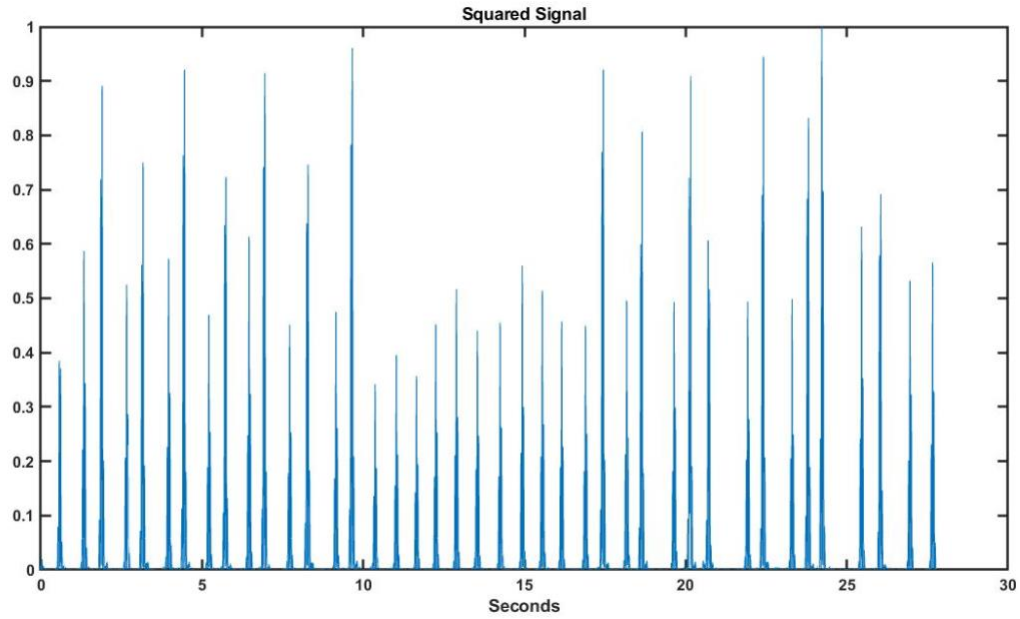

Figure: 6 A squared signal

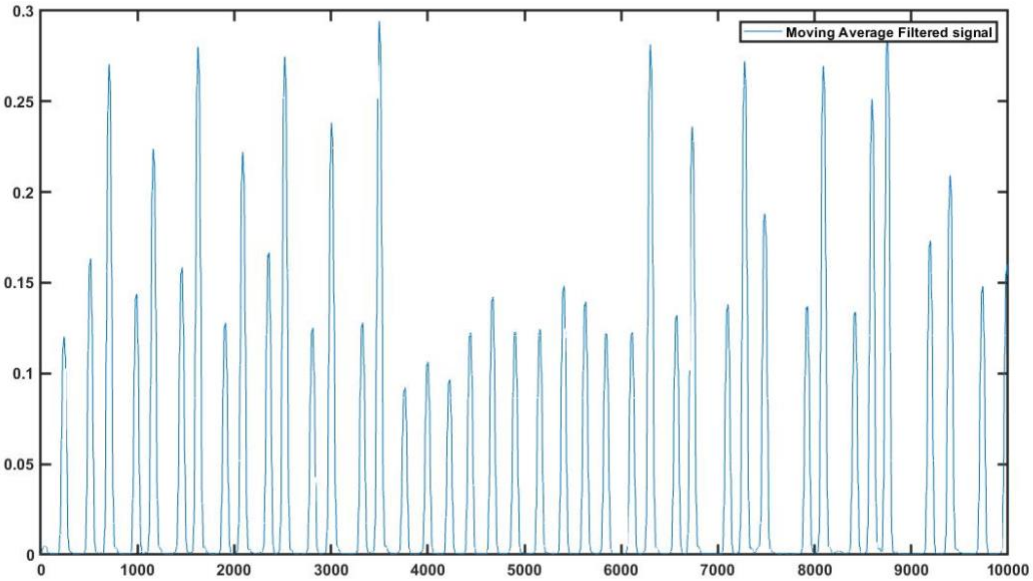

Figure. 7 A moving average filtered signal known as integrated signal.

In order to detect a QRS complex, the local peaks of the integrated signal are found. A peak is defined as the point in which the signal changes direction (from an increasing direction to a decreasing direction). After each peak, no peak can be detected in the next 200 ms (ie. the lockout time). This is a physiological constraint due to the refractory period during which ventricular depolarization cannot occur even in the presence of a stimulus.

The QRS complex corresponds to the rising edge of the integration waveform. The time duration of the rising edge is equal to the width of the QRS complex. A fiducial mark for the temporal location of the QRS complex can be determined from this rising edge according to the desired waveform feature to be marked such as the maximal slope or the peak of the R wave.

Each fiducial mark is considered as a potential QRS. To reduce the possibility of wrongly selecting a noise peak as a QRS, each peak amplitude is compared to a threshold ($Threshold_I$) that considers the available information about already detected QRS and the noise level:

$$Threshold_I = NoiseLevel_I + 0.25(SignalLevel_I - NoiseLevel_I)$$

where $NoiseLevel_I$ is the running estimate of the noise level in the integrated signal and $SignalLevel_I$ is the running estimate of the signal level in the integrated signal.

The threshold is automatically updated after detecting a new peak, based on its classification as signal or noise peak:

$$SignalLevel_I = 0.125PEAK_I + 0.875SignalLevel_I \text{ (if } PEAK_I \text{ is a signal peak)}$$
$$NoiseLevel_I = 0.125PEAK_I + 0.875NoiseLevel_I \text{ (if } PEAK_I \text{ is a noise peak)}$$

where $PEAK_I$ is the new peak found in the integrated signal.

If a new $PEAK_1$ is under the $Threshold_1$, the noise level is updated. If $PEAK_1$ is above the $Threshold_1$, the algorithm implements a further check before confirming the peak as a true QRS, taking into consideration the information provided by the bandpass filtered signal.

In the filtered signal the peak corresponding to the one evaluated on the integrated signal is searched and compared with a threshold, calculated in a similar way to the previous step:

$$Threshold_F = NoiseLevel_F + 0.25(SignalLevel_F - NoiseLevel_F)$$

$$SignalLevel_F = 0.125PEAK_F + 0.875SignalLevel_F \text{ (if } PEAK_F \text{ is a signal peak)}$$

$$NoiseLevel_F = 0.125PEAK_F + 0.875NoiseLevel_F \text{ (if } PEAK_F \text{ is a noise peak)}$$

where the final F stands for filtered signal.

Figure. 8 shows the found QRS based on the aforementioned algorithm. The location of those peaks has also been plotted over the bandpassed ECG, containing information about the QRS complex, and it can be seen that the width of the integrated signal lies over the width of the QRS complex, as shown in Figure. 9.

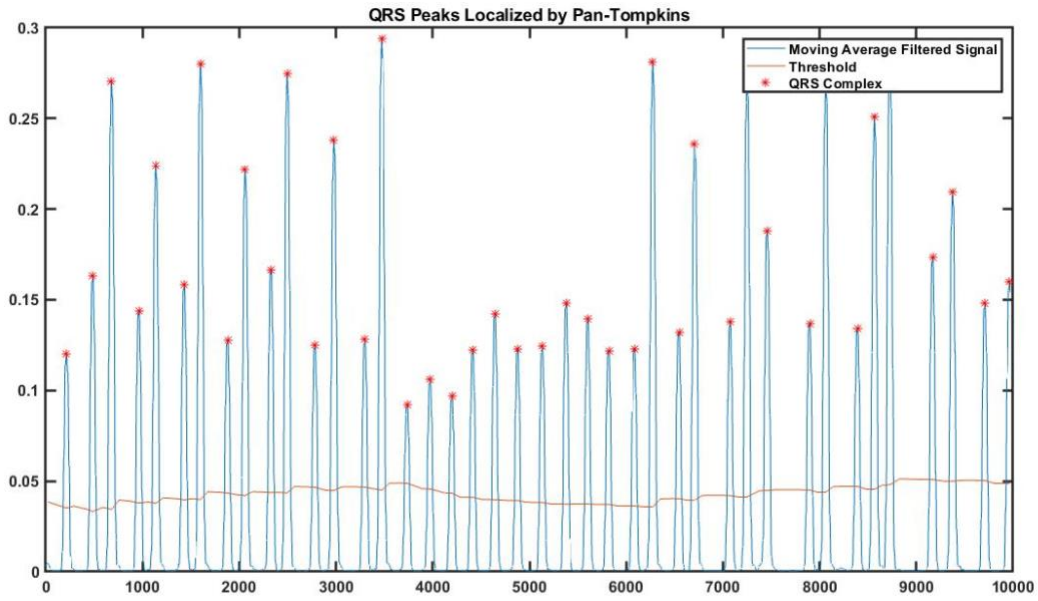

Figure. 8 QRS detected based on Pan-Tompkins algorithm

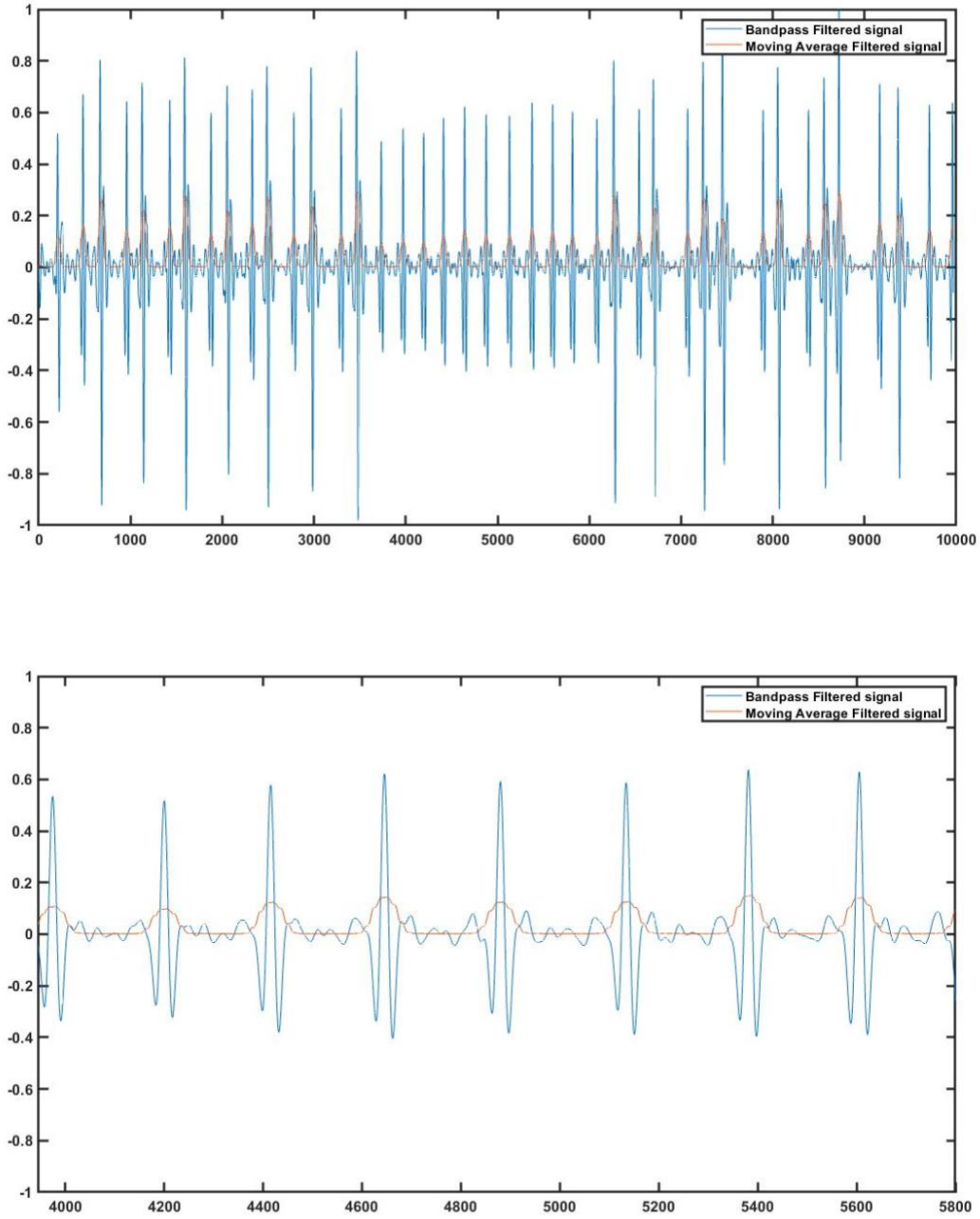

Figure. 9 Integrated signal mapped over the bandpassed signal

Moreover, Figure.10 shows that the annotations of QRS found through Pan-Tompkins is same as that of the originally provided annotations.

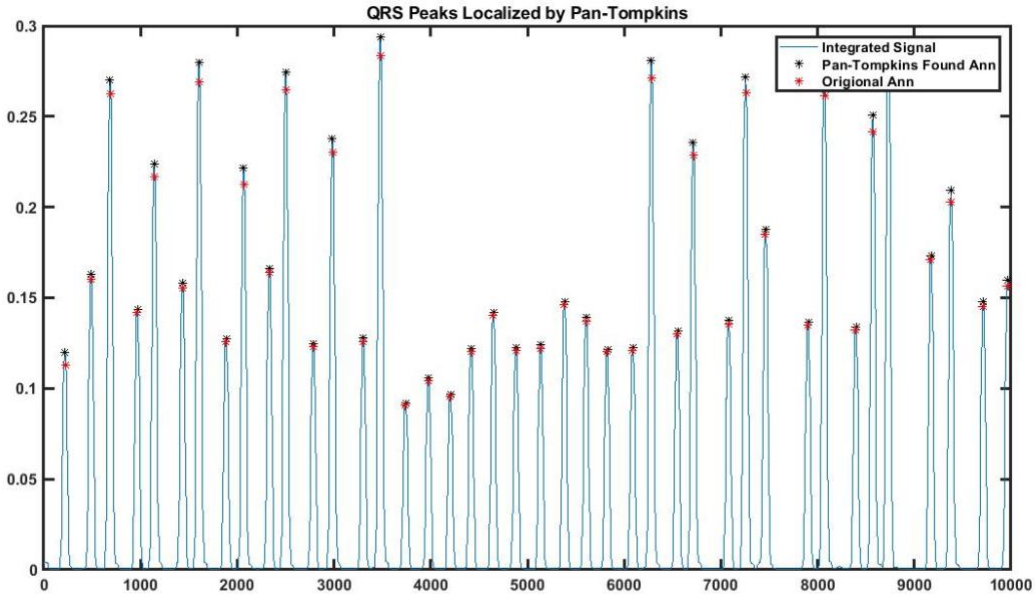

Figure. 10 Original Annotations and annotations found using Pan-Tompkins are mapped over integrated signal

Discussion:

QRS complex has been found using two different methods: detection using wavelet decomposition of the ECG and using Pan-Tompkins Algorithm. From both the methods same heart rate has been found 88.72 beats/minute which shows both methods are equally good. However, Pan-Tompkins has been found to be more robust and a method that can be generalized to different ECG signals. This is because the Pan-Tompkins algorithm is based not just on the slope of R wave but also on the width of QRS complex. Moreover, as the first method of detecting the QRS waveform is based on the shape of symlet4 wavelet corresponding to the QRS complex but in many cases all three components of the QRS waveform are not always visible due to variations in the lead acquiring ECG. Therefore, in case if there is no Q or S wave e.g. in case of non-Q wave

myocardial infarction with absent Q wave, the wavelet transformation may not be sufficient to detect the QRS complex.

Conclusion:

Two different methods have been implemented to detect QRS complex of an ECG automatically using wavelets and using Pan-Tompkins algorithm. Both methods have been found equally good to detect QRS complex automatically as evident from the heart rate evaluated and location of QRS complex.

References:

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[i] https://www.utmb.edu/Pedi_Ed/CoreV2/CardiologyPart2_EKG/CardiologyPart2_EKG3.html