TS114

MICA Project

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1 Introduction

The main goal of the project is to detect heart diseases by using different methods to analyse a given signal via MATLAB functions. Hopefully, it will be possible to monitor the heart rate but also to find irregularities in the patient's electrocardiogram or heart spectrogram.

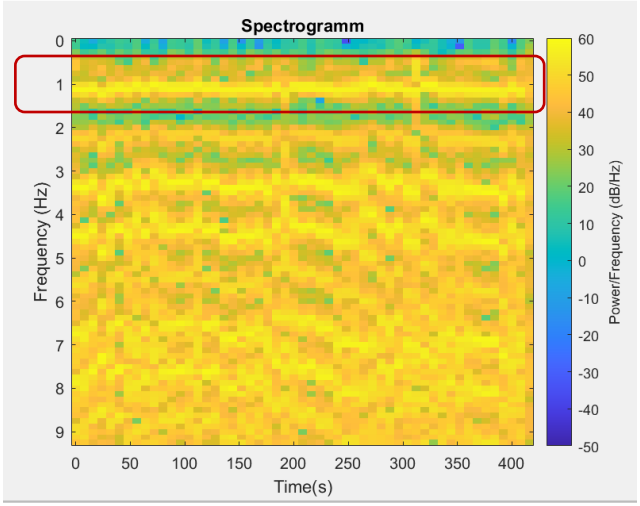

Figure (1): Spectrogram of a healthy patient

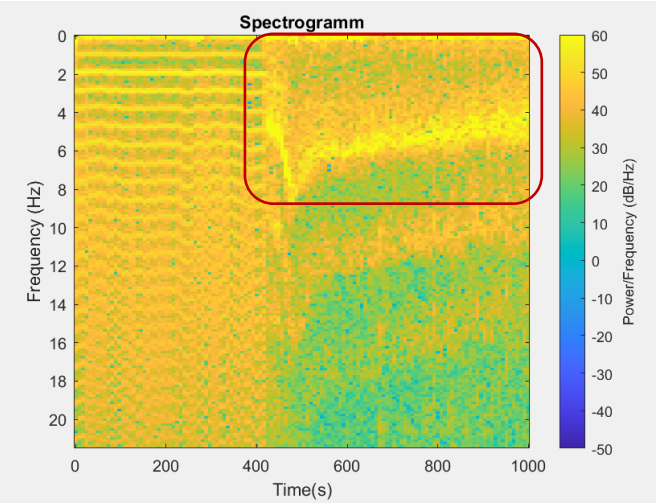

Figure (2) Spectrogram of a patient with ventricular fibrillations

There are above several notable differences between the spectrograms of a healthy patient (Figure 1) and that of a sick patient (Figure 2). Here, the patient is suffering from ventricular fibrillation. On the first one, the fundamental frequency, which corresponds in fact to the heart rate of the patient, is around 1 Hz, or 60 BPM (Beats per second). It is therefore normal. On the contrary, on the sick patient's spectrogram (Figure 2), at first, the beginning of the signal is normal, whereas from about 420 seconds, the signal degrades, and it becomes difficult to detect a clear fundamental frequency. A characteristic symptom of ventricular fibrillation is precisely the abrupt and irregular change of the heart rate, which correlates with what is clearly shown in the spectrogram.

2 Detection of the PQRST complexes

There are 5 key parts in the signal of a heartbeat. They will be called P, Q, R, S and T for the rest of this study (Figure 3). The first goal is to detect these PQRST complexes in any given electrocardiogram.

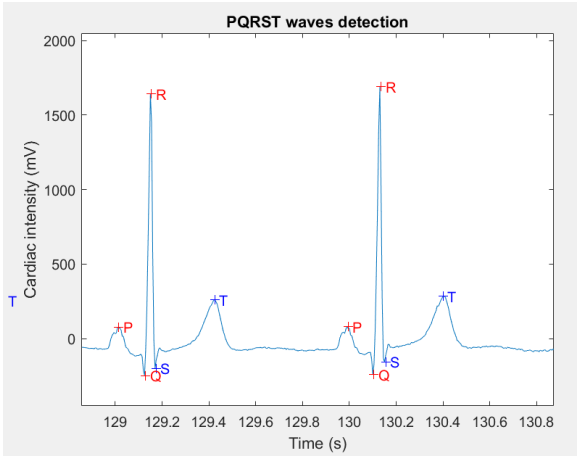

Figure 3: Typical electrocardiogram

2.1 Pan and Tompkins algorithm (R wave detection)

The most important part in the heartbeat is the R wave, which is the highest peak in a electrocardiogram. The detection of the R peaks will lead to the detection of the Q, S, P and T peaks, the PQRST complexes can then be identified and studied.

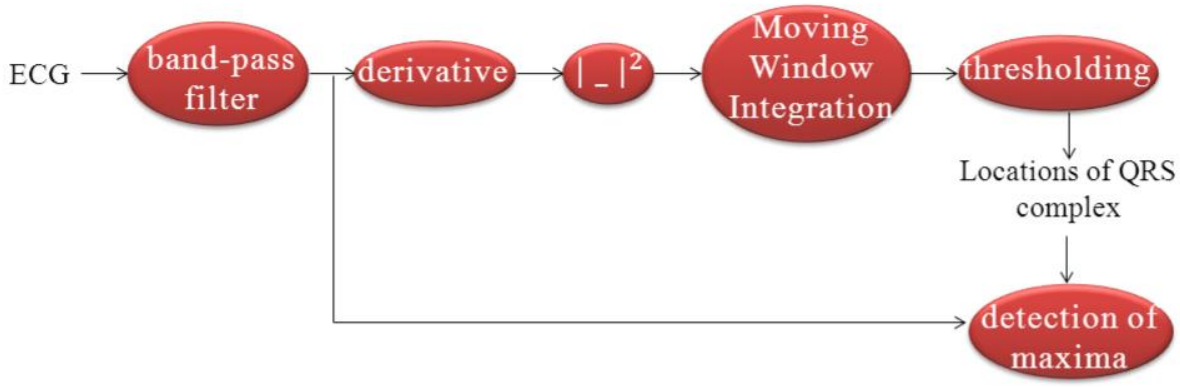

Figure 4: Pan and Thompkins algorithm

In order to do so, we used the Pan and Tompkins algorithm. The Pan and Thompkins algorithm seemed to be the most appropriate way to detect these peaks efficiently. This algorithm is done in several steps.

First, a bandpass filter is applied to the signal and then a derivative filter. Next, the signal is squared, a moving integration filter is applied and finally the PQRST complexes are identified using a threshold.

The purpose of using a bandpass filter is to maximise the signal to noise ratio. Indeed, the signal is disturbed by muscle noise at a frequency of about 60Hz, whereas the frequency to be maximised (representing the QRS complexes) is between 5 and 15Hz.

The bandpass filter consists of a low-pass and a high-pass filter. The transfer function of the low-pass filter used is:

$$H(z) = \frac{(1 - z^{-6})^2}{(1 - 1)^2}$$

It is an infinite impulse response (IIR) filter, so it is not linear phase filter. It is causal and has a group delay of 2.5 samples.

The transfer function of the high-pass filter is:

$$H(z) = \frac{(1 + 32z^{-16} - 32z^{-17} + z^{-32})^2}{(1 - z^{-1})}$$

This is an infinite impulse response (IIR) filter, so it is not linear phase filter. It is causal and has a group delay of 0.

Finally, the transfer function of the derivative filter is:

$$H(z) = \frac{1}{8T_s}(-z^{-2} - 2z^{-1} + 2z^{1} + z^{2})$$

It is a finite impulse response (FIR) filter, which is not causal and has a group delay of 2 samples. As MATLAB vectors are always causals, the signal has to be delayed by two samples to make it causal. This is a linear phase filter because its zeros are 1 and -1.

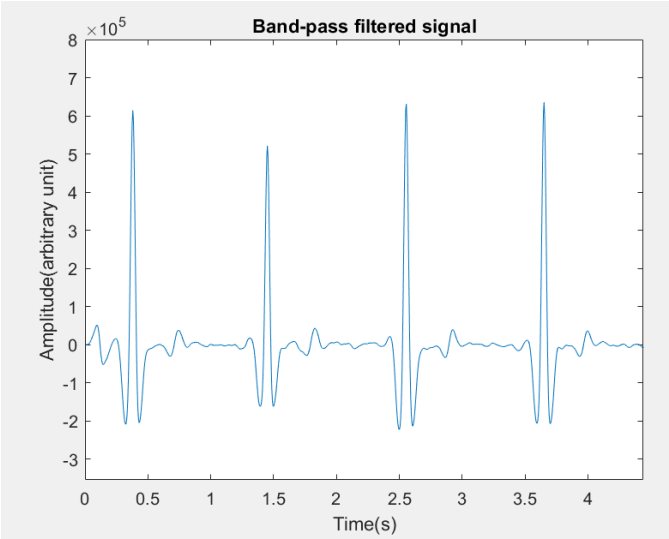

Figure 5: Band-pass filtered signal

Then the signal is derived to show the change in slope. Indeed, the slope changes of the QRS complex are very abrupt and high compared to the rest of the signal. This allows the QRS complexes to be isolated more clearly.

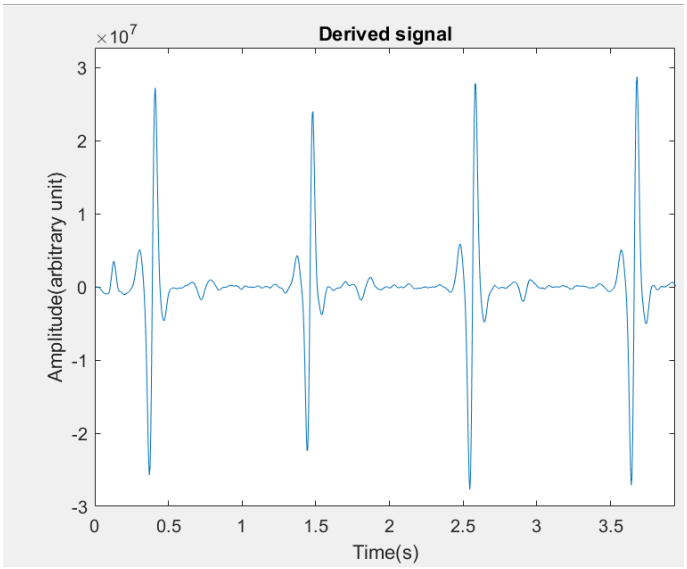

Figure 5: Derived signal

Squaring this signal makes it positive and amplifies it in a non-linear way, emphasising the higher frequencies. This reduces the probability of identifying a T wave as an R peak.

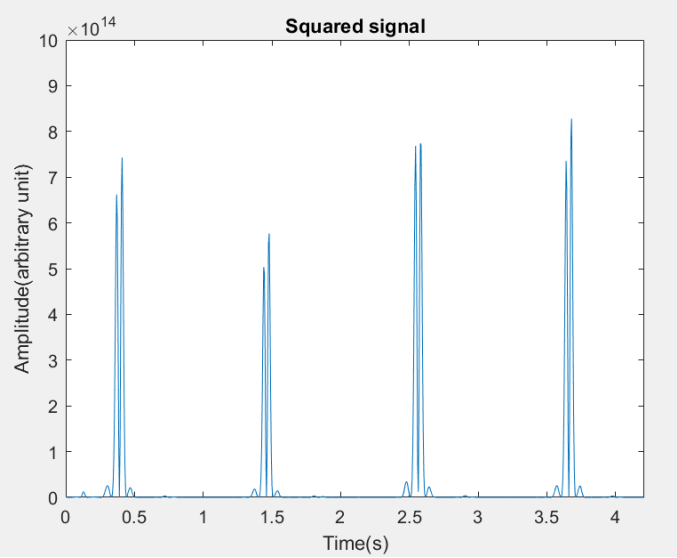

Figure 6: Squared signal

The moving integration window will allow, instead of having several peaks for the QRS complex, to smooth it into only one. At the end of the algorithm, the signal obtained is a square signal (see Figure 7) where each interval between two peaks corresponds to a PQRST complex. This signal is called the integral.

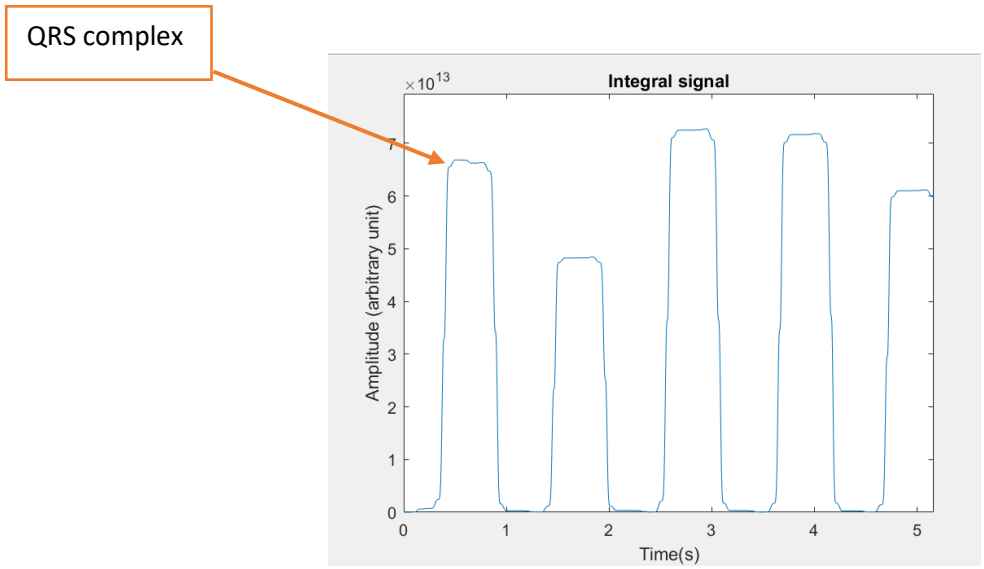

Figure 7: Integral signal

When the directrix of the integral exceeds a certain threshold, the beginning of a new PQRST complex is identified (see code). Each PQRST interval is then marked.

To find each R peak, it is only necessary to look for the maximum of the original signal (the electrocardiogram) on the intervals found on the integral.

2.2 Detection of Q and S waves from R peaks

Once the R wave is detected, as the Q and S waves are respectively the first minimum before and after the R wave, they may be located looking for the minimum of the electrocardiogram just before and just after the R peak (see code).

2.3 Detection of P and T waves from Q and S waves

The P and T waves being respectively the maximums just before the Q wave and just after the S wave, they can be located in the same way as for the detection of the Q and S waves but by looking for the maximum this time (see code).

3 Automatic detection of heart malfunctions

Now that every PQRST complexes are detected, they may be used to find pathologies.

3.1 Tachycardia/Bradycardia

A low frequency (lower than 60 bpm) means bradycardia, a high one (above 100 bpm) means tachycardia.

By analysing the time between two R-peaks, the patient's heart rate can be determined. It is possible to obtain the average heart rate or the heart rate in real time.

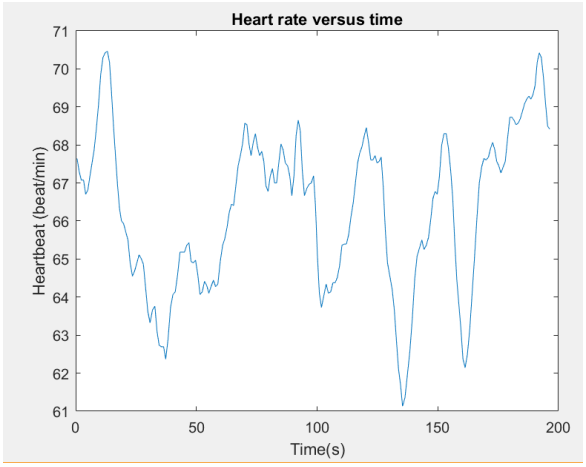

Figure 8: Normal Heart rate (64 average heartbeats)

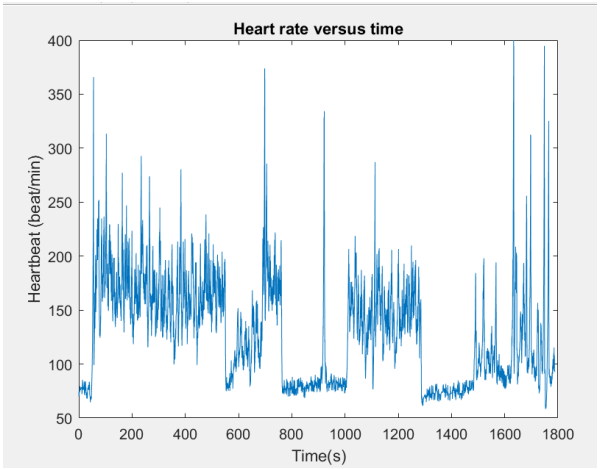

Figure 9: Tachycardia (124 average heartbeats)

3.2 Ectopic beat

Ectopic beats, caused by atrial or ventricular premature contraction, alter the duration of the R-R interval. More precisely, ectopic beats are characterized by the appearance of an early R wave, followed by a prolonged R-R interval.

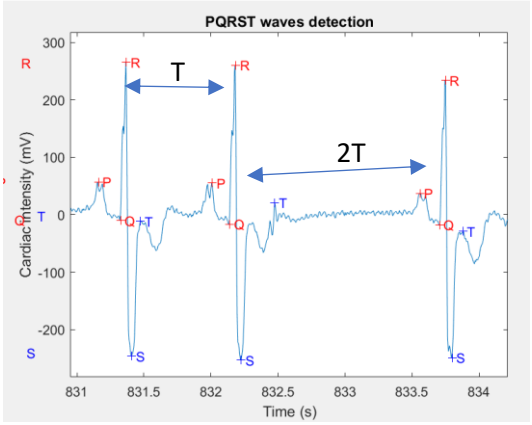

Figure 10: Ectopic beat

Ectopic beats can be identified by comparing the duration of one R-R interval with the next one. If that one is twice longer than the former one, then it is an ectopic beat.

The problem is that sometimes the signal is so degraded that it is possible to find ectopic beats that do not exist, simply because the detection of R peaks becomes very difficult.

This pathology is the most difficult to detect by our algorithms.

3.3 Fibrillation

Another frequent phenomenon, known as fibrillation, is defined by the anarchical disorganization of electrical activity in some parts of the heart. There are two types of fibrillation: the atrial fibrillation and the ventricular fibrillation.

3.3.1 Atrial fibrillation

The atrial fibrillation occurs when the original electrical stimulation of the sinoatrial node is "overwhelmed" by the chaotic circulation of many small electric wavelets taking place in the atrium. The atrial fibrillation is characterized by rapid oscillations and the absence of P wave.

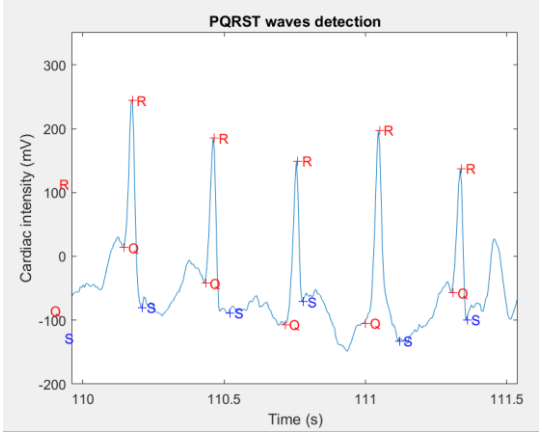

Figure 11: Atrial fibrillation

To detect this pathology, a statistical test can be computed to decide whether an ECG signal segment is under atrial fibrillation or not. This statistical test is based on the following feature:

$$\hat{\gamma}_k = \frac{1}{N-k-1} \sum_{n=0}^{N-k-1} (\Delta_{n+k} - \bar{\bar{\Delta}})(\Delta_n - \bar{\bar{\Delta}})$$

which represents the sample auto-covariance function of the process Δ_n, representing the R-R duration.

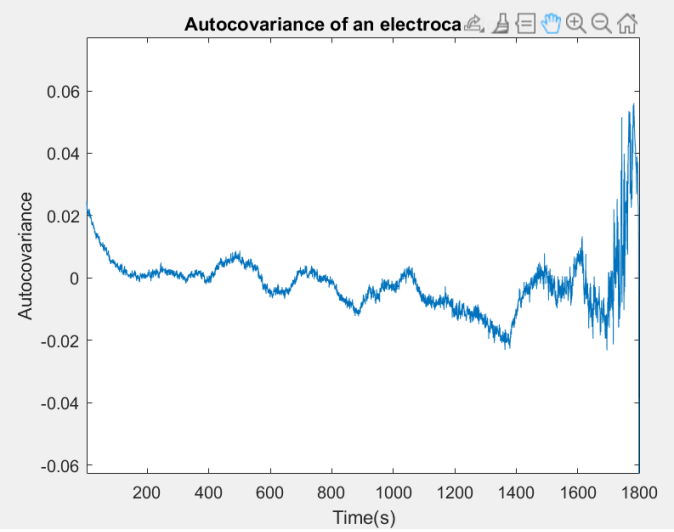

Figure 12: Sample auto-covariance of the process Δ_n

3.3.2 Ventricular fibrillation

Ventricular fibrillation occurs in the ventricles and is characterized by a similar phenomenon, that is, an addition of many rapid and small depolarizations. Unlike the atrial fibrillation, the ventricular fibrillation is generally fatal within 5 minutes, unless a defibrillator is used.

Episodes of ventricular fibrillation are usually characterized by a total absence of traditional P, Q, R, S and T waves, and by an ECG signal similar to a pure sine, with rapid oscillations between 240 to 600 bpm.

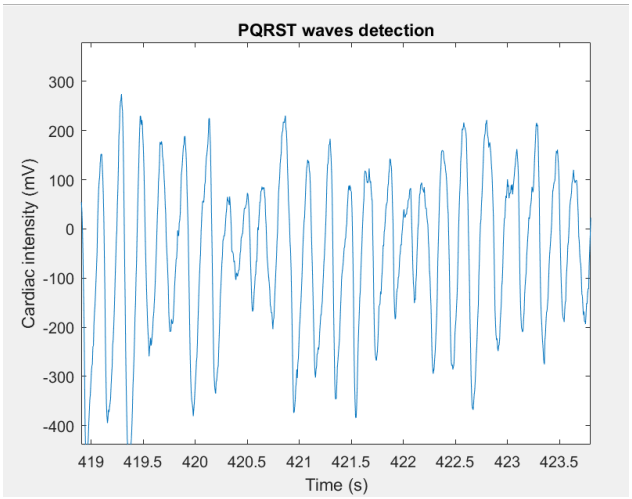

Figure 13: Ventricular fibrillation electrocardiogram

To detect this pathology, the best way is to look at the heart rate.

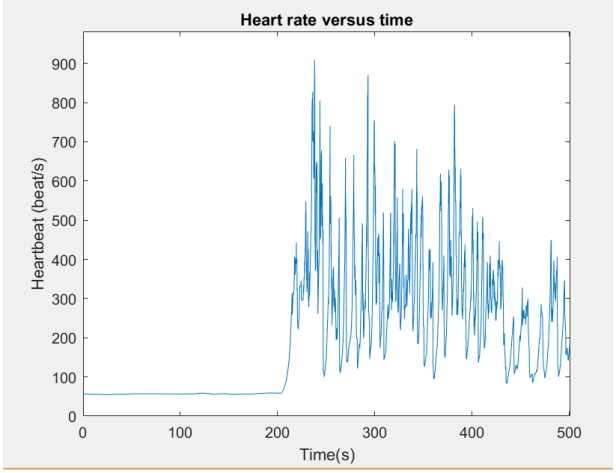

Figure 14: Heart rate of a patient with ventricular fibrillation

As you can see, this patient does have very abrupt heart rate oscillations between 240 and 900 bpm, which is characteristic of ventricular fibrillation.

4 Conclusion

In conclusion, this study led to the development of an electrocardiogram spectrogram as a first step in the analysis of the patient's heart. For physicians who are not able to decipher such data, the use of an algorithm allowing the detection of each heartbeat and their key points allows for easier detection of abnormalities. This leads to the diagnosis of possible cardiac disorders in the patient whose heart is analysed. However, this study is only a first step to facilitate the diagnosis of cardiac disorders, as shown above, these algorithms are not infallible. The most advanced recent research aims to develop a complete and live mapping of a patient's heart. This technology uses an electromagnetic field to create real-time, three-dimensional anatomical and electrical maps of the patient's heart chambers (atria and ventricles). This system helps the electrophysiologist to navigate inside the heart and to accurately determine the location and orientation of tools used for the diagnosis and treatment of arrhythmias.