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A NOVEL METHOD FOR MOTION ARTIFACT REMOVAL IN WEARABLE PPG SENSORS BASED ON BLIND SOURCE SEPARATION

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Abstract: *The recent development of healthcare systems has provided a significant contribution to ambulatory patient monitoring. In that context, signal quality and disturbances induced by noise or motion artifacts play an important role in the field of signal processing tasks. Especially the Photoplethysmogram (PPG) is very liable to movement artifacts which severely hamper the extraction of vital parameters like the heart rate or oxygen saturation. To record patient movements, an innovative sensor system is proposed, which acquires accelerometer data next to the PPG. As in Adaptive Noise Cancelers, we propose to use the acceleration as reference to recover corrupted PPGs by means of the Blind Source Separation. Sophisticated methods of ICA have been used, resulting in a novel approach for artifact suppression in the PPG that has been tested on laboratory datasets.*

Keywords: *Blind Source Separation, Motion Artifacts, Body Sensor Network, ANC, ICA*

Introduction

Transmissive PPG systems basically consist of a finger clip which contains at least a red and infrared LED, emitting light through the finger to a photodetector [1]. Additionally equipping this finger clip with an accelerometer is a neat way to acquire a movement reference signal which has already been proposed by different groups in the literature [2] [3].

Prior to any signal processing tasks and their subsequent evaluation, considerable effort is put in preprocessing procedures, aiming at the removal of unwanted signal disturbances. As is well known, common filtering techniques like lowpass and highpass filters fail in reconstruction tasks when the components of signal and noise overlap in the frequency domain or the noise has a non-stationary nature [4]. The Adaptive Noise Cancelation (ANC) as shown in Figure 1, constitutes a thoroughly tested approach in PPG preprocessing, to cancel out unwanted signal components, that correlate with the reference signal which itself is provided by the accelerometer [2] [5].

These ANC implementations seem to achieve reasonable results in terms of increased signal-to-noise-ratios (SNR) of the reconstructed signal. In real applications however, these algorithms still experience difficulties in their tasks of reliable artifact suppression.

Alternatively, the more sophisticated method of Blind Source Separation has been proposed as a powerful approach to noise reduction by means of separating the independent components of the acquired signals [4] [6].

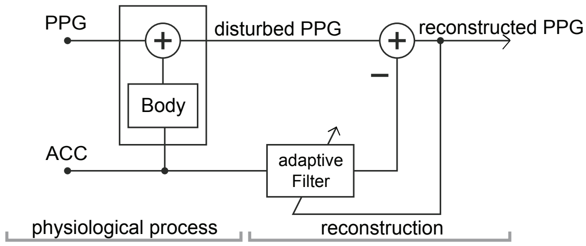

Figure 1: ANC with acceleration reference [5]

Methods

Independent Component Analysis

Basically, the ICA approaches try to find an estimated solution of the generative linear model

$$\mathbf{x} = \mathbf{A}\mathbf{s} \tag{1}$$

where the observation vector $\mathbf{x}$ is described by an instantaneous mixture of the statistically independent sources $\mathbf{s}$ [7]. The goal of ICA is to find the original sources by estimating the inverse of the mixing matrix $\mathbf{A}$. Stetson assessed the performance of different ICA methods on synthetically mixed pulse oximetry signals [8]. In the tests conducted in the scope of our study, these instantaneous models did not yield satisfying results.

Volmer [6] experienced similar problems and in turn suggested to resort to the convolutive mixing model which is consecutively solved by the SOBI algorithm [9]. Using only the red and infrared channel as input for this ICA model, Volmer was able to provide a robust method for oxygen saturation measurement [6]. Using this approach for pulse wave reconstruction in the time domain does not provide very satisfying results though. Therefore, we propose to feed the ACC signals to the convolutive mixing model.

Experimental Setup

In the scope of this study, two transmissive pulse-oximetry sensors have been used, which are part of a Body-Sensor-Network (BSN) [3]. The sensor basically embodies an MSP430F1611 microcontroller, equipped with a CC2500 Low-Power 2.4 GHz RF Transceiver for synchronization and communication issues and an SD Card for mass data storage. As initially mentioned, a 3-Axis ADXL330 Accelerometer is built directly into the finger clip, serving as a well located source for movement acquisition.

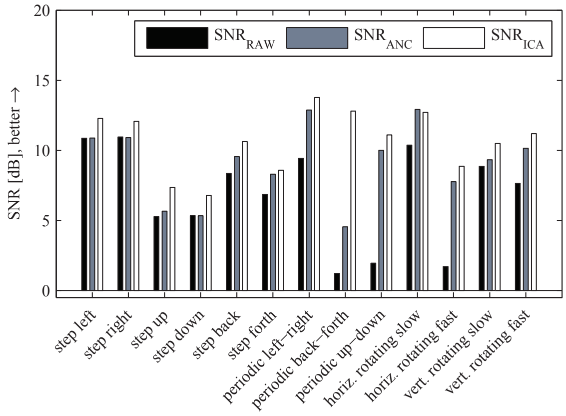

Figure 2: SNR results of raw PPG, ANC PPG and ICA PPG

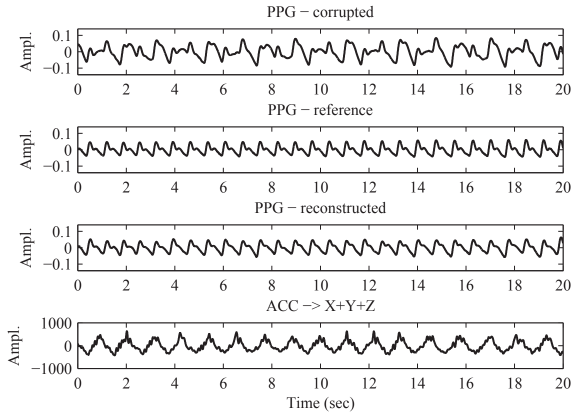

Figure 3: Noise Cancelation of corrupted PPG signal

As described in the previous chapter, the principal objective of this study is to present a convolutive ICA framework to clean the PPG signals from motion artifacts. Therefore, multiple measurements using two transmissive pulse oximeters of 120 seconds duration have been conducted, that contained various movement patterns to induce different kinds of motion artifacts. During each measurement, the right hand was exercising in the experiment, whereas the left remained in a fixed position to provide a nearly undisturbed reference PPG. The PPG signal and the ACC signals have been sampled at 200 Hz.

Results

In order to provide an objective assessment of the achieved results, the SNR values of the estimated PPG signals with regard to the respective reference signals have been calculated. The ACC reference input is calculated by the sum of the ACC signals' x-, y- and z-component. Figure 2 shows the SNR values of the raw signal (black), the SNR of the ANC PPG output (grey) and the SNR of the estimated PPG by the proposed ICA method (white) for the different movements. As can be seen, the proposed ICA method outperforms the ANC approach in terms of increased SNR values. A visual impression of the noise cancelation is given in Figure 3, showing the reconstruction of the PPG signal which has been disturbed by periodic back and forth movements during the experiment.

Discussion

In this work, a novel method for artifact removal of transmissive PPG signals has been proposed. It was shown that the performance of this new approach yields better results than the methods proposed by using classical ANC algorithms. This results in more robustness of physiological applications like pulse rate detection. It should be mentioned, that compared to the ANC method the convolutive ICA approach demands higher computational load which might require more powerful architectures for mobile applications as were presented in [10].

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