A New Tool for the Analysis of Heart Rate Variability of Long Duration Records

Ricardo Chorão[1], Joana Sousa[2], Tiago Araújo[1,2] and Hugo Gamboa[1,2]
[1]*Physics Department, FCT-UNL, Lisbon, Portugal*
[2]*PLUX Wireless Biosignals S.A., Lisbon, Portugal*

Keywords: ECG, Heart Rate Variability, Interactive Tool.

Abstract: The increased masses of data confronting us, originate a pressing need for the creation of a user interface for better handling and extracting knowledge from it. In this work we developed such a tool for the analysis of Heart Rate Variability (HRV). The analysis of HRV in patients with neuromuscular diseases, sleep disorders and cardiorespiratory problems has a strong impact on clinical practice. It has been widely used for monitoring the autonomic nervous system (ANS), whose regulatory effect controls the cardiac activity. These patients need to be continuously monitored, which originates data with huge sizes. Our interactive tool can perform a fast analysis of HRV from such data. It provides the analysis of HRV in time and frequency domains, and from non-linear methods. The tool is suitable to be run in a web environment, rendering it highly portable. It includes a programming feature, which enables the user to perform additional analysis of the data by giving direct access to the signals in a signal processing programming environment. We also added a report generation functionality, which is extremely important from a clinical standpoint, on which the evolution in time of relevant HRV parameters is depicted.

1 INTRODUCTION

The ever increasing development of clinical systems for patients' biosignals monitoring has given the clinician and the researcher a way of assessing the patients' health state (Silva et al., 2011). The possibility of drawing relevant medical conclusions from the analysis of biosignals arises from the fact that they contain information which is directly related to the physiological mechanisms that originated them (Bronzino, 2000).

The constant monitoring of ambulatory patients, with conditions such as neuromuscular diseases, sleep disorders or chronic heart problems, has great value and may provide the clinician with a way for a more objective therapy (Davenport et al., 2009). It also plays a preventive role, enabling the clinician to undertake a faster medical response.

Recordings of several hours originate huge amounts of data, which need to be processed and analysed rapidly.

The Heart Rate Variability (HRV) is a very important tool to analyse ECG signals with detail. In HRV analysis, the oscillations between consecutive heartbeats are measured, both in time and frequency domains.

Since the HRV is strongly associated with neuro-regulation mechanisms, it also allows one to evaluate the modulation of the heart rate by the ANS (Ryan et al., 2011).

The first step of HRV analysis is the measurement of all the inter-beat intervals, which can be achieved through the detection of the peaks in the ECG record, as shown in figure 1.

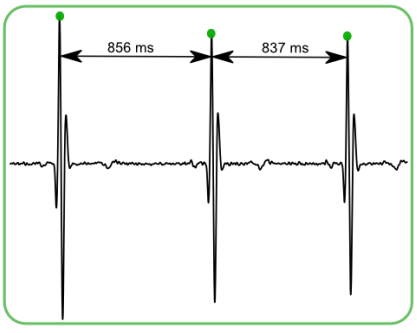

Figure 1: Highlight of 3 ECG peaks (the R peaks) and measurement of 2 heartbeat intervals (or RR intervals).

There are several methods of analysis of HRV that can be divided mainly into Time and Frequency

Chorão R., Sousa J., Araújo T. and Gamboa H..
A New Tool for the Analysis of Heart Rate Variability of Long Duration Records.
DOI: 10.5220/0004166602150220
In *Proceedings of the International Conference on Signal Processing and Multimedia Applications and Wireless Information Networks and Systems* (SIGMAP-2012), pages 215-220
ISBN: 978-989-8565-25-9

domain methods (Camm et al., 1996).

Time domain analysis of HRV allows calculation of statistical parameters concerning the RR intervals, tachogram (evolution of the RR interval duration in time) and instant heart rate representations. These visual representations are extremely important to identify disturbances of the cardiac rhythm, such as arrhythmias or skipped heartbeats.

Frequency domain analysis methods are particularly useful for analysing long term ECGs. They are based on power spectral density (PSD) analysis of RR intervals and provide information about how power distributes itself among the various frequencies. The power in different frequency bands is closely related to different branches of the ANS, which makes the power distribution a very important tool to identify ANS related problems.

We present a new tool capable of performing a HRV analysis from several hour long ECG records.

There are many HRV analysis tools available, such as "Biopac HRV Algorithm", "HRVAS: HRV Analysis Software" (using Matlab) and the "HRV Toolkit" (PhysioNet). They all provide frequency and time domain analysis of ECG records. However they are not interactive or do not allow one to deal directly with long duration ECGs, which was our main concern. In our tool, the HRV analysis begins in the very ECG records, in spite of the available tools, which assume the ECG peak detection was made elsewhere. Our tool also surpasses the currently available tools in what portability is concerned, since it can be executed in a web environment.

The analysis takes only a few seconds despite of the recording length of several hours. Its flexibility and possibility of a personalized and detailed analysis make it suitable for both the clinician and the researcher.

Its user-friendliness makes it pleasant to use and easy to learn, two very important characteristics in any software project according to (Holzinger, 2005).

In the following section the programming architecture of the application is explained and the features of the developed tool are depicted. Finally, we discuss some improvements that can be made, and conclude the work at the end of the paper.

2 HRV ANALYSIS TOOL

We developed a user-friendly and interactive tool which runs in a web environment, and therefore can be accessed easily from anywhere with an internet connection. It gives the user control over powerful signal processing algorithms, enabling a human-computer interaction and the exploration of large datasets comprising biological signals.

The developed tool allows a detailed analysis of ECG records with several hours. It is coupled to a previously developed biosignals visualization tool (Gomes, 2011); (Gomes et al., 2012) making it possible to simultaneously visualize the portion of the signal being analysed and the processing results.

The analysis tool also includes a report generation feature, in which the evolution of the patient's heart rate, among other significant parameters can be tracked. The report is extremely important from a medical point of view, making the processing results portable and an extension of the patient's clinical file.

For fast and random accessing of processing results, we used the HDF5 file format, specifically designed to store and access large datasets (The hdf group, 2012).

2.1 Acquisition System

The signals were acquired with the aid of a chest wrap, which integrates respiration, ECG and accelerometer sensors. They are sampled at 1 kHz and with a 12 bit resolution and are then sent by Bluetooth to a mobile phone.

The acquisition process is occurring under project "wiCardioResp". This project is developing technology to remotely monitor patients with neuromuscular diseases and cardiorespiratory problems while the patients are comfortably at home (PLUX, 2012). The acquisitions were carried out with their agreement, during the night, and last approximately 7 hours.

2.2 Application Platform

We coupled the HRV analysis tool to a previously developed web-based biosignals visualization tool. The application is executed in a web browser, rendering it highly portable, and giving it the potential of being accessed from anywhere with an internet connection.

All signal processing algorithms were written in Python and used SciPy (SciPy, 2012), a Python package for scientific computing. The application platform was created using JavaScript and HTML, browser-supported languages.

2.3 Programming Architecture

HRV analysis requires the detection of the different

heartbeats. This is typically achieved using an ECG peak detection algorithm, because the ECG peak morphology (see figure 1) makes it an easily detectable feature in the ECG waveform.

The utilized peak detector was an adaptation of the Pan and Tompkins algorithm (Pan and Tompkins, 1985).

To apply an ECG peak detection algorithm over a long duration record, as a whole, is unfeasible, because of the amount of memory required to perform the computation. The strategy employed to solve this issue consisted in partitioning the record into several equally sized portions, processing them individually. This approach gives rise to possible detection errors in the borders, which we overcame considering a fixed number of overlapping samples between consecutive portions. We used an overlap of 400 ms, carefully chosen after analysing several ECG records. The bigger the overlapping period, the longer the processing will last. However, when dealing with long duration records, the additional processing time due to the overlapping size is negligible (at worst a few seconds more in a record with several hours).

The strategy that we undertook regarding double peak detections (one of them in an overlapping region and the other in the beginning of the subsequent portion of the signal) has a physiological basis, as following explained:

When a muscle contracts, an action potential is generated. Then, there is a long absolute refractory period, which, for the cardiac muscle, lasts about 250 ms. During this period, the cardiac muscle can't be re-excited, which results in an inability for heart contraction (Widmaier, Raff and Strang, 2005). Thus, we can theoretically consider a maximum heart rate of about 4 beats per second, or 240 beats per minute. Under this assumption, considering that in a signal sampled at 1 kHz, 250 ms would be represented by 250 samples, and after a thorough observation of the behaviour of the peak detection algorithm, we stated that if the same peak were detected twice, the detection would never occur with such deviation in samples. Therefore, we considered that if two R peaks were detected and separated by less than 50 ms, we were dealing with a double detection and only considered one of them. With a tolerance of 50 ms, we ensured that double detections would not occur on the overlapping regions, while not dismissing any occurrence of a physiologically possible RR interval.

The amount of time it takes for the peak detection to complete depends on several factors: the sampling frequency at which the signals were acquired, the signals' duration, the peak detection algorithm and the processing unit of the machine in which the computations take place. It took us about 8 minutes to process a 7 hour long ECG, sampled at 1 kHz on a single 2.2 GHz processor.

The peak detection phase can be regarded as pre-processing and only has to be done once. Its duration may be easily decreased applying parallel programming techniques, due to the embarrassingly parallel nature of the problem.

The peak detection information was stored in a .h5 file (HDF5 file extension) for fast and random access, a necessary feature to make the analysis of portions of the signal possible.

For analysing a specific part of the ECG, for instance, between the first and second hour of the recording, all that has to be done is accessing the processing results in the .h5 file and select the samples between the first and second hour. This information is then analysed in just a few seconds. The simultaneous visualization of the signal and the processing results is an extremely important capability allowing a more detailed and accurate analysis by the clinician and the researcher.

2.4 Tool Features

The HRV analysis provided is composed of time and frequency domain parameters and also of some visual representations, which, allied to the biosignals visualization tool allow a more detailed data inspection.

The time and frequency domain parameters provided are depicted in figure 2.

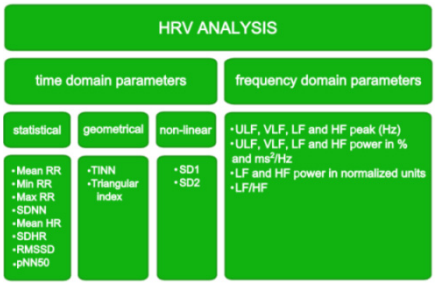

Figure 2: The most important HRV analysis parameters provided by our tool.

Besides time and frequency domain parameters, our tool includes several important visualization features as well:

- tachogram and instantaneous heart rate (figure 3). Since each point in these representations is directly associated with a cardiac cycle, we included a zooming feature, directly synchronized with the

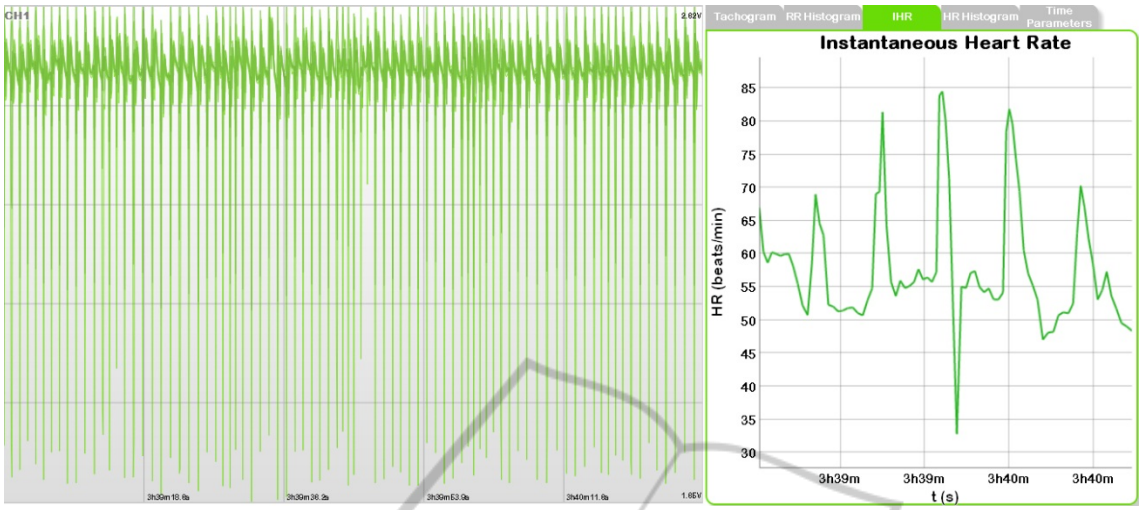

Figure 3: Instantaneous Heart Rate of a 1m30s period from a night recording with a duration of 7h17m.

ECG visualization. This makes the inspection of the processing results interactive and gives the clinician the possibility to rapidly identify periods of arrhythmia or other significant events and observing them on the ECG record;

- RR Interval and Instantaneous Heart Rate histograms with a bin size of 1/128 s (standard bin size according to Camm et al., 1996);
- Power Spectral Density, with highlight of the relevant frequency bands and zooming feature for a more detailed analysis. The frequency range of the different frequency bands is as follows: ULF (0 - 0.003 Hz), VLF (0.003 - 0.04 Hz), LF (0.04 - 0.15 Hz), HF (0.15 - 0.04 Hz);
- Poincaré plot.

Extremely important as well is a report generation feature. The report includes a global analysis in which the parameters and representations already described are presented. It also illustrates the evolution of those parameters in time.

We also included a programming feature, particularly focused on the researcher, in a console. This way, additional signal processing can be done, using all of the SciPy capabilities (SciPy, 2012). We loaded several important variables into the namespace: the sampling frequency, an array with all the R peaks, in samples, that were detected in the selected time range, the beginning and ending of the selected time range, in samples. All these variables contain the necessary and sufficient information to enable a personalized analysis by the programmer or the researcher.

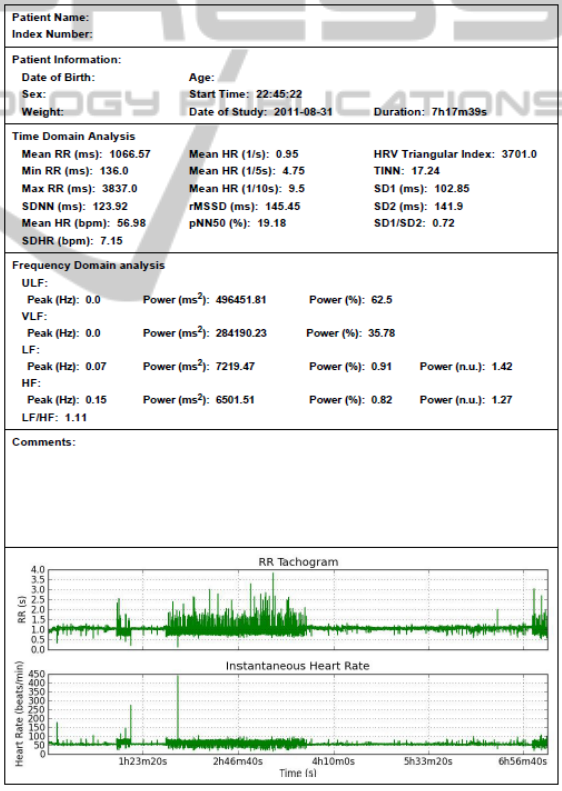

Figure 4: First page of a HRV analysis report from a night recording which lasts 7h17m. This page presents a global time and frequency domain analysis.

3 CONCLUSIONS AND FUTURE WORK

In this work we developed an HRV analysis tool

suited for the analysis of long duration records.

Taking into account all described tool features, we conclude that it offers a flexible, detailed and accurate way of analysing long duration ECGs. The report generation and the programming mode features are very important and give the tool a greater flexibility and portability, besides that of a web-based application.

The zooming capabilities and the synchronism with a biosignals visualization tool make it highly interactive and provide a way for better and faster data discovery.

The user interface allows control over powerful signal processing algorithms and can be regarded as a way to allow the non-expert to still utilize them for clinical or research purposes.

In future work we intend to develop an algorithm which will allow us to determine the minimum number of overlapping samples for optimal ECG peak detection. We also aim to add the functionality of analysing several records simultaneously and to generate the corresponding HRV analysis reports using parallel programming techniques.

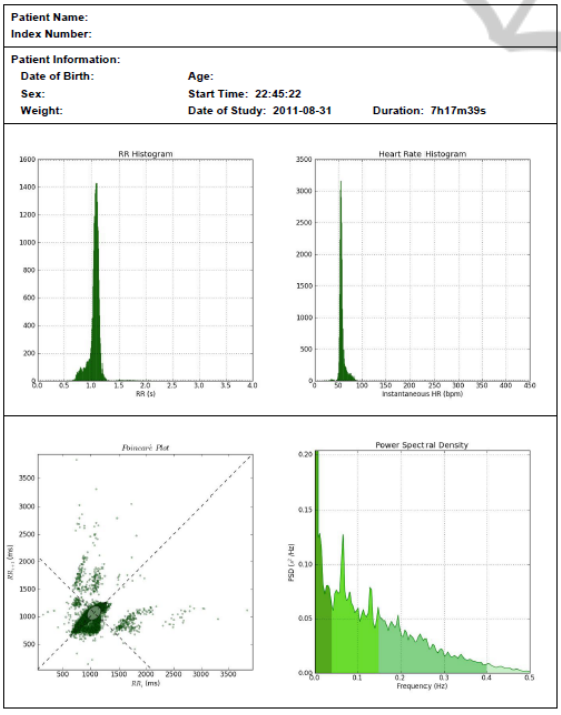

Figure 5: Second page of the report showing power spectral density, histograms and Poincaré plot.

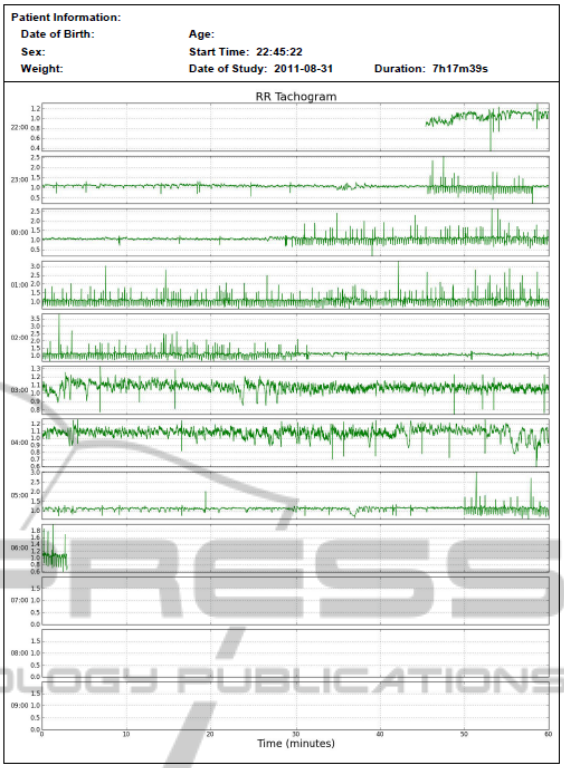

Figure 6: Tachogram hour-by-hour evolution. This representation is extremely useful for identifying periods of arrhythmia and other events through the night.

ACKNOWLEDGEMENTS

This work was partially supported by National Strategic Reference Framework (NSRF-QREN) under project ”wiCardioResp” and ”AAL4ALL”, and Seventh Framework Programme (FP7) program under project ICT4Depression, whose support the authors gratefully acknowledge. The authors also thank PLUX, Wireless Biosignals for providing the acquisition system and sensors necessary to this work.

REFERENCES

H. Silva, S. Plama, H. Gamboa., 2011. AAL+: Continuous Institutional and Home Care Through Wireless Biosignal Monitoring Systems. *Chapter in Handbook of Digital Homecare, Lodewijk Bos, Adrie Dumay, Leonard Goldschmidt, Griet Verhenneman and Kanagasingam Yogesan*, Springer.

J. D. Bronzino., 2000. *The biomedical engineering handbook*, volume 2. CRC Press. Boca Raton , 2nd edition .D.M. Davenport, FJ Ross, and B. Deb., 2009.

Wireless propagation and coexistence of medical body sensor networks for ambulatory patient monitoring. In

D. M. Davenport, F. J. Ross, and B. Deb., 2009. Wireless propagation and coexistence of medical body sensor networks for ambulatory patient monitoring. In *Wearable and Implantable Body Sensor Networks. Sixth InternationalWorkshop* on pages 41–45. IEEE, 2009.

M. L. Ryan, C. M. Thorson, C. A. Otero, T. Vu, and K. G. Proctor., 2011. Clinical applications of heart rate variability in the triage and assessment of traumatically injured patients. *Anesthesiology research and practice, 2011*.

A. J. Camm, M. Malik, J. T. Bigger, G. Breithardt, S. Cerutti, R. J. Cohen, P. Coumel, E. L. Fallen, H. L. Kennedy, R. E. Kleiger, et al., 1996. Heart rate variability: standards of measurement, physiological interpretation, and clinical use. *Circulation, 93(5):1043–1065*.

PhysioNet – http://physionet.org/tutorials/hrv-toolkit/. Accessed 26/05/2012

Holzinger, A., 2005. Usability engineering methods for software developers. *Communications of the ACM*, 48(1):71–74.

R. Gomes, N. Neuza, J. Sousa, H. Gamboa., 2012. Long-term biosignals visualization and processing. *Proceedings of Biosignals - 5th International Conference on Bio-Inspired and Signal Processing (BIOSIGNALS 2012),* Vilamoura, Portugal.

Ricardo Gomes., 2011. Long-term biosignals visualization and processing. Master thesis, Universidade Nova de Lisboa, Faculdade de Ciências e Tecnologia, 2011.

The hdf group – http://www.hdfgroup.org/why_hdf/. Accessed: 26/05/2012

PLUX (2012) – http://wicardioresp.plux.info/pt-pt. Accessed: 25/05/2012

Scipy – http://www.scipy.org/. Accessed: 26/05/2012

Pan, J. and Tompkins, W. (1985). A real-time qrs detection algorithm. *Biomedical Engineering, IEEE Transactions on, (3):230–236*.

Eric P. Widmaier, Hershel Raff, and Kevin T. Strang., 2005. *Vander's Human Physiology: The Mechanisms of Body Function*. McGraw-Hill International Edition, 10th edition.