Wavelet Analysis of Biosignals: From Pretty Pictures to Product

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Introduction: The determination of a clinically useful physiological parameter is a distinctly non-trivial task. Aside from the core algorithm at the heart of the parameter (e.g. the ratio of ratio for pulse oximetry, the determination of cyclical modulation for respiration rate, the modulation strength for fluid responsiveness), a sophisticated algorithmic infrastructure is required. This takes the raw biosignal, processes it, presents it to the core algorithm, then applies further processing to the output in order to produce a value with the integrity necessary for display on the screen of a medical monitoring device [1]. This infrastructure generally includes a number of pre-processing and post-processing code modules, as well as alarm management systems, hardware interface routines (including signal acquisition processes), and often involves thousands of lines of computer code. These advanced filtering and logical decision making processes are inherent in all monitoring devices. However, the genesis of a new parameter often involves a "softer" side of signal processing where the tools involved need to inform the researcher at the conceptual level.

Method: A technique employed by the author involves decomposing the signal in order to decouple the various underlying components (including: cardiac pulse, respiratory modulations, movement artifact, blood pressure effects, vasomotion effects and electronic noise). Often these constituent elements involve a complex super-positioning within the signal not amenable to traditional filtering. A method providing strong decoupling should ideally render hidden signal information visible to the naked eye. Although a number of tools exist to perform signal decomposition, including the short time Fourier transform, phase space representations, principle and independent component analysis, the author has found the continuous wavelet transform (CWT) optimal in this regard [2].

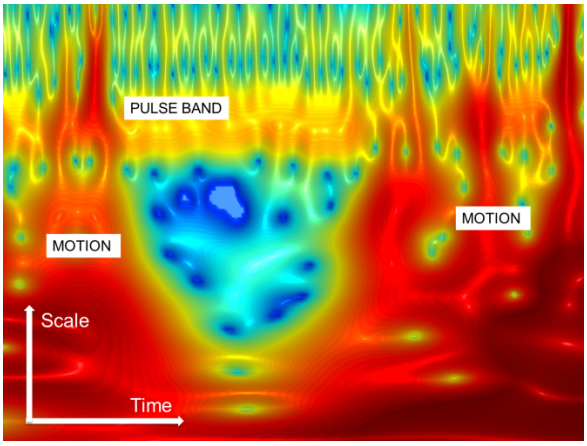

Figure 1: Wavelet Transform Modulus of a Noisy Neonatal Signal

Figure 1 contains a wavelet transform modulus representation (a scalogram) of a photoplethysmogram ('pleth') acquired from a neonate. The pulse band present in the top portion of the plot (yellow) corresponds to the cardiac pulse components of the original signal. Motion manifests itself as dominant (red) structures within the time-scale plot. The decoupling of this noisy signal in this way allows a rapid comprehension of the temporally complex interaction of signal components and aids the formation of signal processing options for attacking the problem at hand. From figure 1, we can clearly see that extraction of the pulse information should be

possible from this noisy signal: useful for the determination of both pulse rate and oxygen saturation [3], and, with further sophisticated processing, respiration rate [1].

Results: The wavelet transform visualization tool was critical in driving the success of the commercial pleth-based Respiration Rate algorithm developed by the author and colleagues (RRV.1.0, Covidien, Boulder, CO, USA). The method provided crucial insights into the multiple respiratory modulations contained in the pleth waveform (baseline modulation, cardiac pulse amplitude and frequency modulations [1]). Elements of the advanced wavelet-based signal processing were, in fact, incorporated within the final algorithm.

Conclusion: The continuous wavelet transform is well known to be a powerful tool used in the development of signal processing strategies for optimizing information. It is an integral part of numerous signal processing algorithms, finding use across disciplines in, for example, the analysis of geophysical flows, astronomical time series, engineering vibration signals, financial indices, etc. [2]. In the medical arena it has found particular use in the analysis of many biosignals [4], including: the ECG [5], EEG, photoplethysmogram [1,3], phonocardiogram, electromyogram, blood pressure signal, upper airway sounds, etc. Here, however, the author promotes its "upstream" use as a soft tool to aid the comprehension of biosignals, where it may provide a particular useful technique for initiating and driving the development of physiological parameters by providing rapid visualization of the underlying components of the signal. The method aids comprehension of the signal characteristics; provides insight into the feasibility of the underlying task; and, facilitates the development of signal processing strategies for attacking the problem to be solved.

References:

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