ADAPTIVE FILTER TO AUTOMATIC PREPROCESSING OF YOUNG ADULTS TACHOGRAMS

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Abstract
The Heart Rate Variability (HRV), which is quantified by the variation between RR intervals, is dependent on biological modulators such as the activity of the sympathetic and parasympathetic systems. The presence of ectopic beats and extraneous effects, while perturbing and introducing numerical artifacts into the RR tachogram, interferes with the HRV analysis and, therefore, can lead to erroneous results. To handle this problem and at the same time to facilitate the analysis, the present study proposes an automatic method of data filtering based on an adaptive filter that is able to quickly analyze a large number of tachograms. The method was applied to 62 RR tachograms from normal subjects (healthy). Compared to the costly and time consuming conventional method, wherein the correction of an occasional ectopic beat and removal of aberrant RR intervals are executed by an expert, the proposed method makes use of correlation coefficients (Pearson or Spearman) and the Student's t unpaired test or the Mann-Whitney test to confirm the reliability of the results. It was found a high correlation between the results, thus ensuring the use of the proposed method.

Key words
Automatic Adaptive Filter and RR Intervals Time Series

1 Introduction

Used in the heart rate variability (HRV) analysis [Pagani, 2000; Acharya *et al*, 2006; Convertino, 2009], the sucessive values in the instantaneous heart rate or RR intervals (tachogram), are displayed in a plot showing in the horizontal axis the events over time and in the vertical axis the values of the intervals between heartbeats. In general, the analysis of tachograms or experimental time series requires that these series be properly filtered in a way that excludes ectopic beats or anomalous tachograms.

For sequential analysis of intervals between heartbeats it is essential to remove artifacts (e.g, double recognition), impulses not initiated by the sinoatrial node (ventricular premature complexes - VPC) [Wessel *et al*, 2000] and spurious interference as those due to muscle tremors, poor placement of electrodes, atypical electronics effect on the environment to capture the signal, and so forth.

In analysing heart rate variability it is necessary that the heart rhythm be sinusal (the origin is in the sinus node). Atrial or ventricular extrasystoles (wherein heartbeats are initiated by the atrial or ventricular cells rather than by the sinus node) are not the deciding factor when it comes to the issue of excluding artifacts, but instead several other situations that can make a tachogram unsuitable for analysis. In these situations the "human eye" has been considered the gold standard to discern about the use or not of a particular RR tachogram pattern

The use of an automatic method, yet with the same purpose of the conventional procedure, could be very important to quickly process and analyze a large volume of data. Often displaying artifacts and aberrant outliers, raw biomedical time series can be properly handled by the adaptive filter method. The adaptive filter can self-adjust its parameters according to the input signal [Haykin, 1996; Ingle and Proakis, 1997] and improve its performance over analysis. The main objective of this work is to validate and apply the adaptive filter method for time series of the heart rate variability study considering healthy subjects.

2 Methodology

This section described the data of the HRV used, the conventional and adaptive filters, as well statistics analysis using the measures of the Poincaré plot.

2.1 Time series

In this way, the case series comprise 62 healthy young adults. All tachograms are from databases from previous studies of Transdisciplinar Nucleus for Chaos and Complexity Study [Selig *et al*, 2011; Leal *et al*, 2012]. All theses studies were approved by respective ethic committee. There are time series with 15 minutes up to 1 hour recording period from patients in a supine rest position without visual and sound stimulations. The equipment used was Polar Monitor (S810i or RS800), which has been proven [Gamelin, Berthoin and Bosquet, 2006; Vanderlei *et al*, 2008; Nunan *et al*, 2009] to be feasible and reliable for measuring heart rate variability according to recognized standards [Task Force, 1996]. This device captures RR intervals at a sampling rate of 1000 Hz, by means of electrodes attached to an elastic band placed around the thorax.

2.2 Filter methods

In the conventional filter method, each tachogram was filtered with Polar software. Once the software had indicated 5% or more artifacts, the time series was discarded, except if a better analysis had been carried out by a human evaluator. In the next step, selected tachograms were analyzed through visual inspection by a cardiologist, an occasion when it was possible to remove remaining artifacts.

The visual inspection process used by conventional filter method is very slow and cumbersome because it is required the presence of a specialist and also a huge amount of available data. On the other hand, an automatic filter method allows the data to be preprocessed quickly. In this work, the method used for automatic HRV analysis relies on an adaptive filter [Wessel *et al*, 2000] which takes into account the peculiarities of the signal to be analyzed.

The adaptive filter method, in this work, was applied to interference cancellation, since, the tachogram may be influenced by artifacts, as diverse as Ventricular Premature Complexes (VPCs) and electrode-tissue bad contact, which mischaracterize the sinus rhythm present in the data for HRV analysis.

Following [Wessel *et al*, 2000], the adaptive filter used in this work is based on the adaptive values of the mean and the standard deviation which change and adapt both themselves in a way that follows the variability of the series under analysis. The filtering algorithm comprises three steps.

Briefly, the adaptive filter removes the RR intervals shorter than 350 ms, because they are likely to be equivalent to the absolute or relative refractory periods (during which the heart does not pump) and also because such intervals may represent an increase of the heart rate which turns out to be incompatible with the normal sinus rythm. By the same reason, this step also removes RR intervals longer than 1200 ms.

The basic variability in the series is estimated using a binomial-7 filtered series. Given a tacogram $x_1, x_2, ..., x_N$, where N is the number of the RR intervals, a new filtered series is determined as:

$$t_i = \frac{1}{64} \times (x_{i-3} + 6x_{i-2} + 15x_{i-1} + 20x_i + 15x_{i+1} + 6x_{i+2} + x_{i+3}) \quad (1)$$

After we calculated the mean and deviation standard adaptive and the exclusion rules determining RR interval normal or not normal:

$$|x_i - x_{i-1}| > \frac{\rho}{100} x_{i-1} + a * \bar{\sigma} \quad \texttt{and}$$
$$|x_i - x_v| > \frac{\rho}{100} x_v + a * \bar{\sigma} \quad (2)$$

where ρ (here $\rho = 10$) is a proportional limit and $a * \sigma$ is the 3-sigma generalized rule ($a = 3$), $\bar{\sigma}$ is the mean of σ, and x_v is the last valid RR interval. Not normal values are replaced by random values taken from $[\mu_i - \frac{1}{2}\sigma_i, \mu_i + \frac{1}{2}\sigma_i]$ to maintain the variability of the series upon replacement of a not normal component.

2.3 Poincaré plot

Based on linear and nonlinear dynamics, the Poincaré map is a widely used method for the analysis of RR time series [Brennan, Palaniswami and Kamem,2001; Piskorski and Guzik, 2007; Karmakar *et al*, 2009; Vanderlei *et al*, 2009], considered an important method with features to enable analysis by visual inspection summarizing a series of RR intervals in a figure. Moreover, the Poincaré plot is also a technique that provides quantitative information by measuring separately the standard deviation of instantaneous beat-to-beat RR interval variability (SD1) and the standard deviation of continuous long-term RR interval variability (SD2) as well as the SD1/SD2 ratio [Piskorski and Guzik, 2007].

The quantitative descriptors SD1, SD2 and SD1/SD2 provided by the Poincaré plot were used to compare the results obtained from the two filtering methods (conventional and adaptive). These parameters are directly related to the physiology of the heart and to the autonomic nervous system. The parameter $SD1$ relates to the short range of RR intervals, reflecting the variability of successive intervals, connected to the parasympathetic control of sinus node, whilst $SD2$ relates to long range RR intervals, correlated to the sympathetic control sinus node by the autonomic nervous system [Mourot *et al*, 2004].

2.4 Statistical Analysis

A statistics comparison of two filtering methods with respect to the variables SD1, SD2 and SD1/SD2 was made by using the unpaired Student's t test, and, alternatively, for populations not following the Gaussian distribution the significance test was performed according to the Mann-Whitney procedure. An alpha error of 5% was assumed upon considering that the variables were significantly different for $p < 0.05$.

To validate the proposed method against the conventional method, the degree of correlation (or strength of dependence) between two given variables was assessed by the Pearson correlation coefficient, denoted by *r*, or else by the Spearman's when the relationship between the two variables was to be described by a monotonic function.

Lying between -1 (maximum negative correlation) and $+1$ (maximum positive correlation), $|r| < 0.3$ indicates weak correlation, $0.3 \leq |r| < 0.7$ moderate correlation, $0.7 \leq |r| \leq 1.0$ strong correlation, and $r = 0$ implies no correlation between the variables.

3 Results

Once the equivalent time series had been determined, followed by statistical treatment made with the help of the software *StatsDirect*, the comparative analysis of the filtering methods was easily achieved to give the results which follow.

Figure 1 shows an unfiltered RR time series from a healthy young adult and the same series after being filtered by the two methods presented, i.e, one performed by an expert and the other by using the proposed adaptive filter. We see that the filtered series are very similar to each other, both showing removal of visible artifacts in the unfiltered series. The relative amount of artifacts in the series, given by the ratio of the number of replaced RR intervals to the total number of RR intervals in a tachogram was 2.51% and 0.40%, respectively, for conventional and adaptive filters. As a general rule, a series is considered to have good quality to quantify HRV when containing less than 5% of the beats recognized as artifacts, or equivalently, at least 95% of the total RR intervals arise from normal sinus beats.

Table 1 shows the mean and standard deviation values of the parameters $SD1$, $SD2$ and $SD1/SD2$ for the Poincaré plots of the RR time series filtered using the two filtering methods.

4 Conclusions

Through comparison with the conventional method, which requires the intervention of an expert to remove manually ectopic beats in the processing of HRV time series, the present study has shown that HRV analysis can be done efficiently and at a high speed by using

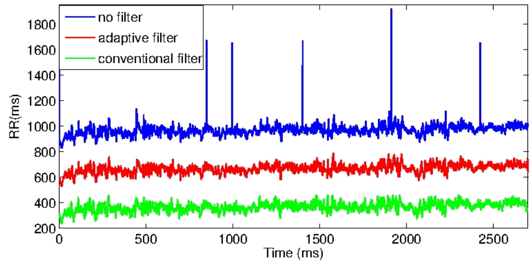

Figure 1. Tachogram of a healthy young adult (medical diagnosis) containing 2700 RR intervals. For better visualization the tachograms are shifted vertically. Note that both filtered tachograms are very similar and show removal of artifacts once present in the unfiltered tachogram. The percentage of artifacts removed by the adaptive filter was 2.51% and the standard filter was 0.40%.

an automatic adaptive filtering method. In addition to facilitating the analysis, the automatic method eliminates any misrecognition that might arise due to visual inspection on the basis of the conventional method.

Applicability of the automatic method was successfully carried out by means of a statistics analysis that showed a strong correlation between the Poincare descriptors evaluated from HRV times series processed in accordance with the two methods taking into consideration 62 RR interval time series of the healthy subjects.

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Table 1. Comparative analysis of the results obtained using the adaptive and conventional filters with reference to variables $SD1$, $SD2$ and $SD1/SD2$ corresponding to healthy young adults. The correlation coefficient (r) of Pearson or Spearman higher than 0.7 indicates a strong correlation. Values of $p < 0.05$ in unpaired Student's t test or Mann-Whitney test indicate that the mean values of the variables in each group are significantly different.

Parameter	Adaptive	Conventional	r	p value
SD1	33.8593 ± 14.3990	37.1512 ± 17.4353	0.9794	0.2578
SD2	85.5807 ± 29.9954	85.4594 ± 30.1717	0.9813	0.9823
SD1/SD2	0.3957 ± 0.1181	0.4317 ± 0.1436	0.9872	0.1325

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