A Real-Time Heartbeat Estimation System Using PPG Signals

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***Abstract*—The heartbeat is one of essential features that wearable healthcare devices utilize. The photoplethysmogram (PPG) is usually used to estimate the heartbeat from the wrist. Accurate heartbeat estimation is very difficult due to motion artifacts. The motion artifacts are caused by periodic hand swings or instant contact errors between the PPG sensor and skin. In this paper, we propose a heartbeat estimation system with wrist based PPG sensing in real-time for wearable devices.**

I. Introduction

A photoplethysmogram (PPG) and an electrocardiogram (ECG) are usually used to estimate the heartbeat rate. The PPG is measured from fingers or the wrist that is a distal part of a body, while the ECG is measured from some parts of the thorax. So the ECG can give better results for estimating the heartbeat over the PPG. However, the ECG cannot be used for wearable devices because of its complexity and inconvenience.

PPG signals are obtained by using a pulse oximeter. A conventional pulse oximeter monitors the perfusion of blood to the dermis and subcutaneous tissue of the skin.

The change in volume caused by the cardiac output is detected by illuminating the skin with a light emitting diode (LED) and then sensing the amount of light reflected to a photodiode. Each cardiac output is seen as a peak in the PPG signal and have the same periodic feature as ECG signals. Therefore, the PPG signal can be used for the heartbeat estimation instead of using the ECG signal. The PPG signal can also be used for monitoring breathing, hypovolemia and other circulatory conditions.

A PPG sensing model with an oximeter is shown in Fig. 1. PPG signal sensing is affected by the movement of people. A small motion artifact can cause significant noise that affect the PPG signal. There are two types of motion artifacts; periodic motion artifact and non-periodic motion artifact. The periodic motion artifact is due to hand swings or breathing. The non-periodic motion artifact is an instant contact failure between skin and sensors. These make PPG signals having false peaks that could be seen as a cardiac cycle [1], [2].

In this paper, we propose a system which senses PPG signals in real-time and an algorithm that filters the PPG signal to reduce the false peaks. By combining the system and algorithm, an accurate heartbeat can be estimated.

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The remaining of the paper is as follows. In Section II, we define a problem to estimate the heartbeat using raw PPG signals. Section III proposes an algorithm to estimate the heartbeat accurately by resolving the problem. Section IV introduces a system that used in this research. Section V shows the results and performance of the proposed system.

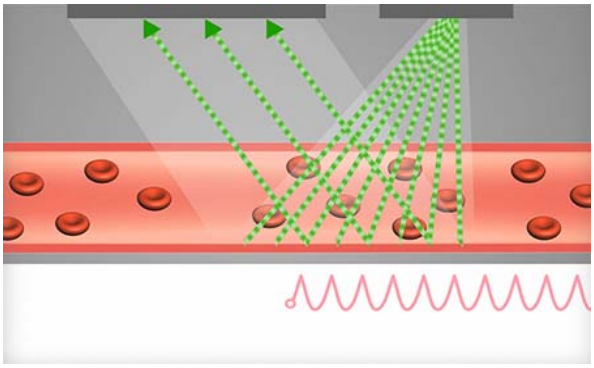

Fig. 1. Heartbeat rate detection with an oximeter [2].

II. Problem Statement

The main problem when estimating the heartbeat from PPG signals is the motion artifact. An instance of a periodic motion artifact and non-periodic motion artifact included in a PPG signals are shown in Figs. 2 and 3, respectively. The periodic motion artifact makes false periodic peaks in the raw signal, while the non-periodic motion artifact makes instant distortion in the raw signal. Both periodic and non-periodic peaks cause a problem on detecting peaks and hence these cause significant errors in the heartbeat estimation.

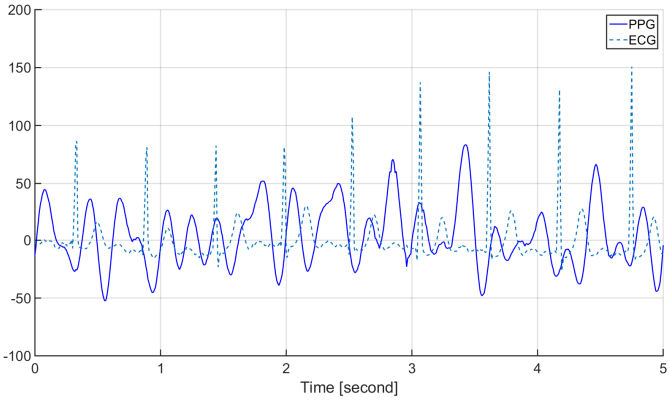

Fig. 2. Periodic motion artifacts in PPG signals and reference ECG signals.

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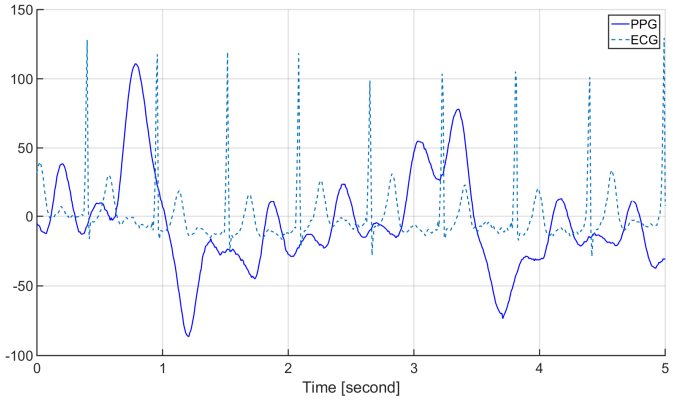

Fig. 3. Non-periodic motion artifacts in PPG signals and reference ECG signals.

III. Proposed Algorithm

One possible method for estimating the heartbeat from PPG signals is using the spectra of PPG signals [3] - [5]. Section II, however, showed that there is still a problem in estimating the heartbeat from the spectra of PPG signals. We propose an algorithm that uses two channels of PPG signals and a mean value of a previously estimated heartbeat rate to check whether there is a significant noise or not. The block diagram of the proposed system is given in Fig. 4.

The first and second PPG signals are measured with 2 cm distance on the wrist. The fast Fourier transform (FFT) is used for extracting the spectra of signals. Then we aggregate two spectra of the two PPG signals. A peak detection is following the aggregating part. It detects the peaks (denoted by *P*) within certain range which is decided by using mean value of the previously estimated heartbeat rate (denoted by *P_mean*). Then, it selects the closest peak frequency to *P_mean*.

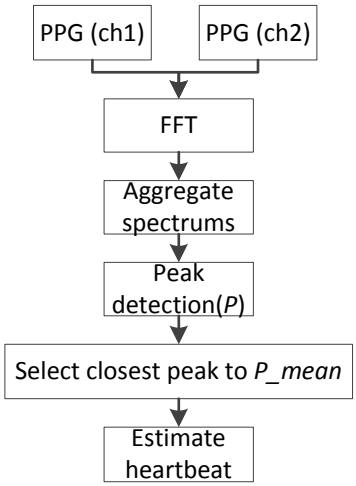

Fig. 4. The proposed heartbeat estimation algorithm.

IV. System

We used an oximeter, which is composed with an LED of wavelength 620 nm, a single photodiode, an amplifier and analog digital converter. The system communicates with a computer by RS232 terminal. The block diagram of the hardware system is shown in Fig. 5.

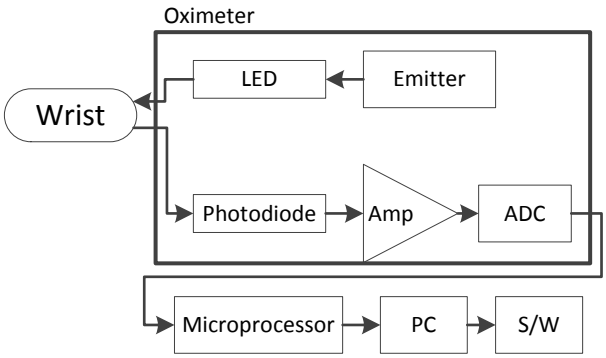

Fig. 5. The block diagram of the proposed system.

V. Results

From the two spectra of the PPG signals, there are peaks at 1.3 Hz and 2.6 Hz in Fig. 6 for the true heartbeat rate of 2.3 Hz. These errors were aroused due to the motion artifacts. The proposed algorithm detects a proper peak from the aggregated spectrum. It showed that the true and estimated heartbeat rates are at almost the same location.

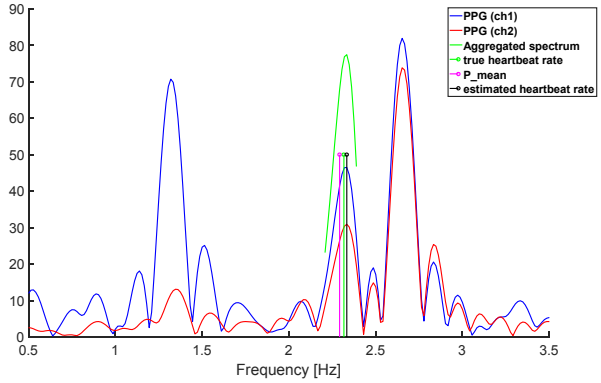

Fig. 6. Spectra of two PPG signals and the estimated heartbeat rate.

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