Long Term Heart Rate Monitoring Using Photoplethysmography Sensor

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Abstract. *This paper presents a method for long-term monitoring of heart beat and motion reduction artifacts from PPG signal. Photoplethysmography (PPG) is a noninvasive measurement technique to monitoring variation in blood volume in tissue. It can provide an important information about cardio-respiratory system and assist to indicate serious diseases of cardiovascular system of patients. Long term monitoring in daily life requires miniaturized sensors and placement at the body to guaranteeing wearing comfort.*

Limiting factor can be distorted signal by motion artifacts. There are many techniques to reduce artifacts from PPG signal like moving average (MA), periodic moving average (PMAF), wavelet transform, least-mean square (LMS), variable-step LMS (VSLMS) etc. Motion of human body was measured simultaneously with the PPG by 3-axis MEMS accelerometer and it assists to recovery PPG signal and cancelled motion artifacts.

Keywords

PPG, In-Ear sensor, Heart beat, Long-Term Monitoring, Motion artifacts, PMA, Wavelet transform.

1. Introduction

In the last few years the interest in this technology has risen, due to its cheapness, simplicity and portability. The population in the whole Europe is getting older. Post-productive population is more likely to suffer from, besides others, cardiovascular diseases. The preventive health examinations and early detection of the hazardous factors can lower the extensive costs of the final treatment or surgical intervention. Besides the financial issue, the early recognition of the oncoming disease keeps patient‘s health and life conditions in better quality in general, [6]. PPG is used in the broad spectrum of commercial medical equipments, specifically in the measurement of the oxygen saturation, blood pressure, and cardiac output. It is suitable for telemedicine purposes, e.g. distant patients monitoring. Their life functions can be monitored and under control in a long time scale without hospitalization. There are three main requirements of the construction that help to satisfy patient’s comfort ż miniaturization, robustness and easy controlling. Nowadays, there are many works and projects which are focused on PPG and its practical use [1].

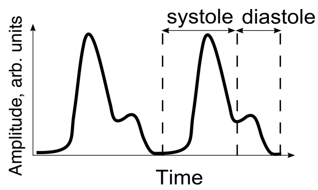

Fig. 1. Typical PPG pulse wave with systole and diastole phase

The basic photoplethysmographic sensor includes one light source and one light detector. Transmitter (LED) emits a light into the tissue and photodetector (in our case phototransistor) detects changes of intensity of the backscattered light that depends on the blood volume changes in tissue. Typical PPG waves are shown in Fig. 1. There are two main PPG operational configuration: transmission and reflection mode. The tissue is placed between the light source and detector in the transmission mode or the light source and detector are placed abreast in the direct contact with the tissue in the reflection mode [1].

Fig. 2. Customized In-Ear PPG sensor to monitoring heart beat in left ear

Transmission probe can be applied only to slim parts of human body like a finger and the ear lobe. These sensors limit movement during the daily activity, therefore they are not suitable for 24/7 monitoring. An in-ear PPG sensor placed inside the auditory canal and working in the reflective mode was chosen for measuring and testing, because it provides the relevant signal in a critic situation, e.g. shock or hypothermia, then comfort using and can be applied in long-term monitoring [4, 3]. The special in-ear PPG sensor has been developed at the RWTH Aachen [4], but it was not available for us at the beginning of this work, therefore a simple prototype of the in-ear PPG sensor has been developed in our laboratory, see fig. 2. More details about design and realization of used in-ear PPG sensor are described in diploma thesis [12].

2. PPG Signal and Motion Artifacts

The analog preprocessing of PPG signal includes filtering by Butterworth high-pass and low-pass filter. High-pass filter with bandwidth 0.5 Hz removes DC component and low-pass with bandwidth 15 Hz removes noise mainly power frequency 50 Hz. Therefore, frequency spectrum of recorded signal is in the range 0.5 – 15 Hz. In this frequency band are as well frequency of respiration and motion artifacts [2]. Example of signal with artifacts is shown in fig. 3. Motion artifacts are the most limiting factor in a PPG signals due to the movement of human body or a part of body where the PPG sensor is placed [5] . Thus there is effort to reject of artifacts from signal.

Experiments were performed to determine an effect of the motion artifacts on the PPG signal corruption and following heart beat detection. Effects of artifacts were tested in the long-term monitoring experiment on a treadmill. The experiment was extended by measuring of ECG signal and body movement by 3-axis MEMS accelerometer. There are many techniques to reduce artifacts from the PPG signal and some of them will be presented in section 3. Well known and described filtration methods were used. Data were processed offline in Matlab environment.

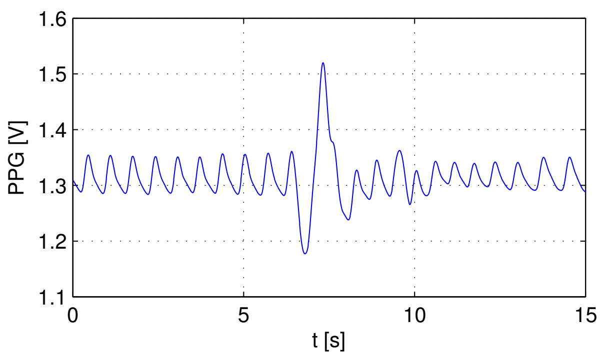

Fig. 3. PPG signal with motion artifacts measured by In-Ear sensor

3. Filtering Methods

Moving average (MA)

Moving average is a simply filtration method using a set of N previous elements to calculate average value. It is given by equation

$$y(k) = \frac{1}{N} \sum_{i=k-(N-1)}^{k} x_i, \qquad (1)$$

where k represents place of element x in the data set. There is evident dependence of the window length N to quality of filtering [10].

Periodic moving average (PMA)

MA averages N previous elements from the data set, PMA is a modification of MA and averages L previous period. It is suitable to use for a periodic and quasi-periodic signals. PPG signal is segmented into periods and resampled with the same m number of samples. Each of m^{th} samples of L periods are averaged. Resampled and filtered periods are finally joined together [2].

Wavelet transform

Wavelet transform (WT) allows to decompose the signal into a linear combination of simpler signals in the time-frequency domain, therefore, provides localization of frequency in the time. WT provides multi-resolution analysis of input signal into approximation and details respectively approximation coefficients and detail coefficients. The principle of WT decomposition is in fig. 4.

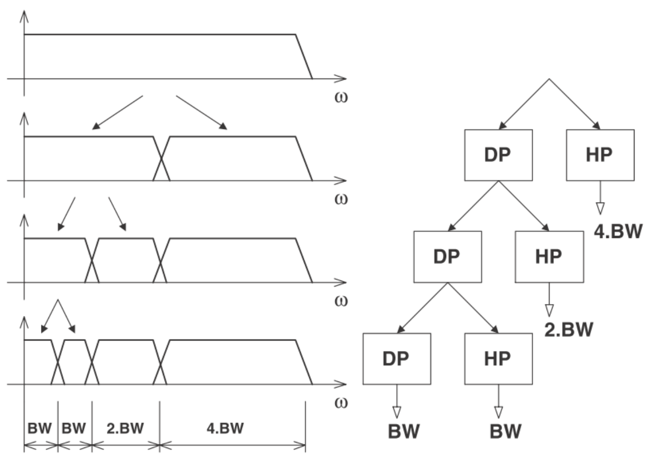

Fig. 4. The principle of wavelet transform decomposition, DP denotes low pass and HP high pass, [11]

Artifacts removing by WT is based on assumption that the PPG is represented by a different set of coefficients than the artifacts. For supression of the individual coefficients is used thresholding. Coefficients represent the PPG are preserved [8, 10].

4. Experiments and results

The main objective of this paper is testing of the filtraction methods for long-term monitoring of heart rate and noise cancellation. The simplest mentioned method is MA filtration. MA with various window length N ($1/8$, $1/4$ and $1/2$ of sampling frequency f_s 200 Hz) is shown in fig. 5. Higher filtering quality of periodic signal is achieved with a PMA. MA and PMA are simply methods and their using is limited by motion artifacts quantity in the PPG signal. This situation occurs in our case during experiment on a treadmill. Signals with large artifacts amount have to be filtered by advanced methods. Compared MA a PMA is in fig. 6.

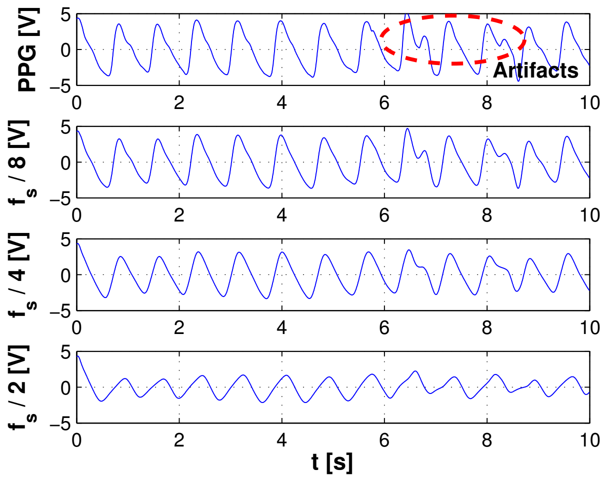

Fig. 5. Compared MA with various window length

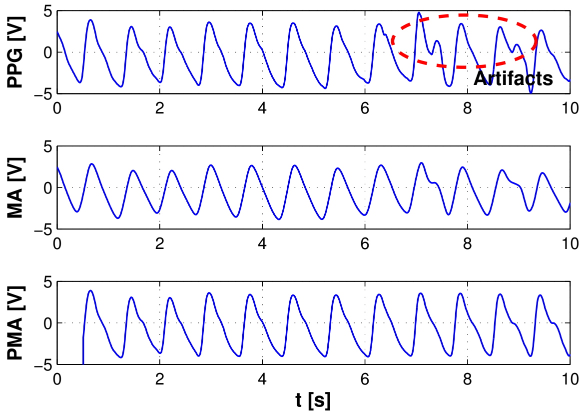

Fig. 6. Compared MA and PMA artifacts filtering

Another approch to filtering is presented by wavelet transform, see fig. 7. It was used for decomposition and reconstruction of 8-level Mutli resolution analysis (MRA) for distorted PPG. The 7th and 8th coefficients were cancelled by thresholding. See [9] for more details about MRA.

Experiment on a treadmill was used as a source of very disturbed PPG signal thanks to walking and running. Data from the ECG, in-ear PPG, finger PPG on the left and right hand and accelerometers were processed by measuring PC card. Tested person was at rest, walking and running. In fig. 8 is shown detection of the heart beat - person was at rest and then started to go. Detected HB was verified by

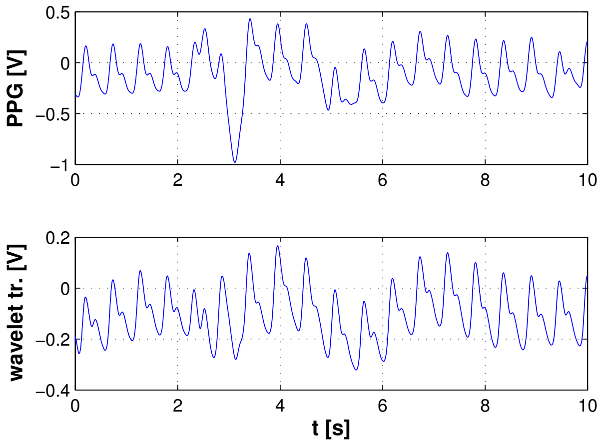

Fig. 7. Wavelet transform - cancelling of moving artifacts

ECG. Wavelet transform provides powerful tool also in this disturbed PPG.

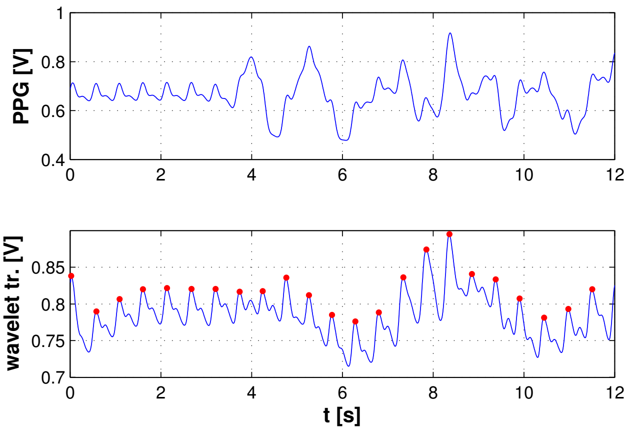

Fig. 8. Wavelet transform - cancelling of motion artifacts during experiment on a treadmill, detect heart beat are signalized by red marks

5. Conclusions

In this paper has been presented a verification of the methods to recover contaminated PPG signal due to body motion. There were tested 3 methods - MA, PMA and wavelet transform. WT is the powerfull method and it is still able to extracts the main PPG waves from disturbance signal causes running.

Another way to successfully filtering of contaminated PPG is applying popular adaptive filters as LMS, NLMS, VSLMS [7] etc. They used to filtering PPG with noise and measured movement of patient's body with accelerometers. This method was not used because wavelet transform achieves high quality results. However, it will be applied in the next work. Other way is using accelerometers to detect frequency of body movement and applying it as a priori information to coefficients thresholding at wavelet transform.

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