Blood Pressure Measurement Using Finger ECG and Photoplethysmogram for IoT

Anh Dinh, Loc Luu, and Thang Cao

Abstract

This paper presents the design and developing of a device which uses electrocardiogram signal obtained from electrical potential integrated circuit sensors and the photoplethysmogram signal from the fingers to obtain beat-to-beat systolic and diastolic blood pressures along with the heart rate. The system comprises the sensors and needed electronic circuits to obtain the ECG-derived features. The re-useable dry ECG and optical sensors are used to reduce cost and make it simple and convenience to use. The measured results are displayed locally, sent to the internet via available wifi, and stored in the cloud as a monitoring system. This low-cost, small size, and low power usage device can be easily extended to monitor other cardiac features such as premature ventricular contraction and venous pulsations.

Keywords

Electrocardiogram • Electrical potential integrated circuit sensor • Photoplethysmogram • Systolic blood pressure • Internet of things

1 Introduction

Blood pressure is one of the most important vital parameters indicating physiological information of a human body. Measuring blood pressure devices have been continuously developed and evolved with cuff and without cuff. The continuous and cuff-less measurement of blood pressure is desirable for home healthcare or easing workload of clinicians at hospital settings. There are numerous non-invasive techniques to measure blood pressure. These include non-continuous methods, auscultatory and oscillometric, and continuous methods including arterial tonometry, plethysmography and pulse transit time (PTT) [1]. It has been accepted that PTT can be regarded as an index of arterial stiffness and has been employed as an indirect estimation of blood pressure [2]. PTT can be measured as the time interval between the peaks of R wave of the electrocardiogram (ECG) and a characteristic point at predetermined thresholds of the photoplethysmogram (PPG) in the same cardiac cycle. PPG is the blood propagation period from the aortic valve to a measuring point. The PTT is calculated as the temporal difference between the R-peak in an ECG and the finger photoplethysmograph (PPG) [3, 4]. The starting point of PTT is the R wave peak and there are several different choices of the ending point [5]. The end points can be at the foot, at the middle, or at the top of the PPG waveform. Figure 1 provides the definition of a PTT [6].

From the two received waveforms (ECG and PPG), PTT is to be calculated and eventually blood pressure can be estimated using various techniques. Techniques and methods have been developed to calculate blood pressure based on PTT [3, 7–10]. The basic of the system is to receive the ECG and PPG signals, PTT is calculated and blood pressure is to be estimated. ECG is traditionally used the normal 1-lead ECG with left and right electrodes on the chest and the right leg driven ground circuit. PPG is normally obtained by using a photodiode sending light into a fingertip and a photo

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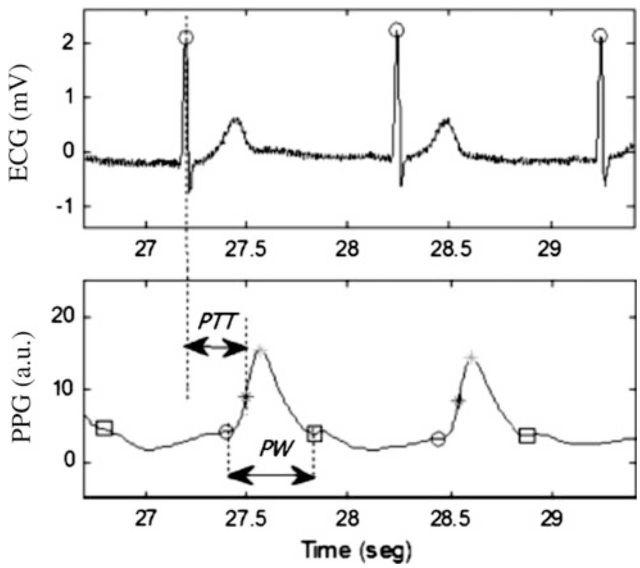


Fig. 1 PPT definition [6]

transistor detects the reflected light [11, 12]. Due to the inconvenience of the ECG sensors using conductive gel or patch, in this design, a capacitance-coupled sensing method is used for measuring the biopotential of ECG. The sensors pick up electrical signals at the thumbs or at the fingertips and process the signals to become a useful ECG. The use of this type of sensors reduces complexity and simple to use as shown in the design of this system.

In addition to the low-cost and simple design, portability has become one of the primary demands of consumers in the biomedical field. In many cases, there is a need for the mobilization of the equipment that the doctors carry for outside visits. It is also necessary to cut the price and size of some of these tools in order to better appeal to those that need continuous monitoring. This design demonstrates the use of new type of sensors to detect ECG and PCG right on the fingertips. PPT method is used to estimate blood pressure along with the heart rate on a small device. The results will be transmitted and displayed on a smartphone and/or to the internet as an internet of thing (IoT) application. The cloud is used to store heart rate and blood pressure for history monitoring purpose. With the explosion in applications of wireless technologies in healthcare awareness, this design satisfies the need for such applications.

2 System Design and Implementation

The system includes two main components: hardware and software. The hardware consists of a rechargeable power supply to run the analog circuits, a microcontroller, and a wireless module. The electrical potential integrated circuit sensors (Plessey Semiconductors) are used to detect the ECG at the fingers. The light sensor is used to obtain the PPG waveform. A microcontroller with 10-bit ADC built-in is used to digitize and process the signals. Heart rate, systolic blood pressure, diastolic blood pressure are estimated and sent to a display and a wireless module. The microcontroller and wireless module are in a single package in the form of an SD card, (Electric IMP). Figure 2 shows the prototype of the designed unit contained in smartphone case. The simple flowchart for the processor and the wifi module is shown in Fig. 3.

The methods to calculate PPT and estimate blood pressure are described in [7]. The coefficients are selected from experimental results by simultaneously measuring ECG, PPG of the prototype and the continuous blood pressure using the Portapres®. Portapres is a standard ambulatory blood pressure monitoring and displays cycle-by-cycle hemodynamic parameters such as stroke volume and cardiac output [13].

Figure 4 below shows the collected ECG, PPG waveforms, heart rate, waveform from the Portapres, systolic and diastolic blood pressures. Figure 4 also shows a closer look at the 2 waveforms from the prototype. The collected data were analyzed to find the relationships between PTT and blood pressures. Using the ECG waveform, all the R peaks were found. The foot, middle, and top of the PPG were also identified and the PPT were calculated. Figure 5 shows the plots and the linear and non-linear regression relationship between blood pressure and PTT. The PTT was taken as the time between R-peak and the foot of the PPG. The foot is defined as the time at which the PPG waveform starts rising from its baseline. Obviously, non-linear regression is more accurate than the linear regression.

As shown, there is an inverse relationship between systolic blood pressure (SBP) and PTT. From the analysis, the two empirical equations for the systolic and diastolic blood pressures were generated and implemented in the microcontroller:

$$\mathrm{SBP} = 4.8008600358 \times 10^{-4} \times \mathrm{PTT} + 1.308532932 \quad (1)$$

$$\mathrm{DBP} = -6.23533972 \times 10^{-4} \times \mathrm{PPT} + 1.37708918 \quad (2)$$

3 Testing Results

In the experiments, there were 11 male subjects age ranging from 20 to 60 year old involve in the testing. The subjects placed 2 fingers at the ECG sensors located in the back of the unit. The thumbs are put on the smartphone case and on the top of the light sensor (PPG). The case is grounded as the

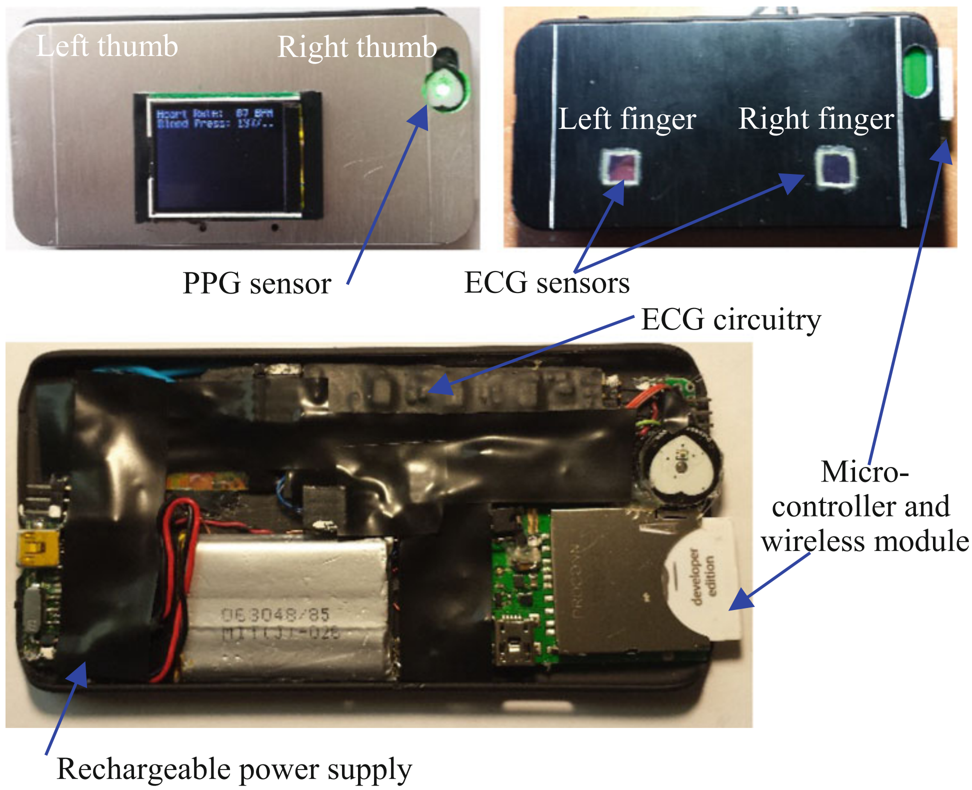


Fig. 2 Prototype includes sensors, circuits, power supply, microcontroller and wireless module insides a smartphone case

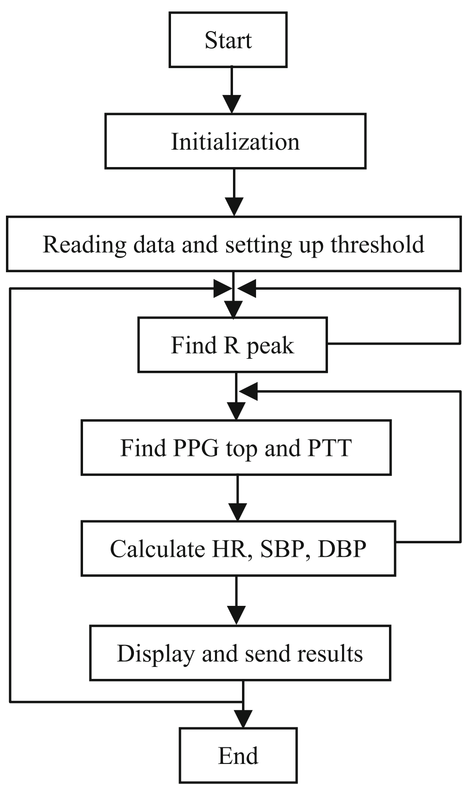


Fig. 3 System flow chart

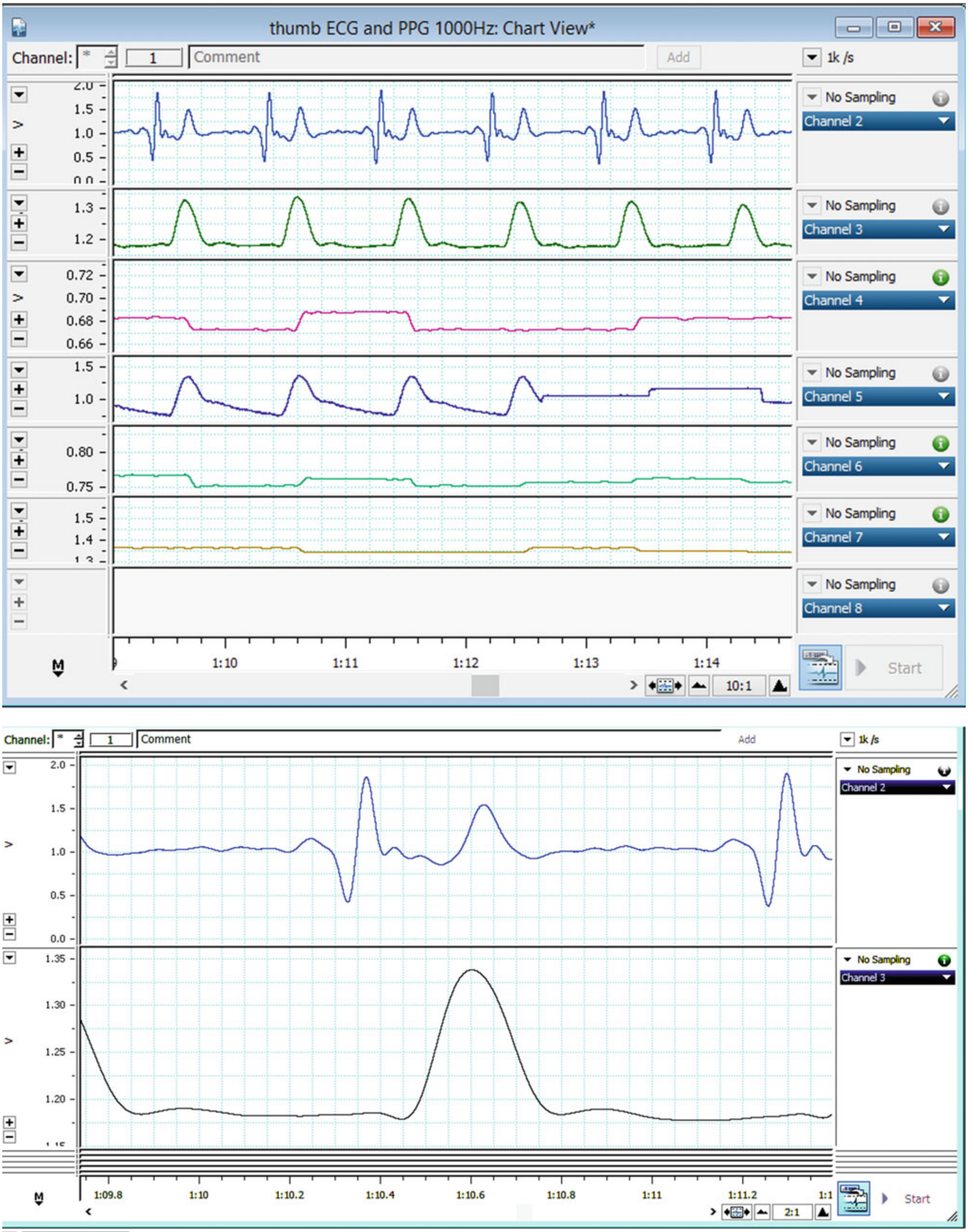


Fig. 4 Waveforms to find coefficients for blood pressure estimation

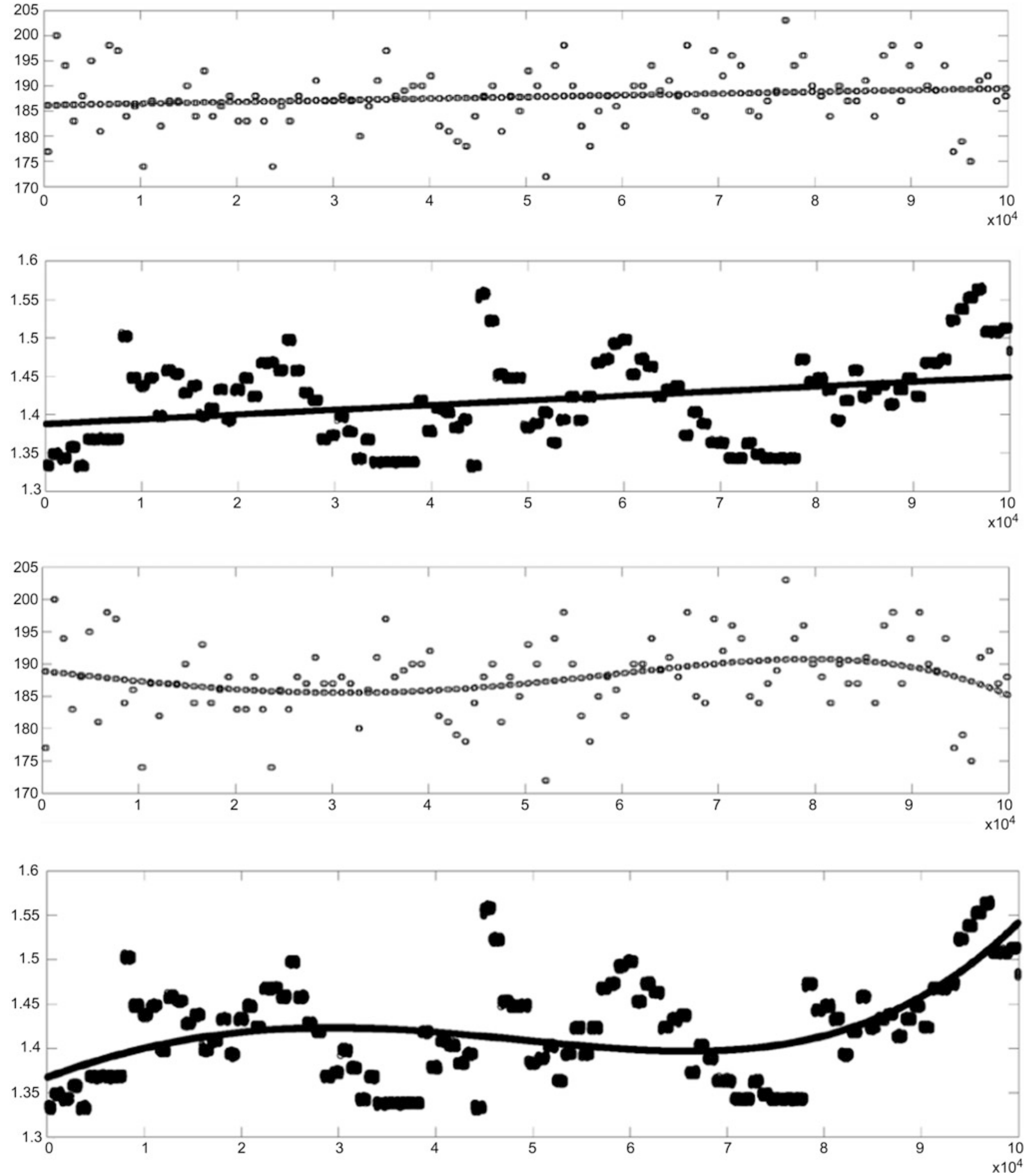
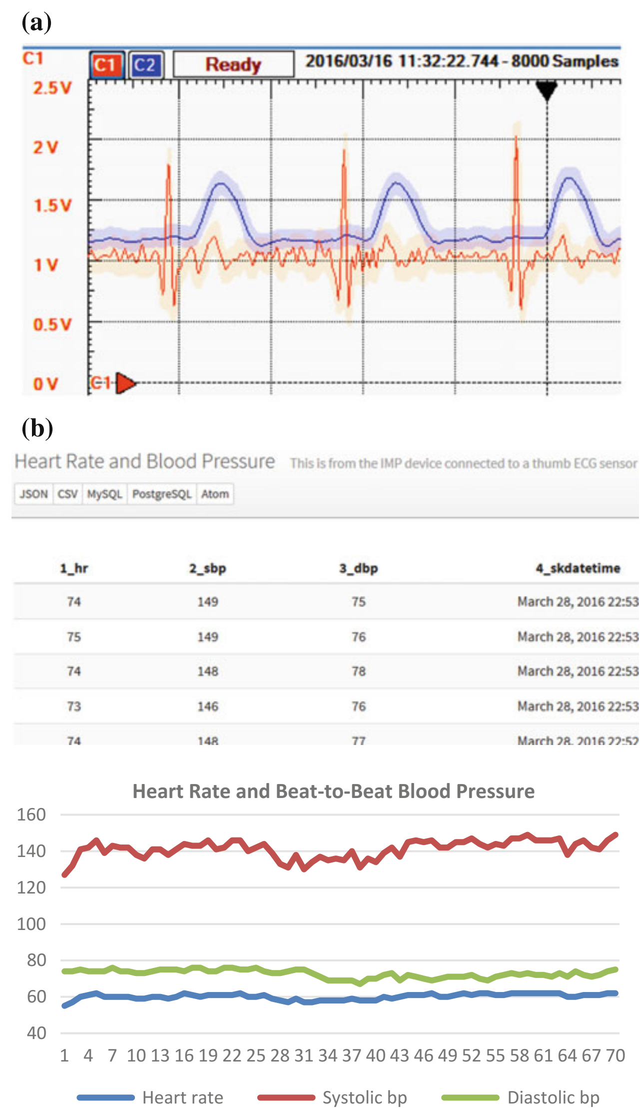


Fig. 5 *Top to bottom*: linear regression of foot PTT, Linear regression of foot SBP, non-linear regression of foot PTT, and non-linear regression of foot

same potential of the ECG circuitry. The unit samples these two signals at a sampling rate of 360 samples per second. This sampling is considered as the standard for the low frequency of the ECG and PPG. However, the high sampling rate provides higher accurate R peak and high precision foot, middle, top, and slope of the PPG.



1_hr	2_sbp	3_dbp	4_skdatetime
74	149	75	March 28, 2016 22:53
75	149	76	March 28, 2016 22:53
74	148	78	March 28, 2016 22:53
73	146	76	March 28, 2016 22:53
74	148	77	March 28, 2016 22:52

Fig. 6 **a** ECG and PPG waveforms from the unit, **b** IoT data storage and display of the heart rate and blood pressure

Figure 6a shows the plots of the ECG and PCG signals off the oscilloscope. It is clearly shown the high quality ECG and PCG waveforms from the fingers. Data from these two waveforms are used to estimate the blood pressure using PTT method. The unit continuously displays the heart rate and the blood pressure for every cardiac cycle. At the same time, data are sent to a database on the internet with the time stamped. Figure 6b shows the data are placed in a website and the data are retrieved and plotted illustrating a working system.

The results were compared against the measurements from the Portapres. The experimental results show the designed system achieved a 93% accuracy compared to a standard system. The majority of power is used by the wireless module and the microcontroller (80–100 mA depending on idle or on transmission mode). The ECG and PPG circuitries draws only 12 and 3 mA respectively on a 3.3 V supply.

4 Conclusions

Using commercially available components, a device to measure continuous blood pressure using ECG and PPG detected on the fingertips to determine blood pressure was designed. The ECG and PPG waves are sent to a processing system in which the blood pressure is estimated. The results are locally displayed and wirelessly transmitted to the cloud as an IoT application. The benefits of this design is the use of small, dry electrodes for R-peak detection of the ECG at the fingertips make it very convenience to use. The simplicity of the design makes it easily to integrate into a smartphone as the hardware can be built to fit its case. USB connection can also be made to further reduce size, power consumption and ease of use to measure continuous blood pressure for other applications. The sensors are low-cost, one-time installment eliminating the use of throw-away ECG patches. Correct measurement of the blood pressure (within 5% of the standard) needs to be further investigated. In addition, different methods to estimate blood pressure can be easily implemented into the system. For future exploration, the constants in Eqs. (1) and (2) must be further studied as these constants depend on individual. Methods must be sought to find the constants automatically if the device is to be commercialized.

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