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Cardiovascular detection system development with Photoplethysmogram and Fast Fourier Transform

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Abstract. Cardiovascular health measurement is very important to prevent the cause of sudden death. Tonometry is known as a very accurate measurement system. However, due to its size, users cannot measure simultaneously. Photoplethysmogram (PPG) sensors are very small and already in use for everyday life to measure the pulse at the wrist. The accuracy is still ~~in~~ an issue but its mobility can help users to measure all-day cardiovascular conditions. We developed a PPG sensor-based cardiovascular measurement system: an activity sensor. We measured blood volume with PPG and compared it with a commercial tonometry system: Daeyomedi DMP-Lifeplus. We used a fast Fourier transform to remove noise from the signal and successfully matched the result with DMP-Lifeplus outcome. As the measurement spot is different, we have a negative correlation between tonometry and PPG sensor and successfully found a method to detect the cardiovascular system with a PPG sensor.

Keywords: Cardiovascular, Hemodynamics, ICT, Pulse-wave, Plethysmogram, Tonometry

1. Introduction

Early stage arrhythmia detection is very important to prevent or postpone the progress of the disease. The most accurate way to detect cardiovascular diseases is to use the tonometry device. However, the tonometry system is not a portable system and

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it is impossible to detect cardiovascular status simultaneously. Photoplethysmogram (PPG) sensor can detect blood volume variation using a diode and optical sensor. PPG sensors are widely used for mobile devices such as an apple watch [1, 2]. PPG sensor is extremely portable and easy to detect blood volume simultaneously, low accuracy needs to be handled properly. Many devices using PPG sensors attached to their devices to improve detection accuracy. Still, PPG's blood volume detection accuracy needs to be improved. Tonometry device measures pressure at the radial artery vessel by changing the physical pressure. As tonometry is known as one of the most accurate ways of detecting cardiovascular detection at the wrist, we compared our activity sensor's PPG signal to a commercial tonometry system: Daeyomedi DMP-Lifeplus (DMP-Lifeplus). DMP-Lifeplus is a light tonometry device that is connected to a personal computer and attached to a radial artery with a consumable detector holder. Though; DMP-Lifeplus is a light device, it is not easy to carry the device in everyday life. As PPG sensors are already in our life in the watch form, we analyzed PPG sensor data and compared it with the result from DMP-Lifeplus. PPG sensors were processed using fast Fourier transform (FFT) to remove noise and accurate heartbeat count. We successfully developed an algorithm to transfer the PPG sensor to be used for heartbeat and cardiovascular detection. The result showed that the PPG sensor can be used for as a simultaneous cardiovascular measuring device to detect anomalies and announce users to check with more reliable devices when an anomaly is measured.

2. METHODS

A. Daeyomedi DMP-Lifeplus and radial artery signal analysis

DMP-Lifeplus is a commercial product developed at DAEYOMEDI Co., Ltd. and we used the analysis metric used in the previous research conducted at [3]. We extracted t1, t2 and t3 mentioned in the previous research from PPG signals to evaluate cardiovascular age. Additionally, we used FFT to determine t2 and t3 for not significantly distinguished cases. Instead of using relative t2 and t3, we used t2-t1 and t3-t1 as t1 is not related to cardiovascular age.

B. Activity sensor and signal process

The activity sensor is designed to detect heartbeat and walking steps using a PPG sensor and accelerometer, respectively [4]. MAX30101 PPG sensor was implemented on our activity sensor. MAX30101 sensor consists of infra-red, green, and red light emitting diode (LED) and a photon detector. Analog-Digital converter and analog front end are combined in MAX30101 as well. LSM6DSLaccelerometer was chosen for the activity sensor. LSM6DSL contains an accelerometer and gyroscope with a proper algorithm to count walking steps in the chip. The activity sensor chip structure is shown in Fig. 1.

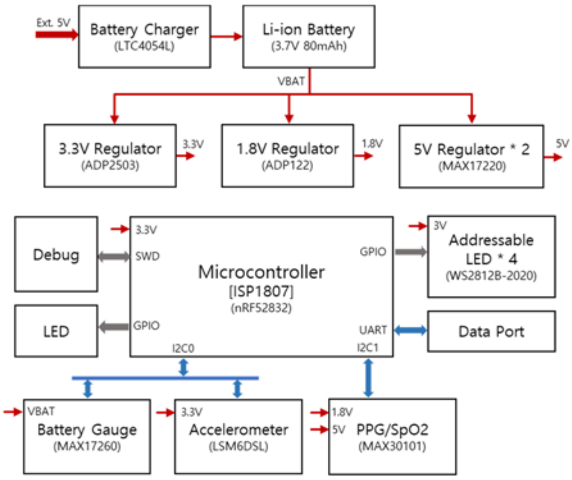

Figure 1. Block diagram for activity monitoring system

ISP1807, which uses microcontroller unit nRF52840 based on low power cortex-M core, was chosen for the system control. For the simultaneous data scoring, 1MB of Flash memory was implemented as well. Timestamp (4byte), heartbeat rate (1byte), walking steps (2byte) are recorded every minute with checksum (1byte). The activity sensor is expected to hold data generated in 2days. Addressable LED was implemented for fast activity sensor status monitoring.

Data is acquired at 100Hz and transferred via UART to a serial converter. Then Tera term, which is a serial port handling program, records transferred data. Data is saved as comma-separated values provided by Tera term as well. Time tag and raw signal value are saved accordingly. The Data recording process is shown in Fig. 2.

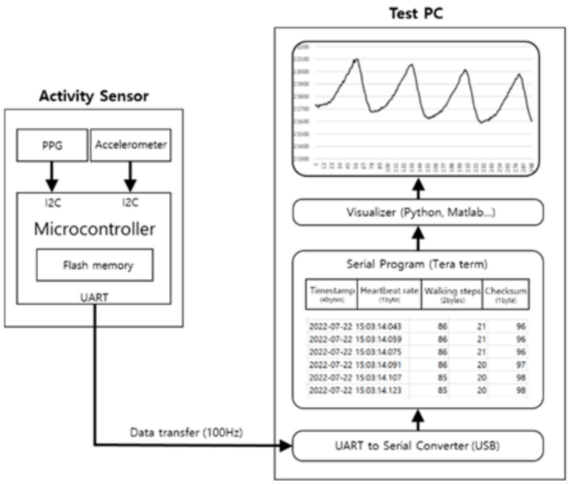

Figure 2. PPG sensor to raw data recording process diagram.

C. FFT and signal processing

Since our raw signal was highly disturbed by low-frequency content less than 0.1Hz, the signal should be analyzed with various digital filters followed by FFT. The whole progress was conducted with Matlab R2020a update 3. The low-frequency signals are generated from the patient's movement, breathing, and electrode skin impedance [5, 6]. Because it is a primary distraction of our FFT analysis, we applied a high-pass filter (HPF) with a cutoff frequency of 1Hz. We applied a 1Hz cutoff frequency instead of 0.5Hz or 0.05Hz to emphasize peak signals. In addition, high-frequency content resulted from low amplitude harmonics or the presence of muscle noise also one of the distractions of our study. Both a moving average filter and a low-pass filter are adopted to eliminate low amplitude harmonics or the presence of muscle noise. An adaptive filter is one of the widely used filters in the research of heartbeat signals [5, 6]. It is efficient for the removal of noises ranging from 1Hz to 10Hz which are similar to the main pulse signal. A Normalized variance of least-mean-square (LMS) algorithm was used in this research, and DSP Toolbox in Matlab is used for this procedure as well.

3. Results

A. PPG sensor data and FFT result compared to DMP-Lifeplus

PPG sensor signals processed with a highpass filter with 1Hz cutoff and IIR notch filter with 1Hz and 0.2 bandwidth from 4 users are shown in fig. x. For each user’s data, we observe the low-frequency noise but the peaks in each signal. The user (a) and (c) shows significant t1 and t3 while (b) and (d) does not show strong t3 peak in fig 3.

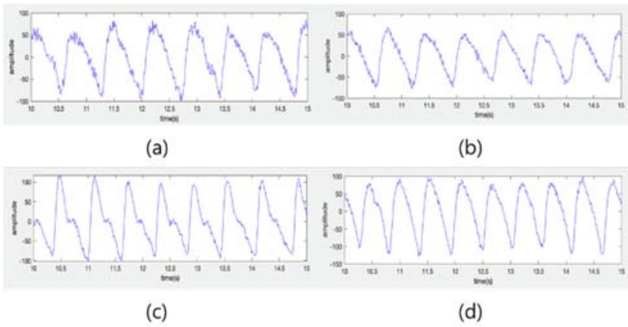

Figure 3. PPG sensor data process with highpass filter (cutoff 1Hz) and IIR Notch filter (Frequency = 1Hz, Bandwidth = 0.2) for different users.

FFT results of signals in fig. x are shown in fig. x. We found that the peak frequency for the user (a), (b), (c), and (d) are 1.38, 1.42, 1.37, and 1.8 Hz, respectively. We can directly convert these frequencies to heartbeat per minute by multiplying 60 and the heartbeat signals are 83, 85, 82, and 108 rounds to one decimal place, respectively. We compared the PPG result with the DMP-Lifeplus heartbeat signal as well. The heartbeat signal measured with DMP-Lifeplus was 73, 98, 85, and 109, respectively. The difference between PPG and DMP-Lifeplus was the biggest for a user (b) and the smallest for a user (d). The average difference was 6.75 and less than 10% of the average heartbeat measured from DMP-Lifeplus. The plot is shown in fig 4.

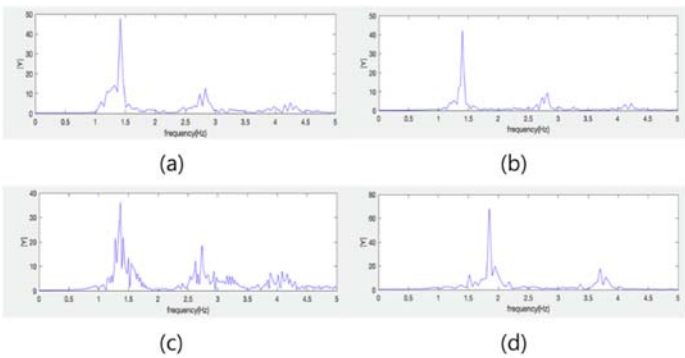

Figure 4. PPG sensor data passed the FFT filter to calculate all users' heartbeat rates.

B. Detecting cardiovascular status with PPG signals

We applied a moving average filter with window size 8 to the signal shown in fig. 5 to remove high-frequency noise in the signal. The results are shown in the following fig. 5.

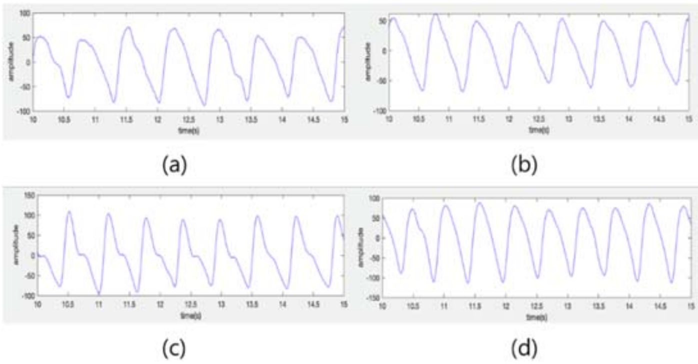

Figure 5. PPG sensor data are denoised with FFT for all users.

We analyzed t1, t2, and t3 from PPG data as well. The table is shown in table 1.

TABLE 1. PULSE PHASE RESULTS FROM PPG SIGNALS

	User 1	User 2	User 3	User 4
t2-t1	0.365	-	0.196	0.271
t3-t1	0.494	0.355	0.248	0.51

With DMP-Lifeplus, only user3's cardiovascular status was 20^{th} while the rest of the users' are $30\text{-}40^{th}$. Unfortunately, we could not calculate t2-t1 for user2. However, Both t2-t1 and t3-t1 increased for the aged cardiovascular system measured with the PPG sensor.

4. CONCLUSION

We successfully developed an activity sensor that can monitor heartbeat and cardiovascular status. Analysis algorithms were developed using FFT and the signal was compared to the commercial tonometry system DMP-Lifeplus. We figure out that the heartbeat measurement was lying at 10% of an average heartbeat. However, some users' heartbeat was not very accurate due to the short time measurement from the PPG sensor. We compared processed PPG signals and measured local minimum and maximum points defined for tonometry signal analysis [3]. All users' cardiovascular aging detection results measured from the PPG sensor were identical to DMP-Lifeplus analysis results. The time interval was larger for the radial artery vessel while the PPG sensor was opposite. We successfully developed activity sensors and analysis methods to simultaneously detect cardiovascular status.

Acknowledgment

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