Portable Heart Rate Detector Based on Photoplethysmography with Android Programmable Devices

U Kin Che, Chi Kin Lao, Sio Hang Pun, Peng Un Mak, Feng Wan, and Mang I Vai

Abstract—**In this paper, a miniature portable heart rate detector system is implemented by modern hardware ICs and simple sensor circuit with software executable on Android platform. The biosignal is first extracted via photoplethysmography (PPG) principle into electric signal. Then a microprocessor is used to covert biosignal from analog to digital format, suitably for feeding into an RF module (nRF24L01 for RF transmission). On the receiver end, the computer and/or smart phone can analyse the data and display the heart rate status for health care monitoring. The housing for portable devices and PCB is tailored made by using the new 3-D printer with ergonomic design. Initial prototype size is 40 x 30 x 20 mm^3 and could be smaller in later version. Some application software running on Window application and Android phone have been developed to display result for users. In the future, pure Bluetooth technology will be used for wireless personal communications instead of RF modules. At the same time, the data can be sent to computer console using existing available networks (3G, 4G, WiFi, etc.) for health database logging purpose.**

Keywords—**Android programming, Healthcare monitoring, Photoplethysmography, Wearable Devices .**

I. Introduction

BECAUSE OF the rapid medical development of our modern societies, the health care system becomes much more mature and professional. Migrating regular mature in-clinic/in-hospital health system to individual wearable monitoring systems for chronic disease becomes popular. This trend will go on in forthcoming years as the average number of elderly has continued to occupy large portions worldwide. In order to check the healthy status of the people, many techniques in Biomedical Engineering have been developed for making faster and more accurate diagnoses with ease to use. The traditional devices are quite bulky, so the patients usually need to go hospital every time they have follow-up checks. This is quite inconvenient, especially for the patients with chronic diseases and/or with moving difficulty. Although some small mobile devices [1] [2] have been developed recently, they are still equipped with some unwieldy cables, which lead to some inconvenience. Lately, biomedical devices using wireless techniques are developed, and their sizes become much smaller than those before.

Generally speaking, there are two types of mini mobile biomedical devices: invasive and non-invasive. Even invasive type devices usually give out more reliable & accurate information; they are not popular due to many problems in invasive type: infection, rejection reaction, battery changing, and etc. Non-invasive will be easier to implement and is safe and more acceptable for general public. Photoplethysmogram (PPG) is one of non-invasive method for measuring biomedical signal of organs. In general, it can be taken on either fingertip or ear lobe to monitor heart rate, blood oxygen level, respiration, etc.

In this paper, a portable biomedical detector prototype that monitors heart rate and potentially measures blood oxygen level in the future using PPG will be designed and implemented. In minimizing the size of the system, hardware devices were carefully chosen with multiple functions on the same chip. Also wireless communication is realized by small size RF module and leave further analyses for computers/PDAs.

The next Section gives system overview. Section III introduces various subsystems/building blocks & prototype results for our implementation. Prototype result and conclusion are given in Section IV while future improvement suggestion can be found in the end.

II. System Overview

The overall design block diagram of our PPG heart rate detector is shown in Fig. 1. The sensor was used to detect the PPG from the patient's fingertip. Then, a simple conditioning circuitry was designed to prepare the signal for the ADC embedded in the microcontroller. Within the microprocessor, the digitized PPG signal was packeted and passed to the server computer via a pair of RF transceiver. Within the server computer, the PPG data was processed and stored for the sake

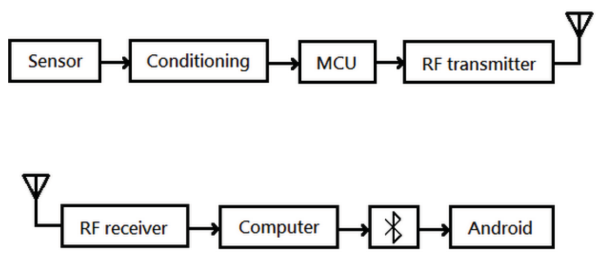


Fig. 1 Block diagram of the PPG heart rate detector

Manuscript received February 27, 2012. This work was supported in part by the Science and Technology Development Fund of Macau under Grant 063/2009/A, and Grant 024/2009/A1; the Research Committee of the University of Macau under Grant UL12/09-Y1/EEE/VMI01/FST, Grant RG077/09-10S/VMI/FST, and Grant RG072/09-10S/MPU/FST.

All authors are with Department of Electrical and Computer Engineering, Faculty of Science and Technology, University of Macau, Macau SAR, China (phone: 853-8397-4393; fax: 853-8397-4275; Corresponding email: fstpum@umac.mo).

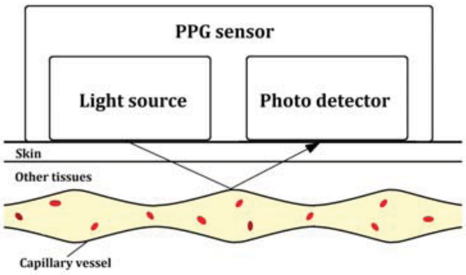
of better diagnosis and treatment/record in the future. In the meanwhile, related information was sent to a smartphone for user's concern via Bluetooth. In the next Section, the function of each component will be briefly discussed.

III. FUNCTIONAL PARTS & PROTOTYPE RESULT

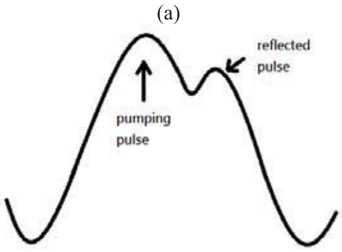
A. Wearable Sensor

To facilitate plethysmography measurement, three sensing mechanisms are commonly used, namely, volume displacement plethysmography, impedance plethysmography, and photoplethysmography[3]. The photoplethysmography is preferred in our design because measurement can be performed on fingertip without precise positioning. Additionally, the design can easily upgrade to blood oxygen saturation measurement. Photoplethysmography (PPG) is based on plethysmography and photovoltaic technique, as displayed in Fig. 2 (a). Every time when blood pumps to periphery (ejection phase), blood vessels expand due to the blood pressure from the heart, a pulse will be generated. And every time when the blood flows back (diastolic filling phase), another pulse follows. So the PPG signal will be the superposition of the pumping pulse and the reflected wave, as shown in Fig. 2 (b).

Fig. 3 depicts our conceptual diagram of PPG measurement on fingertip. An infra-red LED and a detector were placed beneath the fingertip of the patient for measuring the change of blood volume by the activities of the heart. The volume change of the blood within the artery will directly affect the scattering light received by the photo-detector and thus, a simple circuitry, as shown in Fig.4, is used to generate the electric pulsation related to the plethysmography. A sample output of the sensor in both time and frequency is shown in Fig. 5. One can observe the heart rate is located around 1-2 Hz while the power line 50 Hz is strongly presented.



(a)

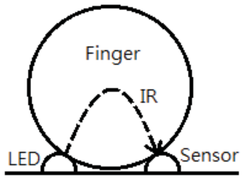


(b)

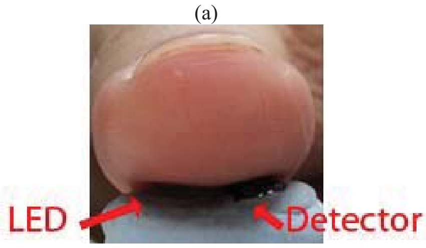
Fig. 2 (a) Basic PPG technique; (b) sample PPG waveform

B. Signal Conditioner

As one can observe the PPG signal in Fig. 5, the raw signal from the sensor is quite weak (~8 mV_{p-p}) and contaminated with noise (especially 50 Hz power-line) on top of a DC component. Therefore, a high pass filter with stop corner frequency of 0.5 Hz, as shown in Fig. 6, is applied.



(a)



(b)

Fig. 3 (a) Illustration of PPG sensor schematic; (b) physical case during signal extraction.

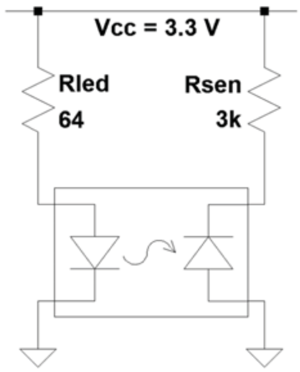


Fig. 4 Sensor Circuit for detecting the PPG signal

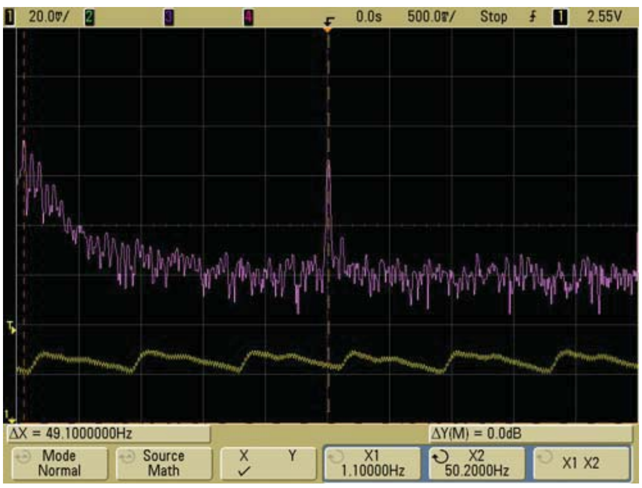


Fig. 5 Acquired Electric pulsation of the plethysmography from sensor (Yellow colour: Time domain & its FFT in purple colour)

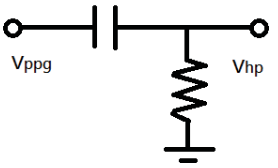
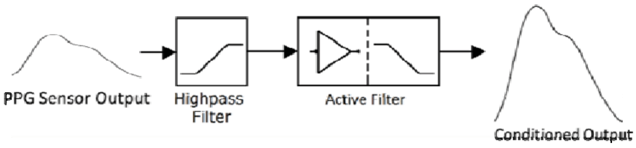
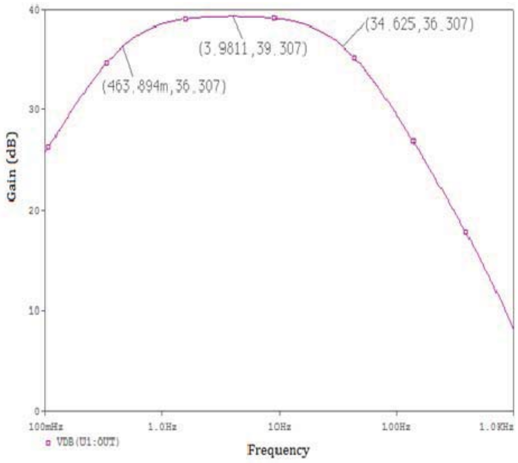


Fig. 6 Circuit to filter out the DC components of the PPG signal



(a)



(b)

Fig. 7 (a) Schematic of the pre- conditioning module; (b) Its frequency response

Additionally, an operation amplifier (AD626), which has maximum 100 V/V voltages gain and intrinsic structure for adding low pass filter (corner frequency set to 34 Hz), was used to eliminate the noise component in the signal and boosted the signal for the A/D converter in the next stage. The schematic of the pre-amplified can be found in Fig. 7(a) while its frequency response is shown in Fig. 7(b). The corner frequencies of high pass and low pass filters in this signal conditioning block setting satisfied the ordinary PPG signal with frequency in several Hz [4], and its bandwidth of the PPG signal is 0 – 30 Hz [5].

Fig. 8 displays the processed PPG signal before entering the next stage of microprocessor. The PPG signal and its characteristics can be clearly identified.

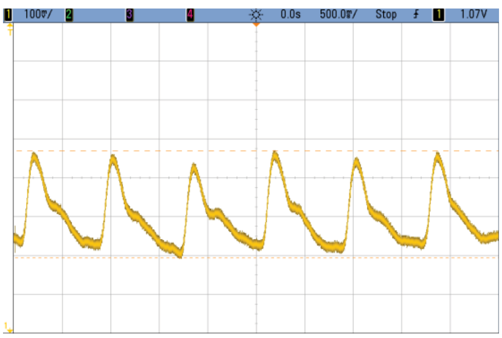
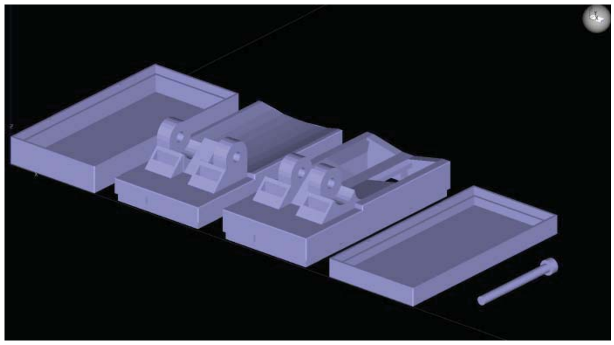
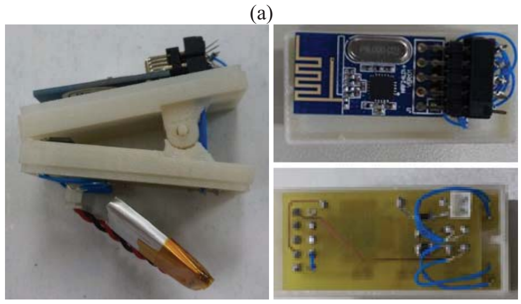


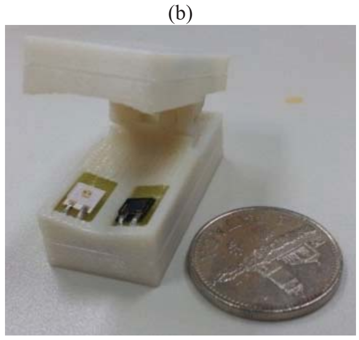
Fig. 8 Sample Conditioned PPG signal



(a)



(b)



(c)

Fig. 9 (a) Finger clip housing; (b) microprocessor, and RF module (c) Sensor circuit with $1 (Macau dollar)

C. Microprocessor

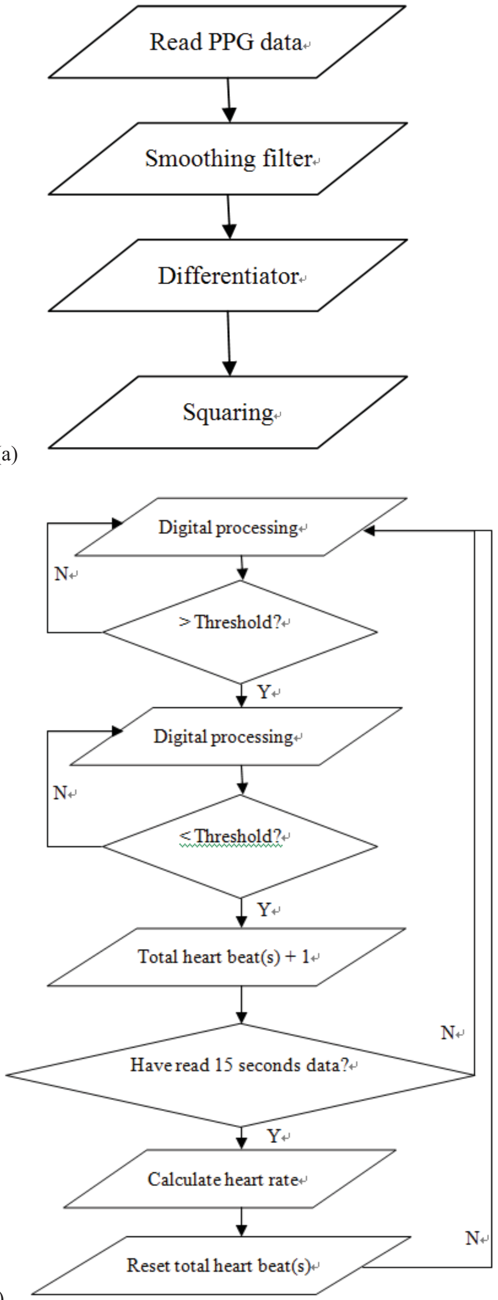
To build a wearable PPG device with extended battery life, we select the C8051F930, which belongs to an 8051 family microprocessor with built-in 10-bit ADC, 90 μA supply current, and small form factor 9 x 9 x 1.6 mm^3. The sampling frequency of the ADC is set to be 250 Hz.

D. RF Transceiver

nRF24L01 [7] is used to wirelessly transmit the PPG signal to the server computer or equivalent. It is chosen because of its small size of around 4 x 4 mm^2 and can be operated through a standard Serial Peripheral Interface (SPI). The carrier frequency is ISM frequency band around 2.4 GHz and operates up to 1 Mbps data rate. The supply voltage is 3.3V from lithium ion battery of 70 mAh capacity.

E. Finger Clip Housing

In order to accommodate all the hardware of aforementioned subsystems, we use a 3-D printer, Fortus 400mc model [6] to print our finger chip housing. This can allow us to flexibly minimize the mechanical housing of our clip in ergonomic consideration; and at the same time, to



(a)

(b)

Fig. 10 (a) Digital Processing & (b) Heart Rate Calculation

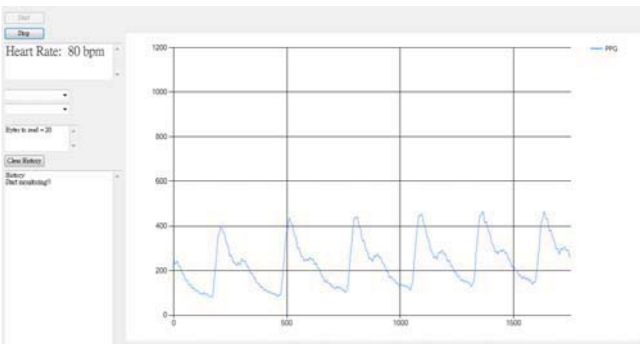


Fig. 11 Sample PPG plot from the server computer

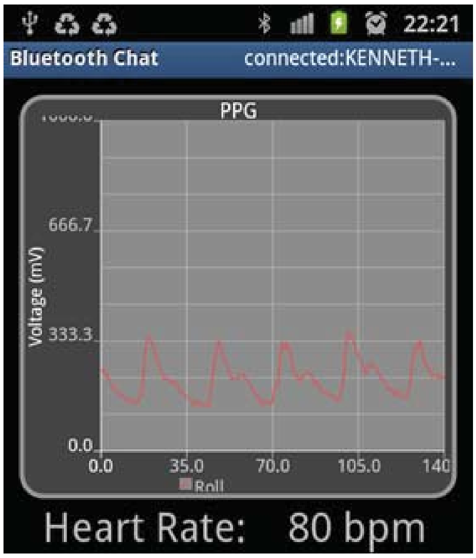


Fig. 12 Sample PPG plot in a Smart Phone

provide hidden room for various electronic building blocks. Fig. 9(a) shows our home-made finger clip housing outlook while Fig. 9(b) & 9(c) display various electronics components in assembly. The initial prototype size is around 40 x 30 x 20 mm^3.

F. Windows Application

As Android phones and iPhones are the most popular phones nowadays and possibly in near future, we would like to select one of them to develop our PPG application. Finally we choose Android because development on *i*OS has much more limitations in comparison to those on Android, which belongs to Open-Source. However, apps that are not from the Apple Apps Store cannot be installed to a non-jailbreak iPhone. For an Android phone (even if it's not rooted), we just need to develop our app to be a signed app and enable the "accept unknown source" setting on the phone, then our app can be installed on the phone and start the testing. A Windows application written in Visual Basic is developed as a server for processing the PPG signal. The acquired PPG data is first conditioned by digital processing algorithm similar to normal famous ECG real-time monitoring process [8], as shown in Fig. 10(a). Then the heart rate calculation is done through flow chart given in Fig. 10(b).

It continuously receives the PPG from the wearable sensors wirelessly, processes the PPG signal (e.g. heart rate detection), stores for future reference, and retransmits the PPG signal & information to a smartphone app via Bluetooth. In addition to the basic function described, the server computer can also display the PPG signal in real time (as shown in Fig. 11). One can observe that Fig. 11 basically retains most information carried by Fig. 8. Heart Rate can be readily obtained.

G. Android App

In order to display the PPG signal in smartphone devices, an Android apps was developed. The Bluetooth APIs of Android supports the cable replacement protocol RFCOMM which provides serial port (RS-232) emulation. By using the serial port emulation mode, the PPG data with necessary information can be easily delivered to the smartphone apps without excess computing consumption. The main technique of this kind of communication is to establish a virtual serial port while pairing with the Android phone using Fig. 10 algorithm. Finally, an open source pure Java API, AndroidPlot, was used to create dynamic PPG chart. Its library was added to our Android application, then the plot view can be added to the layout main file and the corresponding program which is based on the AndroidPlot example "Orientation Sensor" is added to the main activity file. When there is new PPG data reading, the PPG plot will be updated, as shown in Fig. 12.

IV. CONCLUSIONS

In this work, we have successfully implemented a portable heart rate detector prototype based on Photoplethysmography with appropriate design of several functional blocks, housing in a tailor made finger clip. The system includes a simple PPG sensing circuit, an 8051 microprocessor and programmed for getting and transmitting the PPG data to the computer wirelessly via RF module. Also, a PPG Windows application is written in Visual Basic and a PPG Android App which can receive the PPG data from the computer is written. Both of the smart phone and the computer can show the plot of PPG in time domain & report heart rate reliable.

V. FUTURE DEVELOPMENTS

In the future development, we would test more subjects and compare our result with the standard Holter ECG medical equipment for accuracy evaluation. On the other hand, to increase the versatile of heart rate during exercise, we shall add acceleration sensor to remove the motion artifacts. Also, we would like to extend the program in Android, so that it can transmit the PPG data to the Internet via 3/4G networks.

To the final end, we can integrate all electronic devices in transmitter module into a single chip, like SOC, so that the device can be extremely small or even implanted into human for signal extraction.

REFERENCES

[1] P. Wei, *et al.*, "A New Wristband Wearable Sensor Using Adaptive Reduction Filter to Reduce Motion Artifact," in *Proceedings of the 5th International Conference on Information Technology and Application in Biomedicine, in conjunction with The 2nd International Symposium & Summer School on Biomedical and Health Engineering* Shenzhen, China, 2008.

[2] K. I. Wong, "Design and Experimentation of Wearable Body Sensors," in *Rapid Prototyping Technology - Principles and Functional Requirements*, M. E. Hoque, Ed., ed: Intech, 2011, pp. 273-288.

[3] R. B. Northrop, "Ch.9: Plethysmography," in *Noninvasive instrumentation and measurement in medical diagnosis*, ed Boca Raton: CRC Press, 2002, p. 525

[4] Sokwoo Rhee, J, "Finger Photoplethysmographic Sensors for Vital Sign Monitoring", PhD dissertation, Massachusetts Institute of Technology, May 2000.

[5] M. Nitzan, A. Babchenko and B. Khanokh, "Very low frequency variability in arterial blood pressure and blood volume pulse" *Med. Biol. Eng. Comput.* Vol. 37, No. 1, pp. 54-58, 1999

[6] http://www.fortus.com/products/fortus-400mc.aspx Last accessed on Feb. 2012

[7] www.nordicsemi.com/eng/Products/2.4GHz-RF/nRF24L01 Last accessed on Feb. 2012

[8] J. Pan & W. Tompkins, "A Real-Time ARS Detection Algorithm" *IEEE Trans. on Bio-Medical Eng.,* Vol. 32 (3), pp.230-236 , 1985