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Validation of heart rate extraction through an iPhone accelerometer

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***Abstract*—Ubiquitous medical technology may provide advanced utility for evaluating the status of the patient beyond the clinical environment. The iPhone provides the capacity to measure the heart rate, as the iPhone consists of a 3-axis accelerometer that is sufficiently sensitive to perceive tiny body movements caused by heart pumping. In this preliminary study, an iPhone was tested and evaluated as the reliable heart rate extractor to use for medical purpose by comparing with reference electrocardiogram. By comparing the extracted heart rate from acquired acceleration data with the extracted one from ECG reference signal, iPhone functioning as the reliable heart rate extractor has demonstrated sufficient accuracy and consistency.**

***Index Terms*—heart rate, accelerometer, iPhone, ubiquitous healthcare**

I. Introduction

WIDESPREAD burden on limited medical resources may be ameliorated through the convergence between ubiquitous technology and medical one. Ubiquitous medical technology may provide advanced utility for evaluating the status of the patient beyond the clinical environment. For example, Marshall proposed a support system that enables chronic disease patients to do self-management in their home and automatically communicates with clinics for expert care using smartphone and pulse oximeter with bluetooth interface [1]. For instance, Oresko proposed a wearable smartphone-based platform for real-time cardiovascular disease detection [2].

As the smartphones equipped with numerous and diverse sensors such as accelerometer are emerged, there are active movements trying to apply these advanced sensors to medical applications. LeMoyne evaluated the 3-axis accelerometer in an iPhone for quantifying gait characteristics and for characterizing Parkinson's disease tremor [3][4]. Sleep Cycle alarm clock application for iPhone [5] monitors user's sleep stage through perceiving his toss and turn using built-in accelerometer and gives the alarm at the best time to wake up easily. Snoring U application detects the snoring using built-in microphone and delivers a small nudge such as vibration or alert sounds to try to gently stop the user from snoring [6].

Heart rate is one of the most useful medical indicators to check cardiac status. With the progressive advancement of accelerometer technology, the capacity of the accelerometer to measure heart rate has been advocated [7]. The iPhone provides the capacity to measure the heart rate, as the iPhone consists of a 3-axis accelerometer that is sufficiently sensitive to perceive tiny body movements caused by heart pumping.

In this preliminary study, the iPhone was tested and evaluated as the reliable heart rate extractor to use for medical purpose by comparing with reference electrocardiogram. The test and evaluation involved five subjects. The iPhone was mounted to the middle of the chest. We acquired the acceleration data from six less-active postures that user can pose easily in daily life. We developed the mobile application enabling iPhone to record the raw data of its accelerometer at a prescribed sampling rate to do post-processing.

The iPhone successfully demonstrates the capacity to extract reliable heart rate. As this potential ability meets the flexibility and accessibility of the smartphone, the device can be effective ubiquitous medical resources to cardiac disorder patients in their daily life.

II. Data Acquisition

The test and evaluation of the iPhone accelerometer system for extracting the heart rate involved five subjects.

A. Acceleration data acquisition

The axis of iPhone accelerometer is shown in Figure 1. We developed an iPhone application which acquires 3-axis acceleration data at the maximum sampling rate(100Hz) that iOS APIs supports (see Figure 2). As illustrated in Figure 3, the iPhone was mounted to the middle of the subject's chest using elastic band. To consider the effects from the body shape difference, five subjects consist of three men and two women.

The subjects posed six inactive or less-active postures that are easily posed in daily life: sitting, standing, sleeping (supine, lateral, prone) and slow walking (1Km/h, 3Km/h) on a treadmill. Each posture was posed for more than five minutes. The iPhone 4 model without any covers and any shields is used in this experiment.

B. Reference electrocardiogram measurement

To obtain the reference electrocardiogram signal for evaluating the accuracy of the heart rate extracted by iPhone, BIOPAC MP150 ECG module (BIOPAC, USA [8]) with

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conventional Ag/AgCl electrodes was used. BIOPAC system acquired subject's ECG signal at the sampling rate 250Hz. The acquired ECG signal was down-sampled to 100Hz. To extract heart rate from accelerometer data, we developed the digital band pass algorithm and the peak detection algorithm using MATLAB 2010a. The accelerometer data were filtered with 5^{th} order Butterworth high pass filter at the cutoff frequency of 5Hz then filtered with 5^{th} order Butterworth low pass filter at the cutoff frequency of 35Hz. Our peak detection algorithm [9] is designed for real-time processing at mobile computing environment. First of all, assuming the approximate expected period of the peaks (e.g., usually one second in ECG signal) is given, our algorithm divides the input stream of one period into four same segments. After the segmentation, the algorithm finds max value of each segment, and tries to find the peaks among these four max values. Sometimes this routine is able to find wrong peak, so the algorithm monitors whether the duration between the two adjacent peaks is shorter than the half of the expected period to filter out the wrong peak. In addition, the algorithm periodically updates the expected period to consider the variation of the peak interval of input signal. This algorithm can save processing cost by finding the peaks among the max values from the segments, and therefore it can be suitable for mobile computing environment.

Figure 1. the axis of iPhone accelerometer

Figure 2. Acceleration data acquisition software for iPhone

C. Experimental Protocol

The following experimental protocol acquired acceleration data from different postures for each subjects.

1. Attach the electrodes to subject's chest, which is connected with BIOPAC ECG module.
2. Check the status of subject's ECG signal.
3. Mount the accelerometer to the middle of the chest with the iPhone oriented superior (top pointing up) using an elastic band.
4. Synchronize the start time of data acquisition between the accelerometer and ECG signal.
5. Activate the data acquisition software of the iPhone and BIOPAC.
6. Instruct the subject to pose and keep the prescribed posture comfortably for 5 minutes, while the iPhone and BIOPAC software is acquiring the acceleration data and ECG signal.

Figure 3. Heart rate extracting using iPhone accelerometer

III. RESULTS

The data of the 3-axis accelerometer is shown in Figure 4. Among the 3-axis accelerometer data, Z-axis data has clear quasi-periodic peaks. It is because that only Z-axis is parallel to the axis of the movement caused by every heart pumping.

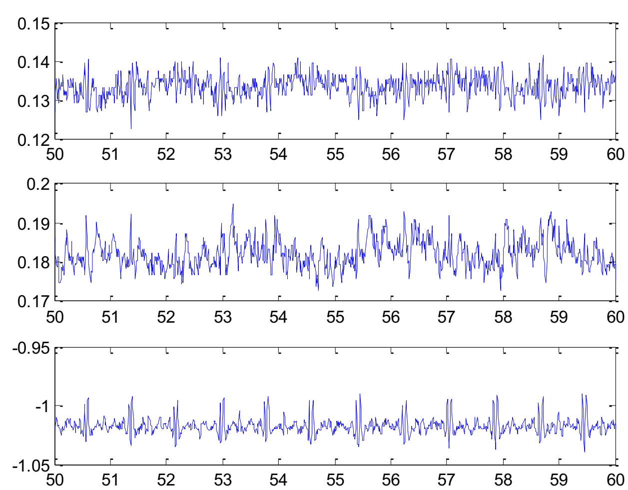

Figure 4. Raw data of 3-axis accelerometer
(Top: X-axis middle: Y-axis bottom: Z-axis)

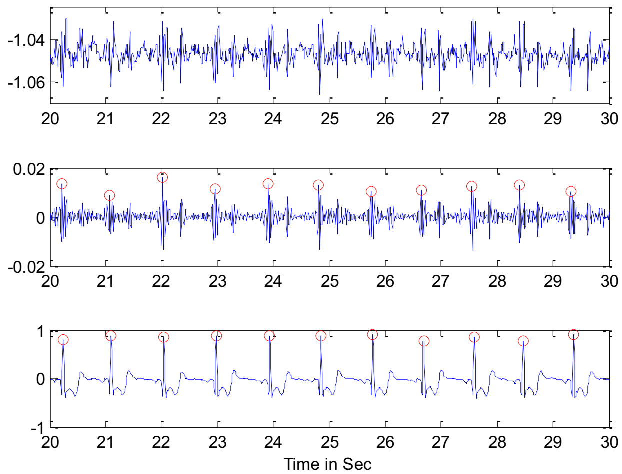

Figure 5. Raw data of z-axis accelerometer (Top), Filtered data of z-axis accelerometer (Middle), ECG reference (Bottom)

Such a clear peaks shown in Z-axis were not found in X and Y axis data. The raw data of Z-axis was filtered by band pass filter which is described in the previous section. Figure 5 shows the raw data of Z-axis (Top), filtered data of Z-axis (Middle) and ECG reference signal (Bottom). With simple peak detection and modification algorithm, we extracted heart rate from ECG signals and peak intervals from filtered z-axis data. The extracted peaks are described as red circle in Figure 5. To validate the heart rate extraction from accelerometer data, we analyzed heart rates from ECG and z-axis data with linear regression analysis. The results are shown in Table I and Figure 6.

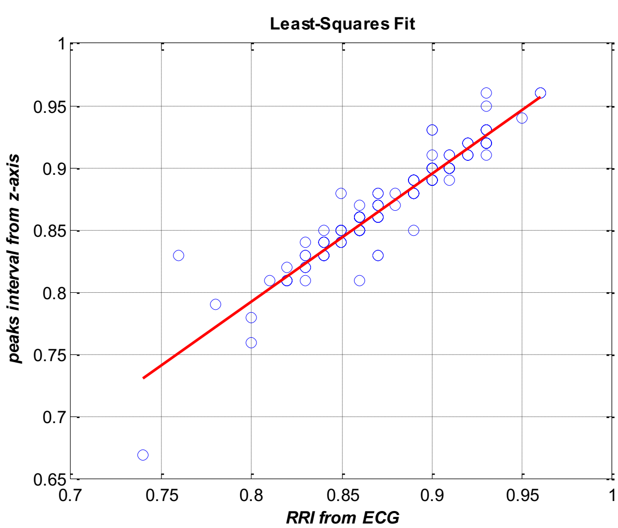

Figure 6. Linear regression between RRI from ECG and peaks interval from z-axis

IV. DISCUSSION

Regardless of the subject's postures, heart rate could be extracted by the accelerometer on the iPhone that was tightly attached to the subjects. However, we couldn't find any quasi-periodic peaks which are synchronized with QRS-complex in ECG signal during slow walking. It may be caused that the body movement from stepping is much stronger than small movement from heart pumping. There is no clear quasi-periodic peaks synchronized with QRS complex in ECG signal in the Figure 7.

TABLE I

CORRELATION COEFFICIENT BETWEEN RRI FROM ECG AND PEAK INTERVALS FROM Z-AXIS DATA

	supine	prone	Lateral	sitting	standing
Subject1	0.9421	0.8901	0.9715	0.8598	0.916
Subject2	0.9856	0.8854	0.7639	0.7854	0.8451
Subject3	0.9498	0.8450	0.9021	0.8451	0.9152
Subject4	0.9212	0.8152	0.925	0.8154	0.8765
Subject5	0.9716	0.8245	0.8152	0.8011	0.8455

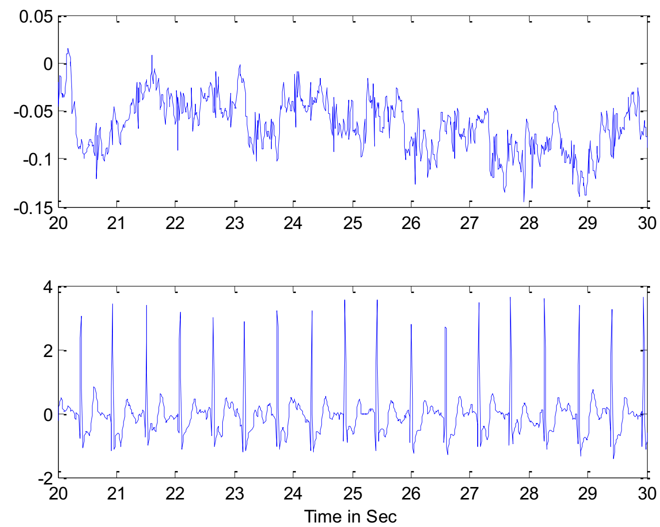

Figure 7. Raw z-axis data during walking (1Km/h) (Top), ECG reference (Bottom)

V. CONCLUSION AND FUTURE WORK

In this paper, we evaluated reliable heart rate can be extracted at the static postures using only the accelerometer system of iPhone. From the result of this preliminary study, we expect people can extract the heart rate at medically reliable level using their smartphone without location and time limitation.

In the future study, we are going to apply the similar approach to other part of the body, such as the wrist, where the pulse can be detected. Studies for reducing motion artifact are also carried out in the further study. In addition, by distributing the smartphone application to cardiac disorder patients, in which our approach is fully implemented, we will study the potential medical benefits from the application.

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