Detection of Cardiac Pathologies through alterations of the PQRST complex

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Abstract

Waves'appearance and their duration are essential to decipher an ECG signal and to identify repetitive patterns that are useful to detect cardiac and non-cardiac conditions. The aim of this project is to collect information about the time ranges between the different sections of the PQRST complex and to develop a MATLAB software capable of detecting possible diseases in case the ranges are out of the established limits for a healthy person. The final step of this project is to acquire physiological signals via Bitalino to analyse how the software processes them and alerts the user to potential pathological conditions or critical situations.

1. Introduction

Cardiovascular diseases (CVDs) are the leading cause of mortality worldwide, accounting for approximately 17.9 million deaths annually (WHO, 2021). CVDs can be prevented by avoiding unhealthy habits (unhealthy diet and obesity, use of alcohol and tobacco and physical inactivity) although, prevention, intended as an early detection through non-invasive methods, such as ECG, can save lives and improve quality of care. Cardiologists and emergency physicians hold the primary responsibility for the definitive interpretation of the ECG waveform, particularly in critical situations, but the use of dedicated algorithms may provide preliminary diagnostic suggestions. Early detection of CVDs can lead to interventions that significantly reduce the risk of future complications or adverse events. The benefits are many, from improved quality of life for the patient to the ability to treat the disease with less invasive procedures. It can also lead to reduced long-term healthcare costs for both individuals and healthcare systems [4.1]. Some diseases cause alterations in the PQRST complex either in changes in amplitude or variations in the time intervals between the different segments of the complex. The aim of this work is to develop a software that allows these anomalies to be detected automatically by detecting these times.

2. ECG Waveform

The electrical activity of the heart can be traced and recorded by an electrocardiogram (**ECG**). The standard ECG is obtained using 10 electrodes and it is referred as a 12-lead ECG. The resulting electrocardiograph shows one diagram for each lead and each of them represent a measure of the difference in electrical potential between two points depending on the position of the electrodes. The coordination of atrial and ventricular contractions is mirrored in the ECG as the P wave, QRS complex and T wave, repeated cyclically.

The **P wave** reflects the atrial depolarization (activation) and it's the overlap of the depolarization of the right atrial (beginning of the P wave) and the left atrial (ending of the P wave). It is always positive and it has a low amplitude because the activation of the atria doesn't require a high value of the electrical current because of their small muscle mass.The **PR interval** is the time period between the start of the P wave and the beginning of the QRS complex and the **PR segment,** that defines the baseline of the ECG signal, is the flat line between the end of the P wave and the beginning of the QRS complex.

The **QRS complex** represents the depolarization of the ventricles (activation) and it can be splitted in:

- Q wave: the first negative wave of the complex
- R wave: positive wave of the complex
- S wave: the second negative wave of the complex

The **T wave** is a positive wave that represents the ventricular repolarization (recovery). The **ST segment** corresponds to the plateau phase of the action potential where the membrane potential remains unchanged and most ventricular cells are simultaneously depolirezed. The PR segment is the reference for measuring deviations of the ST segment.

RR interval is the distance between two R peaks and it's linked to the heart rate measure:

$$HR\ (bpm) = \frac{60}{RR\ Interval\ (s)} \quad \text{[a]}$$

An heart rate of 60-100 bpm is measured in healthy conditions. [2.1][4.1]

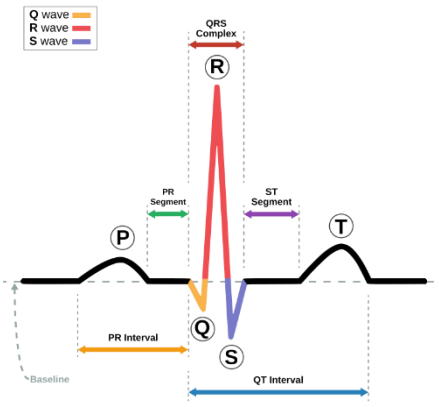

***Figure 1**. PQRST complex of the ECG signal.*
https://en.wikipedia.org/wiki/Electrocardiography

2.1. ECG Interpretation based on time ranges

ECG interpretation focuses on both amplitude and time ranges of the PQRST complex. Considering that the ultimate goal of this project is to identify pathologies by exploiting the duration of the segments that make up the ECG signal, our attention will focus on their **temporal ranges**, making a comparison between normal and pathological values and reporting their duration in relation to specific pathologies.

After analysing the state of art of several CVDs, it has been discovered that the duration of the PR interval, QRS complex and RR interval are the most useful to recognize certain pathologies.

The relevant notions, regarding normal and abnormal values and pathology related values, are summerized in ***Table 1*** and ***Table 2***. The CVDs listed in ***Table 2*** are those that show the most information in literature, according to [4.2], regarding several time ranges belonging to the segments of the PQRST complex.

In ***Table 2***, the following pathologies are listed:

- *WPW Syndrome*: it is caused by an additional electrical pathway between the atria and the ventricles.
- *First-degree AV block*: the electrical impulses that pass through the AV node are slowed down.
- *First-degree AV block with wide QRS complex*: when it occurs there's a high probability of a bilateral block in the bundle branches, with a risk of progression to a third-degree AV block.
- *Incomplete RBBB and LBBB*: partial delay of conduction in the right and left bundle branches.
- *Complete RBBB and LBBB:* complete blockage of conduction in the right and left branch of the bundle of His.
- *Tachycardia*: accelerated heart rate condition.
- *Bradycardia*: slowed heart rate condition.

The descriptions regarding these pathologies are taken from [4.3].

	Normal Duration	Abnormal Duration	Pathologies	
PR Interval	0.12-0.22 s	short or longer than normal	< 0.12 s	pre-excitation syndromes
			≥ 0.22 s	first degree AV block, second degree AV block,AV dissociation
QRS Complex	< 0.12 s (normally 0.07-0.10 s)	longer than normal	0.10-0.12 s	incomplete LBBB or RBBB, non specific IVCD
			≥ 0.12 s	complete LBBB or RBBB,WPW Syndrome, Hyperkalemia; also caused by class I antiarrhythmic,tricyclic antidepressants
ST Segment	shortens with increasing HR	the detection of a pathology is generally on elevation or depression of the ST segment in terms of *amplitude* , rather than its absolute duration.		
RR interval	0.6-1 s	shorter or longer than normal	It's irregular when associated to pathological cases; shortened in tachycardia or prolonged in bradycardia.	

Table 1. *Normal and pathological values of the time intervals of the segments of the PQRST complex.*

WPW syndrome	PR interval	0.08 s <PR< 0.11 s
	QRS Complex	≥ 0.12 s
	RR interval	< 0.60 s
	Delta Wave	present
first-degree AV block	PR interval	≥ 0.22 s
	QRS Complex	present
first-degree AV block with wide QRS complex	PR interval	≥ 0.22 s
	QRS Complex	> 0.12 s
incomplete RBBB	QRS Complex	0.11 s ≤ QRS < 0.12 s
incomplete LBBB	QRS Complex	0.10 s < QRS < 0.12 s
complete LBBB/RBBB	QRS Complex	≥ 0.12 s (sometimes > 0.16 s especially with mid-portion slurring)
Tachycardia	RR interval	< 0.60 s
Bradycardia	RR interval	> 1 s

Table 2. *Limit values of the time intervals of the segments of the PQRST complex of specific pathologies.*

3. Methodology

The MATLAB algorithm has been implemented thanks to **ECGdeli**, an open source ECG toolbox that comprehends both **ECG pre-processing and wave delineation algorithms.** The model is implemented using MATLAB's Signal Processing Toolbox, Image Processing Toolbox, Statistics and Machine Learning Toolbox and Wavelet Toolbox. The ECG pre-processing includes baseline removal, filtering and a isoline correction performed lead by lead. `QRS_detection.m`, `T_detection.m`, `P_detection.m` are the algorithms that are used to annotate QRS complex, P wave and T wave's fiducial points – FP of a single lead. ECGdeli funcionalities are discussed in detail in [2.2].

3.1. ECGdeli-Based Processing Model.

Once all the FPs of a single lead have been properly detected, some modifications to the existing algorithm must be made to adapt it to our purpose. `Time_measures.m` function has been created to perform the time ranges calculation, whose workflow is shown in ***Figure 2***.

The function has two inputs, a multilead ECG and its sampling frequency (fs), and four outputs; three of them are time measures belonging to the segments of the PQRST complex, and a warning message.

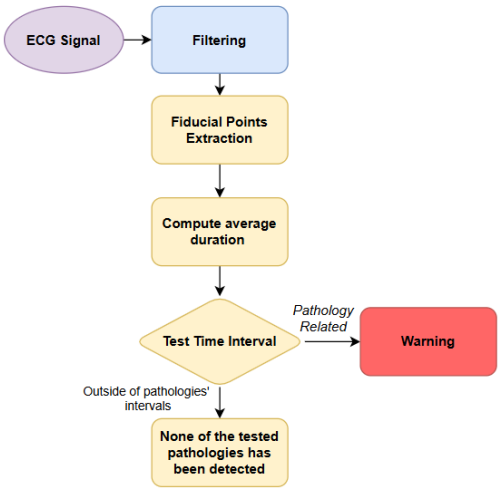

***Figure 2**. Algorithm workflow of Time_measures.m*

ECG signals are obtained from the **MIT-BIH Arrhythmia Database**, freely available on PhysioNet [4.4]. It is a collection from the Beth Israel Hospital Arrhythmia Laboratory (1975-1979) and the database contains 23 recordings (numbered 100 to 124, with some numbers missing) randomly selected from this set and 25 recordings (numbered 200 to 234, again with some numbers missing) selected from the same set. The subjects were 25 men, ages 32 to 89, and 22 women, ages 23 to 89. In most recordings the upper signal is a modified limb branch II (MLII) and the lower signal is usually a modified V1 derivation, obtained by placing the electrodes on the chest. The records were digitized with a sampling frequency of 360 Hz [2.3]. WFDB toolbox has been exploited to convert the signal belonging to the Physionet Bank into a **.mat** file and a **.hea** text file containing the annotation of the record. The .mat file shows a number of column that is equal to the number of samples in the input record. After the signal has been processed, the fiducial point are annotated. Starting with the detection of the FPs of the R peak, as the one with the highest amplitude within the bounds of the QRS interval, a visual proof as the one in ***Figure 3*** is obtained. The distance between adjacent markers is computed, turned in seconds and then averaged with the trimmeand command, setting a 10% cut percentage to avoid considering outliers.

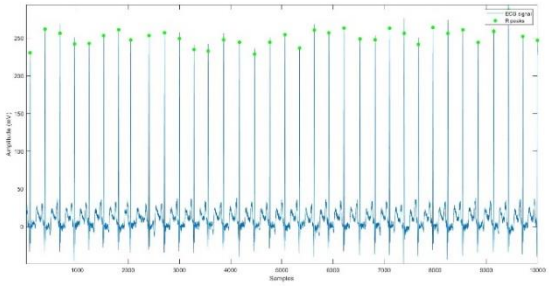

***Figure 3.** Fiducial Points belonging to the R peaks of the QRS complex of the record n100*

A similar process is performed to define the FPs of the QRS complex. Referring to [2.2], Q and S peaks are marked, respectively, at minimum amplitude in the QRS onset to R-peak and R-peak to QRS offset regions. The onset and offset of the QRS complex are 20 ms before the Q peak and 20 ms after the S peak. The FPs distance is calculated and averaged. The PR interval is defined as the distance between the first FP of the QRS complex and the first FP that marks the P wave. Time intervals are tested by computing several *if* controls to check wheter the intervals fell whitin the pathologies ranges defined in ***Table 2***.

4. Results

Testing all the ECG signals belonging to the MIT-BIH Arrhythmia Database with the `time_measures.m` function, the algorithm was able to identify some of the listed pathologies and the results have been saved in the `test.m` matfiles. The relevant results are listed in ***Table 3*** and some of the them are commented below.

The record n113 pathologies' detection is linked to the elongation of both QRS complex and RR interval. Consistently to the 113.hea annotation, there's a variation of the normal sinus rythm, detected by the elongation of the RR interval. Comparing ***Figure 3,*** belonging to record n100 with a HR in the normal range, and ***Figure 4***, a lower number of R peaks is detected. An opposite behaviour is shown in the record n213 with a tachycardia risk: ***Figure 5*** shows a higher number of R peaks compared to ***Figure 3***.

n. record	*PR*	*QRS*	*RR*	*Message*
113	0.182 s	0.119 s	0.55 s	'Risk of incomplete LBBB.'/ 'Abnormal RR interval: risk of bradycardia.'
118	0.128 s	0.146 s	0.792 s	'Risk of LBBB or RBBB.'
207	0.227 s	0.177 s	0.837 s	Risk of first-degree AV block with wide QRS complex.'/'Risk of LBBB or RBBB.'
212	0.146 s	0.112s	0.655 s	'Risk of incomplete RBBB.'
213	0.182 s	0.119 s	0.55 s	Abnormal RR interval: risk of tachycardia.'/'Risk of incomplete RBBB.'
232	0.22 s	0.116 s	0.90 s	Risk of first-degree AV block.'/'Risk of incomplete RBBB.'

***Table 3.** Results*

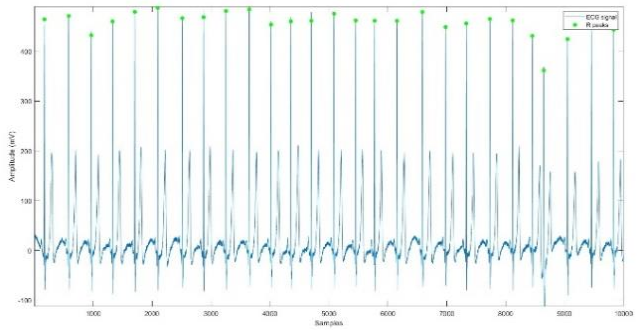

Figure 4. *Fiducial Points belonging to the R peaks of the QRS complex of the record n113*

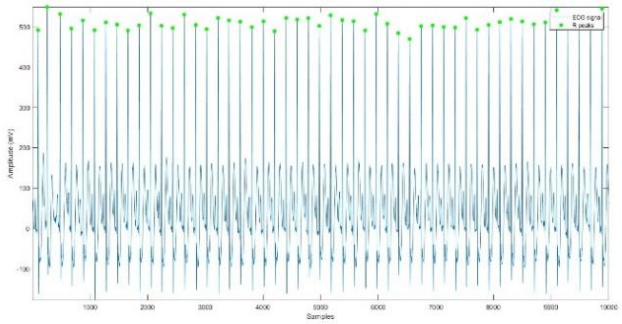

Figure 4. *Fiducial Points belonging to the R peaks of the QRS complex of the record n213*

Regarding the QRS complex variation, record n118 is provided as an example. A risk of LBBB or RBBB is displayed and looking at the algorithm's plot, an abnormal R peaks' detection is obtained. According to [2.2], the R peaks are recorded at the highest amplitude position within the limits of the QRS complex, but regarding this record, the S wave has the highest amplitude. A prominent S wave characterises these pathologies [4.5], expecially regarding RBBB. This behaviour is riflected in an incorrect marking of the FPs of the QRS complex.

When running the algorithm the warning of an incomplete RBBB and LBBB is often shown mostly because the QRS duration limits are really close to the QRS normal ranges.

5. Bitalino & OpenSignals

The algorithm has been also tested using in-house signals. BITalino, a computer board designed to acquire physiological signals, has been connected to OpenSignal, a software that is able to visualize and record real-time data from BITalino. To acquire the ECG signals, a three-electrode connector is used and connected to the A2 BITalino port. Once the signal is acquired, the .edf file, belonging to OpenSignals, is converted in .mat format and loaded to test the algorithm through the `time_measures.m` function.

5.1. Results with BITalino & OpenSignals

The signal acquired via BITalino is tested and the results are shown in ***Figure 6*** and ***Figure 7***; the FPs are correctly detected and the following time ranges are measured: PR value is 0.172 s, QRS value is 0.107 s and RR value is 0.868 s. No pathologies has been detected as all the values are in the healthy range, except for an incomplete LBBB warning, but as already mentioned, this is probably due to the fact that the time ranges are very close.

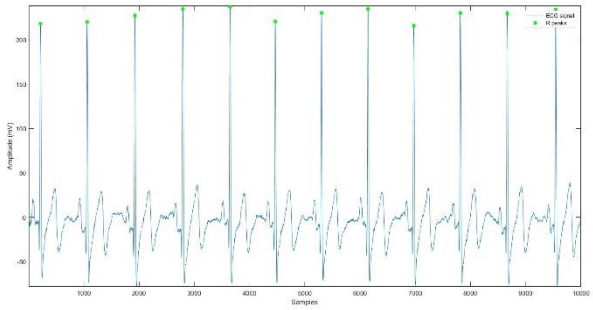

Figure 6. *Fiducial Points belonging to the R peaks of the QRS complex of the record obtained using BITalino*

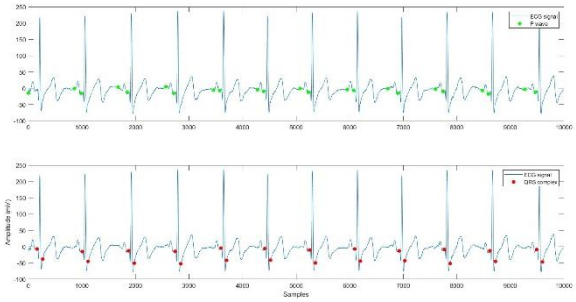

Figure 7. *Fiducial Points belonging to the P wave (above) and to the QRS complex (below) of the record obtained using BITalino*

References

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