

R-HRV: An R-based software package for heart rate variability analysis of ECG recordings

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Abstract: The heart rate variability (HRV) analysis has been proven to be an effective tool for the diagnosis of several diseases, such as heart failure or diabetes. To measure the HRV, various algorithms have been developed employing different programming languages. In this paper, we present a new package for R, a free software environment for statistical computing and graphics. This package, called R-HRV, offers functions for performing power spectral analysis of heart rate data. We will use this package for the study of several diseases, such as obstructive sleep apnea or chronic obstructive pulmonary disease.

Keywords: Heart Rate Variability. Electrocardiogram. Spectral Analysis.

1. Introduction

The heart rate variability (HRV) can be defined as the variations in time of the period between two consecutive heart beats, and it is predominantly dependent on the extrinsic regulation of the heart rate. Moreover, the HRV represents the balance of the parasympathetic nerves, which slow down HR, and the sympathetic nerves, which accelerate it.

The starting point for measuring the HRV is the detection over the electrocardiogram (ECG) of each R-wave, and the calculation of the interval between them. This interval is called RR interval, and it measures the heart period, being its inverse the heart rate (Akselrod, 1995).

The HRV analysis has been proven to be a powerful tool for predicting mortality after a myocardial infarction (Bauer, 2006), for measuring the risk stratification of diabetic patients (Astrup, 2006), for evaluating the fetal cardiovascular system maturation (Ortiz, 2006), or for obstructive apnea detection (Suhas, 2007).

The Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (Task, 1996) propose several techniques for measuring the HRV. Two different types or methods are proposed: a) statistics in the time domain over the RR series. Examples are the standard deviations or the calculation of the percentage of values that differ more than 50 ms from the previous one; and b) analysis in the frequency domain, or spectral analysis, which allows for decomposing the full variability in its frequency components: both low- and high frequency components.

It must be remarked that commercial or free software tools for developing HRV analysis are practically inexistent. Because of this, researchers have to implement their own applications. Some of them implement algorithms using programming languages, such as C or Java. Others prefer to develop toolboxes or software packages for general purpose data analysis environments, like LabVIEW¹ (Lerma, 2003), or Matlab² (Drinnan, 2000) Other software platforms are arising as promising tools for implementing data analysis algorithms in different research fields. An example is the R language³, which is a free software environment for statistical computing and graphics, and compiles and runs on a wide variety of UNIX platforms, Windows and MacOS. Similar to Matlab, R can be considered a computing environment and programming language. R has a core functionality and a great variety of packages developed for different users (advanced graphics, neural network training, advanced statistics,...)

In this paper, we present an R package for developing HRV analysis. The functions comprised in this package follow the international standard methodology (Task, 1996), and include some improvements developed by the authors (Vila, 1998).

1 <http://www.ni.com>

2 <http://www.mathworks.com>

3 <http://www.r-project.org>

2. Materials

The dataset employed to test the tool was downloaded from the Physionet website⁴, and was constituted by several ECG recordings, digitized at 250 Hz, with a 12-bits resolution.

Physionet is a Web-based library of physiological data and analytic software sponsored by the US National Institutes of Health's National Center for Research Resources, and it provides free access to the database of ECG recordings (Moody, 2000).

3. Methodology for HRV analysis

The proposed methodology is a 4-step process that involves: 1) obtaining of the heart rate signal; 2) artefacts suppression; 3) interpolation; and 4) power spectral analysis.

This methodology has been successfully used by the authors in clinical studies related to sclerosis patients (Monge, 1998), ischemia detection (Vila, 1998) or brainstem lesions (Monge Argilés, 2000).

3.1. Obtaining of the heart rate signal

Initially, the heart beats of the ECG recordings had to be identified and labelled. For this task, an automated function downloaded from the Physionet website and written in C language was used and incorporated to our R software package. Basically, this algorithm reads the annotation file for the ECG register, and writes a text-format translation of it on the standard output, one annotation per line. The output contains the time of the annotation in hours, minutes, seconds, and milliseconds; the time of the annotation in samples; and other auxiliary information string.

The instantaneous heart rate can be defined as the inverse of the time separation between two consecutive heart beats. Once the beats have been identified, and since the only valid values contributing to the heart rate signal are the corresponding to normal beats preceded by other normal beats, a further operation should be performed. In mathematical terms, this corresponds to the calculation of the series:

⁴ <http://www.physionet.org>

$$HR(i) = \frac{1000}{(T(i) - T(i-1))}$$

where $HR(i)$ is the instantaneous heart rate, and $T(i)$ is the position of the i normal beat, measured in milliseconds, from the initial point of the register. Figure 1 shows an example of a typical heart rate plot.

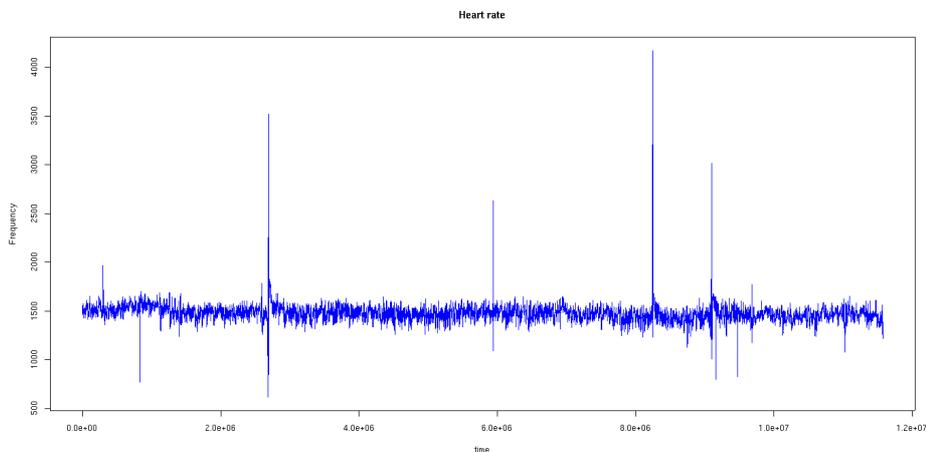


Figure 1 – Example of a heart rate plot.

3.2. Artefacts suppression

Unfortunately, the algorithms for developing and classifying heart beats usually present fails and can yield incorrect outputs. If an erroneous value of the instantaneous heart rate is included, then it can distort the result of the analysis. Figure 1 shows some of these incorrect values. Because of this, an algorithm for reducing the artefacts is required. To perform this task, and considering as the starting register the signal obtained in step 1, we have applied an algorithm that uses adaptive thresholds for rejecting those beats different from the given threshold more than a certain value. This algorithm was published in Vila et al. (Vila, 1997). In this way, the filtered non-equispaced heart rate signal was obtained.

3.3. Interpolation

The main goal of this work was the spectral analysis of HRV. This means that the equispaced heart rate signal had to be obtained for calculating the spectrum. To perform this task, a cubic spline interpolation was applied. The default frequency for interpolation was 4 Hz. After this step, we have obtained a new heart rate signal, adequate for performing the spectral analysis.

3.4. Power spectral analysis

The time domain methods are computationally simple, but they lack the ability to distinguish between sympathetic and parasympathetic contributions of the HRV. The power spectrum estimation techniques avoid the problem of leakage and provide better frequency resolution. In this way, spectral analysis of HRV can be a powerful method for studying the pathophysiologic processes in certain diseases, and it can also be used in the daily clinical practice.

The standard frequency bands used for power calculation (Task, 1996) were the very low frequency (VLF) band, ranging from 0 to 0.04 Hz, the low frequency (LF) region, from 0.04 to 0.15, and the high frequency range, from 0.15 to 0.40 Hz.

The HF reflects the fast changes in the beat-to-beat variability due to the parasympathetic or vagal stimulation, while the VLF range is thought to reflect mostly sympathetic stimulation. The LF region represents a mixture of both sympathetic and parasympathetic stimulation of the heart.

The spectrogram was obtained and, after that, the power spectra were calculated for each region, as well as the total power spectrum. The LF/HF ratio, of interest for the clinical diagnosis, was also calculated.

4. R-HRV software package creation

Once all the individual functions were implemented in R, a software package that included all the developed routines, called R-HVR, was created. To perform this task, the corresponding commands and functions of R were used.

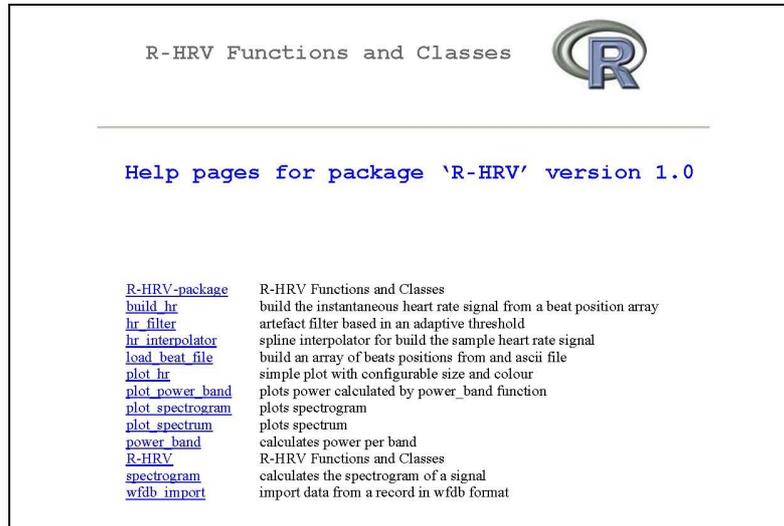


Figure 2 – Functions of the R-HRV software package.

A help manual and examples were also added for each implemented function. Figure 2 shows the functions and routines that includes the R-HRV software package.

The R-HRV can be downloaded from <http://cran.es.r-project.org/>.

5. Results

In this work, we have focused on the implementation of a computerized tool for analyzing the HRV of ECG recordings. The system was trained employing several ECG signals obtained from the public Physionet database. For each ECG, the following measures were obtained: mean VLF power, mean LF power, mean HF power, total power, and LF/HF ratio. Figure 3 shows an example of the output of the R-HRV software package, which represents a plot of the spectrum for the heart rate register presented in Figure 1. Figure 4 shows the graphics for the VLF, LF, HF powers, and for LF/HF ratio.

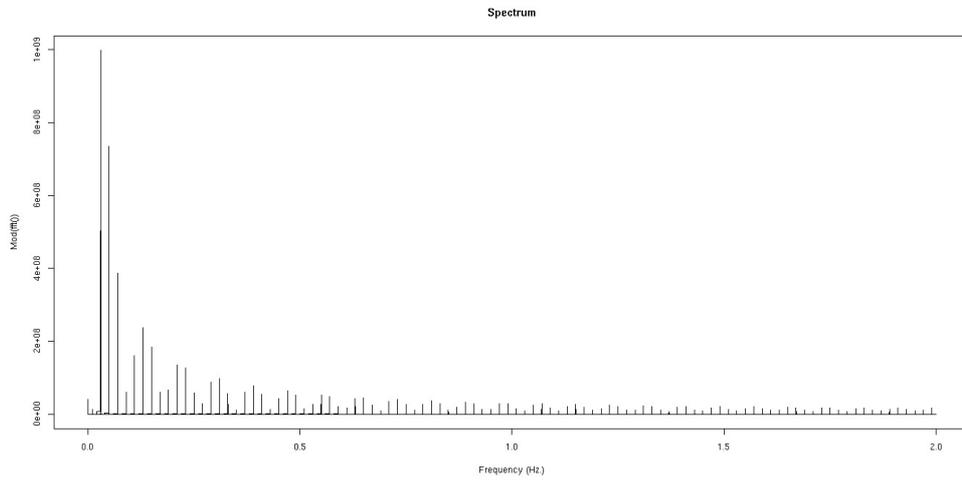


Figure 3 – Spectrum of a cardiac frequency signal.

6. Conclusions

Acknowlegments

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