Respiratory Frequency Estimation from Heart Rate Variability Signals in Non-Stationary Conditions Based on the Wigner-Ville Distribution

Eva Cirugeda, Michele Orini, Raquel Bailón and Pablo Laguna*

Aragon Institute for Engineering Research (I3A), Universidad de Zaragoza, Zaragoza, Spain

Respiratory sinus arrhythmia is a modulation of heart rate synchronous with respiration, which allows the estimation of respiratory frequency from the high frequency (HF) component of heart rate variability (HRV). The extraction of the respiratory frequency from the maxima of the smoothed pseudo Wigner-Ville distribution (SPWVD) is challenging, since the time-frequency smoothing used to suppress the interference terms of the WVD introduces an estimation error which can be high both in mean and standard deviation. Additionally in non-stationary conditions the error can be augmented due to the non-linear trend of the instantaneous frequency (IF). In this study the respiratory frequency is estimated from the HF band maxima of the SPWVD of the HRV signal. The algorithm adjusts the degree of frequency filtering (time-lag window length) to the time-frequency structure of the signal, in order to reduce the estimation error of the IFs. The optimal time-lag window length, at each time instant, depends on the instantaneous amplitude estimates of the signal components as well as on the noise present in the signal. The instantaneous amplitude is estimated independently of the time-frequency smoothing by deconvolving and correcting the instantaneous power estimates. The instantaneous power of the signal components is obtained by bounded integration of the SPWVD. The method has been evaluated on simulated HRV signals with time-varying amplitudes and non-linear frequency trends, obtaining a mean amplitude error of -0.319 $\pm$ 4.694% and a mean frequency error of -0.314$\pm$4.059% (0.07$\pm$11.0 mHz) for a SNR of 20 dB. A database containing the ECG and respiratory signals simultaneously recorded for 58 subjects during the listening of different musical stimuli has been analyzed. The method estimates the respiratory frequency with a mean error of

-0.217$\pm$15.181% (-2.38$\pm$ 39.8 mHz) during musical stimuli and of

-0.262$\pm$28.542% (-6.92$\pm$73.74 mHz) during transitions between stimuli, which are highly non-stationary and non-linear.