ECG2HRV: A NEW TOOL FOR THE RESEARCH IN HEART RATE VARIABILITY

PROYECTO DE SISTEMAS INFORMÁTICOS

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Project report

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Special Regards

En el estudio no existe la saciedad
Erasmo de Rotterdam (1469-1536)

Intelligence is the ability of sorting and interlacing all acquired knowledge and possible resources, in order to efficiently solve problems that may arise during our lives. Education is the cornerstone of such process; each learned concept entails a new tool to solve such matters.

Firstly, I want to aknowledge all the time, effort, and support that my parents have brought me during these past years. In second place I would like to thank the Complutense University of Madrid (UCM) for offering me the opportunity to improve the tools I am able to use today, as well as to bring me the chance to learn similar contents from different points of view thanks to study abroad scholarships. The year I studied at Bordeaux (France), made my curiosity bloom to learn from other cultures and their methods. It was not until this year when I studied in the University of Oklahoma that my brain developed a research way of thinking. Without that cultural exchange I would probably had not even thought about building something like this project or other I am working on, but thanks to that European scholarship, I was able to adapt to a different University system and blend it with the Spanish one in order to get best of both.

I hope that this kind of opportunities will never disappear from the educational budget of Spain or any other country. If they are given to students with thirst of knowledge, they will make those seeds grow along with the prosperity of the nation.

To finish, I would like to credit my directors Dr John and Dr. Hidalgo for their guidance an continuous help in this project.

Education is the most powerful weapon
which you can use to change the world.

Nelson Mandela

Abstract

Man is a tool-using animal. Without tools he is nothing, with tools he is all.

Thomas Carlyle

Heart Rate Variability (HRV) is a non invasive and simple source of markers that have been proved to be clinically relevant in studies to predict patient evolution like survival after Myocardial Infarction (Buccelletti et al., 2009) and classification of others like Diabetic Neuropathy (Pagani, 2000). Furthermore, Medicine is not the only field it has being applied. Transition from one emotional state like happiness to other like sadness have been successfully detected and predicted by correlating various HRV markers (Wu et al., 2010).

Despite all the applications and studies in which HRV has utilized, its usefulness as research tool remains unexploited in many fields in which relations between the investigation and HRV parameter have not been explored. We noticed that there was no software allowing the possibility of storing all ECG recordings in order to make sense of extracted HRV data, and so we have created a tool to encourage researchers to discover new lines of inquiry.

In this report we present the development of a new clinical tool , ECG2HRV, based on personal computing devices. This software allows the user to automatically analyze an electrocardiograph (ECG) for heart rate variability (HRV) and store it in a database along with all the relevant non-demographic patient information. For this purpose we developed a new QRS detection algorithm with low complexity and implemented it in order to give the user a time and frequency domain HRV analysis. A transformation algorithm to resample at 4 Hz, proposed by (Berger et al., 1986), is applied to the time-irregular signal, in order to convert the input to a time-continuous wave that can be now subject of Fourier analysis in the frequency domain.This process is transparent to the user showing only the visual RR detection and HRV report, saving time in this way to the researcher and enabling storage of the results with all the ECG relevant information so that it can be used to cross search groups of patients with certain clinic features.

Key Words

- HRV
- ECG
- ECG2HRV
- HEART
- RATE
- VARIABILITY
- DATABASE
- TIME
- FREQUENCY
- DOMAIN

Resumen

La Variabilidad de la frecuencia cardíaca (VFC) es una fuente de marcadores que ha demostrado una clara relevancia clínica en la predición del Infarto de Miocardio (Buccelletti et al., 2009) y en la clasificación de otras enfermedades tales como el trastorno neuropático (Pagani, 2000). Es mas, la VFC no sólo se emplea únicamente en el campo de la Medicina. Diversos marcadores de la VFC han sido correlacionados satisfactoriamente con diversas transiciones emocionales tales como el paso de la alegría a la tristeza (Wu et al., 2010).

Independientemente de los estudios en los que la VFC ha sido empleada, su potencial como herramienta de investigación está aun por desarrollar y en muchos campos las correlaciones con la VFC permanecen inexploradas. Al darnos cuenta de que no se disponía de software adecuado que permitiera el almacenamiento de registros de Electrocardiogramas (ECG) para poder extraer a partir de ellos datos útiles de VFC, creamos una herramienta que permitiera impulsar a los investigadores hacia nuevas líneas de desarrollo .

En este trabajo, presentamos una nueva herramienta clínica, ECG2HRV, capaz de ejecutarse en cualquier ordenador personal. Este software permite al usuario analizar automáticamente resultados de un ECG parar averiguar la VFC y almacenar la información en una base de datos junto con todos los datos no demográficos relevantes del paciente. Para ello, hemos desarrollado un nuevo algoritmo de detección de los complejos QRS de un ECG de baja complejidad, que permite al usuario obtener un análisis de la VFC en el dominio del tiempo y de la frecuencia. Para efectuar el análisis del espectro de la frecuencia se ha implementado un algoritmo prpuesto por (Berger et al., 1986) que muestrea a 4 Hz la señal irregular en el tiempo transformándola en continua para poder realizar análisis de Fourier. El proceso es transparente para el usuario, de tal forma que muestra únicamente la detección de intervalos RR y el informe de la VFC, ahorrando de esta forma tiempo al investigador. Esto permite también el almacenamiento de los resultados junto con toda la información relevante del ECG, con el fin de que pueda ser utilizada en búsquedas cruzadas de pacientes con determinadas características clínicas.

Palabras Clave

- HRV
- ECG
- EKG
- VFC
- ECG2HRV
- VARIABILIDAD
- FRECUENCIA
- CARDÍACA
- BBDD
- ANALISIS

Contents

Figure Index

Table Index

Chapter 1

Introduction

Abstract: This chapter will introduce the importance of Heart Rate Variability and depict the structure of this document.

1.1. Introduction

ECG is well known to be a marker for various pathologies of the cardiac excitation cycle. When the ECG is collected from multiple leads in the classic 12- lead arrangement, a number of mechanical heart pathologies can also be detected and diagnosed (Geiger, 1939; Einthoven, 1925). More recently, HRV is a secondary parameter that has been extracted from the ECG, which helps differentiate the clinical diagnosis of heart and lung diseases, such as COPD (*Chronic Obstructive Pulmonary Disease*) and CHF (*Congestive Heart Failure*), (Volterrani et al., 1994; Huikuri, 1995). HRV is closely related to the activity of the autonomic branch of the body's central nervous system (Pomeranz et al., 1985), and is also predictive of potential heart rhythm pathologies in elderly patients.

ECG measurement devices have built-in implementation of the HRV parameters, but those values are difficult to extract and relate with a desired ECG time segment. Without this skill, testing any hypothesis using HRV markers based on obtained data, becomes a tedious task that obliterates future research by shadowing data we already have, not allowing the physician to easily correlate that information. In this reality it was our main purpose to prevent looses of that precious content as well as promoting HRV future research.

The second reason that led us to start this task was the fact that many health professionals do not have the required knowledge, time, or experience to extract those values from a raw ECG signal. This application enables any non related signal processing user to import a single lead ECG with any valid sampling frequency as input, and get it filtered, processed, and analyzed by following three simple steps. To ensure user confidence, this procedure is backed up with visual feedback, so that he can guess what is being worked out in the background.

1.2. What is ECG2HRV?

The work presented in this report implements industry-standard measurements of HRV within the construct of a platform-independent utility coded in JAVA that allows the clinician to immediately assess a patient HRV status and store this information along with other relevant clinical features. HRV parameters are computed in both the time domain and the spectral domain based on a five minute, single channel ECG recording. The values are presented to the clinician, as well as the ECG itself, providing an opportunity for the user to override or exclude any part of the ECG determined not acceptable for the analysis. This mobile device-based tool is useful because it supports a new paradigm in clinical diagnosis that joins the power of computer and database analysis helping to work out a differential diagnosis for each patient.

1.3. Who is intended to use ECG2HRV?

If you are a physician or researcher that deals everyday with 5 minutes ECG info, this may be the perfect tool for you. It enables you to safely store all the collected data while maintaining its order. ECG2HRV should not only be used as a data management tool, but also as a source of research ideas or for research itself.

In-built ECG2HRV capacity to automatically detect all the NN intervals, allows to calculate all the HRV parameters with a single click, instantly translating them to a time gain for the user. No more complex programs or software will be needed to get the desired HRV markers. In addition to this comfortable advantage, this software allows to perform different searchs in which any field can be crossed with each other so that ECG groups can be isolated to identify potential research lines, or to select a particular block of patients.

The only requirement this software needs is having a reliable source of ECG measurement. Technology is evolving in this field and many devices are being approved by the FDA (*US Food and Drug Administration*) and can be obtained at a quite reasonable prize, this is, less than 200 $. This new hardware pieces have simplified clinical information gathering by enabling research to move through different paths easily without high budget requirements. Taking safe ECG measurements from patients now becomes as easy as to let them hold a phone with a piece of hardware for five minutes.

Not only researchers are the only sector designated for the use of ECG2HRV, but anyone with access to any of these devices curious enough about HRV and their conditions is also a perfect target. They could even conduct research taking ECG of themselves at different situations and scenarios.

1.4. History example of a potential ECG2HRV user

Paul is a fifty-three years old cardiologist that worked for twenty years diagnosing diverse abnormalities related to heart diseases. He has always dreamed on conducting research on HRV but never had enough evidence of where to start in. After twenty years of work he has realized that there may be a link between Vagus nerve stimulation and improvement in heart rate variability. He came to that hypothesis after taking five minutes ECG recordings from patients that used listening aid devices. His guess is that a small intensity of the electric field generated from this hardware is conducted through Tragus and absorbed by the parasympathetic Vagus nerve. In his observations, patients with reduced high frequency HRV improved their numbers by more than ten times when being tested while using those devices.

Paul had a good guess, and it took him around twenty years of field work to do it so. Can you imagine if he could check if that hypothesis was correct with past twenty year patient data? What is more, can you think of how easy it could be for him to perform a simple search in order to discover if he may be right by comparing all the data he had from all his patients? This functionality may not only lead him to check if an hypothesis may be correct, but to discover new possible research lines by isolating patient groups with certain characteristics associated to each ECG.

ECG2HRV is intended to promote research in Heart Rate Variability by offering the user required tools to store, process, and search HRV for a raw ECG detaching the user from signal processing. If Paul had started using this tool twenty years ago, he would probably had arrive to that intuition or another way before than he did.

1.5. Chapter Structure

This document is structured with the following sections:

- Chapter 2 will define the required concepts to understand what this application does and the physiological proporties that lay behind ECG.
- Chapter 3 explains in detail the algorithms developed to get the industry-standard HRV measurements along with all the process description.
- Chapter 4 spans the end-user manual describing how to use the application. If the reader is not a developper, he will probably only be interested in this section.
- Chapter 5 presents the architecture of the application following the standard UML (*Unified Modeling Language*) notation. This part is conceived for other developpers to diminish the burden of modifying it to include new features.
- Chapter 6 Will disscuss advantages and shortcomings of ECG2HRV.

Chapter 2

Background

One's mind has a way of making itself up in the background, and it suddenly becomes clear what one means to do.

A. C. Benson

Abstract: This chapter will explain the required concepts to understand what concepts and tools are used by the application as well as the relevant physiological information that is attached to them.

2.1. What is an ECG?

From the body's perspective, the heart's function is that of a hydraulic pump, moving blood through the vessels that course through the body. In order to accomplish this, the heart has both mechanical and electrical structures that have important characteristics related to health and illness.

The heart consists of four chambers: two upper chambers, left and right atriums, and two lower chambers, right and left ventricles. From a mechanical standpoint, the muscle mass of the two atria contracts when the SA Node first excites the local myocardial tissue. There is a delay point between the upper and lower chambers called the AV Node. This node delays the electrical excitation to ensure that the atria fully contract and fully charge the ventricles with blood. Subsequently, the electrical signal travels down two major bundle branches through the center wall of the heart (called the ventricular septum). These bundle branches are insulated so that the electrical signal does not excite local septum myocardium. As the fibers reach the tip (called the apex) of the heart, they exit the insulating sleeves and electrically excite the ventricular muscle mass.

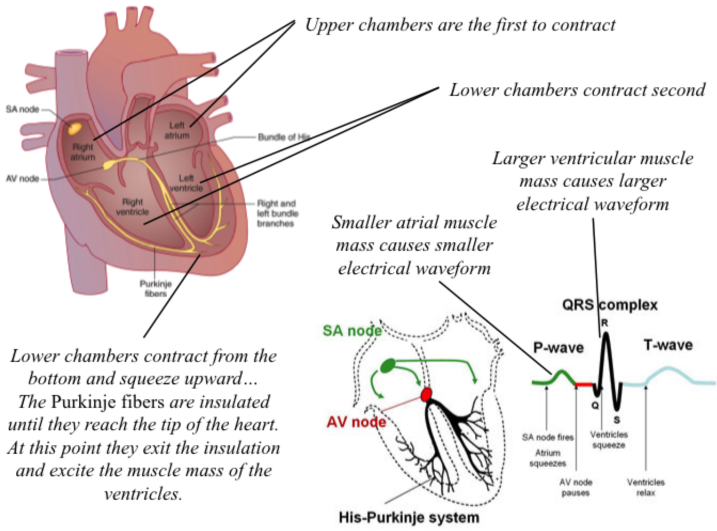

Figure 2.1: The graphic on the upper left shows the outer structure of the heart, for anatomical reference, with part of the heart wall cut away to show the location of the electrical fibers. The graphic on the lower right is a schematic of the activation sequence for these fibers and their electrical manifestation on the body surface.

Excitation wave starts at the apex and moves up towards the upper part of the ventricles. In this fashion, the ventricles squeeze the blood out into the body. The key to ensure that the atria and ventricles operate in the proper sequence, and with appropriate timing, is the electrical system of fibers in the heart. But, it is the mass of contractile muscle tissue that produces the electrical signal that can be recorded from the body surface. The body surface recording of the cardiac electrical signal is the electrocardiogram, often referred to as the ECG.

2.2. What is an RR interval?

The time lapsed from one QRS complex to the next is called RR interval. The fiducial mark we have used to determine the QRS complex is the end of the rising edge, this is the R peak, due to its easily recognizable pattern. This duration is measured in miliseconds and can be used to calculate the heart rate frequency. An example is shown below in 2.2

An special case of RR interval is the normal-to-normal Interval or NN Interval. Synus RR intervals whose neighbours follow synus rhytm too, are considered to be Normal. Only normal intervals are taken into account to calculate the Heart Rate Variability of the pacient; the remaining beats are discarded.

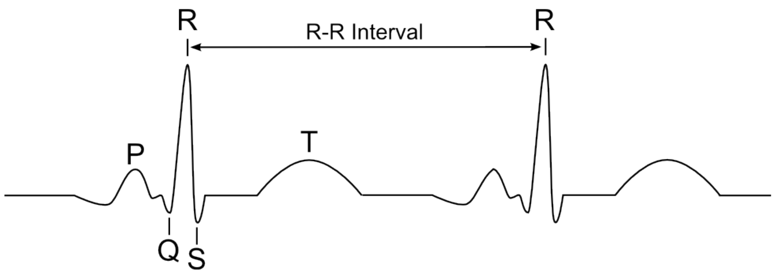

Figure 2.2: Example of RR-interval

2.3. What is HRV?

The change in duration between NN intervals due to physiological factors is called Heart Rate Variability. In 1996 the European Society of Cardiology along with the North American Society of Pacing and Electrophysiology standarized the 5 minutes and 24 hours ECG recording markers for HRV, in order to prevent incorrect conclusions from excessive or unfounded extrapolations of such measures.

There are several domains when it comes to HRV, each of them with its own marker. In this project we only consider 5 minutes ECG recordings. The time domain markers are shown in Table 3.1 and the frequency domain domain markers are at Table 3.2

In the next chapter...

Once we have explained the required concepts, we will proceed to explain how we filter the signal to remove artifact, process it to detect R-peaks, and describe the transformations required to perform PSD (*Power Spectral Density*) of the series of NN intervals to obtain all HRV parameters.

Chapter 3

Signal Processing

The process of scientific discovery is, in effect, a continual flight from wonder.

Albert Einstein

Abstract: This chapter describes the process that was developed in order to get HRV analysis from a single lead ECG raw signal at any sampling rate.

3.1. Process overview

This procedure can be divided into the following subsequent tasks:

- *Filtering* the signal to remove artifact.
- *Preprocessing* the filtered signal for the next step.
- *Detecting NN intervals* disregarding abnormal ones.
- Convert irregular time function of intervals to a regular *continuous* output.
- Calculate *time domain* HRV parameters.
- Calculate *frequency domain* HRV parameters.

3.2. Filtering Process

ECG signal can be misinterpreted due to different kind of *artifacts*. Removing them to get a clearer signal is vital to get neat results. The main artifact sources of ECG are:

- *AC interference*: Alternating Current is the power source used for all electronic equipment can cause the signal to look like thick and "hairy".

- *Baseline Wonder*: When the isoelectric line changes its position, a roller coaster like behavior is observer in the output, changing the level that is considered to be the ground. This interference usually is the low frequency band of the ECG

- *Muscle artifact*: Movement of the muscles generate electric impulses that are recorded by the leads and can obscure ECG output. When muscle tremors occurs, continuous random values are passed to the leads making sometimes the signal unintelligible.

To remove most of the artifacts described above we followed part of the process proposed at (Pan y Tompkins, 1985) with some modifications. They propossed a bandpass filter composed by a high pass andd low pass sequential filtering process. Instead, we used a butterworth filter of 6th order to allow only frequencies in the range of 2-20 Hz. This procedure gets rid of two artifacts: baseline wondering dissapears because it is below the low cut frequency, and AC interference of 50 or 60 HZ gets removed too from the output because of the fact that it exceed he high cut-off frequency. Muscle artifact is removed at high frequencies, but random generated tremors that lay in the frequency of 2-20 Hz can not be separated from the original signal.

Not all artifact can be removed, ECG segments can be targeted by unexpected patient movements, lead misplacements, or muscle tremors. Even though, the algorithm described later will not count RR intervals that are not considered as normals, which solves this issue.

The filter was implemented in JAVA using an Infinite Impulse Response (IIR) algorithm shown in formula 3.1, where P is the filter order,b_i are the numerator filter coefficients, a_i are the denominator filter coefficients, *x[n]* is the input signal, and *y[n]* is the output signal. The coefficients for a and b where calculated using Matlab©and stored staticaly in te source code.

To remove the delay from the filter, the output of the bandpass IIR Butterworth filter was reversed, then filtered again with the same parameters, and reversed again.

Figure 3.1(a) shows the filtered ECG signal. Note that the AC artifact that made the signal go up and down at high frequencies is removed as well as baseline wonder. Now we can fully apreciate all the features of the ECG: *P-wave* at the beggining, *QRS complex* in the middle, and *T-wave* at the end of each beat.

$$y[n] = \frac{1}{a_0} * \left[\sum_{0 \le i \le P} b_i x[n-i] - \sum_{1 \le j \le P} b_j x[n-j] \right] \tag{3.1}$$

3.3. Preprocessing Filtered Signal

The second part of this process consists in creating an integrated moving average window. The size of the window has to be wide enough to create hill-like waves as shown in Figure 2 (c), but not as big as to merge R peak and T waves. A default size of $0,2 * F_s$ (Sampling Frequency), as suggested in **??**, ensures optimality based on all the empirical tests that were made. The results for this processing are shown for a three QRS complex example illustrated in Figure 3.1(c).

The last step of the preprocessing part is to derivate the output of the moving average window. A single and not computationally expensive algorith was used based on formula 3.2. The purpose of this last part is to detect the rising and the falling edge of the hill so that pattern can be recognized in the following step. The output of this part is shown in Figure 3.1(d).

$$y[n] = y[n+1] - y[n] \tag{3.2}$$

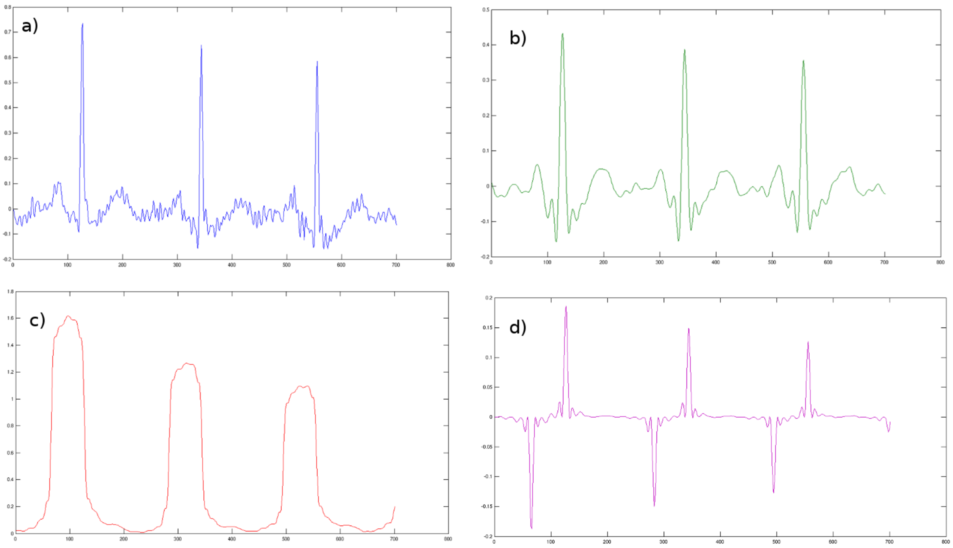

Figure 3.1: ECG Preprocessing: a) Original ECG. b) ECG after bandpass filter. c) Bandpass filter output after applying the moving integration window. d) Differentiation from the moving integration window.

3.4. NN-Interval Detection

Differentiated signal allowed us to recognize the QRS complex with the unique feature described above, but it is not enough to create a simple decision maker in some case scenarios like abnormal QRS due to heart diseases or very noisy segments. These situations prompted us to develop a NN-Interval detection algorithm.

The approach is to find the first biggest valley within time threshold THRESHOLD1, then detect if there exists a peak within a second time threshold THRESHOLD2 that meets the requirements; these are, being a peak with one of the highest heights in the differentiated waveform, and having a peak with an acceptable height in the original waveform.

To prevent bigger T-waves to be detected, all data from last positive QRS detection to 200 ms later is not used, given that it is physiologically impossible to have another QRS in such small time lapse.

To classify the different type of RR intervals, we chose to implement the same approach used in [6]. We have a NN-Average calculated with the last eight valid and normal beats and another RR-Average of the last eight beats. A beat is considered to be normal if its duration exceeds 0.92*NN-Average but do not surpass 1.16*NN-Average. All intervals that lay out of normality are disregarded. If last eight RR detections are normal then NN-Average becomes RR-Average 2.

A last threshold THRESHOLD3 was used for the differentiated input to prevent small valleys originated from noise or other sources from being detected as possible beats. This value is initialized with the first detections and is updated with the average value of the last eight positive R peaks. A simple check is used to detect if it is a valid candidate for R peak: if the current valley exceeds k*THRESHOLD3 then the algorithm checks that possible R peak; if not, it skips that value.

3.5. Time Domain HRV Parameters

The selected time domain HRV parameters are displayed in Table 3.1. The values are calculated from the NN-interval output explained before.

3.6. Frequency HRV Parameters

To obtain frequency domain parameters, a more complicated process is required. The NN-interval function is composed of a succession of time values

Variable	Units	Statistical measures
SDNN	ms	Standard deviation of all NN intervals.
SDANN	ms	Standard deviation of the averages of NN intervals in all 5 min segments of the entire recording
RMSSD	ms	The square root of the mean of the sum of the squares of differences between adjacent NN intervals.
SDNN index	ms	Mean of the standard deviations of all NN intervals for all 5 min segments of the entire recording
SDSD	ms	Standard deviation of differences between adjacent NN intervals.
NN50 count	ms	Number of pairs of adjacent NN intervals differing by more than 50 ms in the entire recording. Three variants are possible counting all such NN intervals pairs or only pairs in which the first or the second interval is longer.
pNN50	%	NN50 count divided by the total number of all NN intervals.

Table 3.1: Selected time-domain measures for HRV from Camm et al. (1996)

associated with a duration. These values are not equally distributed along time axis. That is the reason to need to re-sampling data at a rate that will not miss any beat.

For the re-sampling process we used a linear interpolation approach with a sampling rate of 4 Hz (Berger et al., 1986). The fact that it is physiologically impossible to have a beat with length smaller than than 0.25 seconds ensures that there is no NN-interval value missed.

The re-sampling values depend on which NN-intervals are comprised between its current values and the next. If all the NN interval is inside that 500 ms time span, then the value of the NN interval is taken. On the other hand, if the time span contains two segments of different NN intervals, a linear interpolation with a window size of 500 ms is made to calculate each re-sampling point. Figure 3.2 shows an example of how the process works obtained from (Berger et al., 1986).

Now we have an evenly time-spaced signal whose spectrum can be easily recognized by using FT (*Fourier Transform*). For this purpose we decided to compute the FT by using a FFT (*Fast Fourier Transform*) algorithm implemented by the library Eichelberger y Ii (2002). The power spectrum is extracted from the FFT output and added to get the parameters displayed on Table 3.2.

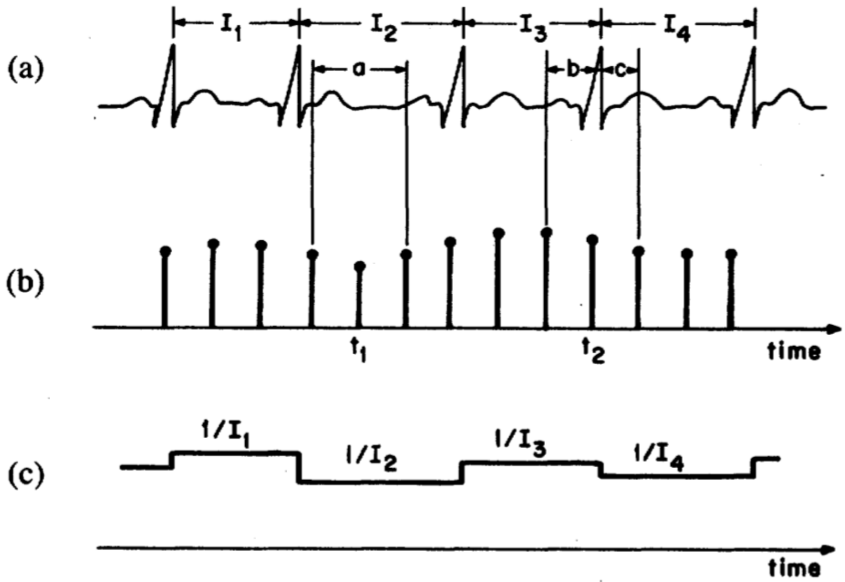

Figure 3.2: Figure extracted from Berger et al. (1986) (b) The heart rate samples corresponding to the ECG signal in (a), determined using our algorithm.The number of RR intervals within the local window centered at t, is a/I2, and at t2 is b/I3 + C/I4. The value of the heart rate at each sample point is taken to be the number of intervals that fell within the local window centered at that point divided by the width of the window, as described in the text. (c) The corresponding instantaneous heart rate signal. The value held during each interval is the reciprocal of the duration of that interval. The sample values in (b) are equivalent to those of the signal that would result from convolution of the signal in (c) with a rectangular window that is two sample intervals wide.

Variable	**Units**	**Description**	**Frequency range**
total spectrum power	ms^2	Power in all spectrum	<= 0.4 Hz
VLF	ms^2	Power in very low frequency range	<= 0.04 Hz
LF	ms^2	Power in low frequency range	0.04-0.15 Hz
LF norm	n.u.	LF power in normalised units LF/(Total Power-VLF) x 100	
HF	ms^2	Power in low frequency range	0.15-0.4 Hz
HF norm	n.u.	HF power in normalised units HF/(Total Power-VLF) x 100	
HF /LF		Ratio LF [ms2]/HF [ms2]	

Table 3.2: Selected frequency-domain measures for HRV from Camm et al. (1996)

In the next chapter...

In this sections we have explained the process in which the HRV parameters is calculated so that the user can verify that the output ECG2HRV is giving is correct.

The next chapter contains a guide detailing the program functions with visual reference so that the end user can check if he has any questions on its use..

Chapter 4

ECG2HRV User Guide

It is my fervent wish and my greatest ambition to leave a work with a few useful instructions for the pianists after me.

Franz Liszt

Abstract: This chapter will present ECG2HRV different functionalities and will detail those features. This section is intended to be read by new users or individuals with questions about a particular characteristic of the application.

4.1. System Requirements

ECG2HRV is a desktop cross-platform application that can run in different software architectures like Windows©,Mac©, an any Linux-GNU distribution if they have JAVA© virtual machine installed. This feature frees the user from being forced to use a particular operating sysem which may be unfamiliar for him.

This application is not intended to run on mobile phones and it will probably not work properly on any of those even if they are JAVA© enabled. The visual interface was build with a default desktop screen size.

If your operating system does not have JAVA installed, the required files can be downloaded and isntalled from Oracle webpage.

To install ECG2HRV simply download the zip file and extract its content to the desired isntallation folder. Do not touch any of the contents of that folder. If desired, a shortcut can be created to ECG2HRV.jar.

Regarding the execution of the program, right click on ECG2HRV.jar or its shortcut and right click it, then select your installed JVM (Java Virtual Machine). After a few seconds the program will start.

4.2. First Run

The first time the program is executed will be like the rest. Run the program as described in 4.1, a window like the picture shown in Figure 4.1 will appear. To access in the Login dialog, introduce the default password:

myPassword

We strongly reccomend selecting Utilities in the Main Menu and the click on change password option, in order to prevent malicius users fron accessing any of the future contents that the database will have

There is nothing more that is required to be done differently than the rest of the runs. Now you are ready to start ECG insertion.

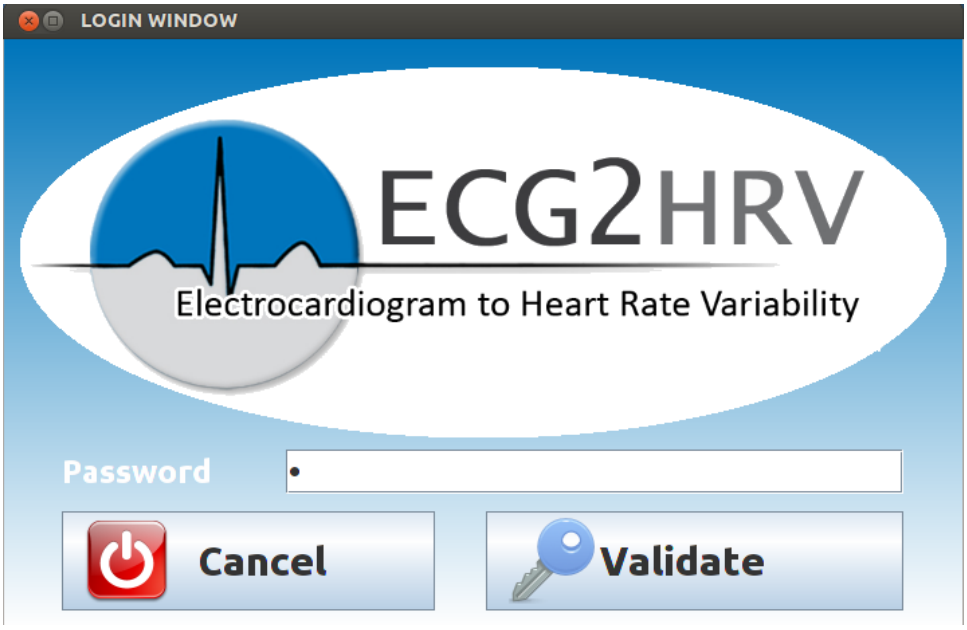

Figure 4.1: Login Dialog Frame

4.3. ECG Insertion

Once the user has logged in, he will be able to insert new ECGs to the database by selecting *Insert ECG* option in the main menu. Then, a screen like depicted in Figure 4.2 will be shown.

Figure 4.2: Insert ECG Frame

In this window, we will be able to associate all relevant information of the patient to the ECG entry without giving away any important demographic details. This prevents any intruder, if he was able to decrypt and access database data, to match any of the recorded information to the physical patient. The options we thought that were relevant are shown in the window. None of the options are mandatory except for the data of the ECG itself. To add a new ECG the import process must be successful. Below a more detailed explanation of the meaning for each field is shown:

- *Gender*: If the patient is Male or Female.
- *Age*: Age of the patient when the ECG was recorded. If it is unknown set it to -1.
- *Date*: Date the ECG was recorded. Its default value is the current day. If it is not known you can click on it and then select *none*.
- *Heart Failure*: Select the value if the patient has suffered of a heart

failure following NYHA (*New York Heart Association Functional Classification*) Classification.

- *Mitral Valve Prolapse*: Select if the patient suffers from this disease and pick its degree between Mild, Modere, or Severe. If it does not have MVP or it is not know leave selected NONE.
- *Smoker*: Check if the patient is a smoker.
- *Caffeine*: Check if the patient has ingested caffeine in the past 24 hours.
- *Alcohol*: Check if the patient has ingested alcohol in the past 12 hours.
- *Sport*: Check if the patient has practised sport in the past 24 hours.
- *Sinus*: Check if the ECG is mostly following Sinus Rhytm.
- *Cardiomyopathy*: Check if the patient suffers from a known cardiomyopathy.
- *Hypertension*: Check if the patient suffers from uncontrolled hypertesion.
- *Vaso-Vagal*: Check if the patient suffers from recurrent vaso-vagal syncopal episodes that made him faint.
- *Depression*: Check if the patient suffers a depression that is not being currently under treatment.
- *Diabetic neuropathy*: Check if the patient has received a diagnosis of a diabetic neuropathy.
- *Myocardial infarction*: Check if the patient has experienced a myocardial infarction in the last year.
- ***Keywords***: This part will allow you to associate any other feature that is not in the ones introduced above so that the researcher does not loose any relevant information he may want to attach to each inserted ECG If the word is not on the database, click on the green cross and a new dialog will allow you to add the desired keywords with a small description. Then you will be able to relate any new ECG to that keyword. Removing any keyword from the database is possible, but doing so will also delete any relationship between any other ECG to that keyword.

To import an ECG, you need to have the data in a (CSV (*Comma Separated Values*)) file using the following format: each value will represent the voltage output for the ECG at the specified time position. The time will be recreated with the sampling frequency (F_s). Once the data follows the restricted format, click on the folder button and select the file location. ITs contents will be loaded and ready to be stored at the database.

When all the desired inputs are filled and the ECG has been succesfully loaded, the user will be able to save and insert a new one or to detect the RR intervals in order to perform the HRV analysis. If the user decides not to perform RR analysis, this option will be available selecting in the search mode the ECG and clicking on RR analysis. Note that a specific ECG can be hard to distinguish from others except for its identification number, so we strongly reccomend detecting the RR intervals and subsequent HRV analysis right after the ECG insertion. In this way, HRV parameter will be stored along with the ECG data and related information.

There are two more options we have not mentiones yet: Reset fields and Main menu. The first one will roll back all fields to its default value while the second one will return to the last menu without saving any changes made to the information.

4.4. ECG Search

Once the user has logged in, he will be able to search any of the inserted ECGS by selecting *Search ECG* option in the main menu; then a window like shown in Figure Figure 4.3 will be displayed.

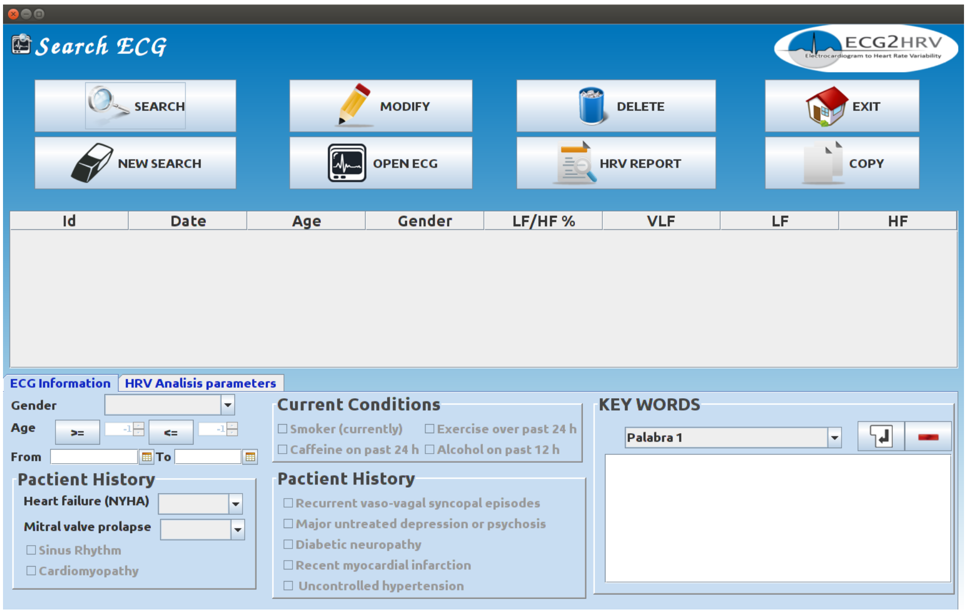

Figure 4.3: Search ECG Frame

In the frame we can observe a top panel, where all the possible actions are displayed, a white table where search results will be displayed, and a tabbed panel with filtering options for the search. The first one allows the following actions:

- *Search*: Perform the search on the database using as filter the currently selected options. If nothing is in the filter, the full database will be displayed.
- *New Search*: Selecting this action will reset all the search parameters to its default value and erase previous results.
- *Modify*: If a search has been performed, and an ECG has been selected in the table, this will show a frame that will let the user modify any of the chosen ECG properties.
- *Open ECG*: As with *modify*, if a search has been performed, and an ECG has been selected in the table, a new window will appear displaying the stored signal and the NN intervals. In case the NN intervals were not detected before, an automatic process will do it.
- *Delete*: This will delete the currently selected ECG on the table from the database.
- *HRV Report*: This click will show detailed information of the HRV parameters for the selected ECG in the table. If no NN detection was made for this record, RR detection will be performed and shown to the user.
- *Exit*: This action will close Search Frame and show again the main menu.
- *HRV Report*: This option will allow the user to export the results of the search along with all the ECG properties, except for the ECG data, to a CSV file.

The middle table can be reordered by clicking on any of the headers. It also allows selection of any of the visible rows so that operations like *modify* or HRV report generation can be done on that chosen record.

The tabbed panel at the bottom allows the user to filter the search by changing any of the fields. Every field is deactivated by default so that the search has no filters. To enable a particular field just click on it and set its value. If it is an input field like age, click on the button on its left to activate or deactivate it. To set HRV analysis parameter filtering click on the *HRV Analysis parameter* tab and set the desired values. All changed properties will be included for the search. This means that all fields that haven't got its default value will be concatenated in the search with conjunctive condition (AND) except for the keywords, which follow disjunction (OR) logic.

4.5. RR Detection

When inserting an ECG or after a search, the user can select the option to view RR intervals. A window like the one shown at Figure 4.4 will appear.

The window is composed by a top option panel and a Graph displaying selected ECG data and the obtained RR intervals. The upper panel allows the following options:

- *Previous Misdetection*: Clicking this action will navigate through the graph to display the previous miss-detection or ectopic beat.
- *Next Misdetection*: Same as the option above but showing the next one.
- *Save Changes*: Use this button to store in the database the changes made to the NN detection.
- *Reset RR detection*: This procedure runs the default RR-detection algorithm disregarding any performed modifications. The data will not saved until Save button is clicked.
- *HRV report*: Shows the HRV report for current NN intervals.
- *Rollback*: RR intervals will be reseted to las stored value on the database.
- *Back*: Returns to the search frame.

The graph under the top panel allows visualizing ECG's RR and NN intervals overlaying its signal using red and green rectangles with its duration as height value. Modification of the beginning and end of the intervals is allowed by clicking on the desired R peak and dragging it to the new position. If the dragging process ends near another RR interval, the selected peak will disappear. Clicking on a segment far enough from any R-peak will create a new R-peak detection where the user releases the mouse if it is in between the previous and the next R-peak and far enough from both.

After doing any changes, do not forget to press on save in order to permanently store the modified detections.

4.6. HRV analysis

Once the user has logged in, he will be able to search any of the inserted ECGs by selecting *Search ECG* option in the main menu; then a window like the one shown in Figure 4.5 will be displayed.

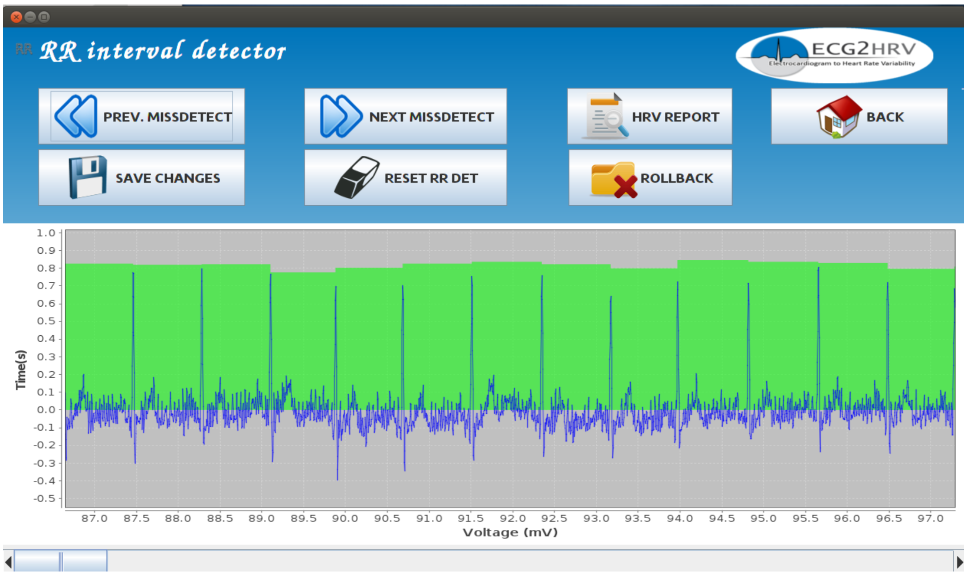

Figure 4.4: RR detection Frame

HRV Analysis window displays the results obtained from the process described in Chapter 3. The power spectrum density is shown on the top left chart while the LF to HF ratio is on the bottom left one. Time domain results and frequency domain parameters are displayed on the right side of the window.

4.7. Utilities

Some database options are available through the *Utilities* option of the main menu. A window like the one illustrated in Figure 4.6 will be displayed. Two options are available: Change passwod and Compact database.

4.7.1. Change password

This option permits the user to set a password of his choice. We strongly recommend to do this after the installation or wherever the integrity of such key is not ensured. A window like displayed in Figure 4.7 will appear in the screen.

4.7.2. Compact database

After several modifications or deletions database size may increase considerably. This option will compress the information to reduce the size that is occupied by that information. It is recommended to do it from time to

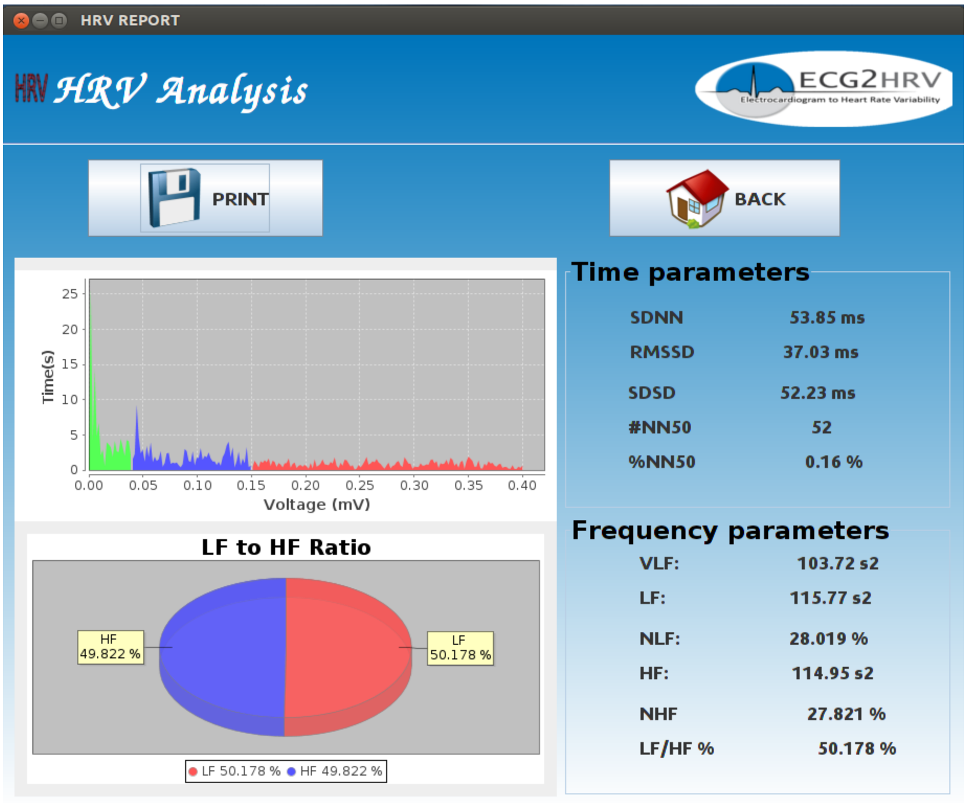

Figure 4.5: HRV Analysis Frame

time or after big database changes. It does not take a long time to execute and it may improve its integrity.

In the next chapter. . .

This chapter may be useful for users of the application, but developers require much more information than a simple guide. The next chapter will explain he architecture of the application so that the coder is willing to modify this piece of software byto adding a new feature or improving it, he won't face to a hard task.

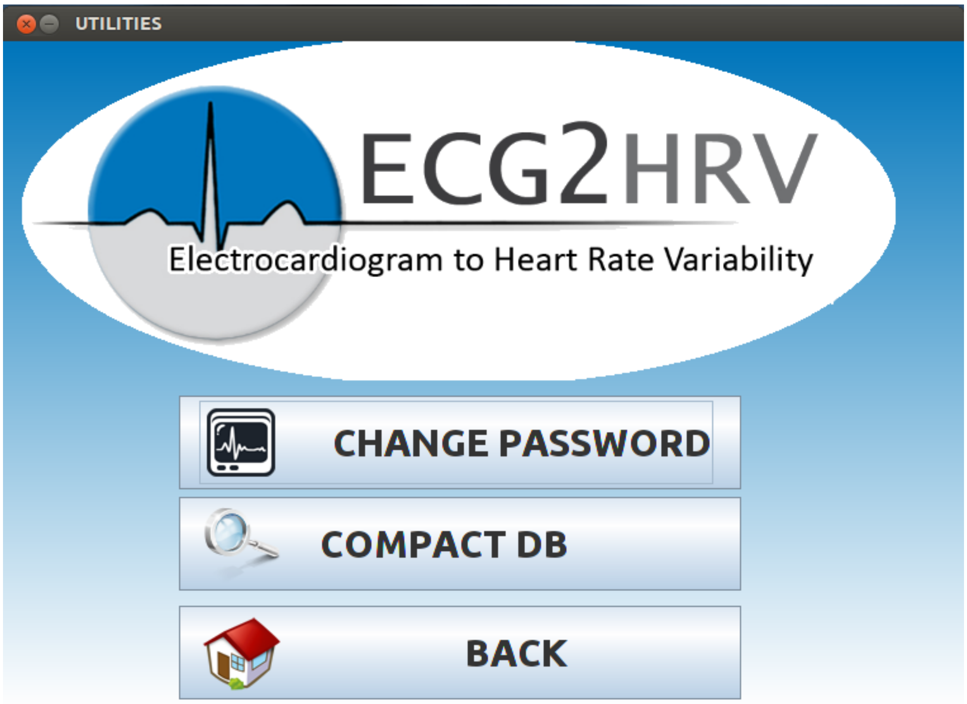

Figure 4.6: Utilities Frame

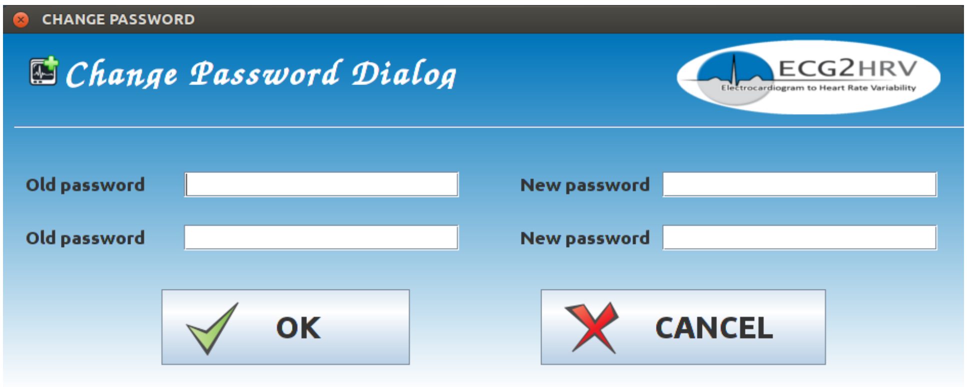

Figure 4.7: Change Password Frame

Chapter 5

Architecture

Structure is one of the things that I always hope will reveal itself to me.

Richard Russo

Abstract: This section will describe the architecture the application has followed and its relations following UML notation and standard diagrams.

5.1. Overview

This chapter is not intended to explain how the project was developed, but to detail its functionalities and inner structure. The purpose is to relieve the difficulty of modifying this program for unknown coders.

First we will introduce the definitions of several concepts that will be used during this section. Then the Use Case section will describe each of the implemented functionalities at a high concept level. Next section will deal with applications's data model and last part will describe ECG2HRV component architecture and the relations that each module has.

5.2. Definitions

5.2.1. Use Case

Fragment of functionality of the system that enables the user to perform an important action in the application. They are detailed in the Use Case Document.

5.2.2. Class Domain

Description of the structure of ojects that the program uses to exchange and store information, as well as their connections, associations, and compositions. It is represented by a Diagram class in UML 2.5.

5.2.3. Architecture

Essential organization of a system, expressed in its components, the relations between them in the application environment and the principles that guide his design and evolution.

5.2.4. Component Diagram

Visual depiction of the relations that a component has with the rest of the architecture using UML 2.5 standards.

5.2.5. Use Case Diagram

Visual depiction of the segmented functionalities of an application following UML 2.5 standards.

5.2.6. Model View Controller

MVC refers to the software architecture pattern that divides the visualization from the control agents and the data model used within the application. This structure separates each component in different parts so that can be reused and easily modified to correct bugs or to integrate new features.

5.3. Use Case Document

This section will explain the functionality of the application dividing each part in Use Cases. The general overview is shown in Figure 5.1. There are two possible actors, a Validated user, this is the one that has already logged in, and the rest. A normal user beccomes validated when successfully inputs the proper identfication.

In general, the application Use Cases allow insertion, modification, search, deletion of the data the applicaiton stores. The second functionality is to permit automatic HRV analysis, which needs NN-Interval detection. We also though that visualization could be useful to gain the trust of the users by showinf them what is being done and included it as requirement.

The following subsections will present each Use Case with more detail. Each part will contain a brief description to explain its functionality and importance, event flow ennumeration, special requirements, preconditions, and postconditions.

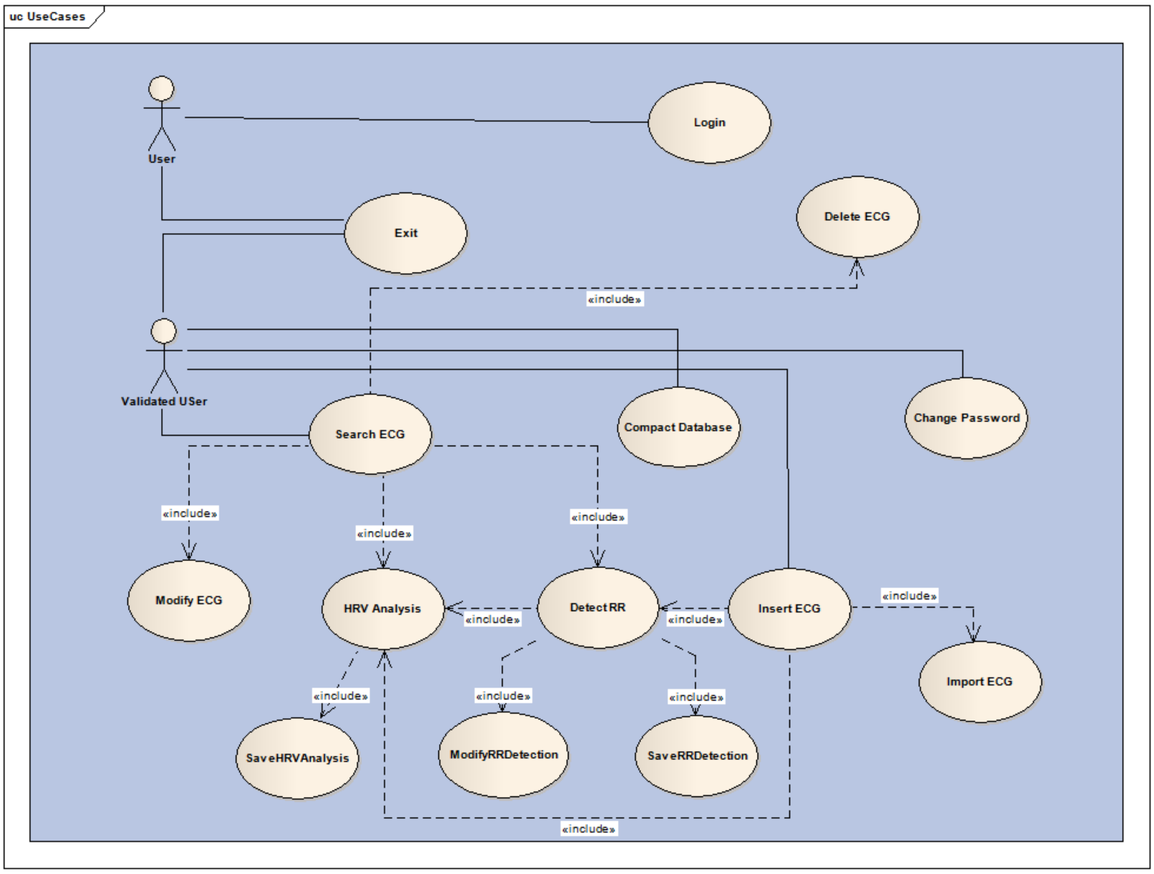

Figure 5.1: Global Use Case diagram

5.3.1. Login

- **Brief Description**: this Use Case encapsulates the functionality required to start the application and make sure that the user is the owner of the data contained in the persistence by validating with a password dialog or other methods. IT is also responsible for starting the required components that will make the application work after its identity success.

- **Event flow ennumeration**:

  1. The application starts and shows an input dialog
  2. The application receives correct input and validates the user

3. The application start the next component to show program options and closes the login dialog.

- **Alternate event flow enumeration**:

  1. The application starts and shows an input dialog
  2. The application receives wrong input and validates the user
  3. If it is not the third try, the application will let the user validate again, if it is the third program will terminate execution.

- **Special requirements**: the user must have Java Virtual Machine installed in order to launch.

- **Preconditions**: User must know the password

- **Postconditions**: If successful, the actor User will mutate to Validated User and start the next module and the database model interface.

5.3.2. Exit

- **Brief Description**: this Use Case describes how to exit and what to do depending upon the actor that requests this feature.

- **Event flow ennumeration**:

  1. User requests exit.
  2. Program closes visualization and terminates.

- **Alternate event flow enumeration**:

  1. Validated User requests exit.
  2. Database gets shut down.
  3. Program closes visualization and terminates.

- **Special requirements**: None.

- **Preconditions**: Application must be running

- **Postconditions**: Application will shut down, memory will be freed, database will be safely closed, and all processes related to ECG2HRV will be terminated.

5.3.3. Search ECG

- **Brief Description**: This Use Case may be the most important feature of the application. It enables multi-field cross related search so that any stored characteristic can be subject to filter the results obtained. This enables Validated User to find potential groups with common markers that may lead to new lines of inquiry. HRV analysis results and ECG associated information will be responsible for the filtering. If the parameter is numeric or it can be ordered in time or quantity, range search with $\geq$ and or $\leq$ will be available.

- **Event flow enumeration**:

  1. Validated User inputs the desired filtering parameters and requests the search
  2. Database performs the search and returns the results
  3. Results are visually displayed and record selection is allowed

- **Alternate event flow enumeration**:

  1. Validated User inputs the desired filtering parameters and requests the search
  2. Database performs the search, but has an error
  3. An error dialog is shown to Validated User with a plausible reason.

- **Special requirements**: None.

- **Preconditions**: Being Validated User, connected to the database, and have a visual interface open to allowing search filtering.

- **Postconditions**: If successful, results for the search will be displayed and the following new options will be available: modify ECG, delete ECG, RR detect, HRV analysis.

5.3.4. Insert ECG

- **Brief Description**: ECG insertion will permit the user to associate an ECG to the desired characteristics. Default properties will be offered to fill, but will not be required. Additionally, key words will b available to create and associate in order to add any other non-static field.

- **Event flow enumeration**:

  1. Visual input is offered to the user
  2. Validated User enters the desired associations with the only requirement of correctly imported ECG data.

3. Validated User decides to save and detect RR intervals.
4. Data is saved, Visualization hides, and RR detection is started.

- **Alternate event flow enumeration**:
  1. Visual input is offered to the user
  2. Validated User enters the desired associations with the only requirement of correctly imported ECG data.
  3. Validated User decides to save and enter a new ECG.
  4. Data is saved, and state transitions to the first.
- **Special requirements**: Visual input methods will be offered to simplify this part of the process.
- **Preconditions**: Being Validated User, connected to the database, and request of the user to insert ECG.
- **Postconditions**: If successful, saves the ECG and offers the next selected option.

5.3.5. Modify ECG

- **Brief Description**: After an ECG has been inserted the data is stored in the database. This feature will enable the user to modify that information using a visual interface.
- **Event flow enumeration**:
  1. Validated User selects an ECG and requests its modification
  2. A new visualization window appears like the one that inserts ECGs but with the values stored in the database.
  3. Validated User changes the desired information and saves.
  4. Data is updated and the selected action, back to search or view RR intervals, is requested.
- **Alternate event flow enumeration**:
  1. Validated User selects an ECG and requests its modification.
  2. A new visualization window appears like the one that inserts ECGs but with the values stored in the database.
  3. User decides to cancel the modifications.
  4. Data is not saved, visualization is closed and the program goes back to the previous window.
- **Special requirements**: Being Validated User.

- **Preconditions**: A uniquely identified ECG that still exists in the Database, and the request of the user to modify it.
- **Postconditions**: If successful, update the database content with the input.

5.3.6. Delete ECG

- **Brief Description**: This feature will enable the permanent removal of any inserted ECG from the database.
- **Event flow enumeration**:
  1. Validated User selects an ECG and requests its deletion.
  2. Its content gets successfully deleted from the persistence.
- **Alternate event flow enumeration**:
  1. Validated User selects an ECG and requests its deletion.
  2. An error message is shown to the user and application continues its run. ECG reamins recorded in dataabse.
- **Special requirements**: Being Validated User
- **Preconditions**: A uniquely identified ECG that still exists in the Database, and the request of the user to delete it.
- **Postconditions**: If successful, deletes the selected ECG from the presistence.

5.3.7. Import ECG

- **Brief Description**: This characteristic will be responsible of importing ECG data from the selected source.
- **Event flow enumeration**:
  1. Validated User selects ECG file data location from any operating system drive disk and inputs sampling rate.
  2. The program verifies the format of the file and imports its data.
- **Alternate event flow enumeration**:
  1. Validated User selects ECG file data location from any operating system drive disk.
  2. The program fails to validate file format.
  3. An error message is shown to Validated User

- **Special requirements**: Being Validated User
- **Preconditions**: Being inserting or modifying an ECG record. Having a CVS file with the required format, this is, sampled voltage values separated by commas and the knowledge of the recording sampling rate.
- **Postconditions**: If successful, adds data content from the file to the current ECG model. Data will not be stored until save Use Case is selected.

5.3.8. DetectRR

- **Brief Description**: This functionality will enable automatic detection of RR-Intervals and its classifications as normal (NN) or not normal.
- **Event flow enumeration**:
  1. Validated User requests RR-interval detection for a particular ECG from Search or new Insert.
  2. The program checks that ECG has no RR-Interval detection stored in database and performs it
  3. RR-detection is saved to the database and displayed andmodification of RR-inervals is called.
- **Alternate event flow enumeration**:
  1. Validated User requests RR-interval detection for a particular ECG from Search or new Insert.
  2. The program checks that ECG has already an RR-Interval detection stored in database
  3. RR-detection is retrieved and ,odification of RR-inervals is called.
- **Special requirements**: Being Validated User
- **Preconditions**: Being inserting or modifying an ECG record. ECG data and Sampling rate is known.
- **Postconditions**: RR detection is made and stored in database if needed. A -ew window is then shown allowing its modification.

5.3.9. Modify RR-detection

- **Brief Description**: This option will offer the required visual tools to modify the detections obtained to correct possible miss detections.
- **Event flow enumeration**:

1. User request RR-interval detection
2. When it is done a new window appears with a chart containing ECG data.
3. User presses the mouse left button near the beginning or the end of an interval inside the chart.
4. RR interval is modified where the user releases the mouse. If the mouse is further away than previous or next RR interval, the R peak disappears and the new RR interval is considered to be from past RR interval to the next.

- **Alternate event flow enumeration**:

1. User request RR-interval detection
2. When it is done a new window appears with a chart containing ECG data.
3. User presses the mouse left button far enough from any interval extreme inside the chart.
4. RR interval is modified where the user releases the mouse. If the mouse is released far enough from previous and next intervals, a new RR interval is created.

- **Special requirements**: Being Validated User
- **Preconditions**: Having an ECG with the RR-interval detection done.
- **Postconditions**: Modificacions on the RR-Interval detection will be stored to the data model. This will not permanently save information, clicking the save RR option will be required.

5.3.10. Save RR-detection

- **Brief Description**: This feature brings the possibility of saving the RR-detection after any modification made.
- **Event flow enumeration**:

1. User request to save RR-interval detection
2. RR detection is saved in the database
3. An information message is displayed to the user saying that it was successfully saved.

- **Alternate event flow enumeration**:

1. User request to save RR-interval detection
2. RR detection fails to be saved in the database

3. An error message is displayed to the user saying what happened.

- **Special requirements**: Being Validated User
- **Preconditions**: Having an ECG with the RR-interval detection done.
- **Postconditions**: Modificacions on the RR-Interval detection will be stored to the database permanently.

5.3.11. HRV Analysis

- **Brief Description**: This is the second most important Use Case of the application. It is responsible for converting the NN-intervals from the RR-detection to HRV parameters in time and frequency domain using the techniques explained in Chaptter 3.
- **Event flow enumeration**:
  1. User request HRV analysis for an already RR-Interval detected ECG
  2. Program runs required algorithms to obtain time and frequency parameters.
  3. Results are displayed with charts and text inside a new a frame
- **Alternate event flow enumeration**:
  1. User request HRV analysis for an ECG without RR-detection made.
  2. RR detection Use Case is executed for that algorithm
- **Special requirements**: Being Validated User
- **Preconditions**: Having an ECG from the database selected.
- **Postconditions**: HRV is done if RR-detection is too.

5.3.12. Save HRV Analysis

- **Brief Description**: This feature allows to store calculated HRV parameters in the database
- **Event flow enumeration**:
  1. HRV analysis is performed on an ECG.
  2. data is saved in the database.
- **Alternate event flow enumeration**:

1. HRV analysis is performed on an ECG.
2. data fails to save in the database.
3. An error message is shown with the reason of failure.

- **Special requirements**: Being Validated User
- **Preconditions**: Having an HRV analysis performed on an ECG stored in the database.
- **Postconditions**: if successful, HRV analysis is associated to the selected ECG permanently.

5.3.13. Change Password

- **Brief Description**: This feature permits to change the current password of encryption and access for the database.
- **Event flow enumeration**:

1. Validated user inputs correct old password and a new alphanumeric chain bigger than eight characters.
2. Database password is changed to the new password

- **Alternate event flow enumeration I**:

1. Validated user inputs incorrect old password and a new alphanumeric chain bigger than eight characters.
2. Database password is not changed and a message is shown

- **Alternate event flow enumeration II**:

1. Validated user inputs correct old password and a new alphanumeric chain bigger than eight characters.
2. Database password fails to change
3. An error message is shown with the reason of failure.

- **Special requirements**: Being Validated User. Having enough memory to remember a new password.
- **Preconditions**: Know the new password
- **Postconditions**: if successful, password is changed

5.3.14. Compact Database

- **Brief Description**: This feature allows to compress the database in order to safe disk space. Persistence may span more size than required after severe changes like modification of ECG data or deletions.

- **Event flow enumeration**:

  1. Validated user requests compression.
  2. Database is compressed
  3. Information dialog is displayed with a message of success.

- **Alternate event flow enumeration** :

  1. Validated user requests compression.
  2. Database fails to compress compressed
  3. Error message is displayed with failure reason.

- **Special requirements**: Being Validated User.

- **Preconditions**: None.

- **Postconditions**: if successful, database size is reduced to its minimum.

5.4. Data Model

Every application uses data storage in order to work. Some static programs rely in volatile memory because they do not require permanent storage, but this is not our case. ECG2HRV needs to record ECG information as well as its signal and other data in the disk so that they can be queried and accessed later.

In first place we will describe the structure that ECG2HRV handles, this is its class domain. In Figure X and Figure Y all the classes and its relations are represented using a class Diagram. The following subsection will explain the use and importance of each illustrated object.

5.4.1. Class Description

- **ChangePassword**: Stores the value of the old and new password in an array of characters so that the contained information can be safely removed after use. Be aware that strings are deleted using JAVA garbage collector and may remain in memory until they are no longer needed and other object overwrites its content.

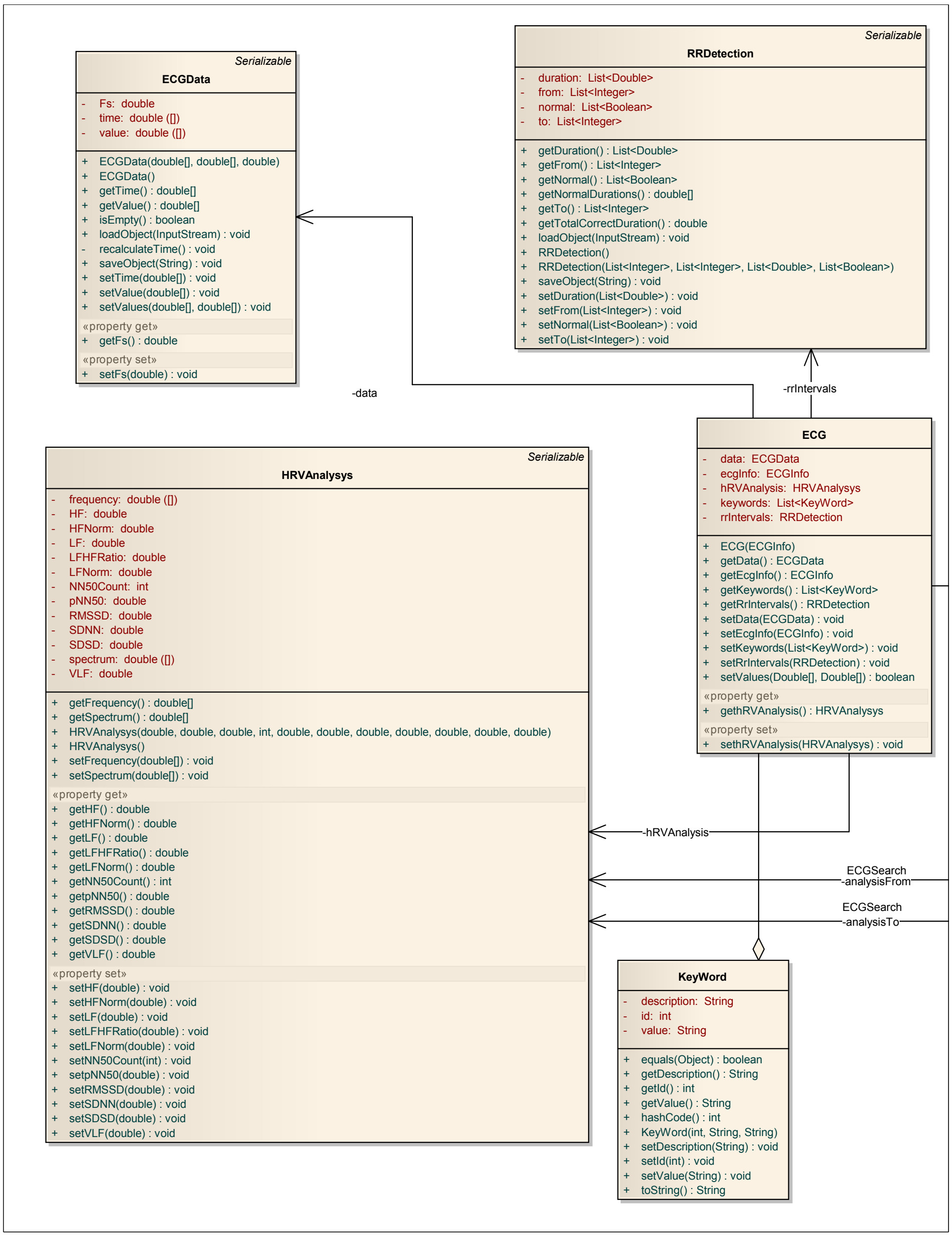

Figure 5.2: Class Domain First part

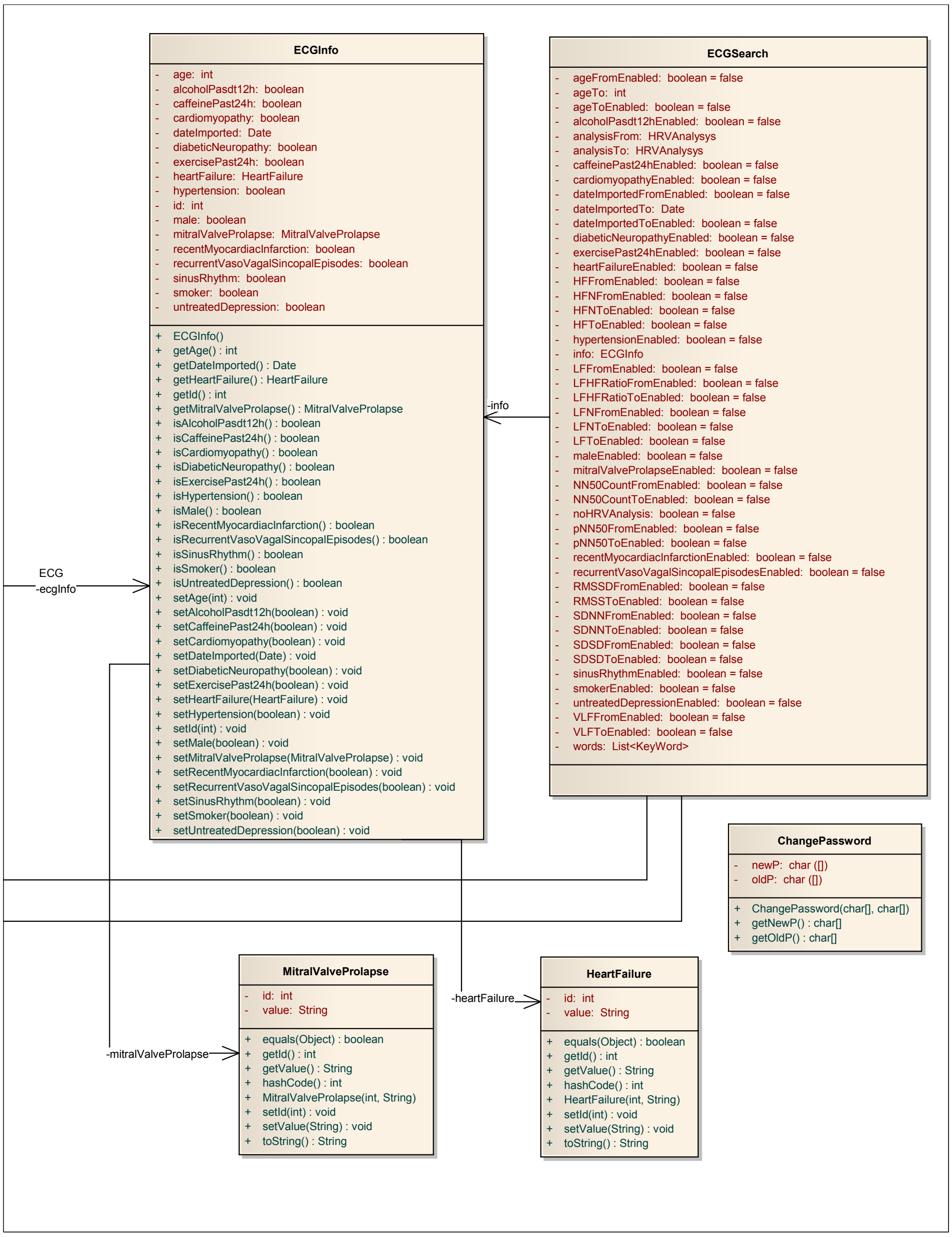

Figure 5.3: Class Domain second part. ECGSearch does not show any of its functions in order to be able to fit in this page.

- **ECG**: This class represents the core of class domain. It stores the value of a single ECG record. It contains an ECGInfo object as well as a list of keywords representing the associations of that particular ECG to clinical or other features. This object also stores the value of the raw ECG, RR-detection and HRVAnalysis. If any of those have not been made yet, its value will be null.

- **ECGData**: This container will store the raw ECG data. It contains two array of double with the time and the values for each sampling point. It is serializable, this means than can be easily saved in JAVA object format. This was implemented in order to store the full ECG in the database in a single record instead of thousands. By doing that, we prevent database size from growing exponentially and permit accessing data faster too. Time is not saved in the database in order to occupie less space. Instead, it is recreated from the sampling frequency starting by zero.

- **ECGInfo**: Contains all relevant medical characteristics detailed in the Userguide section4.3.

- **ECGSearch**:This class was created so that all the search filtering variables where included in a single class. It contains an ECGInfo variable for the value of default properties, two HRVAnalysis items to store the value of $\geq$ and $\leq$ parameters. A list of keywords with no length restriction is also included for the search. The rest of boolean variables are indicators of whether the represented value is going to be used for the search or not.

- **HeartFailure**: Class representing the different values of heart failures following NYHA convention.

- **HRVAnalysis**: This class will store the results of the Heart Rate Variability analysis in time and frequency domain.

- **KeyWord**: Represents the associations the doctor want to include for and ECG but is not able to because it is not included by default in its properties.

- **MitralValveProlapse**:Object representing the different stages of Mitral Valve Prolapse.

- **RRDetection**: This class contains the information required to recreate the RR-Interval detection done by the application and probably modified by the user. As in the case of ECGData, this class implements serializable for efficiency reasons

5.4.2. Database implementation

Relational databases offer exceptional characteristics for data storage including security, information coherency, ease of use, and many other properties. We decided to use this paradigm so that searches could be executed rapidly and to avoid dealing with information corruption. Relational database operations are usually subject to good properties such as ACID, which stands for Atomicity, Consistency, Isolation, and Durability.

Between all the available options we chose Apache Derby database for its embeddable simplicity, which frees the user form installing third party software, and for its easy encryption properties.

Database normalized model is shown in Figure 5.4. As we explained in last section, ECGData and ECGInfo are stored as objects in a BLOB (Binary Large Object) field to accelerate queries and updates as well as to reduce database size. Our first approach was to create a separate table with ECGData and its values, but after some runs, we observed t hat the size was increasing too fast. In fact, it was more than a hundred times bigger than it is now. Same happens with RRDetection.

The result is a simple model with three tables that is efficient in disk usage. Even though, compression could be made in the serialized object in order to reduce more object space. We left this feature to be developed in future versions.

5.5. Visual Component Architecture

So far, we have explained what functionalities we require and what structure the utilized information has, but we still need to implement Use Cases from their abstract definition to well-defined components.

As we mentioned in the begging of the chapter, the MVC paradigm has guided our steps for the implementation. The visual part is separated from the control so that it could be easily modified, improved or replaced without the need of rewriting the controller or vice-versa.

Visual Components follow the structure illustrated in Figure 5.5. Each visualization will have different implementations based on its needs. They are composed by the following objects:

- **Communication**: This class is the link between the graphic content and control. Any important operation must be called by using this object functions. We would like to remark that this class does not

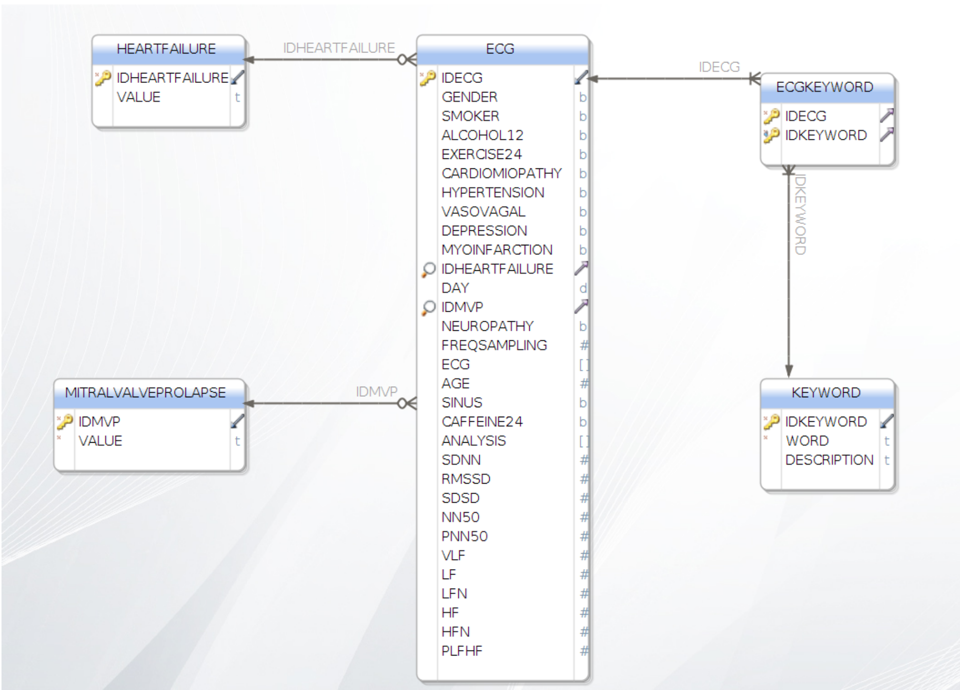

Figure 5.4: Database Schematic Diagram

contain any information on how to do anything, it just has a link to the control interface that is used as communication mechanism to access its functionality. It is on the root package of each visualization resource.

- **Visualization Interface**: This object will contain the functions that the Visualization will require to implement. This interface is used by the control agent to interact with the visualization. It is under the package imp of each visualization.
- **Visualization implementation**: This class is responsible for implementing all the functions defined in the Visualization Interface. It will also initialize the required resources.
- **Resources**: Final implementation for the visualizations. In this category lay all designed frames, panels, dialogs, or any other visual component that the visualization requires. It is under the package imp.gui of each visualization.

We will not describe each of the implemented visual components. Our reason for this behavior is that visualization is subject to current component library, functionality, and developer Dependant. Instead, we will focus on explaining control agents and their interactions and requirements, which are less likely to change.

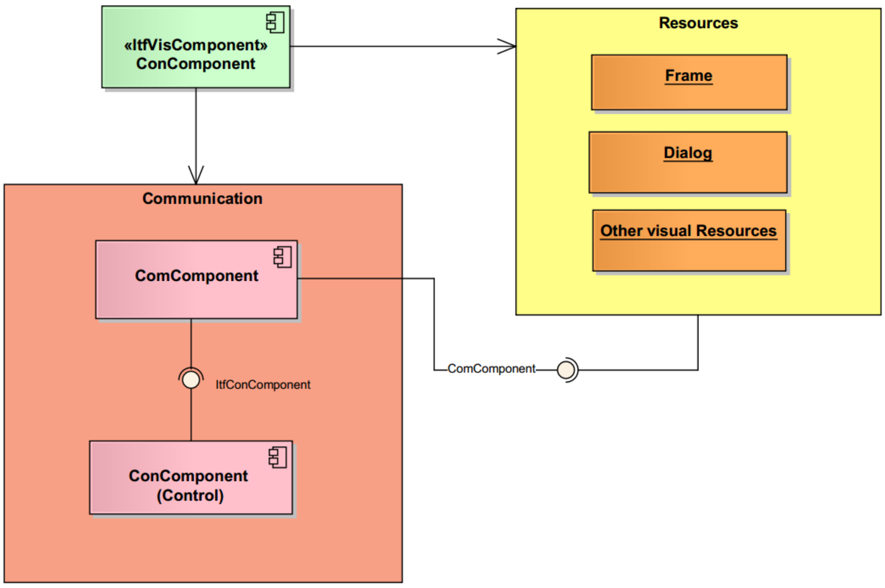

Figure 5.5: Visualization component model

5.6. Control Component Architecture

The Use Cases described in this chapter at section 5.3 have been implemented with the following components:

5.6.1. Login

- **Brief Description**: This component is responsible for initializing database Component interface and Main Menu upon successful login.
- **Use Cases implemented**:
  1. *Login*
  2. *Exit*: User

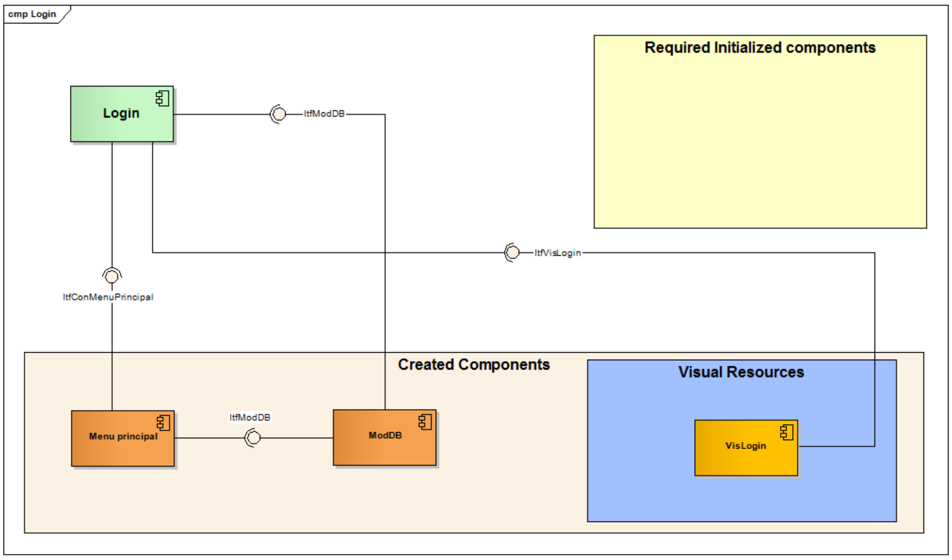

Figure 5.6: Component Diagram of Login control

5.6.2. Main Menu

- **Brief Description**: This component is responsible for giving the user the option to start any of the three following options: InsertECG, SearcECG, or Utilities. It also initializes those components and gives the interfaces they require. It needs a Validated User so that database is connected and can perform any search in the rest of the components.

- **Use Cases implemented**:

  1. *InsertECC*: Just the request part.
  2. *SearchECC*: Just the request part.
  3. *Utilities*: Just the request part.
  4. *Exit*: Validated User

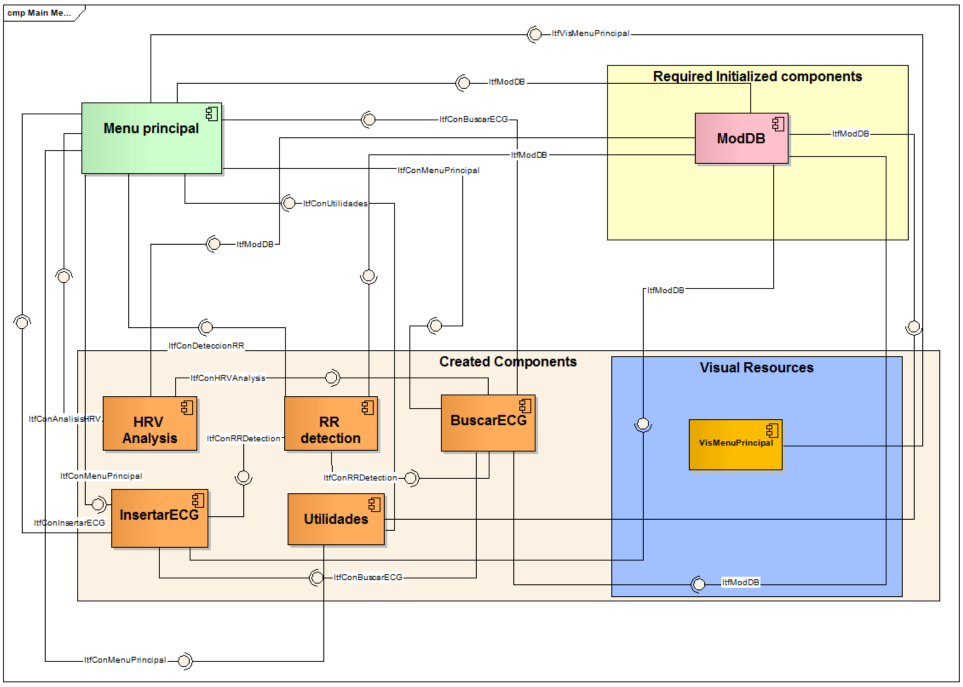

Figure 5.7: Component Diagram of Main Menu control

5.6.3. Insert ECG

- **Brief Description**: This component is responsible for giving the user the option to InsertECG or ModifyECG. successful login. The component requires Search ECG in order to go back to the same search upon modification completion.

- **Use Cases implemented**:

  1. *InsertECC*
  2. *ModifyECG*
  3. *DetectRR*: just the request part.

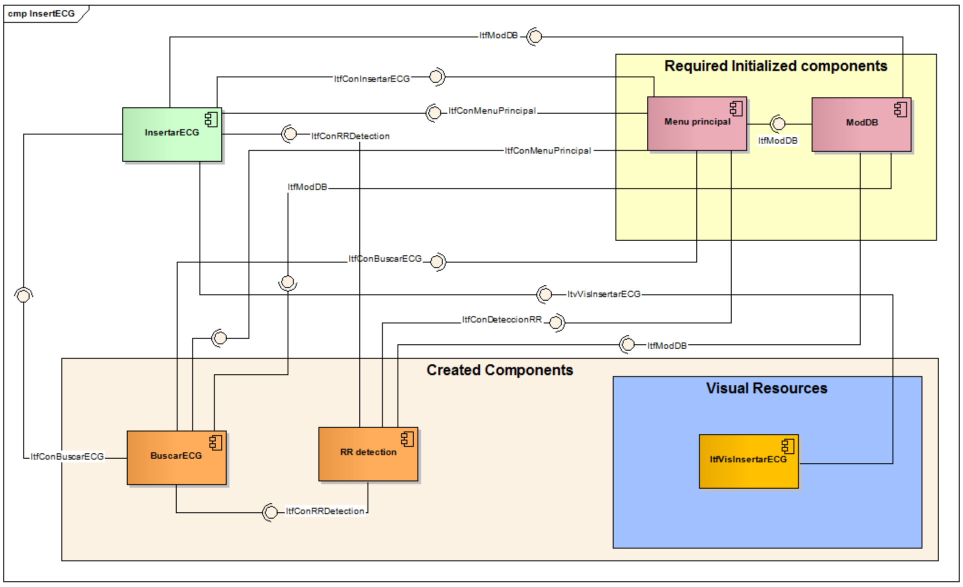

Figure 5.8: Component Diagram of InsertECG control

5.6.4. Search ECG

- **Brief Description**: This component is responsible for giving the user the option to SearchECG and any related ECG selection action.
- **Use Cases implemented**:
  1. *SearchECG*
  2. *ModifyECG*: just the selection and request.
  3. *DeleteECG*
  4. *ModifyECG*: just the selection and request.
  5. *HRVAnalysis*: just the selection and request.
  6. *DetectRR*: just the selection and request.

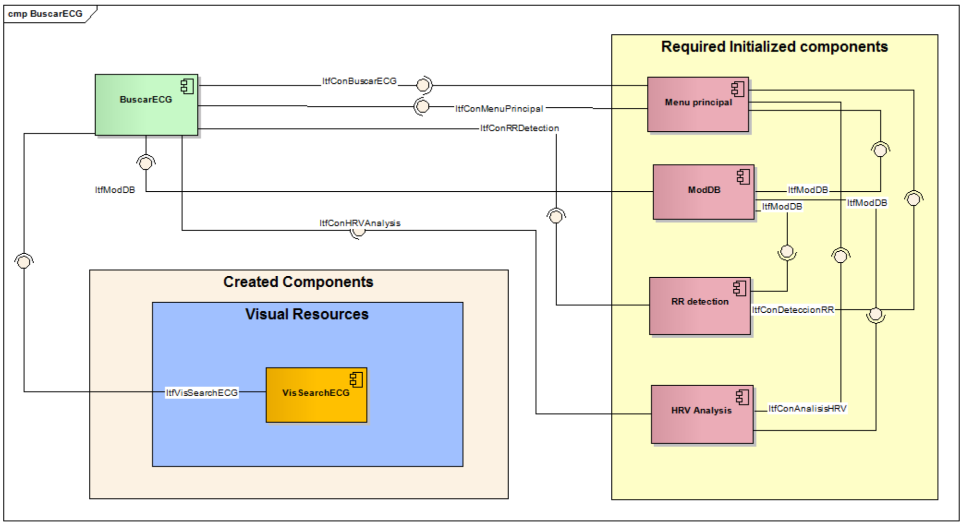

Figure 5.9: Component Diagram of SearchECG control

5.6.5. RR-Detection

- **Brief Description**: This component is responsible for performing the RR-Interval detection and enabling its modification through a visual interface.
- **Use Cases implemented**:
  1. *DetectRR*
  2. *Save RR-detection*
  3. *Modify RR-detection*
  4. *HRVAnalysis*: just the request.

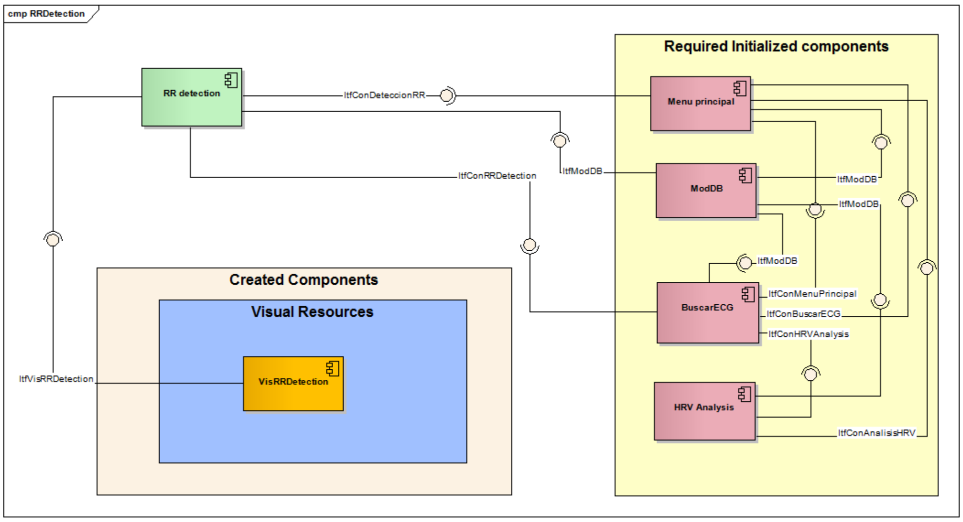

Figure 5.10: Component Diagram of RRDetection control

5.6.6. HRV Analysis

- **Brief Description**: This component is responsible for performing and displaying the results of HRV analysis through a visual interface. It contains the implementation of the signal processing Section described in Chapter 3.

- **Use Cases implemented**:

  1. *HRVAnalysis*
  2. *Save HRVAnalysis*

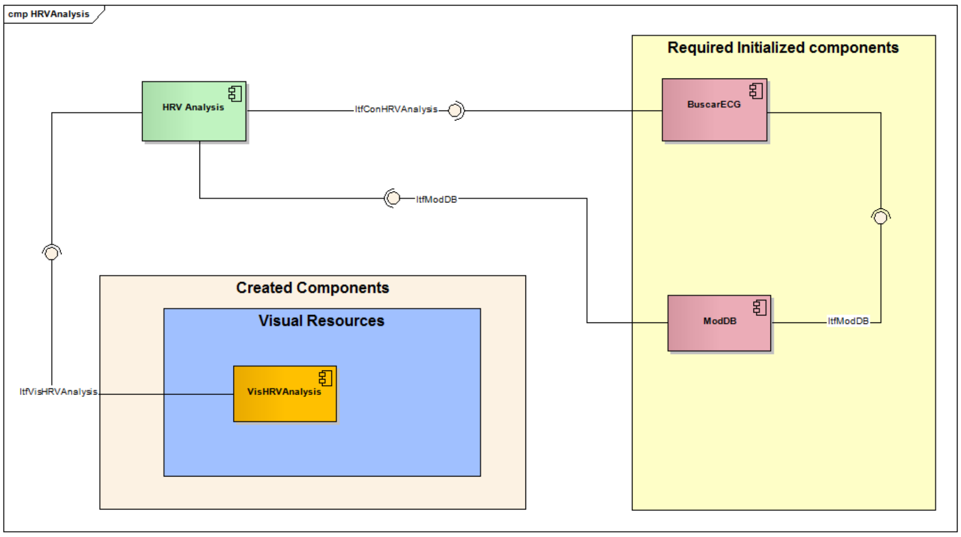

Figure 5.11: Component Diagram of HRV Analysisl control

5.6.7. Utilities

- **Brief Description**: This component is responsible for allowing database utilities to be requested and performed. The only two options alowed are database compression and password changing.
- **Use Cases implemented**:
  1. *Change Password*
  2. *Compact Database*

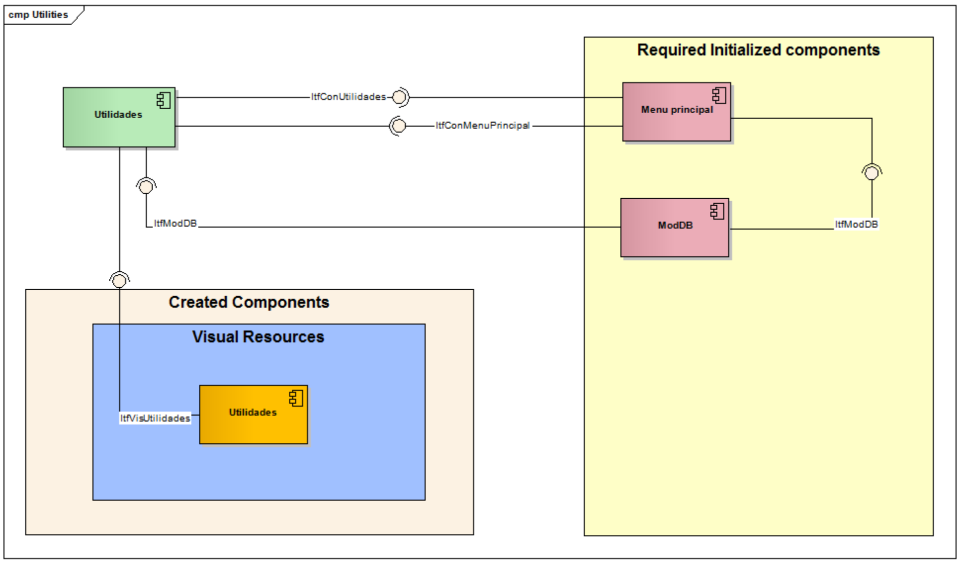

Figure 5.12: Component Diagram of Utilities control

In the next chapter...

The enxt chapter will present the results and depict the state of the art of the application compared to other software.

Chapter 6

Discussion

Don't fear failure so much that you refuse to try new things. The saddest summary of a life contains three descriptions: could have, might have, and should have.

Louis E. Boone

Abstract: This section will summarize what objectives we have obtained with ECG2HRV and suggest future lines of work that could improve what has being developed.

ECG2HRV brings a new paradigm in HRV research field that may seed new ideas for time and frequency domain parameter correlation for clinical diagnosis. This feature reliefs the user from the heavy task of carrying about storage format while enabling same functionalities other programs have in a single binary. This is not the first application that is conceived to calculate HRV. A web survey conducted reveals that ECG2HRV is the only one that allows ECG information to be related to HRV analysis, while offering automatic calculation of required information within a single interface. Next we will discuss some examples supporting these statements.

- *HRV Toolkit*(Goldberger et al., 2000): The application from Physionet is composed by a set of C files that permit obtaining HRV analysis using the command line in time and frequency domain from MIT-BIH database files. Its interface is complicated to handle and many potential users are discouraged by this fact. If we add the point that it does not offer any system to store ECGs we realize that ECG2HRV is far more useful.

- *LabView HRV Analysis*(XU et al., 2003) : The application from National Instruments has a rich visual and easy to use interface with comprehensive on line tutorials. The shortcoming is that it does not allow to store ECGs nor to associate them with patient background. Our application may not have some of the functionality offered here like SDNN graph correlation yet, but our data structure makes ECG2HRV more powerful and comfortable for the user by giving away some parameter analysis in exchange of patient background association. It is also subject to be used by buying the required software while our solution is free and open source.

- *Software for advanced HRV analysis* (Niskanen et al., 2004): This C application includes visual libraries and has same functionality as (XU et al., 2003). It lacks from the same database characteristic explained before and may not be compiled to work an different operating systems.

- *Kubios HRV* (Tarvainen et al., 2009): This software is an easy to use HRV report generator. It is useful to get isolated ECG reports, but not to be used as daily basis. It works under Linux/GNU and Windows, but not under Mac computers.

Many other applications exist to satisfy HRV calculation and reporting requirements, but none to relate obtained results to patient background. We have conceived, designed, and implemented an ECG data management tool, that permits automatic analysis of HRV allowing modification of RR interval detections due to ectopic beats, noise, or miss-detections. This software is platform independent so same program is able to run under Windows, Linux/GNU, Mac, Solaris, or any operating system that is able to run Java Virtual Machine in a desktop platform. The fact of being open source enables the community to carry on with improvements and additional tools that could expand its user impact. This condition also makes the application perfect for low budget research give that it is free to use. We hope that ECG2HRV does not stop growing and that the community will continue improving its available features.

In the next chapter...

Like every day has a night, or every yin has a yang, every beginning has an end. This chapter finalizes the documentation for the project ECG2HRV. We hope that its contents have helped you to understand how it works, how to use it, and how to improve it. The next sections will show the bibliographic references used, the appendix, and a list containing all the acronyms employed.

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*Y así, del mucho leer y del poco dormir,
se le secó el celebro de manera que vino
a perder el juicio.*

Miguel de Cervantes Saavedra

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Acronym List

CHF .... *Congestive Heart Failure*

COPD .... *Chronic Obstructive Pulmonary Disease*

CSV .... *Comma Separated Values*

ECG .... *Electrocardiogram*

ECG2HRV .... *Electrocardiogram to Heart Rate Variability*

FDA .... *US Food and Drug Administration*

FFT .... *Fast Fourier Transform*

FT .... *Fourier Transform*

HRV .... *Heart Rate Variability*

NYHA .... *New York Heart Association Functional Classification*

PSD .... *Power Spectral Density*

UML .... *Unified Modeling Language*

Autorizo a la Universidad Complutense a difundir y utilizar con fines académicos, no comerciales y mencionando expresamente a sus autores, tanto la propia memoria, como el código, los contenidos audiovisuales incluso si incluyen imágenes de los autores, la documentación y/o el prototipo desarrollado.

Fdo: Miguel Ángel Menárguez García