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Rapid Prototyping of a Smart Device-based Wireless Reflectance Photoplethysmograph

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Abstract

This paper presents the design, fabrication, and testing of a wireless heart rate (HR) monitoring device based on photoplethysmography (PPG) and smart devices. PPG sensors use infrared (IR) light to obtain vital information to assess cardiac health and other physiologic conditions. The PPG data that are transferred to a computer undergo further processing to derive the Heart Rate Variability (HRV) signal, which is analyzed to generate quantitative markers of the Autonomic Nervous System (ANS). The HRV signal has numerous monitoring and diagnostic applications. To this end, wireless connectivity plays an important role in such biomedical instruments. The photoplethysmograph consists of an optical sensor to detect the changes in the light intensity reflected from the illuminated tissue, a signal conditioning unit to prepare the reflected light for further signal conditioning through amplification and filtering, a low-power microcontroller to control and digitize the analog PPG signal, and a Bluetooth module to transmit the digital data to a Bluetooth-based smart device such as a tablet. An Android app is then used to enable the smart device to acquire and digitally display the received analog PPG signal in real-time on the smart device. This article is concluded with the prototyping of the wireless PPG followed by the verification procedures of the PPG and HRV signals acquired in a laboratory environment.

Index Terms

Wireless Reflectance Photoplethysmographic Sensor; Heart Rate Variability

I. Introduction

Heart rate variability (HRV) is a comparatively new technique that is used to characterize a variety of health conditions including stress associated with illnesses or medical procedures. HRV is calculated from the changes or differences in the peak-to-peak interval timing of the cardiac cycle, which naturally are sporadically spaced in time [1]. In general, a high HRV has been scientifically proven to be an indication of good health and wellness, whereas a low HRV has been linked to fatigue and stress. The electrocardiogram (ECG) is one of the simplest and oldest recordings that have been used to assess the electrical activity of the heart and to obtain Heart Rate (HR) information. Although heart-monitoring techniques based on ECG recordings traditionally have been used to diagnose heart-related disorders,

this method of monitoring the heart has a noticeable disadvantage: the ECG requires at least a couple of electrodes to be able to operate, and these electrodes must be placed at specific body locations. This clearly represents a certain drawback to this approach as it greatly restricts the flexibility of the users, especially during daily routine activities. This drawback, however, can be overcome simply by replacing the ECG electrodes with a photoplethysmographic (PPG) sensor. A PPG sensor uses an infrared light source and a photodetector to detect blood volume changes in the microvascular bed of tissue. The PPG sensor detects variations in light intensity via transmission through or reflection from the tissue. The variations in the light intensity are related to changes in the blood perfusion of the tissue, and based on these changes heart-related information can be collected from the cardiovascular system. Generally, PPG sensors operate in two different modes: transmittance mode and reflectance mode. In the transmittance mode, the infrared light transmitted through the tissue is detected by a photodetector that is placed in the opposite side of the tissue, whereas in the reflectance mode, the photodetector is placed on the same side as the light source; thus, the photodetector detects the light that is reflected from the tissue. Although transmittance PPG sensors are able to obtain good quality signals, their measurement sites are very limited: sensors must be placed at certain body locations in which transmitted light can easily be detected such as the earlobe and fingertip. The reflectance PPG sensors, however, reduce the challenge related to sensor placement. Sensors can be placed on a variety of measurement sites such as the forehead, chest and wrist, which offer more flexibility to the users, especially during routine daily physical activities. Therefore, developing high performance HR monitoring devices based on reflectance PPG sensors are of great interests in a variety of applications. As an example, HRV that is measured from the reflectance PPG sensors can provide athletes information concerning their recovery and their ability to operate well in a future workout.

II. Heart Rate Monitoring Device

An energy-efficient wireless photoplethysmographic device was custom-designed to collect and analyze the arterial pulse signal. The proposed system as shown in Fig. 1 comprises an optical infrared sensor to sense the arterial pulse in the finger, a signal conditioning unit to prepare the collected signal via filtering and amplification for Analog-to-Digital Conversion (ADC), a low-power microcontroller to digitize the analog PPG signal, and a wireless module to transfer the digital data to a wireless device. An Android app was also used to enable the smart device to obtain and digitally display the received analog PPG signal in real-time on the smart device [2].

A. PPG Circuit Design

The schematic diagram of the proposed PPG circuit is shown in Fig. 2. As can be seen in Fig. 2, the TCRT1000 optical sensor is used for sensing the IR light signal. The TCRT1000 sensor is a widely used reflective optical sensor, which includes both an infrared (IR) emitter and a photodetector placed side by side. By placing a fingertip over the TCRT1000 sensor, the incident light will be reflected and the amount of light that is reflected back from the fingertip is detected by the photodetector. For the signal conditioning stage, the PPG signal is required to be filtered and amplified. This is due to the raw PPG signal consisting of two

main components: the AC component and the DC component. The AC component is mostly generated by variations in arterial blood volume and is synchronous with the pulsation of the heart. Thus, the AC component can provide the heart rate information, whereas the DC component is associated with the tissues and average blood volume. The DC component must be eliminated in order to simplify the detection of AC component with a high signal-to-noise ratio. Therefore, in the signal conditioning stage, the output of the optical sensor must initially be passed through a passive high-pass filter (HPF) to attenuate or ideally eliminate the DC component. A cut-off frequency of 0.7 Hz is used for the HPF. Subsequently, the output from the HPF must be passed through an active low-pass filter (LPF), made of an Op-Amp circuit. The gain of this LPF is set to 11. The active LPF is designed to merely amplify the low frequency signals and pass the high frequency signals unchanged. When the HPF is used in combination with the active LPF, two different goals can be achieved at the same time. On one hand, using this combination can significantly assist in eliminating the undesirable DC signal and high frequency noise, including the 50/60 Hz interference generated from the surrounding environment; on the other hand, it can amplify the low frequency AC component of the PPG signal. The output from the first HPF/LPF combination must go through a similar processing stage (second filtering stage) to further filter and amplify the PPG signal. In this way, the total voltage gain obtained from the two filtering stages is $11 \times 11 = 121$. The PPG signal is captured on an oscilloscope as shown in Fig. 3. For the ADC stage a low-power ARM Cortex-M0 processor is used. In this stage, the analog PPG signal is initially converted to digital format and then the digital data is sent via HC-05 Bluetooth module to a tablet. To choose wireless capability, different low-power technologies as shown [3] were considered to be used. However, in order to ensure the flexibility of the users, in this paper, Bluetooth connectivity is used. The PPG Printed Circuit Board (PCB) is designed using Altium Designer and is shown in Fig. 4a.

III. Signal Processing and Heart Rate Variability

In order to collect PPG data for HRV analysis, the PPG device was connected via a TTL serial cable to a computer. The data were collected and saved as a text file. The data collection process took nearly eight minutes for an individual volunteer. Then, the collected data file was imported into a MATLAB program for further analysis. The program was written to detect the R-R peak intervals of the PPG waveform. A new file was then generated consisting of all the peaks during the recording process. Lastly, by feeding the PPG signal peaks into the Kubios software, the HRV analysis report was generated as shown in Fig. 4.

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References

1. Reyes, I., Nazeran, H., Franco, M., Haltiwanger, E. Wireless photoplethysmographic device for heart rate variability signal acquisition and analysis. IEEE 34th Engineering in Medicine and Biology Society Conference; San Diego, California, USA. August, 2012;
2. Ghamari, M., Soltanpur, C., Cabrera, S., Romero, R., Martinek, R., Nazeran, H. Design and Prototyping of a Wristband-Type Wireless Photoplethysmographic Device for Heart Rate Variability

Signal Analysis. accepted for presentation at the IEEE Wireless and Microwave Technology Conference; Clearwater Beach, Florida, USA. April, 2016;

3. Ghamari M, Arora H, Sherratt RS, Harwin W. Comparison of low-power wireless communication technologies for wearable health-monitoring applications. Computer, Communications, and Control Technology (I4CT) Conference. Apr 21–23.2015 (1–6)

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Fig. 1.
Block diagram of the proposed PPG device

Fig. 2.
Schematic of the proposed PPG circuit

Fig. 3.
PPG signal captured on an oscilloscope

Fig. 4.

a) PPG device, front and back sides b) Digital values captured on a tablet

Fig. 4.
HRV analysis report of an individual by Kubios