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Validation of heart rate extraction using video imaging on a built-in camera system of a smartphone

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Abstract— **As a smartphone is becoming very popular and its performance is being improved fast, a smartphone shows its potential as a low-cost physiological measurement solution which is accurate and can be used beyond the clinical environment.**

Because cardiac pulse leads the subtle color change of a skin, a pulsatile signal which can be described as photoplethysmographic (PPG) signal can be measured through recording facial video using a digital camera.

In this paper, we explore the potential that the reliable heart rate can be measured remotely by the facial video recorded using smartphone camera. First, using the front facing-camera of a smartphone, facial video was recorded. We detected facial region on the image of each frame using face detection, and yielded the raw trace signal from the green channel of the image. To extract more accurate cardiac pulse signal, we applied independent component analysis (ICA) to the raw trace signal. The heart rate was extracted using frequency analysis of the raw trace signal and the analyzed signal from ICA. The accuracy of the estimated heart rate was evaluated by comparing with the heart rate from reference electrocardiogram (ECG) signal. Finally, we developed FaceBEAT, an iPhone application for remote heart rate measurement, based on this study.

I. Introduction

As the ubiquitous technology such as smartphone rapidly evolves and the burden on limited medical resources increases, there is a need for the low-cost physiological measurement solution which is accurate and can be used beyond the clinical environment. A smartphone is becoming very popular and its performance is being improved fast. A smartphone not only capture the diverse information such as imaging and acceleration using built-in sensors, but also process the information in real-time and transfer the data to anywhere using the Internet. These performances of a smartphone show its potential as a physiological measurement solution [1][2][3].

Cardiac pulse leads the subtle color change of a skin. Because the subtle color change can be detected through monitoring the skin image using a digital camera, a pulsatile signal which can be described as photoplethysmographic (PPG) signal can be measured[3][4].

The state-of-the-art smartphones are equipped with high-resolution HD camera. Some previous researches studied extracting the reliable heart rate based on PPG only using smartphone camera system. Scully et al.[3] and Jonathan et al.[4] tried to measure the PPG signal from the video of edge of finger using smartphone camera and extract the reliable heart rate. Mobile applications for measuring the heart rate based on their methods launched on the Apple AppStore and Android Market

Poh et al. showed potential to measure cardiac pulse remotely using video imaging and blind source separation [5]. They recorded the facial video using built-in webcam in laptop only with sunlight as illumination. They extracted the cardiac pulse signal using independent component analysis (ICA) and measure heart rate from the frequency analysis.

In this paper, we explore the potential that reliable heart rate can be measured remotely by recording the facial video using the built-in camera of a smartphone. We followed Pho's methodology [5] for extracting cardiac pulse signal and heart rate. First, facial videos were recorded using the front facing-camera of iPhone 4. Face region of each frame was then detected as region of interest (ROI) using face detection algorithm. We yielded the raw trace signal from the green channel of the image. To extract more accurate cardiac pulse signal, we applied independent component analysis (ICA) to the raw trace signal. The heart rate was extracted using frequency analysis of the raw trace signal and the analyzed signal from ICA. The accuracy of the estimated heart rate was evaluated by comparing with the heart rate from reference electrocardiogram (ECG) signal. Finally, we developed FaceBEAT, an iPhone application for remote heart rate measurement, based on this study.

II. Methods

A. Experimental Setup

A front facing-camera and the video recording app built in a smartphone (iPhone 4 by Apple Inc.) are used to record the videos. Videos were recorded at 29.99 frames per second in 24-bit(3 channels × 8 bits/channel) RGB color with 640 × 480 pixel resolution and saved in MOV(Apple QuickTime Movie) format on the iPhone.10 subjects (8 males, 2 females) from the Advanced Biometric Research Center (ABRC) were

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participated in this experiment with consent. Their ages are between 23-30 years.

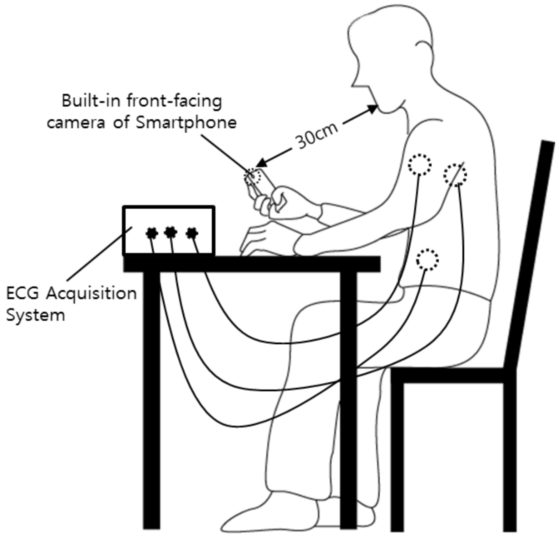

Figure 1. Experimental Setup.

To obtain an electrocardiogram (ECG) signal as the reference, an FDA-approved ECG measurement system, BIOPAC MP150 ECG module (BIOPAC, USA [6]) with conventional Ag/AgCl electrodes, was used. The reference ECG signals were acquired at the sampling rate 1000Hz for validation. The experiments were conducted indoor and only sufficient amount of sunlight was used as illumination without any other one.

Figure 1 shows the experimental setup. Subjects were seated at a table and holding the smartphone using a right-hand at a distance of 0.3m between the built-in camera and their face. Each video recording was conducted one minute. We asked the subjects to sit without movement and stare at the middle of the screen of smartphone during the recording.

B. Heart rate extraction methodology

During the cardiac cycle, the change of volume in the facial blood vessels causes the subsequent changes in amount of reflected light. The RGB color sensors pick up the tiny changes and the changes indicate reflected plethysmographic signal. To estimate heart rate from recorded videos and reference ECG signal, we implemented Poh's methodology [5] and developed the peak detection algorithm using MATLAB 2012a (The MathWorks, Inc.)

Figure 2 illustrates the overview of the heart rate extraction methods we used in this study. First, we separated each frame from the recorded facial video using VideoReader tool offered by MATLAB, and the region of interest (ROI) was detected by face detection algorithm using Open Computer Vision (OpenCV) library [Figure 2 (a)]. The ROI was separated into the red, green and blue channels, and we yielded the measurement point $x_r(t)$, $x_g(t)$ and $x_b(t)$ from each color channel by averaging over all pixels in each ROI [Figure 2 (b), (c)]. The raw traces $x_r(t)$, $x_g(t)$ and $x_b(t)$ were normalized as follows:

$$x'_{ch}(t) = \frac{x_{ch}(t) - \mu_{ch}}{\sigma_{ch}} \tag{1}$$

for each ch = *red, green, blue* where μ_{ch} and σ_{ch} are the mean and standard deviation of $x_{ch}(t)$ respectively [Figure 2 (d)].

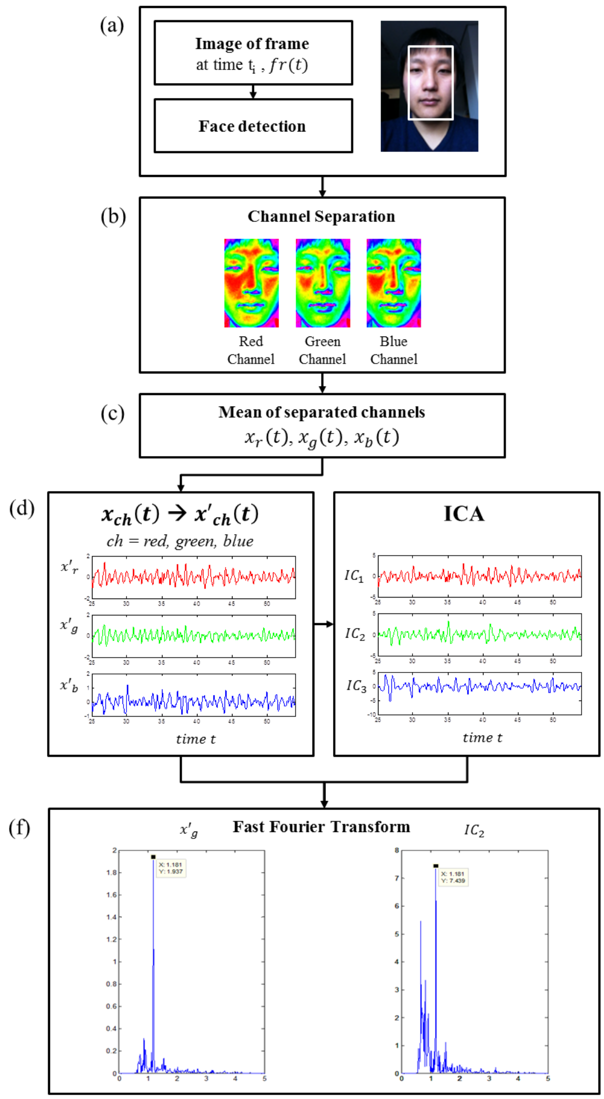

Figure 2. Heart rate extraction methodology. (a) The face region is detected as region of interest (ROI) using OpevCV face detection algorithm. (b) The ROI was separated into the three RGB channels. (c) The x_r, x_g, x_b are the raw traces of each channel. The point of the raw traces was yielded by averaging over all pixels in each ROI. (d) The raw RGB traces were normalized as equation (1). (e) Independent source signals from ICA of the normalized traces, x'_r, x'_g, x'_b. (f) Power spectra of the raw trace of green channel and independent source signals

Three independent source signals were yielded by decomposing of three raw traces using ICA [Figure 2 (e)]. In this study, joint approximate diagonalization of eigenmatrices (JADE) algorithm were used for ICA, which developed by

Cardoso [7]. Refer to the studies about camera-based PPG extraction [3][4] and Poh's study [5], typically the raw trace of green channel and the second independent source signal contain a strong plethysmographic signal relatively. Finally, to extract heart rate frequency, we applied the fast Fourier transform (FFT) on the raw trace of green channel and the second independent source signal [Figure 2 (f)].

III. Results

Figure 3 shows the raw trace signals of three color channels between 30s epoch. As previous camera-based PPG measurement studies, the raw trace signal of green channel contains a strong plethysmographic signal relatively. However, the quality of the signal is not enough high to get all intervals between each pulse.

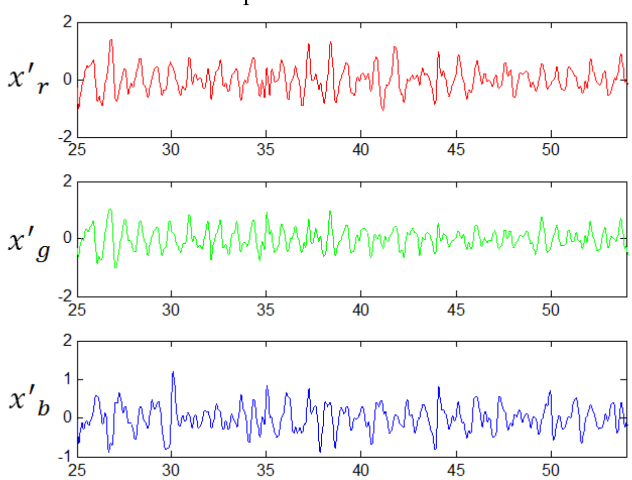

Figure 3. The raw trace signals of three channels between 30 s epoch, the raw trace signal of green channel contains a strong plethysmographic relatively

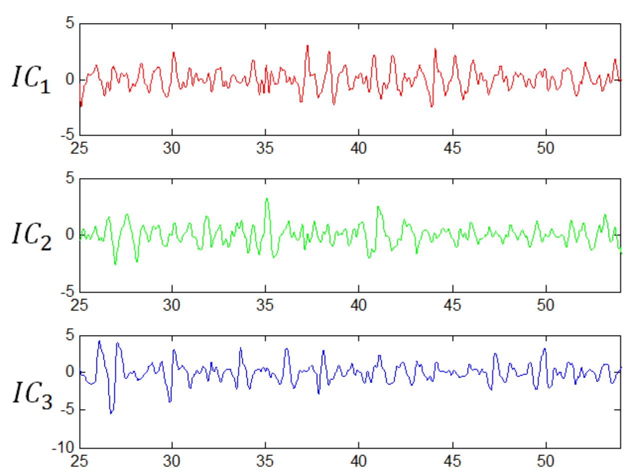

Figure 4. Three independent source signals from ICA between 30 s epoch

Figure 4 shows the three independent source signals obtained by applying ICA to the raw trace signal set shown Figure 3. Unlike Pho's study, the clearness of the pulse peak in the second independent source signal is similar to or worse than the raw trace signals of green channel

We found the max power frequency in each signal using FFT, and estimated average heart rate from the frequency.

Table I shows the estimated heart rates and the error rate between the estimated one and reference one. The average error rates of raw trace and independent source are 1.04% and 1.47% respectively. Very low error rates mean the reliable average heart rate can be measured remotely using built-in camera system of smartphone.

The results of applying FFT to two signals are shown in figure 5. The max power frequency is shown significantly clearly in the case of the green raw trace, but the clearness became worse after ICA.

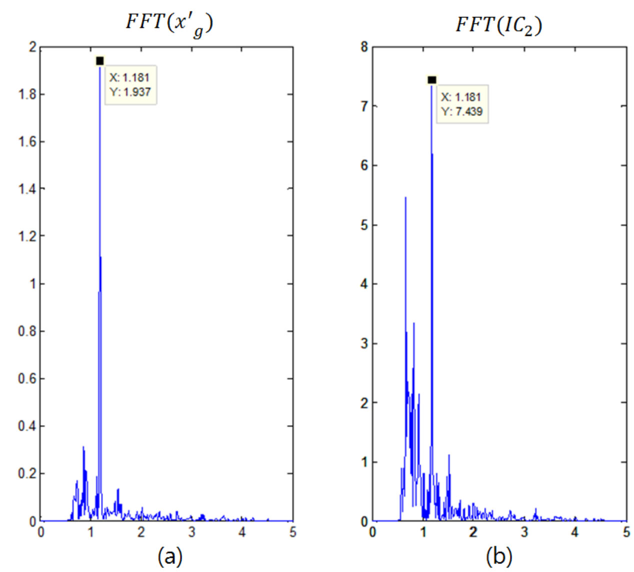

Figure 5. The results of applying FFT to the raw trace of green channel and the second independent source. (a) The max power frequency is shown significantly clearly in the case of the green raw trace signal. (b) The clearness became worse in the case of independent source signal after ICA

TABLE I. The estimated heart rates and the error rate

Subj.	raw trace (BPM)	IC2 (BPM)	Reference (BPM)	raw trace error rate (%)	IC2 error rate (%)
1	64.57	64.57	66.10	2.31	2.31
2	70.89	70.89	70.88	0.01	0.01
3	79.85	57.18	76.49	4.39	7.33
4	86.73	86.73	86.10	0.74	0.74
5	87.58	87.58	86.24	1.55	1.55
6	76.20	76.20	75.06	1.52	1.52
7	68.03	68.03	67.55	0.70	0.70
8	79.91	79.91	78.59	1.69	1.69
9	86.44	85.45	86.06	0.45	0.71
10	72.18	72.18	70.71	2.08	2.08
Total				1.08	1.47

IV. FACEBEAT – THE IPHONE APPLICATION FOR HEART RATE ESTIMATION USING FACIAL VIDEO RECORDING

We developed FaceBEAT, the iPhone application for estimation of heart rate using facial video recording. This smartphone application records the user's face for 20 seconds and estimates his/her heart rate through applying the methodology illustrated in Figure 2 to the recorded video. We leaved out ICA from the processing of our application. Despite spending a large processing cost in mobile computing environment, ICA doesn't help to find max power frequency clearly in this study.

The screenshots of FaceBEAT are shown in figure 6. To secure more than the sufficient face size in video, FaceBEAT shows the overlaid guide view on the recording [Figure 6. (a)]. After recording, FaceBEAT shows the estimated heart rate and the FFT results to user [Figure 6. (b)].

(a) (b)

Figure 6. The screenshots of FaceBEAT. (a) FaceBEAT supports overlaid guide view on the recording. (b) FaceBEAT shows the estimated heart rate and the FFT results to user

V. DISCUSSION

To ensure that the introduced methodology in this paper can be applied to other smartphone camera system, we analyzed the videos that are recorded using other smartphone including HTC Desire HD, Samsung Galaxy S and Galaxy Tab.

Figure 7 show the raw trace signals from the video recorded using Samsung Galaxy Tab. Most of data from the other smartphone showed results similar to the iPhone, but the raw trace of green channel from Galaxy Tab showed very clear and high-lossless cardiac pulse. If the high quality signal like Figure 7 with sufficiently high frame rate can be recorded, smartphone can remotely measure other cardiovascular parameters which requiring the high-accurate pulse measurement such as heart rate variability (HRV).

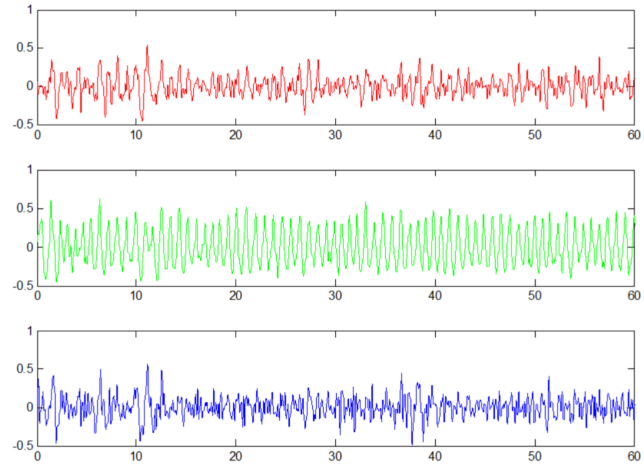

Figure 7. The raw trace signals from the video recorded using Samsung Galaxy Tab

VI. CONCLUSION AND FUTURE WORK

In this paper, we evaluated reliable heart rate can be extracted remotely using smartphone camera system. From the result of this preliminary study, we expect people can measure their heart rate at medically reliable level just by recording their face for few seconds using smartphone camera without location and time limitation.

To find the sufficient condition of smartphone camera system for remote cardiac pulse measurement, we plan to compare the specifications of various smartphone camera systems. The relationship between the ROI size and the quality of the signal will be studied.

FaceBEAT will be updated for real-time heart rate monitoring, and the historical management of measurement will be added on the application. After update for real-time monitoring, we will study about the remotely long-term monitoring of cardiac pulse using smartphone camera system.

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