A Comparison between Time Domain HRV Signals

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Abstract. Heart Rate Variability (HRV) is an extended tool to analyse the mechanisms controlling the cardiovascular system. The Integral Pulse Frequency Modulation (IPFM) model is assumed to explain the beat occurrence times generation. Spectral estimate methods try to infer the HRV spectral properties from the available beat timing and the spectrum is usually estimated through the Heart Period (HP), the Heart Rate (HR) or the Spectrum of Counts (SPC) signals. The Heart Timing (HT) signal is presented as a better alternative to the other time-domain signals. The HT signal allows recovering an unbiased estimate of the HRV spectrum avoiding the spurious components and the filtering effect generated when it is analysed through the HP, HR or SPC signals.

1. Introduction

Power spectral density (PSD) estimate of heart rate variability (HRV) is commonly used as a test of the neural cardiovascular system, since it is related with the regulation of the sino atrial node [1]. The integral pulse frequency modulation (IPFM) model generates the beat occurrence times through a modulating signal, $m(t)$, that reflects the neural activity [2]. PSD methods try to infer the spectrum of the $m(t)$ signal, $M(\omega)$, from the beat occurrence times, usually from the Heart Rate (HR), Heart Period (HP) or the Spectrum of Counts (SPC) signals [3]. However, none of these signals exhibit linear dependence with $m(t)$ and then, its spectra will be distorted. In this work, the Heart Timing (HT) signal is used to deduce $M(\omega)$ [4]. Two simulations with known $M(\omega)$ have been developed to compare the PSD estimation methods. The results show how the proposed method is the one that better recovers $M(\omega)$ and then, the more appropriated for HRV analysis.

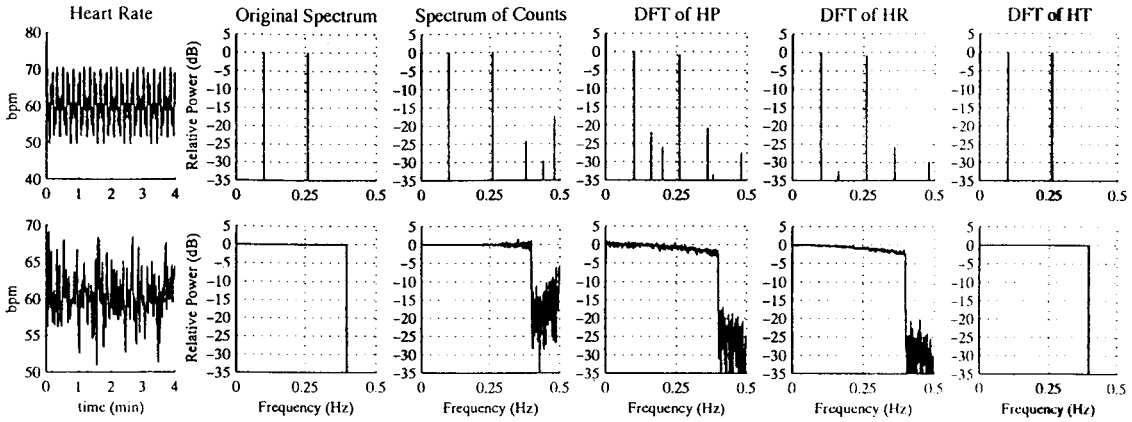
2. The estimation method based on the Heart Timing signal

The continuous time HT signal is defined as the integral of $m(t)$ and its samples can be calculated from the beat occurrence times as $ht(t_k)=k\cdot T-t_k$, where T is the mean heart period in the observation time and t_k is the occurrence time of the kth beat [4]. The spectrum of the $m(t)$ signal can be obtained as $M(\omega)=j\omega\cdot HT(\omega)$ where $HT(\omega)$ is the spectrum of the $ht(t)$. The unevenly sampled $ht(t_k)$ signal is previously interpolated at regularly spaced time intervals by means of fourteenth order spline interpolation. A fourteenth order is used to minimise the low pass filtering effect due to the interpolation. Then, $HT(\omega)$ is calculated by means of the Fast Fourier Transform (FFT).

3. Comparative analysis

Two simulations are carried out to compare the PSD estimation methods. The former is considering that the $m(t)$ is a two tone signal with frequencies of 0.1 Hz and 0.26 Hz. In this case the estimated spectra clearly will reflect the spurious contribution of each method. The latter is considering that $m(t)$ has a flat PSD from 0 Hz to 0.4 Hz. The phase spectrum is taken to be uniformly distributed between $-\pi$ and π to achieve a stationary $m(t)$ signal. This

Figure 1. Spectral estimates of the modulating signal. Each row shows each simulation case. First column shows the heart rate, second column shows $M(\omega)$ and following columns show different estimates of $M(\omega)$.



case will show the filtering effect of each method in the clinical band of interest. These $m(t)$ signals acting through the IPFM model generate beat sequences that will be analysed with different methods based on the SPC, HP, HR and HT signals to estimate $M(\omega)$. In both cases, the simulation has been performed with 1000 beats with a mean heart period T = 1 s.

Figure 1 shows the obtained results. The first row shows the results for the two tone $m(t)$ signal and the second one shows the results for the second case. The first column shows the simulated heart rate (4 min). The second column shows $M(\omega)$ that is the objective to estimate and the following columns show the PSD estimate of each method . These graphs represent the relative spectral power in decibels to reveal the distortion introduced by each method. The first simulation shows the spurious components introduced by the HP, HR and SPC signals due to their lack of linearity and how the estimate based on the HT signal remains free of spurious. The second simulation evinces the high frequency power introduced by the SPC method, the low pass filtering spectra obtained with the HP and HR signals and the accurate recovery of $M(\omega)$ by the described HT method.

4. Conclusion

The Heart Timing signal has demonstrated to be a better alternative to estimate the PSD of HRV assuming the IPFM model. The proposed method based on the spline interpolation of the Heart Timing signal recovers accurately the original spectrum since the Heart Timing signal does not generate spurious spectral components and has no filtering effect. Then, the information obtained from this estimate more accurately recovers the information present at the modulating signal, as is the clinical objective of any PSD estimation method of HRV.

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