MICA project: Matlab Implementation of a Cardiologist Assistant

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Abstract

This project addresses the problem of automated diagnosis of cardiac pathologies, via the signals provided by electrocardiogram (ECG) measurement devices. Basic signal processing techniques are used to remove undesired components altering the ECG quality, and estimate various parameters providing important information about the cardiac activity and detect irregularities such as arrhythmia, tachycardia, brachycardia, etc. As a last step, a graphical interface is designed to help the clinicians through their diagnosis.

Contents

1 Organization and project evaluation

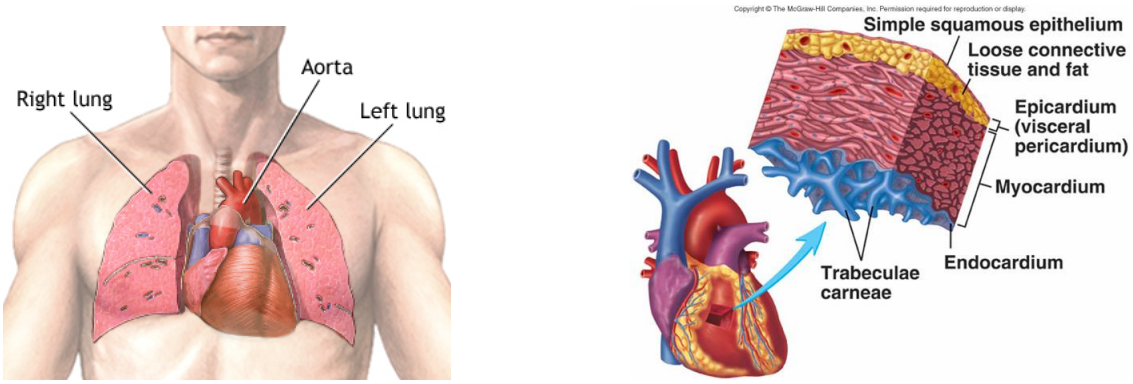
The duration of the project is 20h, divided in 5 sessions of 4h. The work must be carried out by groups of 2 students **maximum**. The assessment relies on a personal grade depending on the **student's behaviour** (assiduity and reliability during the sessions), as well as a **report of the project**. The instructions for the report are given below :

- A first printed version is to be sent at the Language Resource Center (CREL) **on May 20th**. Professors from the CREL will give back their reviews **during group meetings**.
- An electronic **pdf version** of the final report is to be sent by e-mail to the professor in charge of your group, **on May 30th, before midnight**. The MATLAB source code produced during the project must be attached to the e-mail, and **does not have to be included in the appendices of the report**.
- The report should be typed using LaTeXor Word, in plain page format with a font size of 11 points. **The maximum number of pages allowed is 12.** If you are using Word, all equations should be typed with the specific editor, and should be numbered if they are cited. All figures should have a number, a title and labeled axes (with units).
- Concerning the organization of the report, a table of contents should be inserted at the beginning. In a first introductory part, the project topic must be rephrased **with your own words** (do not rewrite the subject !). The remainder of the report should follow the organization of the present document.
- If some documents have been used during the project, they should be cited in a "References" section, at the end of the report.

2 Introduction

The human body is the center of an intense electrical activity arising, for example during brain cells communication, nerve impulses, and in particular during cardiac activity. The blood pumping function of the heart is essentially provided by the contraction of the cardiac muscle which is impulsed by an electrical signal.

Heart The heart is a muscle located in the center of the thoracic cavity (see Figure 1(a)). It is composed of four chambers two atria and two ventricles, at the top and the bottom of the heart respectivily (see Figure 2). These cavities are composed of layers named, from outside to inside, epicardium, myocardium and endocardium (see Figure 1(b)).



(a) Heart location [1]

(b) Herat muscle layers [2]

Figure 1: Human heart schematics

The blood flow is initiated and maintained by the heart (see Figure 2). The atria are responsible for the blood reception while the ventricles are known as blood ejection chambers; both atria and ventricles contract in coordination, first the atria contract together then the ventricles contract. The right side is responsible for receiving blood from the whole body and pumps it to the lungs for oxygenation. In parallel, left atrium and ventricle receive oxygenated blood to be distributed again through the body. Valves force the blood to flow in the right direction and improve the mechanical efficiency of the pump. Between the right atrium and ventricle it is the tricuspid valve, and between the left atrium and ventricle the mitral valve is placed. The pulmonary valve obstructs the reverse flow of blood from the pulmonary arteries to the right ventricle, while the aortic valve does the same between the aorta and left ventricle.

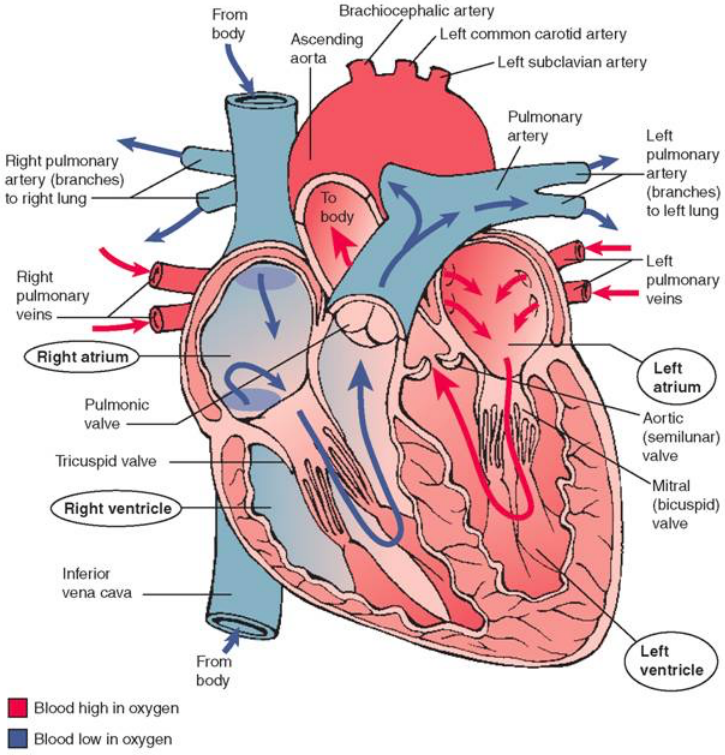


Figure 2: Cardiac anatomy and blood flow [3]

The efficiency of the mechanical activity of the heart is closely related to the synchrony of the muscle fibers when they contract. This synchronization is provided by the cardiac electrical activity. The electrical stimulation triggering cardiac contraction is spontaneously generated in a structure that works as the natural pacemaker of the heart and it is placed in the upper wall of the right atrium, the sinoatrial (SA) node (see Figure 3). The stimulus spreads throughout the atria to reach the atrioventricular (AV) node, in this tissue at the bottom of the right atrium the signal undergoes a delay due to the slow conduction velocity, and the reflection on the mechanical behavior is a delay which sufficies to fill the ventricles with blood. After the delay, the electrical activation spreads into the bundle of His, which is divided into two branches located within the interventricular septum and which lead to Purkinje fibers. These are very thick fibers which allow a very rapid spread causing an almost simultaneous contraction of the entire ventricle. Without any pathology, this normal contraction is named *sinus rhythm*.

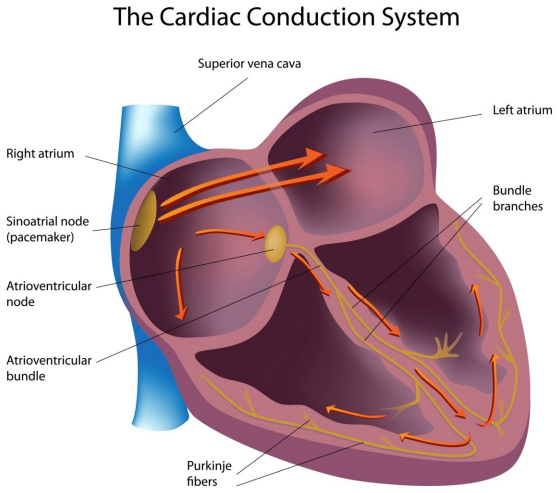
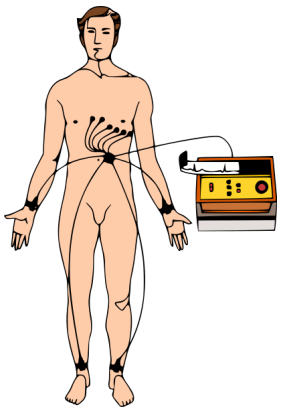
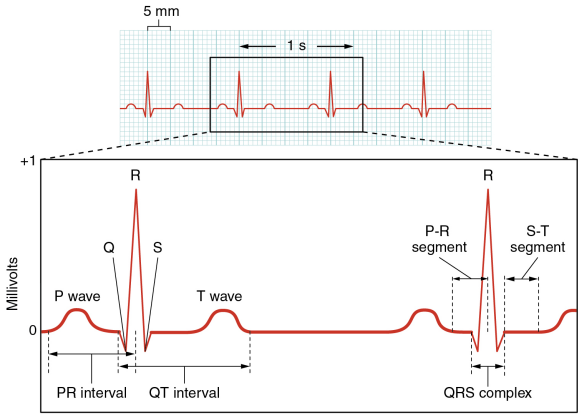


Figure 3: Human heart electrical conduction system [4]

An electrocardiogram (ECG) records the heart's electrical activity (or the polarization changes) by using electrodes placed at specific locations of the body, to measure electric potential between several points, as shown in Figure 4(a).



(a) The ECG device [5]



(b) Normal sinus rhythm [6]

Figure 4: Electrocardiogram procedure

The typical shape of an ECG signal during a cycle of heart contraction is given in Figure 4(b) and is composed of five main variations called *waves*.

Waves [7] The propagation of the initial electrical stimulation through the right atrium to the AV node gives rise to an *atrial depolarization* called *P wave* (see Figure 5). While attaining the left and right ventricles, the electric field undergoes series of three polarization changes occurring in a short time, called the *QRS complex*. Finally, the repolarization of the ventricles give birth to the *T wave*. These five waves can be used to detect abnormalities in the heart cycle.

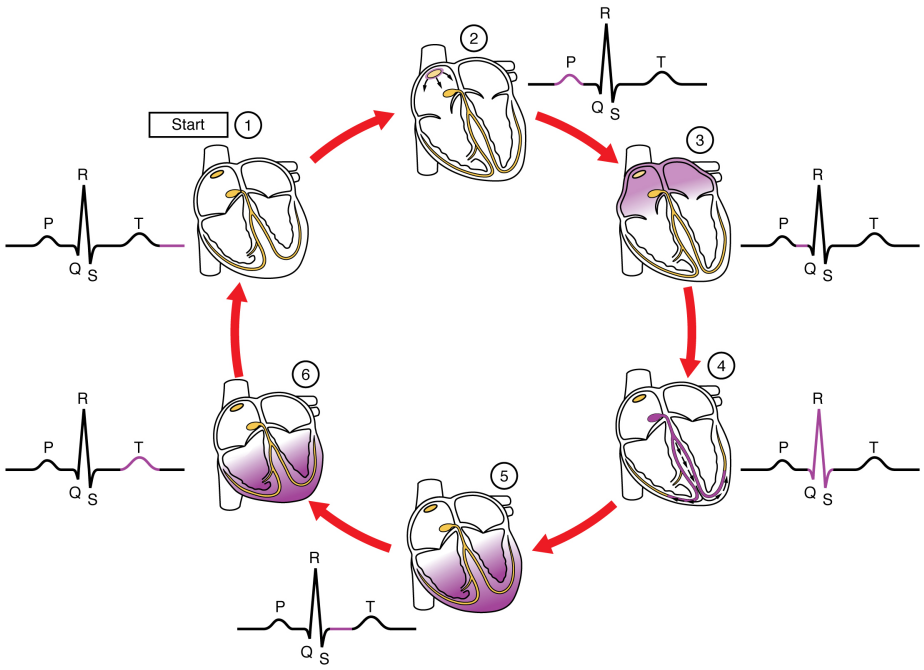


Figure 5: Electrical tracing of the cardiac signal [6]

(1) The sinoatrial (SA) node and the remainder of the conduction system are at rest. (2) The SA node initiates the action potential, which sweeps across the atria. (3) After reaching the atrioventricular node, there is a delay of approximately 100 ms that allows the atria to complete pumping blood before the impulse is transmitted to the atrioventricular bundle. (4) Following the delay, the impulse travels through the atrioventricular bundle and bundle branches to the Purkinje fibers, and also reaches the right papillary muscle via the moderator band. (5) The impulse spreads to the contractile fibers of the ventricle. (6) Ventricular contraction begins.

Time intervals The period separating the different waves also provide important information about the heart activity, and potential pathologies. The *PR interval*, measured from the beginning of the P wave to the beginning of the QRS complex (see Figure 6), represents the duration of propagation of the electrical wave inside the right atrium (more precisely from the SA node to the AV node. The *PR segment* represents the propagation of the electrical wave from the AV node to the right and the left bundle branches, which is characterized by an absence of contraction. The *QT interval* starts from the beginning of the QRS complex and finishes at the end of the T wave, and characterizes the duration of the ventricular contraction. The *ST segment*, starting from the end of the QRS complex and ending at the beginning of the T wave characterizes the time interval during which the ventricles are depolarized. Finally, the *R-R interval* representing the time interval between two recurrences of R waves can be used to measure the duration between two contraction cycles, and it is therefore used as a measure of the heart rate.

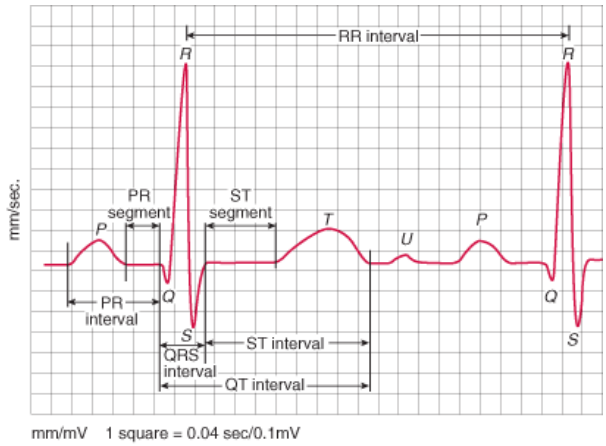
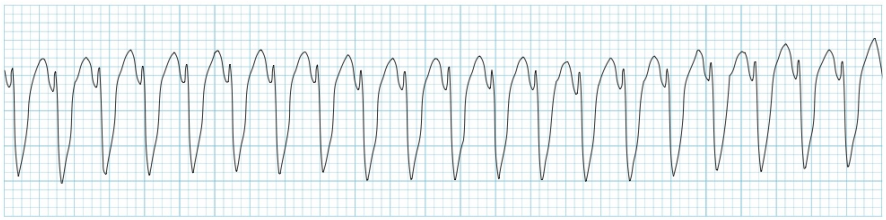


Figure 6: ECG segments schematic [8]

Pathologies The examination of waves and time intervals makes it possible to detect abnormalities in the heart functioning. We introduce below some of these pathologies. *Arrhythmia* is probably one of the most frequent heart troubles encountered in general, and is related to abnormalities in the cardiac rhythm, whose normal value generally spreads from 60 to 100 bpm (beats per minute, for an adult). An example of irregularities is a faster than usual cardiac rhythm ($>$ 100 bpm), a phenomenon known as *tachycardia*, or a cardiac rhythm slower ($<$ 60 bpm), which is known as *bradycardia*.

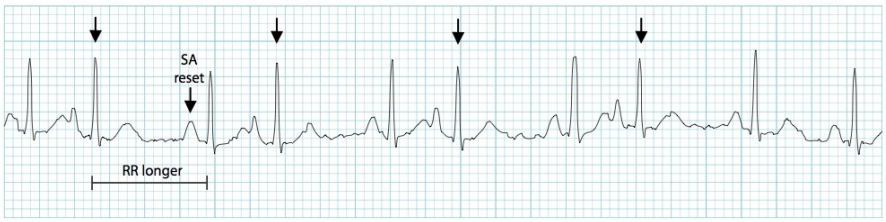
(a) Atrial tachycardia [9]



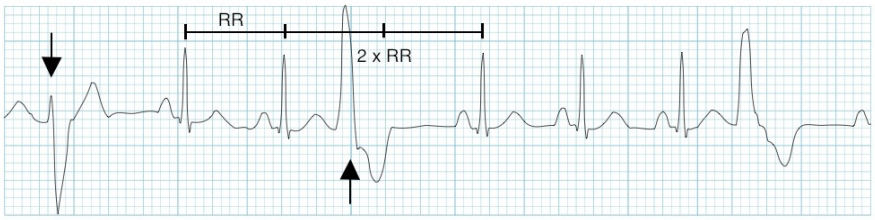
(b) Ventricular tachycardia [10]

Figure 7: Example of ECG with tachycardias (arrows)

In some cases, the electric stimulation initiated originally from the SA node may start from the atrium or from the ventricles, leading respectively to an *premature atrial contraction (PCA)* or *premature ventricular contraction (PVC)*, that is an anticipated reset of the cardiac rhythm.



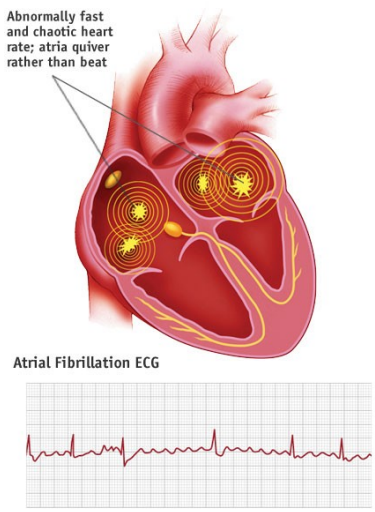
(a) Premature atrial contraction [11]



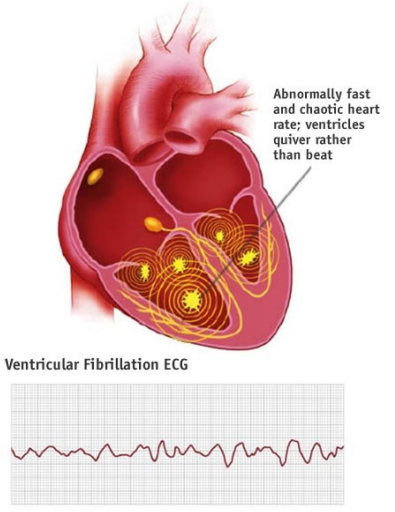
(b) Premature ventricular contraction [12]

Figure 8: Example of ECG with premature contractions (arrows)

Another frequent phenomenon, known as *fibrillation*, is defined by the lack of organization of electrical activity in some parts of the heart, and physically described by a quasi-random circulation of electrical waves. There are two main fibrillation phenomena : the *atrial fibrillation* and the *ventricular fibrillation*. The atrial fibrillation occurs when the original electric stimulation of the SA node is "overwhelmed" by the chaotic circulation of many small electric wavelets taking place in the atrium ; the consequences of the ECG is shown in Figure 9(a). 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 ; the consequences of ventricular fibrillation on the ECG are shown in Figure 9(b).



(a) Atrial fibrillation, characterized by rapid ondulations and absence of P wave [13]



(b) Ventricular fibrillation characterized by an absence of P, T, and QRS complex waves [13]

Figure 9: Effects of fibrillation on the ECG

Objectives of the project The main purpose of this project is to implement under MATLAB basic signal processing algorithms to detect some of the cardiac pathologies mentioned above, and develop a graphical user interface (GUI) to load, process and display ECG, the goal of which is to help clinicians through their diagnosis. The rest of this document, which serves as a guideline, is organized as follows. Section 3 is dedicated to the display and basic characterizations of the ECG, in time and frequency. Section 4 address the study and implementation of basic signal processing algorithms for detection of P, QRS and T waves, which is a fundamental step towards automatic diagnosis. Section 5 exploits the previous detection results to design routines for automatic identification of the main cardiac pathologies. Section 6 focuses on signal processing methods to remove unwanted disturbance on the ECG, e.g. the addition of noise which may occur during the measurement process, and which generally implies a severe degradation of the traditional ECG processing methods. Finally, Section 8 is dedicated to the design of a graphical user interface. A short tutorial on how to use the related MATLAB functions is also provided.

Note: If you want to understand easily, see the following video: `https://www.youtube.com/watch?v=TJR2AfxVHsM`.

3 ECG visualization

The aim of this section is to display and analyze the ECG signals under MATLAB. All the ECG samples, recorded in *.mat* files, can be downloaded at `http://rtajan.vvv.enseirb-matmeca.fr/Cours/Telecom/T1/TS114/`. Each .mat file can be loaded into the MATLAB workspace using the command `load`, and is composed of two variables :

- a variable *ecg* which contains the sample of the related ECG ;
- a variable F_s which contains the value of the sample frequency of the related signal.

Each file is referenced as *ecg_xxx_n* where *xxx* represents the type of ECG : normal, AF (Atrial Fibrillation), VF (Ventricular Fibrillation), SSS (Sick Sinus Syndrome), noisePL (Power Line noise), noiseBL (Baseline Wander noise), PVC (Premature Ventricular Contraction). If different ECG of the same type are available, they are indexed by a number n.

Task.
- *By following step by step the questions given in subsections* 3.1 *and* 3.2*, write a synthesis about the ECG signal analysis in the time and frequency domains (with graphical illustrations) and the consequences of pathologies on the properties of the ECG signal.*
- *Then, create a function which takes as input the ECG signal and a time interval and returns a section of this signal between two times.*
- *Conclude on this section.*

3.1 Time display

3.1.1 Normal ECG signals

- Under MATLAB, load the ECG signals given in files entitled *ecg_normal_n.mat,* $n = 1,2,3$.
- Plot the time evolution of ECG signals.
- Locate and display the QRS complex on a short part (about 4 seconds) of the ECG signals (one figure for each ECG signal). Surround the Q, R and S detected points in the figures. Comment these figures.

- Locate and display the P and T waves on the same figures. Surround the P and T detected waves.
- Compute the cardiac rhythm for all ECG signals. What do you conclude ?

3.1.2 ECG signals with pathologies

- Load the ECG signals given in files entitled *ecg_ AF.mat, ecg_ VF.mat, ecg_ SSS.mat, ecg_ PVC.mat*.
- Display the time evolution of the ECG signal. What do you notice for each ECG signal (abnormalities)?
- Locate the QRS complex and the P and T waves for each ECG signal. Estimate manually the cardiac rhythm.
- Summarize the consequences of each pathology on the ECG signal.

3.2 Frequency display

3.2.1 Normal ECG signals

- Plot the ECG power spectrum of the ECG signals on a short window (choose an adequate number of samples N of the ECG signal).
- From the figure above, compute the cardiac rhythm and check that it is identical to the cardiac rhythm computed in the time-domain.
- Comment these figures (useful frequency interval, cardiac rhythm,..etc).
- Compute the cardiac rhythm for all ECG signals. What do you conclude?

3.2.2 ECG signals with pathologies

- Plot the ECG power spectrum of the ECG signals from 0 to 150 Hz. Compare these figures to the power spectrum of a normal ECG. What do you conclude?
- Compute the cardiac rhythm and check that it is identical to the cardiac rhythm computed in the time-domain.

3.3 Short term analysis

3.3.1 Normal ECG signals

Consider a sliding window of N samples. (Consider cases with N corresponding to 0.5, 2, or 4 seconds)

- For each position of this sliding window store the power spectrum of the previous section as a new column of a matrix.
- Display the result as an image using the Matlab function *imagesc*.
- For each position of the sliding window compute the cardiac rhythm and store it.
- Plot the temporal evolution of the cardiac rhythm $r(t)$.

3.3.2 ECG signals with pathologies

- Display the image of the short term analysis.
- Plot the temporal evolution of the cardiac rhythm $r(t)$.
- Summarize the consequences of each pathology.

4 Detection of P, QRS and T waves

4.1 QRS detection

We have seen in the previous section how to recognize the Q, R and S waves within a QRS complex as well as a P wave and a T wave. In this section, we aim at detecting these five waves automatically. To this end, several signal processing algorithms are studied and tested on different ECG. We first work with the file *ecg_normal_n.mat* which contains an ECG sampled at $f_s = 250Hz$. Since the R wave is the part of the QRS complex with the maximum height, it can be detected more easily than the Q and the S waves. For this reason the first step is to focus on detecting R waves.

4.1.1 R wave detection

Three different methods are used to detect the R wave.

Method of local maxima The first method is rather straightforward and consists in finding all the local maxima in the ECG signals. For this purpose, a threshold is needed so as to discriminate the R waves from other local maxima.

Task.
- *Let $s(n)$ be the n^{th} sample of the ECG. In order to increase the difference between the R waves and the rest of the signal, compute $s(n)^3$.*
- *To compute a threshold, take the first four seconds of the signal and find the first four maxima. From the mean of these maxima, propose a suitable value for the threshold that keeps only the maxima corresponding to the R waves.*
- *Extract from the signal all the values that are above the proposed threshold. From these, find the R waves and the time at which they occur. Display the R waves on the ECG.*
- *Check the method on the signals ecg_normal_2.mat and ecg_normal_3.mat. For both signals, display the R waves on the ECG.*

Method of the derivative Since the detection of the R waves is the same as finding local maxima, another method consists in working with the derivative of the signal. Because the R wave is preceded by a strong rising slope, the derivative yields a high value. Moreover, since the R wave is followed by a strong falling slope, the derivative yields a very low value. The methods consists in finding the local maxima and the local minima corresponding to the preceeding and following slopes of the R wave. From this interval, the position of the R wave can be obtained when the derivative crosses zero.

Task.
- *Compute the derivative of the signal contained in ecg_normal_1.mat. Using what was done in the first method, find the positions of the local minima and maxima.*
- *From the vectors containing locations of the local minima and maxima, deduce the R waves positions.*
- *Compare this method with the previous method on the three signals contained in the files entitled ecg_normal_1.mat, ecg_normal_2.mat and ecg_normal_3.mat. Comment.*

Pan and Tompkins algorithm The last algorithm is named after its inventors J. Pan and W. Tompkins and can be found in [14]. The algorithm consists in the following processing steps on the ECG signal:

a) band-pass filter

b) derivative

c) squaring function

d) moving window integration

e) thresholding

f) detection of maxima

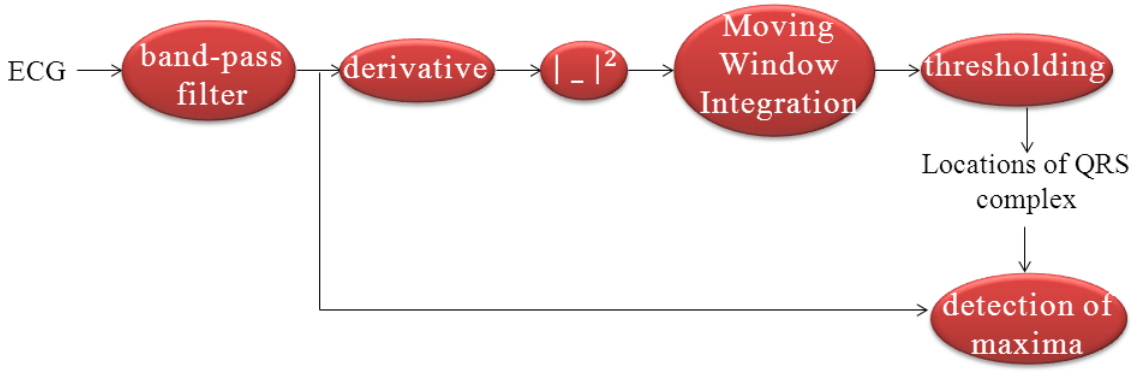


Figure 10: Pan and Tompkins algorithm

We use the ECG signals contained in the file entitled *ecg_ normal_ 1.mat*.

a) The band-pass filter is a combination of a low-pass filter and a high-pass filter. These filters are described in the mat files *H1.mat* and *H2.mat*.

Task. *Plot the amplitude and phase of the frequency responses of $H_1(f)$ and $H_2(f)$ using the function "freqz" and plot the frequency response of the corresponding band-pass filter. For the three filters, evaluate the 3 dB cutoff frequency and the group delay. Plot the ECG signal and its spectrum after each filtering.*

b) After filtering, the signal is differentiated to provide the QRS complex slope information. A five-point differentiation filter is used, whose transfer function is given by:

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

Task. *Plot the amplitude and phase of the impulse response of the filter. Evaluate the 3 dB cutoff frequency for the filter and compute the groupe delay. Plot the ECG signal and its spectrum after the filtering.*

c) After differentiation, the signal is squared so as to intensify the local extrema.

Task. *Square the samples of the filtered and differentiated signal.*

d) The next processing consists in a moving-window integration step. We denote s_{sq} the samples of the ECG after the squaring step and s_{MWI} the output of the moving-window integration. Then :

$$s_{MWI}(n) = \frac{1}{N} \sum_{i=0}^{N-1} s_{sq}(n-i) \tag{2}$$

The width N of the window should be around the width of a QRS complex and is determined empirically.

Task. *Propose a value for the length of the window and apply the moving-window integration step to the squared ECG. Plot the obtained ECG.*

e) A step of thresholding is applied to the processed ECG so as to locate the QRS complex. Indeed, its temporal location is given by the rising slope of the integrated ECG.

Task. *Propose a value for the threshold so as to detect the maxima of the integrated ECG signal. Find the temporal locations (beginning and end) of the rising slopes of the integrated ECG signal.*

f) The last processing consists in detecting the maxima on the ECG signal which are located within the intervals found in the previous step.

Task. *Match the temporal locations of the intervals found in the previous step with the original ECG signal. Locate the R waves and display the result on the ECG.*

Task. *Give a table summarizing the filtering steps in the Pan and Tompkins algorithms containing:*

- *its nature (low-pass, high-pass, band-pass, ...),*
- *its type (Finite Impulse Response (FIR), Infinite Impulse Response),*
- *its 3dB cutoff frequency,*
- *its group delay,*
- *if it is stable of not,*
- *if its phase is linear or not.*

What is the global delay of this algorithm?

4.1.2 Q and S wave detection

Once the R waves are located, the Q and the S waves are defined as the first minima before and after the R wave, respectively.

Task. *From the locations of the R waves on ecg_normal_1.mat, implement the detection of the Q and the S waves using the first derivative. For the three ECG signals contained on the files entitled ecg_normal_1.mat, ecg_normal_2.mat and ecg_normal_3.mat, display the Q, R and S waves on the ECG.*

4.2 P and T wave detection

P and T waves can be detected by using the locations of the R waves. When considering an R-R interval, the T wave is assumed to be the highest peak between the first R peak and 0.7 times the R-R interval. We propose to detect the T wave using a three-step processing based on [15]. The first step consists in filtering the ECG signal with a differiator, the transfer function of which is given by:

$$G_1(z) = 1 - z^{-6} \tag{3}$$

The second step is a low-pass filtering using the following transfer function :

$$G_2(z) = \frac{1 - z^{-8}}{1 - z^{-1}} \tag{4}$$

Finally, the dectection of the T wave is achieved through the detection of the zero-crossing, as in the derivative method (Cf. section 4).

Task.
- *Plot the amplitude and phase of the impulse responses of the filters. Evaluate the* 3 *dB cutoff frequency for both filters and compute the groupe delay. Using the ECG signal contained in the file entitled ecg_ normal_ 1.mat, plot the ECG signal and its spectrum after the filtering.*
- *From the locations of the R waves, implement the detection of the T waves.*

The P wave is the highest peak in the remaing section of the R-R interval.

Task.
- *From the locations of the R waves, implement the detection of the P waves.*
- *Using what was done previously, display the P, Q, R, S and T waves on the three ECG signals.*

5 Automatic identification of cardiac pathologies

In this section, we make use of the methods developed in the previous section to detect P, QRS and T waves, and to detect classic cardiac pathologies.

5.1 Tachycardia/Bradycardia

Basic arrhythmia pathologies, such as tachycardia, bradycardia, can be naively detected based on the inspection of the cardiac rhythm. Usually, bradycardia is declared when the cardiac rhythm falls under 60 bpm while tachycardia is characterized by a rhythm above 100 bpm. As stated in the introduction, cardiac rhythm is defined, for a normal ECG, as the duration of the R-R interval. We assume here that the detection of P, QRS and T waves has been done successfully.

The basic method for estimating the cardiac rhythm consists in computing the mean of all the occurrences of R-R intervals contained in the ECG signal considered. Assume that the ECG signal $s(t)$ contains N R peaks at times $t_0 < \ldots < t_N$. Define the n-th occurrence of the R-R interval as $\Delta_n = t_{n+1} - t_n$. Then the sample mean estimate of the R-R interval is given by

$$\overline{\Delta} = \frac{1}{N} \sum_{n=0}^{N-1} \Delta_n.$$

Task.
- *Create a function implementing the sample mean estimator together with a procedure for detecting tachy/bradycardia.*

- *Give the results obtained for some of the ECG available (in particular ecg_ SSS.mat which contains episodes of bradycardia) ; results should be displayed with two different plots : one in seconds, and the other one in beats/minute.*
- *Give your opinion about the sample mean method ; what are the potential problems associated with it?*
- *Based on the short term analysis, propose a solution to the same problem.*

5.2 Heart rate variability

In normal ECG, measured R-R intervals exhibit slow variations, which are a consequence of respiration, blood pressure, etc ... . The variability of cardiac rhythm (HRV) may also be used as an indicator for detecting for e.g. myocardial dysfunction. Mathematically speaking, this variability is defined as the time process $v(t)$ given by

$$v(t) = \Delta_n + \frac{\Delta_{n+1} - \Delta_n}{t_{n+1} - t_n}(t - t_n), \quad \text{for } t \in [t_n, t_{n+1}),$$

that is, the linear interpolation between two consecutive values of R-R intervals.

Task. *Create a function giving various information on the HRV, including the sample standard deviation of the R-R interval values, the histogram of the occurrences of* (Δ_n)*, and the display of process* $v(t)$*.*

The power spectrum analysis of the HRV $v(t)$ may be useful for clinicians. Usually, the useful part of the spectrum of $v(t)$ is included in the interval $[0Hz, 0.4Hz]$, and is divided in four bands :

- Ultra Low frequency $[0Hz, 3.10^{-3}Hz]$;
- Very Low Frequency $[3.10^{-3}Hz, 4.10^{-2}Hz]$;
- Low Frequency $[4.10^{-2}Hz, 0.15Hz]$;
- High Frequency $[0.15Hz, 0.4Hz]$.

Task.
- *Compare* $r(t)$ *and* $v(t)$*.*
- *Improve the previous function by adding the display of the power spectrum of* $v(t)$*. Different colors must be used for the spectrum plot according to the four previous frequency bands, together with a legend indicating the intervals of frequency.*
- *The respiratory cycle has a significant way contribution in the HRV signal and can be estimated using the HRV power spectrum. What should be the reasonable frequency band where the respiratory oscillations could be detected ? Add to the previous function the estimation of the respiratory rhythm, measured in bpm.*

5.3 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 until the next normal beat. This premature occurence is usually detected by comparing to a certain threshold the difference of durations of the two R-R intervals respectively

preceding and following the heartbeat studied ; for example, for the test of n-th R peak, an ectopic beat is detected if the following inequality is verified

$$|\Delta_n - \Delta_{n-1}| \geq \epsilon,$$

where ϵ is the threshold.

Task. *Propose a reasonable way to set the threshold of the test (hint : you can make use of certain quantities computed in the previous section). Create a function to detect ectopic beats. Apply this function on the samples of the file ecg_ PVC.mat, and plot the related ECG with ectopic beats annotated.*

5.4 Fibrillation

Atrial fibrillation During atrial fibrillation, the process $(\Delta_n)_{n\geq 0}$ describing R-R intervals durations is usually modeled as white noise, and therefore exhibits in practice an almost flat spectral content [16]. In this situation, a statistical test can be computed to decide whether an ECG signal segment is under atrial fibrillation or not.

Task. *Based on the statistic*

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

which represents the sample autocovariance function of the process $(\Delta_n)_{n\geq 0}$, propose a test to detect atrial fibrillation in an ECG signal segment. Plot the autocovariance function for normal and atrial fibrillation signals ecg_ AF.mat to illustrate your test.

Another feature occurring during atrial fibrillation is the total absence of P wave.

Task. *Improve the previous atrial fibrillation detection method by including the detection of P waves developed in the previous section.*

Ventricular fibrillation 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.

Task. *Based on $r(t)$, $v(t)$ or $\hat{\gamma}_k$, propose two methods to detect ventricular fibrillation, and check its efficiency on the signal ecg_ VF.mat.*

6 ECG denoising

Noise contamination of the ECG such as baseline wander, power line interference and muscle activities can pollute the ECG and reduce the clinical value of an ECG signal. Thus, the filtering of the ECG signal is a necessary pre-processing step to conserve the useful information and to remove such noises. This section addresses this issue in order to remove the baseline and the 50 Hz power line from the ECG signal.

Task.

- *Load the ECG file entitled ecg_ noisePL.mat. Plot on a subplot figure the time evolution and the power spectrum of this signal. Comment this figure.*
- *Using fdatool under* MATLAB*, design a low-pass IIR Butterworth filter with minimum degree and plot its impulse response and the frequency response. Use this filter to remove the power line interference. Conclude.*

- *Load the ECG file entitled ecg_ noiseBL.mat. Plot on a subplot figure the time evolution and the power spectrum of this signal. Comment this figure.*
- *Using the fdatool function under* MATLAB*, design a high-pass Chebyshev filter and plot the impulse response and the frequency response. Use this filter to remove the baseline interference. Conclude.*

7 Human patient dataset

The objective of this section is to perform your algorithm on human patient data acquired in clinic.

Task. *Identify the correct diagnosis on patient data set:*

- *Load of ECG signals.*
- *Time/frequency display with an option of time/frequency intervals selection.*
- *Detection and display of the QRS complex and the P and T waves.*
- *Computation of the cardiac rhythm.*
- *Diagnosis of the ECG signal: detection of anomalies and identification of the corresponding pathology.*

8 Graphical interface

The objective of this section is to develop a Graphical User Interface (GUI) using MATLAB GUI builder, based on the different parts carried out in sections 3 to 6. The GUI will be designed as a decision support tool to help clinicians during their medical diagnosis.

Task. *Design a GUI as a support medical decision tool making the following functions:*

- *Load of ECG signals.*
- *Time/frequency display with an option of time/frequency intervals selection.*
- *Detection and display of the QRS complex and the P and T waves.*
- *Computation of the cardiac rhythm.*
- *Diagnosis of the ECG signal: detection of anomalies and identification of the corresponding pathology.*
- *Denoising techniques to enhance the quality of the ECG signal*

8.1 MATLAB GUI builder

- To launch the GUI builder, type *guide* on the MATLAB command window. A "Guide quick Start" window appears. Select the "Blank GUI" template and press "OK"
- Save the GUI figure to a file. When the figure is saved, two files will be created on the disk with the same name but different extents: A FIG file which contains the actual created GUI and a M-file which contains the code to load the figure and skeleton callbacks of GUI objects. The GUI objects are polled from their handles and stores then stored in a data structure called handles.

- Write code to implement the behavior associated with each GUI object on its call back function in the M-file.
- Based on the handles property of the GUI, you can obtain the String Property of a Button having for example a *Tag* named *pushbutton*, using the *get* function : *var = get(handles.pushbutton1,'string')*. To put a data into an *edit box* having for example a *Tag* named *edit1*, use the *set* function : *set(handles.edit1, 'string', var)*

8.2 GUI example

Here we give an example of a GUI developed under MATLAB GUI builder. Using the menu at the left, it is easy to insert button, axis,.. etc. In Figure 11, 2 axis and 3 buttons are inserted as objects.

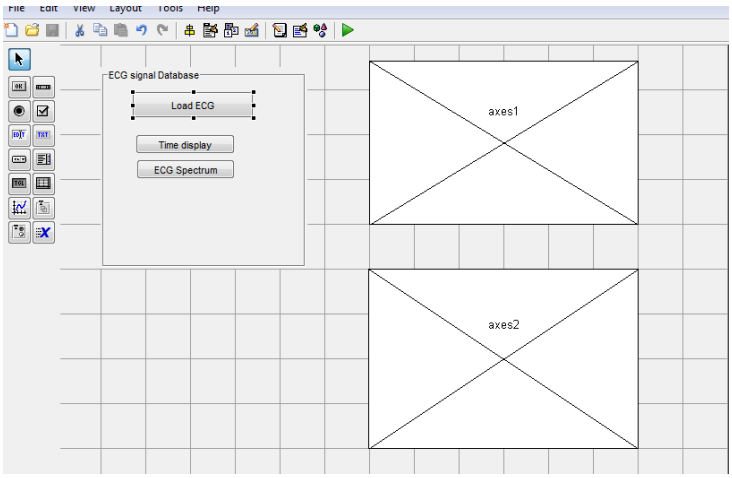


Figure 11: Example of graphical interface in GUI builder

By double-clicking an object, a new window appears. Along with other items, two important features are required as mentioned in Figure 12.

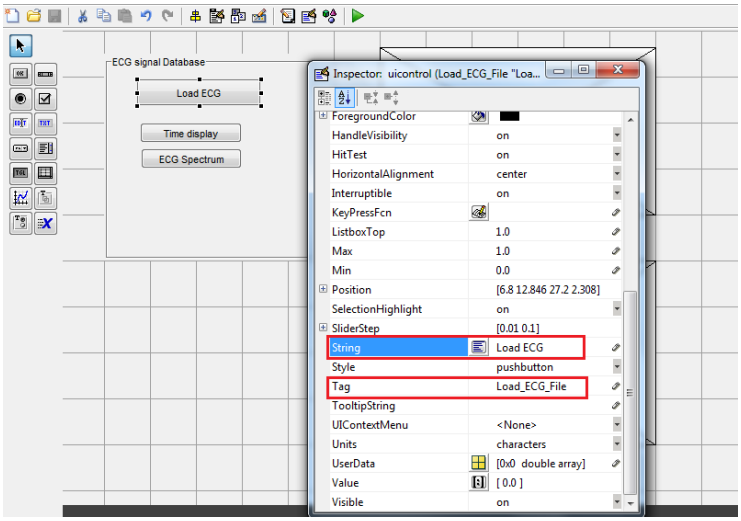


Figure 12: Parameter setting on callback functions

- String: this will give the name of the button on the interface
- Tag: this will give the name of the callback function on the M-file.
- To add a code relative to a given button, right-click on the button, select the callback function on the "View callback".

As a result of the example above, the following interface is obtained (Figure 13) for a given ECG file.

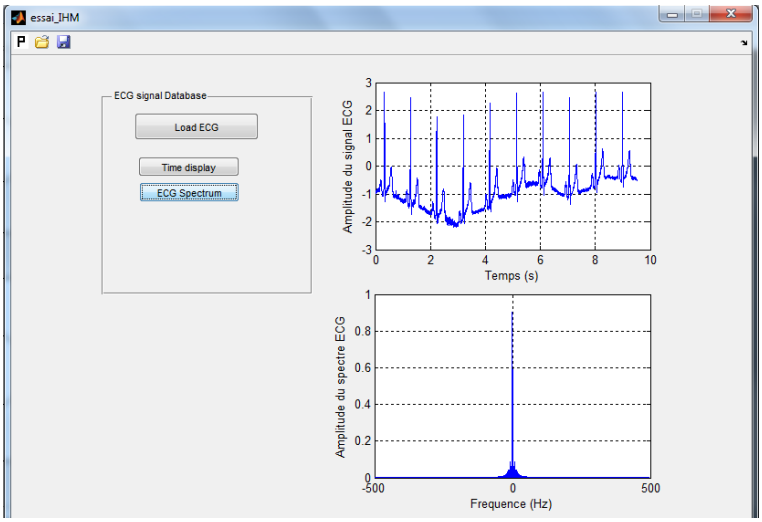


Figure 13: Generated GUI under MATLAB GUI

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