Original Article

WIRELESS COMMUNICATION BASED HEART RATE DETECTION USING WEARABLE DEVICE

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Abstract

Estimation of heart rate is a challenging task from PPG (photoplethysmographic) signal, as motion artifacts gets included during physical activities. The focus of this research work is to automatically estimate the heart rate of the person based on digital signal processing, where this approach is able to classify, process and analyze vital physiological signals for the application of health monitoring in long term. This work presents a novel approach, exploiting Adaptive Wiener filter for attenuating and removal of motion artifacts with a phase vocoder for refining the estimate of Heart Rate (HR). Two PPG signals and three accelerometer signals are obtained from the wearable device in the form of wrist band, are first preprocessed before applying to the adaptive wiener filter. Physionet database that is available publically with 12 PPG recordings is considered for analyzing the performance of the novel estimation of HR system. Ultimately, heart rate estimation is done based on subsequent detection algorithm. MATLAB implementation of the proposed method is able to achieve an average absolute error of 1.08 BPM (Beats per Minute). Correlation coefficient between estimated heart rate and true heart rate is obtained as 0.997. Fine tuning of spectral peak is achieved in this work which is accurately tracked for estimation of heart rate.

Keywords: Motion Artifacts, Phase Vocoder, Estimation, Adaptive Wiener Filter.

Introduction

In the current decade, world is transformed due to usage of wearable devices as these wearable systems are of light weight and can operate in real life applications. Such wearable systems can monitor heart rate and respiratory rate hence applicable in medical applications [1]. These systems utilize various sensors such as oximeter, electrodes, accelerometer able to sense bio-signals [2-4]. Among which photoplethysmography (PPG) is a non-invasive technology for tracking heart rate when the user is in motion. Tracking of heart rate based on PPG is a major challenge due to presence of motion artifacts (MA), as the signal is degraded masking the peak of the heart rate in the spectra. Real time analysis of PPG signals requires removal of motion artifacts in order to provide good performance. The optical technique which can detect changes in blood volume in the tissues is the concept of PPG which involves a pulsating AC signal with a DC component that varies slowly. The synchronous blood volume changes related to cardiac movements is reflected by the AC component that occurs due to heart beat, while the respiration effects is reflected by the DC component [5]. Conventionally Estimation of heart rate is done by applying Fourier methods on AC signal of the PPG waveform which is not the optimal method as the PPG waveforms are non-stationary in nature.

Also the signal quality is strongly affected by the motion artifacts, making them unusable as shown in figure 1. Hence in order to exploit the usage of PPG sensors, improvements are required to remove motion artifacts from PPG signals [6-8]. There are several approaches for identification and removal of motion artifacts from PPG signals. Some methods involve data processing in frequency domain that includes component analysis independent of frequency domain, analysis based on fourier series, Wigner Ville pseudo distribution. Another way to reduce motion artifacts is to implement adaptive filtering of PPG signals [9]. LMS (Least Mean Square) algorithm and its variants was tested utilizing synthetic noise as noise reference or accelerometer (ACC) signals to attenuate motion artifacts [10-12]. Researchers have found from their analysis that singular value decomposition and Fourier analysis are efficient in removing motion artifacts without hardware such as cycle by cycle or accelerometer. During physical activities, effective monitoring of heart rate is possible only if the motion artifacts are removed [13-15].

Figure 1(a) PPG Signal Segment without Motion Artifacts

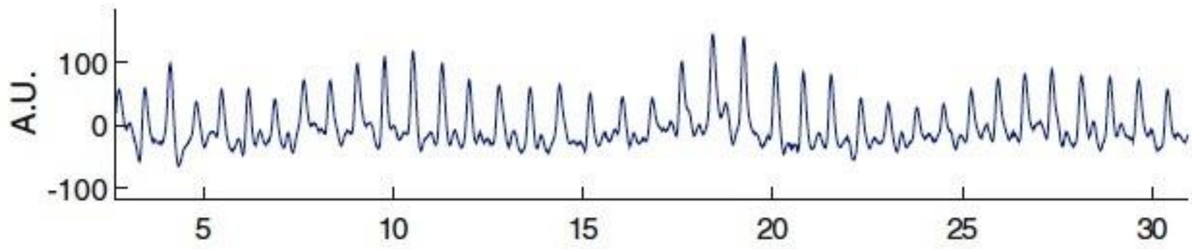
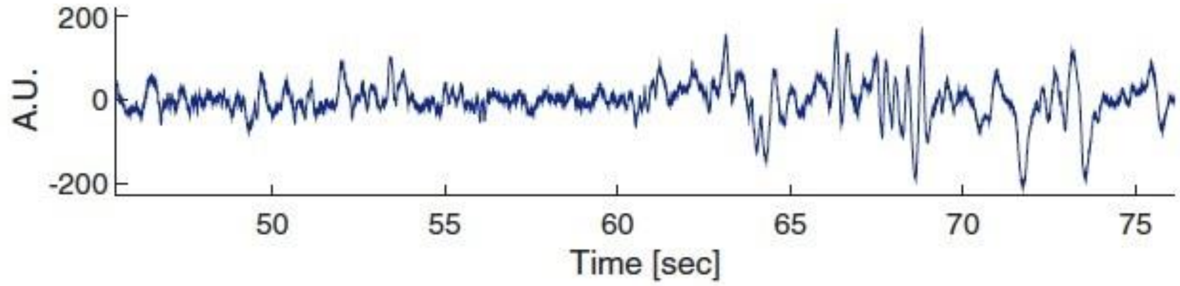


Figure 1(b) PPG Signal Segment with Motion Artifacts

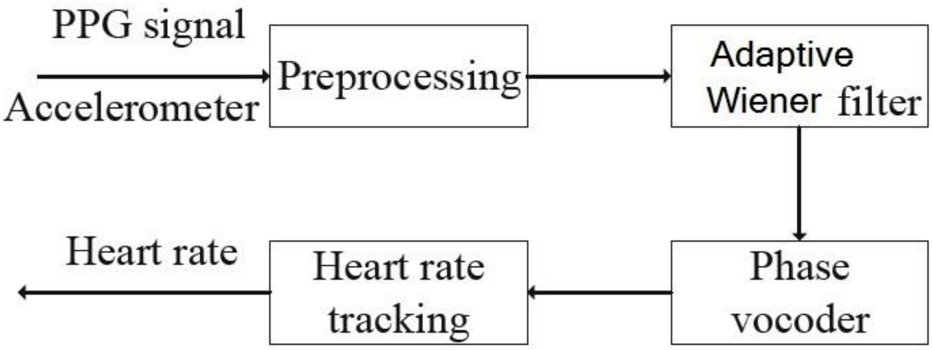


Several approaches are proposed for the estimation of heart rate monitoring using ACC signals and PPG signals while involved in physical exercise. In one of the approach, denoising is done based on signal decomposition then reconstruction of sparse signal and tracking of peak of the spectral [16-18]. Reconstruction of sparse signal generates a spectrum of high resolution in this approach of heart rate estimation where tracking of spectral peak involves initialization, selection of peak of the spectra and verification [19-21]. Also identification of spectral coefficients improves identification and removal of spectral peaks which corresponds to motion artifacts on the sprectrum of PPG based on sparsity constraint. Tracking of spectral peak is successful only if the initialization process is done properly [22-24]. Hence to overcome this issue, tracking of spectral peak is done using multiple schemes of initialization for removal of motion artifacts by adaptive noise cancellation. Once after which the combination of heart rate trajectories provides accurate estimation of heart rate. In one of the approaches, recursive least square filter is utilized as adaptive filtering for the removal of motion artifacts [25].

Proposed method

The proposed method estimates heart rate by utilizing the raw signals of PPG along with simultaneous acceleration signals of tri-axis. The PPG signals and the simultaneous acceleration signal are slide using a time window whose length is about 8 seconds that increments in each step by 2 seconds. Estimation of heart rate is done in time window. The noise in the PPG signals and tri-axis acceleration signals can be eliminated by adopting preprocessing process of these signals using a second order bandpass Butterworth filter whose cut off frequencies varies between 0.4 Hz and 4 Hz. Preprocessing of the signals involves both filtering and scaling of the signals. Estimation of the heart rate is done using adaptive Wiener filter along with phase vocoder. Adaptive wiener filter suppresses noisy signal components occurring due to motion artifacts in the PPG signal, while phase vocoder is used to refine the spectral estimation by advancing the frequency resolution. The overall architecture of the proposed work is as shown in figure 2.

Figure 2. Proposed Block Diagram for Monitoring of Heart Rate



A. Preprocessing

In the preprocessing stage, firstly filtering is done for the combination of two signals of PPG and three signals of accelerometer using second order bandpass Butterworth filter whose cut off frequencies ranges from 0.4 Hz to 4 Hz. Normalization of the two PPG signals is done to attain zero mean value and variance as unity, which are then averaged. Further processing is done by averaging PPG signals and accelerometer signals where down sampling is done from 125 Hz to 25 Hz. Discrete Fourier Transform is applied to the down sampled signals with the bins being 1024 in number.

B. Suppression of Noise

Once after preprocessing of signal, noise suppression is required in PPG signals as these PPG signals are corrupted due to the addition of noise as a result of motion artifacts leading to corrupted signal. In this work, adaptive wiener filter is utilized for removal of motion artifacts. Signals can be popularly enhanced using adaptive wiener filter whose basic purpose is filtering of signal corrupted due to additive noise. Let clean PPG signal is represented as S(n), additive noise due to motion artifact is represented as N(n), then the corrupted PPG signal R(n) can be represented by equation (1).

$$R(n) = S(n) + N(n) \qquad (1)$$

In our work, adaptive wiener filter is utilized for removal of motion artifacts. Adaptive wiener filter is utilized mainly to minimize mean square error (MSE) between the clean PPG signal and the corrupted PPG signal. The error between these two signal is represented by equation (2).

$$e^2 = E[(S(n) - S^\wedge(n))^2] \quad (2)$$

Initial assumption of adaptive wiener filter is that it is a zero mean noise with a variance value of $\sigma^2 n$ and it is by no way correlated with the clean PPG signal S(n). Based on these assumptions, variance and the mean value can be obtained as represented in equation (3) and (4) respectively.

$$\sigma^2 = \frac{1}{XY}\sum_{n,\varepsilon,k} S^2(n) - \mu^2 \quad (3)$$

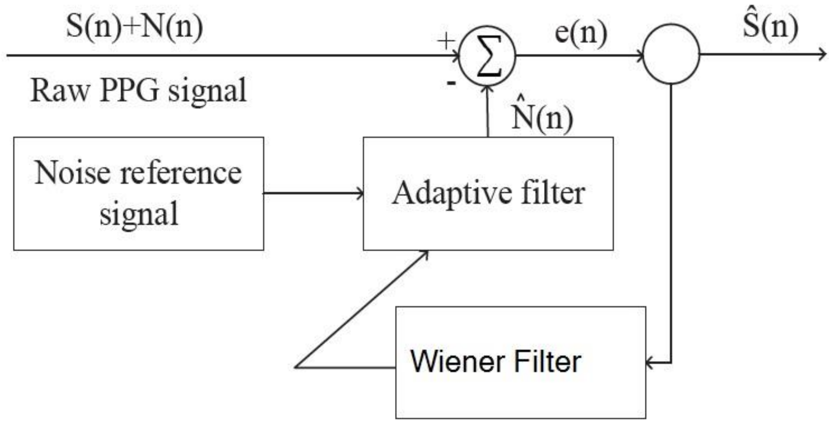
$$\mu = \frac{1}{XY}\sum_{n,\varepsilon,k} R(n) \quad (4)$$

Thus the estimated PPG signal obtained from Adaptive wiener filter is represented by equation (5).

$$R^n = \mu + \left[\frac{\sigma^2 - \sigma^2 n}{\sigma^2}\right](S(n) - \mu) \quad (5)$$

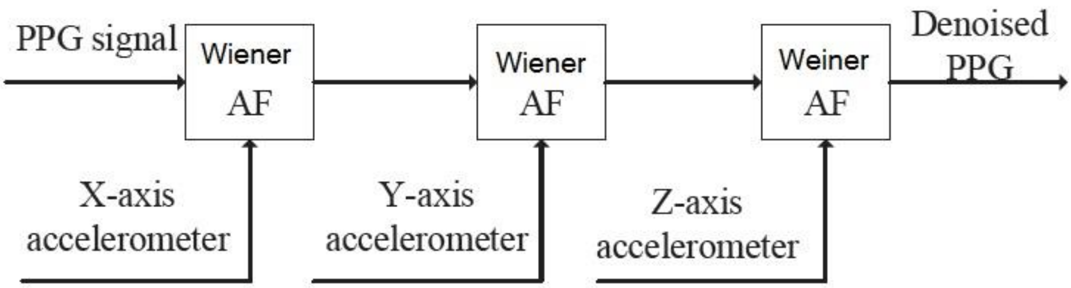
Where e(n) represents estimated error and σ & μ are constants. The PPG signals are commensurable with accelerometer signals only when the two PPG signals are normalized along with three accelerometer signals to a mean value of zero and standard deviation as unity value. The three signals from X, Y & Z axis of the accelerometer in sequence acts as reference noise signal reflecting motion artifacts. The structure of adaptive wiener filter is as shown in figure 3.

Figure 3. Structure of Adaptive Wiener Filter



Architecture of adaptive wiener filter with input as PPG signal and accelerometer signal generating denoised PPG signal by removal of motion artifacts is as shown in figure 4.

Figure 4. Architecture of Adaptive Wiener filter



C. Phase Vocoder

Initial frequency of the PPG signal obtained from adaptive wiener filter is computed by exploiting each frame using Fast Fourier Transform. Spacing of frequency between FFT bins is decreased by utilizing large number of frames such that resolution of FFT is advanced based on the technique of phase vocoder.

D. Tracking of Heart Rate

Estimation of initial heart rate is done based on the first frame which is obtained by searching of initial frequency with highest amplitude in the frequency range of 0.8 Hz to 3 Hz. Subsequently estimation of heart rate in a particular range is obtained based on previous estimation of heart rate. Determination of subsequent heart rate is based on the equation (6).

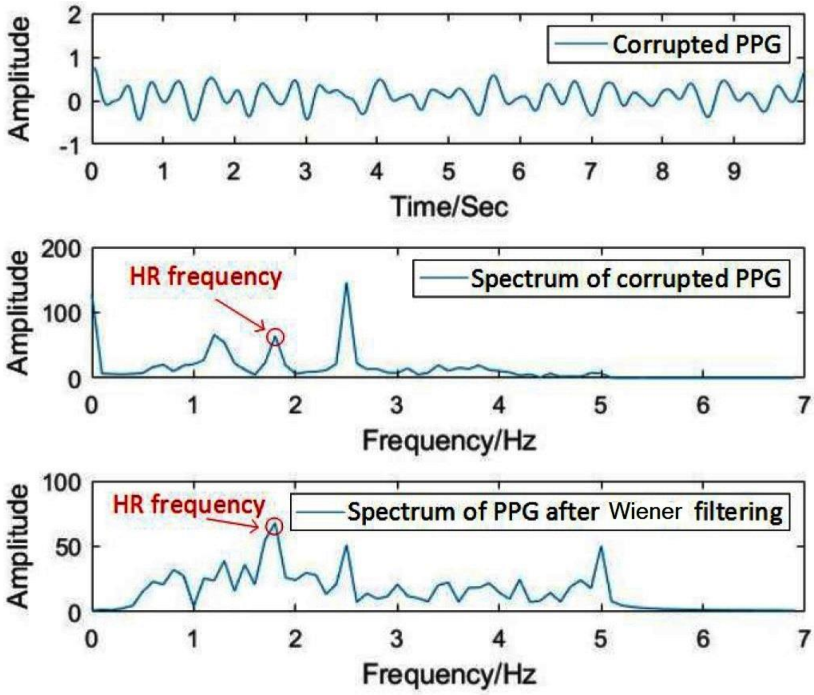
$$SRi = \max|HR(t) - HR(t-1)| + 6 \quad (6)$$

The absolute maximum value of difference between the estimate of heart rate of current frame and previous heart rate estimate added to 6 provides the current estimate of heart rate.

Results and Discussion

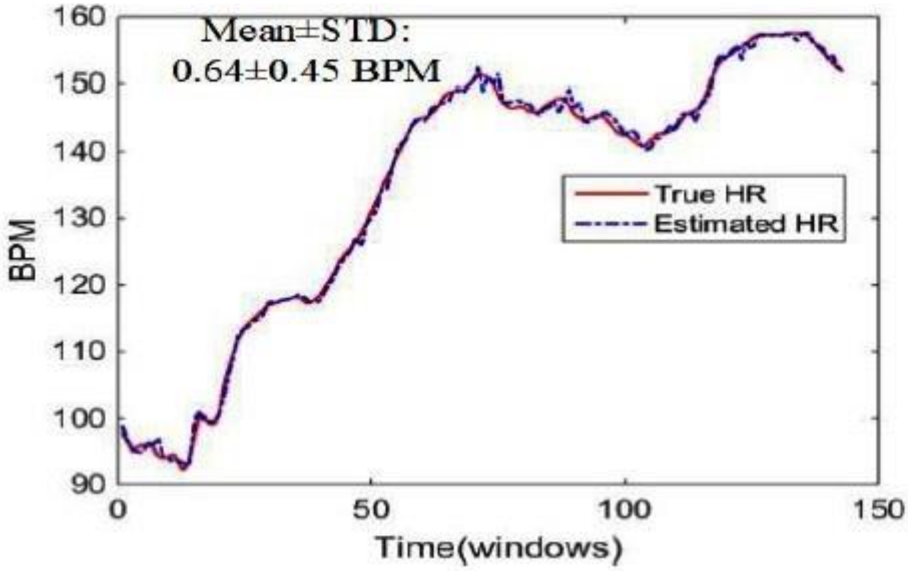
The dataset used in this paper is Physionet dataset which has recorded PPG signals from 12 subjects while involved in different physical exercises. The signal collection is done as these subjects used 2 channel wearable PPG device embedded in a wrist band along with a accelerator sensor consisting of three channels. Simultaneously, the ground truth is extracted using wet electrode fixed on chest of the subject for the estimation of heart rate. Removal of motion artifacts using adaptive wiener filter is as shown in figure 5, where the PPG signal is corrupted due to motion artifacts. The corrupted signal spectrum along with the denoised spectrum of PPG signal after filtering through adaptive wiener filter is also represented.

Figure 5. Removal of Motion Artifacts using Adaptive Wiener Filter



The true heart rate value and the estimated heart rate value for recording of 9th subject is as shown in figure 6. It is obtained based on adaptive wiener filter where the absolute error's mean ± standard deviation value is obtained as 0.64 ± 0.45 BPM (beats per minute).

Figure 6. Estimated and True Heart Rate of 9th Subject



Conclusion

An effective method, implemented in a simple way for heart rate monitoring during physical exercise is represented. The motion artifacts added during physical exercise as additive noise to PPG signals and accelerometer signals is removed using adaptive wiener filter. The combination of PPG signals and acceleration signal are obtained from wearable wrist band fitted with accelerometer sensor fitted along with the wrist band. Resolution of the frequency of the denoised PPG output signal is subsequently increased by utilizing phase vocoder. Ultimately a simple peak selector is utilized for selecting one threshold value from the spectrum in order to tract heart rate. This method obtains a mean ± standard deviation as 0.64 ± 0.45 BPM (beats per minute).

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