A Data Fusion Approach for RR estimation from PPG (STA Engineering Challenge)

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Introduction

Respiration can modulate the intensity, frequency and amplitude of the photoplethysmogram (PPG) waveform [1]. During respiration, the pressure variation in the thoracic cavity causes blood to be exchanged with the pulmonary circuit, resulting in a baseline perfusion variation (intensity variation). There is a corresponding decrease in cardiac output due to reduced ventricular filling, causing an amplitude variation in the peripheral pulse. Also, there is an autonomic response, where the heart rate (HR) variation synchronizes with the respiratory cycle, causing a respiratory induced frequency variation of the PPG waveform. Physical experiments demonstrate varying levels of correlation between the individual respiratory-induced variations of the PPG signal and the reference respiratory measurements [1]. To solve the **STA Annual Meeting 2012 Engineering Challenge,** we suggest improving the predictive value of the non-invasive estimation of respiratory rate (RR) from the PPG by calculating the measurements of the three individual variations and using a data fusion method based on spectral signal quality indices.

Method

The data sets obtained for the engineering challenge were all resampled to 100 Hz and the dominant HR frequency was determined using a Fast Fourier Transform (FFT). The PPG signal was then passed through a 12^{th} order, low-pass elliptic filter with a cut-off frequency set at 1.2 * HR. Then, the derivative of the filtered waveform was computed and its peaks were identified as the inflection point of each pulse, which was subsequently detected. False positives and false negatives in the detected pulses were corrected by using pulse amplitude and interval as verification criteria. The respiratory-induced frequency variation and amplitude variation were determined by calculating the time interval between each pulse and the amplitude of each pulse respectively, and passing the resulting waveforms through a 6^{th} order, low-pass elliptic filter with a cut-off frequency set at 0.8 * HR. To obtain the intensity variation, the raw PPG signal was passed through a 10^{th} order, low-pass elliptic filter with a cut-off frequency set at 0.8 * HR. The RRs from the three waveforms were calculated using FFT and the best estimate was selected using a data fusion method based on spectral signal quality indices. For each dataset, the RR was calculated over a 60 s time period and updated every 10 s.

Results

Implementation: The algorithm was developed in Matlab and structured so that it could be easily adapted to C code, and subsequently implemented in an embedded system. Time-frequency methods were avoided to minimize algorithm complexity and processing speed. The beat detection algorithm and low-pass filters were responsible for the bulk for the computational demands and can easily be implemented in an online, recursive manner.

Computation time: The average computation time divided by the LINPACK benchmark time for processing one-minute data windows sampled at 100 Hz was 2.825. The average raw computation time was 0.254 s, easily allowing for an online implementation where the RR can be updated every second.

Accuracy*:* The mean predicted RR for the given data sets is presented in tables 1 and 2. For validation datasets #2-4, the RR was derived from the intensity waveform. For validation dataset #1, the RR was derived from the amplitude waveform.

Table 1. Training Dataset

	Training Data Set			
	1_Cardi	2_Crani	3_LBNP	4_Shoul
Avg Predicted RR (Breaths/min) ± STD	10.88 ± 0.20	10 ± 0	9 ± 1.16	9.46 ± 2.25
Avg Reference RR (Breaths/min) ± STD	11 ± 0	10 ± 0	12 ± 0	10 ± 0
Root Mean Square Error	0.51	0	3.16	2.27

Table 2. Validation Dataset

	Validation Data Set			
	1_Dataset	2_Dataset	3_Dataset	4_Dataset
Avg Predicted RR (Breaths/min) ± STD	13.67 ± 0.5	10 ± 0	11 ± 0.45	9.63 ± 1.15

References:

1. Li J et al. Comparison of respiratory-induced variations in photoplethysmographic signals. Physiol Meas. 2010;31(3):415-25.