MICA project:
Matlab Interface for a Cardiac Analyst

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1 Introduction :

The heart's electrical system controls all the events that occur when the heart pumps blood. A heartbeat is a complex cycle of electrical conductive events. These events take place inside and around the heart. A heartbeat is a single cycle in which the heart's chambers relax and contract to pump blood. This cycle includes the opening and closing of the inlet and outlet valves of the right and left ventricles of the heart. An electrocardiogram (ECG) is a test that detects and records the strength and timing of cardiac electrical activity. The main goals of our project are :

- Visualizing electrocardiogram (ECG) and analyzing the spectrogram obtained.
- Using Pan and Tompkins algorithm to detect the QRS complexes
- Deducing the position of P and T waves
- Using algorithms to detect cardiac pathologies automatically

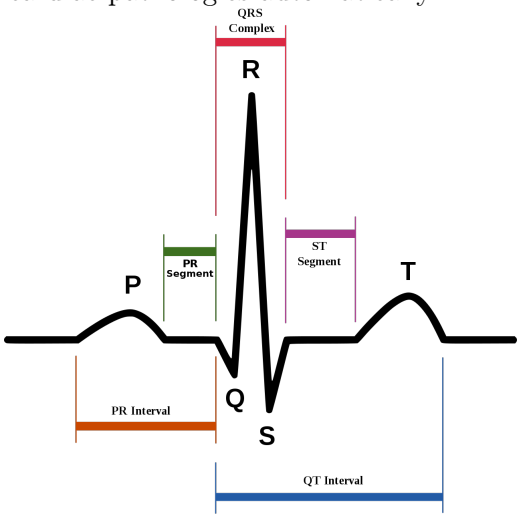


Figure 1 : Example of QRS complex , P and T waves in a signal extracted from an ECG.

2 Visualization of the ECG and spectrograms :

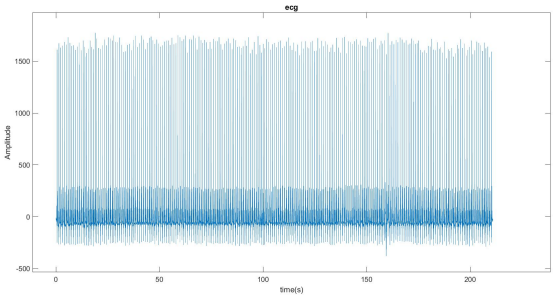


Figure 2 : ECG of a healthy person

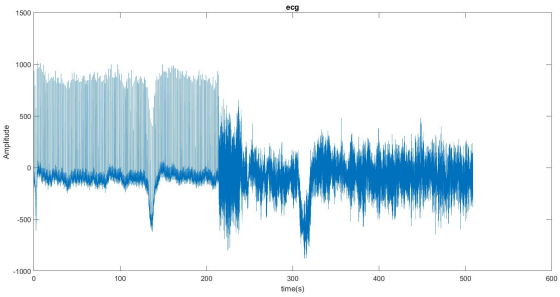
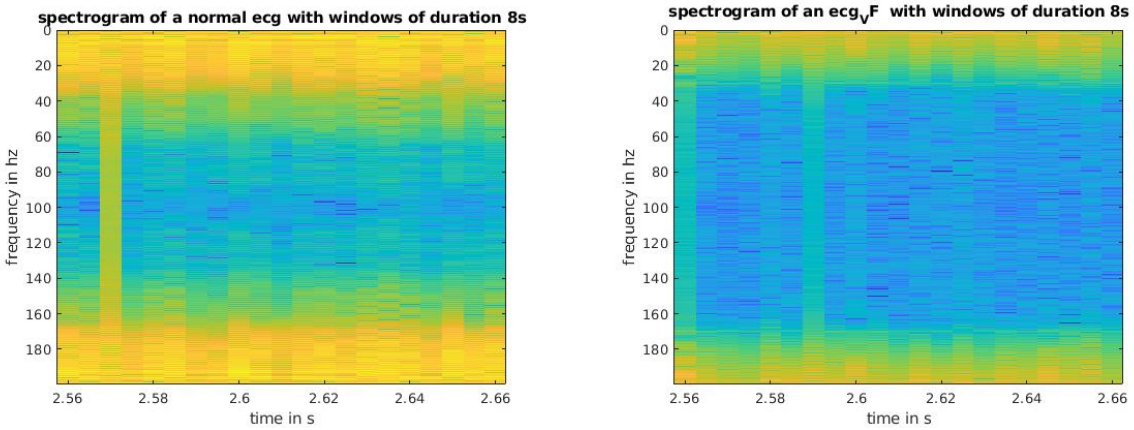


Figure 3 : ECG of a sick person who has ventricular fibrillation

The figures illustrate that the ECG of an average person was a periodic repetition of PQRST complexes. In contrast, the ECG of a sick person was similar to a pure sine during ventricular fibrillation.



(a) Spectrogram of a healthy person (b) Spectrogram of a VF person

Spectrogramms

The figure above shows two spectrograms of a normal ECG and a Ventricular Fibrillation ECG. Three significant regions appeared in the signal's spectrogram : the high-frequency region, the low-frequency region, and the very low-frequency region. For the average person, the blue part was extended over the interval (40Hz : 160Hz), and for a VF person, the blue part was more significant than a normal one.

The spectrograms, seen below, provided a general idea about the heart's electrical activity. Therefore to detect possible abnormalities in the heart, an examination of the central heart's waves was needed. Thus, the ECG signals represented three main waves. The first one was the P wave which was associated with the right and left atrial depolarization. The second one was the QRS. Typically this complex had a series of 3 deflections that reflect the current associated with the right and the left ventricular depolarization. By convention,the first deflection in the complex, if it is negative, is called a Q wave. The first positive deflection in the complex is called an R wave. A negative deflection after an R wave is called an S wave. The third one was the T wave and represented the current of rapid phase 3 ventricular re-polarization.

3 Pan and Tompkins algorithm :

This algorithm was used to characterize the QRS complex.

3.1 R wave detection :

Firstly, the ECG signal was filtered by a band-pass filter composed of a low-pass filter and a high-pass filter to cancel noise. The low-pass filter was a second-order, causal, Infinite Impulse Response (IIR) filter with a group delay of 5 samples and a linear phase. Its transfer function is the following : :

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

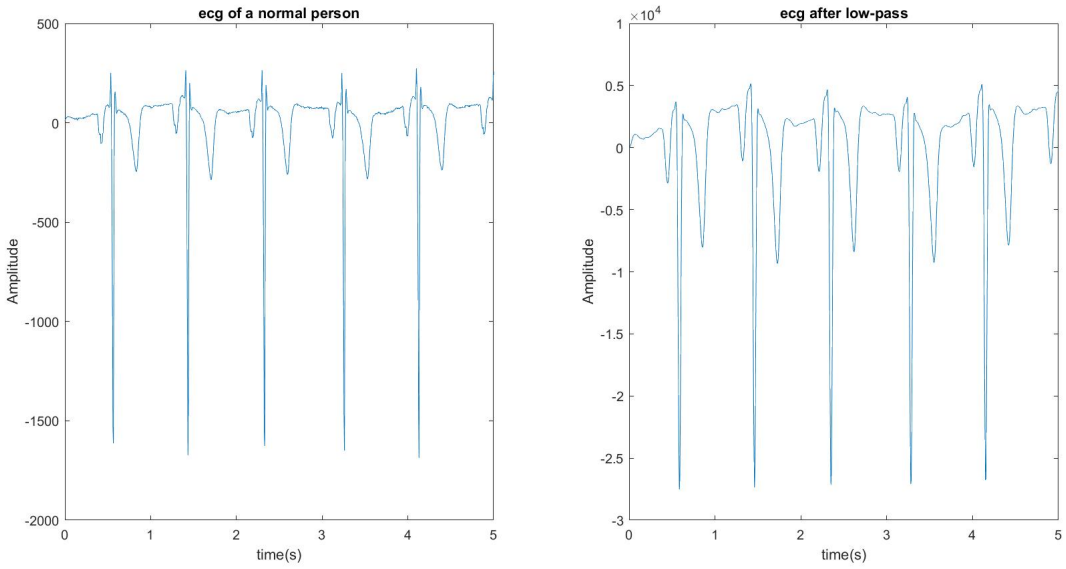


Figure 2 : Normal ECG signal before and after low-pass filter

Comparing the signal before and after the low-pass filter (figure 2) shows that the amplitudes of lower frequencies were amplifying, eliminating the higher frequencies..

The high-pass filter was a causal IIR, with a group delay of 16 samples and a linear phase, and a 3dB cut-off frequency of $F_c = 5Hz$

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

$$H(z) = \frac{(1 - z^{-6})^2}{(1 - z^{-1})^2} \tag{3}$$

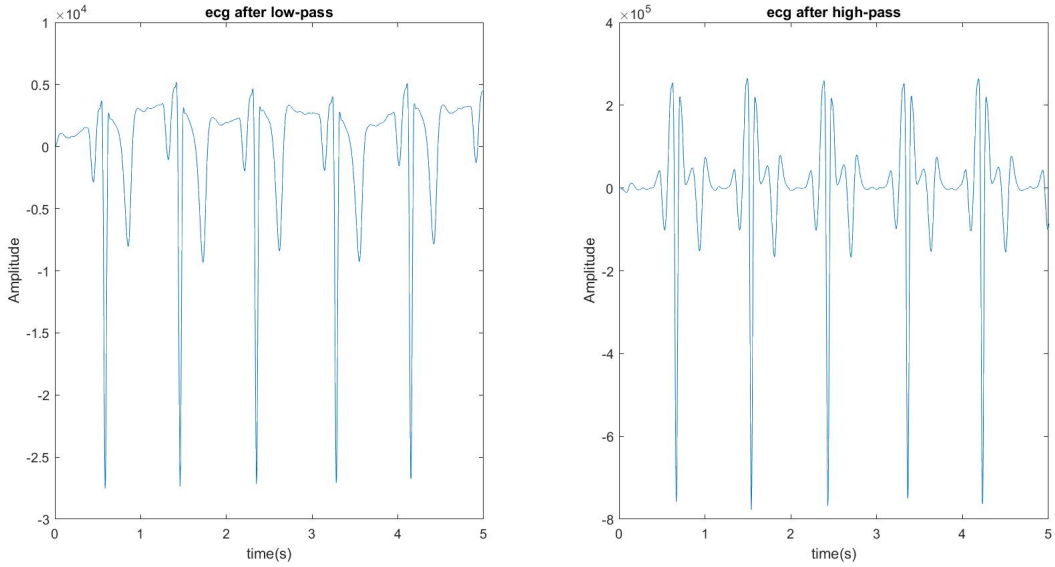


Figure 3 : Normal ECG signal after high-pass filter

Secondly, the output signal was differentiated to provide the QRS complex slope information. The five-point differentiation filter was a non-causal FIR filter with a group delay of 2 samples and a linear phase.

$$H(z) = \frac{-z^{-2} - 2z^{-1} + 2z + z^2}{8T_s} \tag{4}$$

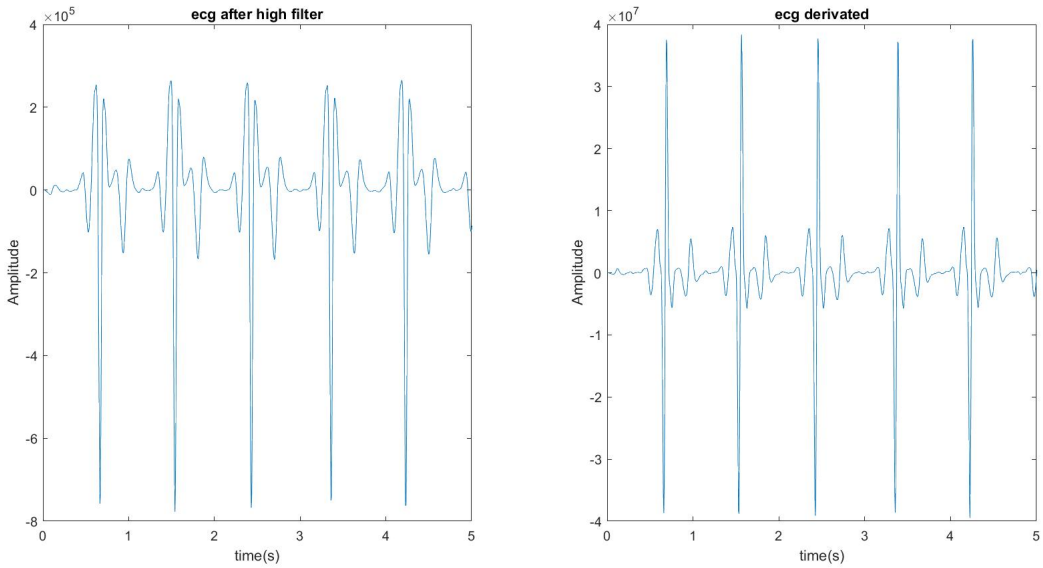


Figure 4 :differentiated ECG signal

After differentiation, the signal was squared point by point to amplify the output of the derivative, emphasizing the higher frequencies. The output signal was denoted S_{seq}. Then, Moving-window inte-

gration detected waveform feature information and the slope of the R wave. The moving window filter was applied to provide information about the duration of the QRS complex. The output signal of the moving window S_{MWI} was calculated using the following expression.

$$H(z) = \frac{1}{N} \sum_{i=0}^{N-1} S_{seq}(n-i) \tag{5}$$

The algorithm calculated all local maximums of the signal S_{MWI} and the intervals where these maximums were located, using the Matlab function *findpeaks*. Once the position of the probable QRS complexes was found, a threshold needed to be applied to reduce the possibility of detecting a peak corresponding to noise. The threshold chosen was the average of the whole ECG signal. The algorithm selected, among the maximums found previously, those which were above the threshold. As a result, intervals of QRS were located. Then, a loop was applied to search in each interval where the ECG signal was maximal ; these positions were precisely the R positions. Finally, a total group delay of 33 samples was counted on the QRS positions to have the exact positions on the initial ECG.

The detection of the QRS complex allowed calculation of the patient's BPM (beats per minute), which was the duration between 2 consecutive R's. This determined whether the patient has tachycardia (BPM>100) or bradycardia (BPM<60).

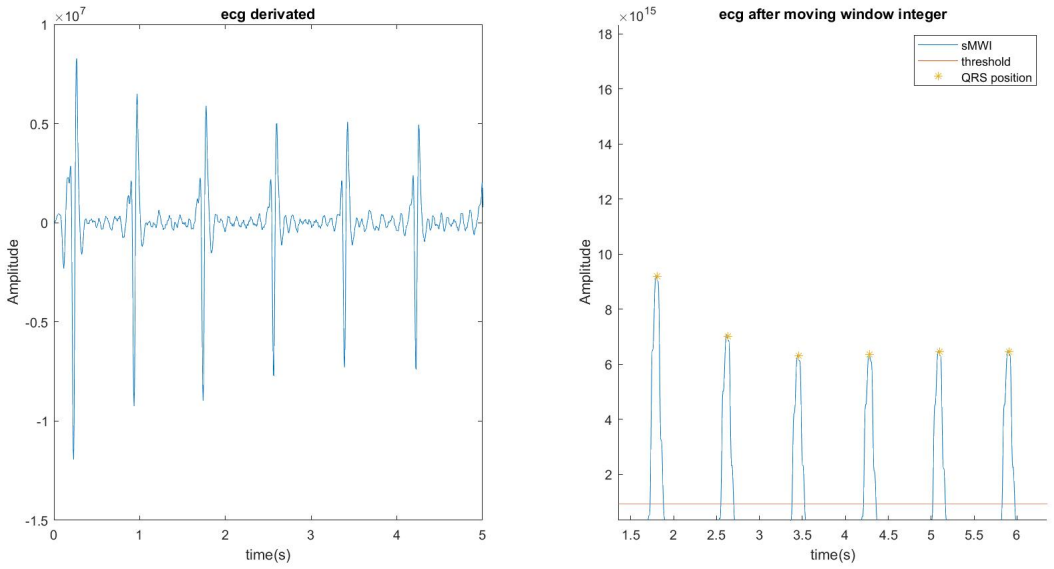


Figure 5 : Noisy ECG signal after moving window integration

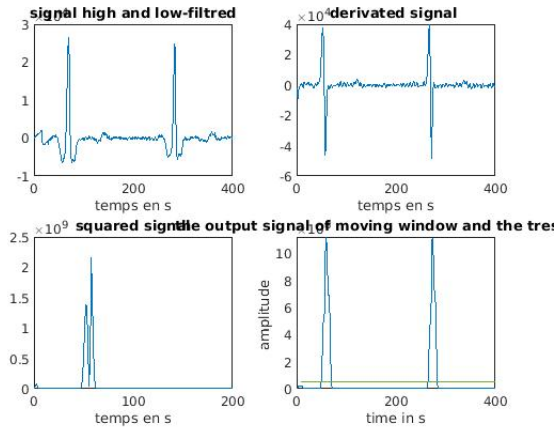
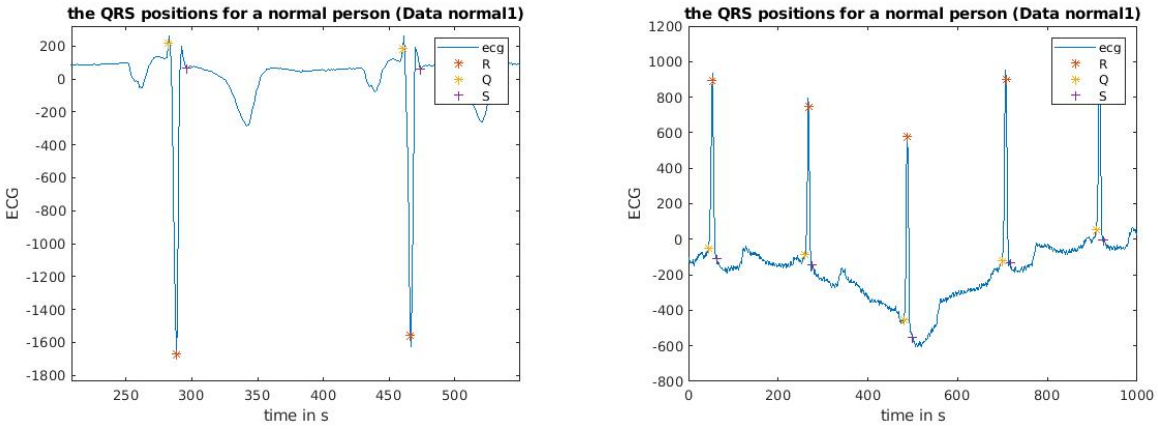


Figure 6 : illustration of Pan and Tompkins algorithm on an ECG VF (person with a ventricular fibrillation)

3.2 Q and S wave detection :

The Q and S were the first minima before and after the R wave, respectively. After R and the intervals of the possible QRS were determined, a research process of the min was executed on the left and on the right of R.The research process consisted of differentiating the ECG signal on each part of the intervals by using the MatLab function *diff*.Afterward, the positions Q and S waves were considered to be the minimum of the differentiated signal.



(a) Normal person (b) A person with a ventricular fibrillation

Figure 7 : The position of the QRS complex for a normal person using the algorithm Pan and Tompkins described above

Then, a group delay (33 samples) was taken into consideration to find the correct positions

3.3 T and P wave detection :

In order to detect the T wave, a three-step processing was applied on an ECG signal.Firstly, the signal was filtered with a differentiator (transfer function number 6), this filter was a FIR, causal.Secondly, the output signal of the first step was filtered with a pass-low filtering which is a RII and causal filter (transfer function number 7).Thirdly ,The detection of T wave was accomplished through detecting

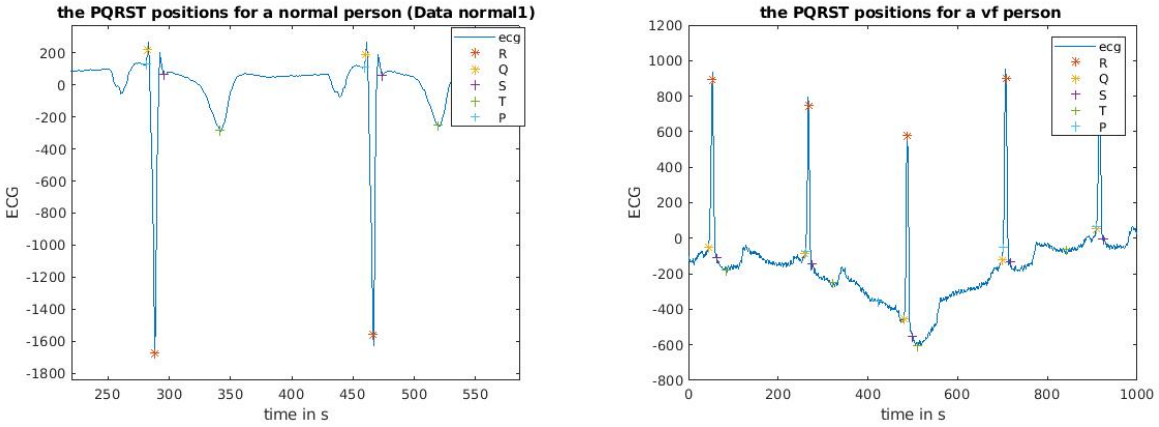
the signal crosses the level 0.The transfer functions of the first and the second filter are :

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

$$H(z) = \frac{1 - z^{-8}}{1 - z^{-1}} \tag{7}$$

The previous filters introduced a group delay of 6 samples.

The P wave was considered to present the highest peak between T and R.



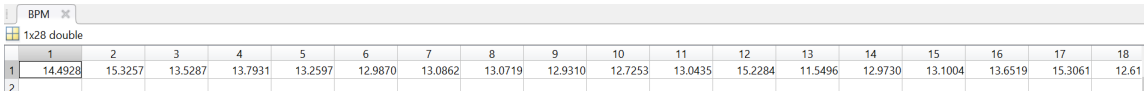
(a) Normal person (b) A person with a ventricular fibrillation

Figure 8 : The position of the PQRST complex for a normal person using the algorithm Pan and Tompkins described above

4 Identification of cardiac pathologies :

4.1 Tachycardia/Bradycardia

In tachy-brady syndrome, called tachycardia-bradycardia syndrome, the heart sometimes beats too quickly (tachy) and sometimes beats too slowly (brady). These abnormalities were recognized by calculating the cardiac rhythm, which was defined, for a normal ECG, as the duration of the R-R interval. In fact, bradycardia was declared when the cardiac rhythm felt under 60 bpm (beats per second), while tachycardia was characterized by a rhythm above 100 bpm. Here are some examples to illustrate Tachycardia/Bradycardia :


BPM

1x28 double

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	14.4928	15.3257	13.5287	13.7931	13.2597	12.9870	13.0862	13.0719	12.9310	12.7253	13.0435	15.2284	11.5496	12.9730	13.1004	13.6519	15.3061	12.61
2																		

Figure 9 : BPM table of a bradycardia case

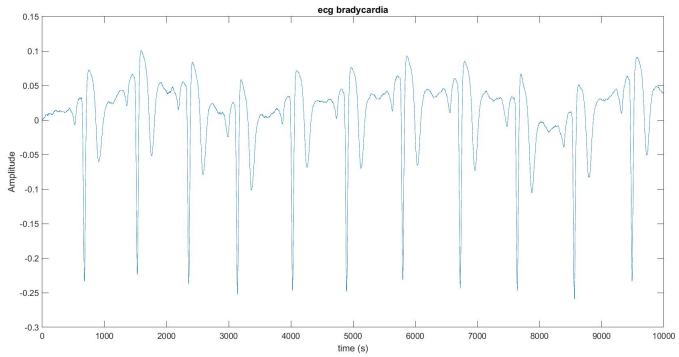


Figure 10 : ECG of a patient affected by bradycardia

The average BPM of this patient was around 13 beats per minute, and the algorithm detected bradycardia during the entire recording.

For the patient Data number 2, tachycardia and bradycardia were present at the beginning of the signal ECG. Their position was detected, like the following, in the intervals R-R.

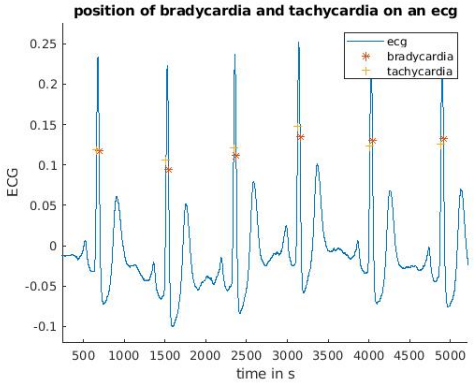


Figure 10 : ECG of a patient affected by bradycardia and tachycardia

4.2 Ectopic beat

A premature ventricular contraction causes the ectopic beat. In the ECG signal, this contraction was characterized by an early R wave. As a consequence, the position of an ectopic beat can be detected by comparing the difference between two consecutive R-R intervals and a certain threshold. Mainly, patient Data number5 suffered from an ectopic beat.

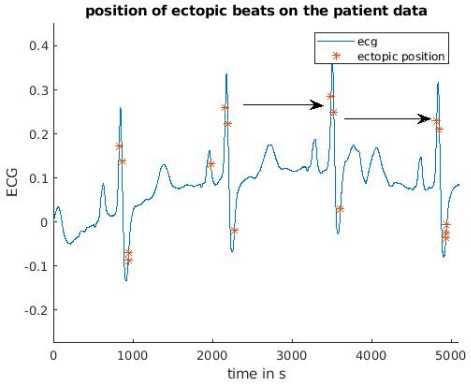
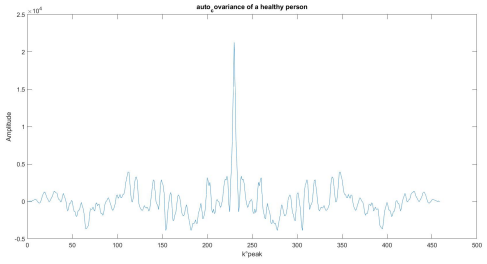


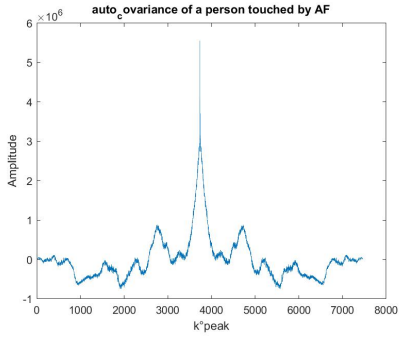
Figure 11 : Ectopic beat

4.2.1 Atrial fibrillation (AF)

In a person with AF, the process describing the RR intervals, which was denoted by (Δ_n), can be modeled by white noise. The auto-correlation function of white noise is a Dirac. Consequently, the algorithm detected the positions of the beginning of AF by calculating the auto-correlation function of the process (Δ_n) and then by detecting the position of Dirac signals. Here is an example :



(a) Autocovariance function of a healthy person



(b) Autocovariance function of a person affected by AF

Figure 12 : Autocovariance functions

In Figure b), the autocovariance looked more like a Dirac than the first one because the secondary lobes fade more rapidly, which is consistent with the theory.

4.2.2 Ventricular fibrillation (VF) :

The ECG signal was similar to a pure sinus during ventricular fibrillation, with large oscillations between 240 to 600 BPM and a total absence of P, Q, R, S, and T waves.

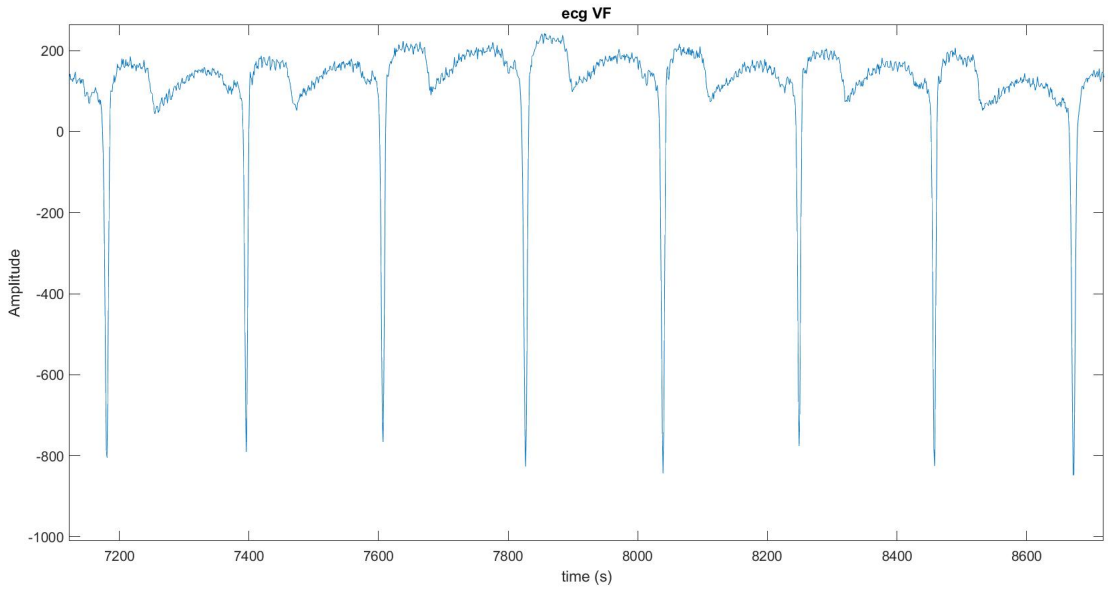


Figure 13 : ECG of a patient affected by ventricular fibrillation

The figure above shows that during ventricular fibrillation, there was a total absence of the traditional PQRST pattern.

5 Conclusion :

To conclude, the ECG and spectrograms gave many pieces of information about the patient's general condition. The algorithm, developed by Pan and Tompkins, enabled the detection of R wave positions. The knowledge of all R positions enabled to diagnose if the patient has bradycardia or tachycardia by calculating the distance between two consecutive R and also enabled to check if an ectopic beat touched the patient by comparing two consecutive R-R intervals to a threshold. Moreover, the calculation of the auto-correlation function of the process describing an RR interval enabled us to know if this process can be modeled by white noise and thus to know if the patient was affected by atrial fibrillation. Finally, the algorithm deduced from the QRS complex, the P and T waves, checked whether the PQRST points were correctly positioned in order to know if the patient was affected by ventricular fibrillation.

6 References :

[1] Pan and Tompkins algorithm : https ://en.wikipedia.org/wiki/Pan

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