Running Wavelet Archetyping for Enhanced Detection of Cardiac Pulse Signal Components

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Introduction: Pulse oximeters display two important parameters: SpO2 and Pulse Rate (PR). During clinical use, deviations of these parameters outside of threshold settings drive alarms on the device. However, the performance of pulse oximeter-based PR often receives less attention than SpO2. The posting of erroneous PR values could, however, have serious consequences, such as increasing the number of false alarms, providing false reassurance, prompting unnecessary interventions, or generally undermining the credibility of the oximeter altogether [1]. Thus accurate detection of the pulse component in the photoplethysmogram (pleth) is of critical importance in the design of a pulse oximeter. Here, a novel time-frequency archetyping method for detecting the cardiac pulse component within a pleth is described.

Method: In order to monitor a repeating pulse feature within a signal we may build up a characteristic, or archetype, signal segment which is representative of the waveform. We may average beats within the vicinity of each other or use an IIR scheme were we build up an archetype by adding a weighted value of the most recent waveform to the current 'running' archetype. Such methods require that fiducial points are detected on each waveform (e.g. beginning and end point) in order for it to be extracted, aligned and used to update the running archetype. Errors in fiducial detection due to signal noise may make it very difficult for such schemes to work well and perform consistently in practice.

The proposed method is based on the wavelet transform of the signal. This produces an unfolding of the signal information in the time-frequency plane, providing a superior view of the signal compared to the Fourier transform, which comprises a spectral-only interpretation [2]. In the proposed method a running wavelet archetype $T_{rwa}(a,b)$ is generated using a weighted averaging scheme as follows:

$$T_{rwa}(a,b)=w.T(a,b) + (1-w).T_{rwa}(a,b-P(a)) \qquad [1]$$

where w is the weight, $T(a,b)$ is the currently computed wavelet transform at scale a and dilation b, and $T_{rwa}(a,b-P(a))$ is the previous archetype value separated from the current value by a scale dependent period $P(a)$. Each time a wavelet transform value is computed it is used with the previous archetype transform value to form a new value of the archetype transform. In the method, the delay time $P(a)$ is set to the natural period of the wavelet at each scale considered, thus there is no requirement for the determination of fiducial points as the wavelet information is naturally 'rolled up' at each scale using $P(a)$.

Results: Figures 1 and 2 illustrate the method. The top plot is a scalogram of a pleth computed using a Morlet wavelet [3]. The signal, acquired as part of an ad hoc bench study on the author, is relatively poor and the pulse band is barely seen across the scalogram. The archetype scalogram is shown in figure 2. The pulse band across the top part of the archetype scalogram is much more distinct than that of the original scalogram and many of the breaks in the pulse band have now merged. This is particularly obvious in the segments outlined by the two boxes in figure 1. It can be observed that the pulse band in the running wavelet archetype of figure 2 is continuous across these periods. This facilitates the extraction of the frequency of the pulse (PR) in the time-frequency domain.

Conclusions: A method has been developed to optimize the detection of the pulse component within a photoplethysmographic signal by employing a novel running wavelet archetyping method. This method will aid in the determination of the pulse rate in difficult monitoring conditions. Additionally, the method is particularly novel in that there is no requirement for the determination of fiducial points as the wavelet information is ‘rolled up’ at the natural period of each scale. This is important as the identification of fiducial points is often the main cause of errors in traditional signal averaging techniques. Note that, as the signal component of interest moves to another scale (for example a pulse band moving due to a change in heart rate), more energy appears in the transform at that scale and thus, through the archetyping process, a new dominant component of the archetype will evolve at the new scale. It is suggested that the method may be used with other transformations which provide realizations of signals at multiple scales where an intrinsic period or periods may be determined.

References

[1] Addison P.S., Mannheimer P.D., Ochs J., ‘Pulse Rate Performance of Two Pulse Oximeters during Challenging Monitoring Conditions’. Covidien White Paper, 2014.
[2] Addison PS. ‘The Illustrated Wavelet Transform Handbook’. New York: Taylor & Francis; 2002.
[3] Addison P.S., J.N. Watson and T. Feng, ‘Low-Oscillation Complex Wavelets’. Journal of Sound and Vibration, 2002, 254(4): 733-762.

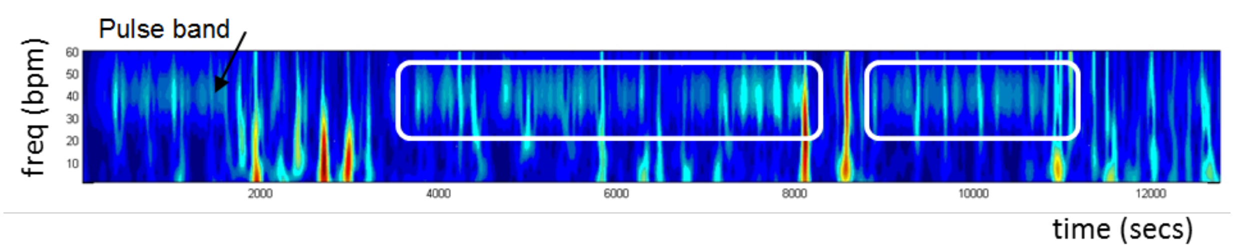

Figure 1: Wavelet Transform Scalogram of a Pulse Oximeter Photoplethysmogram

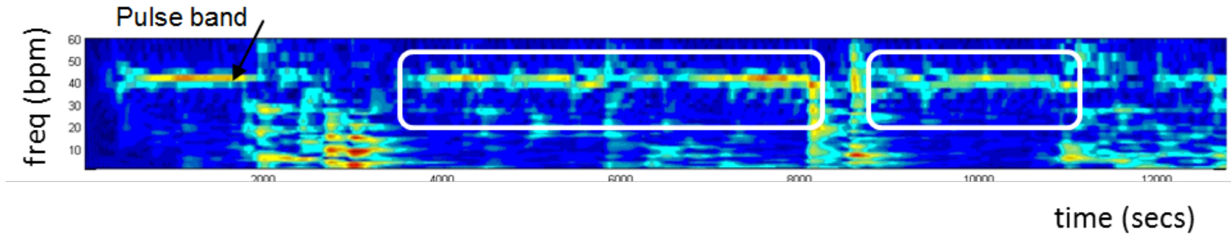

Figure 2: Running Wavelet Archetype Corresponding to the Scalogram of Figure 1.