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An open source tool for heart rate variability spectral analysis

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ABSTRACT

In this paper we describe a software package for developing heart rate variability analysis. This package, called RHRV, is a third party extension for the open source statistical environment R, and can be freely downloaded from the R-CRAN repository. We review the state of the art of software related to the analysis of heart rate variability (HRV). Based upon this review, we motivate the development of an open source software platform which can be used for developing new algorithms for studying HRV or for performing clinical experiments. In particular, we show how the RHRV package greatly simplifies and accelerates the work of the computer scientist or medical specialist in the HRV field. We illustrate the utility of our package with practical examples.

1. Introduction

In ancient times, physicians believed that our heart beats regularly with a fixed rate, rising or falling due to external stimulus, such as fear, anxiety, relaxations, etc. When it was possible to measure the heart rhythm with more precision, it was discovered that it was not constant but experienced some amount of *variability*. Until the past century, physicians thought this variability was simply *noise* and had no clinical relevance. It wasn't until the period between 1970 and 1990, that key research findings demonstrated that this variability had physiological origins and was related to phenomena such as the respiratory rate or the neurovegetative control system [1,2].

Explicit relationships between spectral components of heart rate variability (HRV) and the different components of the neurovegetative control systems were experimentally demonstrated by Akselrod et al. [3], who described three relevant peaks: the VLF (very-low frequency) containing frequencies below 0.03 Hz, the LF (low frequency), having frequencies between 0.03 and 0.15 Hz, and the HF (high frequency) peaks which lie between 0.18 and 0.4 Hz. Using drugs for selectively blocking different components of the neurovegetative control systems, Akselrod discovered that the parasympathetic system modulates the LF and HF peaks, the sympathetic system alters the LF peak, and the renin–angiotensin system modulates the VLF peak. A practical consequence of this experiment was that the heart rate variability could be used as an *indicator* or indirect measure of the status of the neurovegetative control system.

HRV has been an active research field since the 1990s. Several analysis techniques have been developed and improved [4,5] including time indices, spectral analysis, and non-linear analysis. The relation of HRV with some pathologies such as myocardial infarction, sudden cardiac death, heart failure, hypertension, and ischaemia has been established in several

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studies [6,7]. As an indication that HRV continues to be an active practical field with unresolved problems, there were 21 papers directly related with HRV in the recent 2009 Computers in Cardiology Conference [8].

Unfortunately, clinical practitioners have not included HRV analysis in their standard diagnostic protocols. As a consequence, medical device manufacturers have not traditionally placed a high priority on including this type of analysis in their products [7]. First generation monitoring systems of the 1990s permitted the analysis of only a limited number of basic parameters in the time domain and provided only rudimentary spectral analysis. The principal disadvantage of these early systems, however, was the inherent limitations for modifying measurement parameters as well as the inflexibility of data format interchange.

Modern commercial monitoring systems have improved considerably due to greater computational capability of embedded systems and to the ability to include a greater range of flexibility. For example, our research related to signal processing of apnea, a chronic sleep disorder, has benefitted from recent commercial polysomnographic systems such as the *Ultrasom Network* by Nicolet and the *Somnoscreen* of Sonomedics, where variability analysis may be performed both in the time and frequency domain. Such systems also offer the possibility of using different standard formats required by various data processing software and hardware tools.

Despite these improvements, present commercial systems are designed for clinical uses and do not have the programmability needed by researchers in signal processing, looking for new and yet unforeseen discriminators or algorithms. For this task, researchers rely upon software post-processing. As an example, such systems do not directly permit the customization of the spectral bands, nor other analysis parameters such as the size of temporal windows, type of spectral estimators, etc. Thus, researchers rely upon software tools, and not commercial clinical systems for exploring new diagnostic techniques.

In this paper we present a software tool useful for researchers in the HRV field. The paper is structured as follows. In Section 2 we review the state of the art in the field of software for HRV analysis. Section 3 contains a general description of our software package and an example for presenting the use of our tool. In Section 4, we present another example in order to explain how our tool could be used to validate a medical hypothesis related with HRV. Finally a discussion section is included in which we summarize the main advantages of our software tool and describe future work.

2. Background

The development of our HRV software package grew out of what we perceived as a need to unify software functionality into one open source and easily extendible tool. We based our decision to develop the package in the R-language after a thorough bibliographic review, paying careful attention to the software tools being employed and developed.

The majority of researchers have obtained their data from commercial acquisition systems or from a standard database such as Physionet [9]. Besides, a large collection of available tools to study HRV, consists mostly of custom software packages or a loose collection of utilities (a significant number of them using Matlab or Octave). Some authors describe their algorithms, yet do not give specifics of the implementation platform or language. Among the few authors that describe specific environments for studying HRV signals, many of the tools are proprietary and not made available in the public domain for use by other researchers.

Recently, National Instruments described how variability analysis can be performed in LabVIEW [10]. While they freely offer both the LabVIEW model and documentation, the LabVIEW software platform is a commercial product and is more frequently used by hardware designers or experimentalists than by computer scientists working in the field of medical informatics.

We have previously mentioned Physionet, which is a web portal containing an extensive database of physiologic signals as well as software tools, such as the WFDB [11] library, that are freely available. Amongst the utilities offered at this site is the C language based HRV Toolkit [12] that utilizes the WFDB library to obtain signals of heart rate and parameters of variability, both in the time and frequency domain. This is a basic software tool and requires installation of both the libraries and the HRV Toolkit on systems that support C.

Recently, Physionet published a news item on their website [13] which suggests three different options available for performing HRV analysis with their databases:

- The preliminary version of our package RHRV [14].
- A collection of Matlab scripts [15] which implement functions for the linear and non-linear spectrum. Nonetheless, these Matlab scripts do not include convenient interfaces for importing data, nor does it include specific graphics utilities.
- A software package called KUBIOS-HRV [16,17]. The latest version of this software is based on Matlab and is multiplatform. It imports ASCII files as well as data files from Polar and Suunto heart rate monitors (HRM and SDF/STE files, respectively). It has a well designed graphical interface and performs analysis in time and frequency domain as well as non-linear dynamical studies.

The most complete and useful software tool that we encountered for HRV analysis is the *aHRV*, developed by Nevrokard [18]. This is a very well designed commercial tool that provides many options. With this software, heart rate data from multiple sources such as ASCII files, binary files in European Data Format [19], or other proprietary formats may be imported. Other aspects of this software include time and frequency analysis, flexibility for modifying input processing parameters, and a well designed user interface. Nevorkard also offers other modified versions of this tool, such as *LT-HRV* for analyzing segmented ECG records or *OSAS* for apnea screening.

As researchers, however, we believe that our use of the *aHRV* system has several drawbacks. Foremost, it is a closed commercial tool, which is not typically an issue for hospital users, but poses significant limitations for researchers interested in developing new algorithms. Thus, beyond the provided functionalities, it isn't possible to implement new algorithms,