Signal Processing Methods For Heart Rate Variability Analysis

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Heart rate variability (HRV), the changes in the beat-to-beat heart rate calculated from the electrocardiogram (ECG), is a key indicator of an individual's cardiovascular condition. Assessment of HRV has been shown to aid clinical diagnosis and intervention strategies. However, the variety of HRV estimation methods and contradictory reports in this field indicate that there is a need for a more rigorous investigation of these methods as aids to clinical evaluation. This thesis investigates the development of appropriate HRV signal processing techniques in the context of pilot studies in two fields of potential application, sleep and head-up tilting (HUT).

A novel method for characterising normality in the ECG using both timing information and morphological characteristics is presented. A neural network, used to learn the beat-to-beat variations in ECG waveform morphology, is shown to provide a highly sensitive technique for identifying normal beats.

Fast Fourier Transform (FFT) based frequency-domain HRV techniques, which require re-sampling of the inherently unevenly sampled heart beat time-series (RR tachogram) to produce an evenly sampled time series, are then explored using a new method for producing an artificial RR tachogram. Re-sampling is shown to produce a significant error in the estimation of an (entirely specified) artificial RR tachogram. The Lomb periodogram, a method which requires no re-sampling and is applicable to the unevenly sampled nature of the signal is investigated. Experiments demonstrate that the Lomb periodogram is superior to the FFT for evaluating HRV measured by the $\frac{\mathrm{LF}}{\mathrm{HF}}$-ratio, a ratio of the low to high frequency power in the RR tachogram within a specified band (0.04–0.4Hz). The effect of adding artificial ectopic beats in the RR tachogram is then considered and it is shown that ectopic beats significantly alter the spectrum and therefore must be removed or replaced. Replacing ectopic beats by phantom beats is compared to the case of ectopic-realted RR interval removal for the FFT and Lomb methods for varying levels of ectopy. The Lomb periodogram is shown to provide a significantly better estimate of the $\frac{\mathrm{LF}}{\mathrm{HF}}$-ratio under these conditions and is a robust method for measuring the $\frac{\mathrm{LF}}{\mathrm{HF}}$-ratio in the presence of (a possibly unknown number of) ectopic beats or artefacts.

The Lomb periodogram and FFT-based techniques are applied to a database of sleep apnœic and normal subjects. A new method of assessing HRV during sleep is proposed to minimise the confounding effects on HRV of changes due to changing mental activity. Estimation of $\frac{\mathrm{LF}}{\mathrm{HF}}$-ratio using the Lomb technique is shown to separate these two patient groups more effectively than with FFT-based techniques. Results are also presented for the application of these methods to controlled (HUT) studies on subjects with syncope, an autonomic nervous system problem, which indicate that the techniques developed in this thesis may provide a method for differentiating between sub-classes of syncope.

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