HiLL PUBLISHING

Engineering Advances, 2023, 3(1), 43-46
https://www.hillpublisher.com/journals/ea/
ISSN Online: 2768-7961

Development of a Reflective PPG Signal Sensor

Cui Zhang[1,*], Xiaofei Li[2]

[1]School of Electrical and Automation Engineering, Liaoning Institute of Science and Technology, Benxi, Liaoning, China.
[2]MCC Coke Resistance (Dalian) Engineering Technology Co., Ltd, Dalian, Liaoning, China.

How to cite this paper: Cui Zhang, Xiaofei Li. (2023) Development of a Reflective PPG Signal Sensor. *Engineering Advances*, 3(1), 43-46.
DOI: 10.26855/ea.2023.02.009

Received: January 12, 2023
Accepted: February 10, 2023
Published: March 6, 2023

***Corresponding author:** Cui Zhang, School of Electrical and Automation Engineering, Liaoning Institute of Science and Technology, Benxi, Liaoning, China.

Abstract

PPG signal which reflects the blood volume changes in the microvascular bed of tissue plays an important role in the cardiovascular disease diagnosis. It possesses high value to acquire the PPG signal accurately. Because the available measurement site of transmission mode PPG sensor is very limited, this paper presents a reflective PPG signal sensor which consists of a photodiode and four light sources surrounding the photodiode. The Monte Carlo simulation was performed to decide the distance between the light source and photodiode. To test the efficacy of the developed sensor, PPG signals were captured from five different measurement sites. The experiment results reveal that the proposed PPG signal sensor could acquire high quality PPG signals. As can be seen from the figures, all the captured PPG signals have high quality, except for the chest PPG signal which is inferior to other signals, this may be accounted by the influence of respiration.

Keywords

PPG signal, sensor, Monte Carlo simulation, source-detector separation

1. Introduction

PPG which reflects the blood volume changes in the microvascular bed of tissue is a low-cost optical noninvasive technique that plays an important role in the clinical applications [1] including clinical physiological monitoring (blood oxygen saturation [2, 3], pulse rate [4], blood pressure [5], cardiac output [6] and respiration [7, 8]), vascular assessment (arterial disease [9], arterial compliance and ageing [10], endothelial function [11], venous assessment [12], vasospastic conditions [13] and microvascular blood flow and tissue viability [14]) and autonomic function (vasomotor function and thermoregulation [15], blood pressure and heart rate variability [16], orthostatic intolerance [17], neurology[18] and other cardiovascular variability assessments [19, 20]).

The PPG signal acquisition usually utilizes monochromatic light emitting into the biological tissue and a photodetector to receive the emergent light. Such as the pulse oximeter [2], which utilizes the PPG signal to measure the oxygen saturation of arterial blood, employs a pair of LEDs (red and infrared light) to irradiate human tissue (such as fingertip, toe, earlobe, forehead, etc.) and a photodiode locating at the same or opposite side to detect the emergent light. In the process of PPG signal acquisition, light emitter irradiates photons into the tissue, the photons in the tissue propagate along random paths due to the highly scattering property of tissue, during the propagation some of the photons will be absorbed by the molecule, while others will escape from the tissue boundary, photodetector placed in the skin surface receives the information-bearing emergent light and then transforms it into electric information for succeeding processing. In the systolic phase, the arterial blood is pumped into the aorta from the left ventricle, then flows through peripheral arteries, the quantity of absorbed photons increases during this process because of the increase of blood volume in the peripheral artery, this in turn results in the decrease of detected light intensity. In the diastolic phase, the blood flows back to heart through veins, the detected light intensity increases during this phase because of the decrease of blood volume in the human periphery. This process produces a pulsatile component ('AC') in the PPG signal. Another component of PPG signal is a slowly varying baseline ('DC') due to constant light absorption by the unchanged tissue, slightly varying venous blood and respiration effect, etc [1, 21, 22].

The PPG sensor could be classified into transmission mode and reflection mode according to the relative location of

the light source and photodetector. The transmission mode, which usually selects human periphery sites (such as fingertip and earlobe, etc.) as the measurement sites, is more widely used to capture the PPG signal due to its high signal quality. However, it may cause discomfort and mobility inconvenience for the individuals when long-time wearing. What's more, the available measurement site of transmission mode is often very limited. The reflection mode, which locates the light source and photodetector on the same side could deal with these problems effectively and the placement of the sensor could be more flexible and comfortable. Whereas, there are fewer presentations of the reflective PPG sensor than the transmission one [23]. This may be accounted by two difficulties that the reflection mode faces: one is that the tissue is highly forward scattering which results in that signal quality of reflection mode is no better than that of the transmission mode [24, 25]; the other is that how to determine the distance between the light source and photodetector. In this paper, we utilize a LED array as the emitter to improve the signal quality in terms of the first problem. For the second problem, we utilize the Monte Carlo [26, 27] simulation, which could reflect photon distribution approximating to reality by simulating the light propagation in tissue. To test the efficacy of the developed sensor, PPG signals were captured from five different measurement sites of human. The experiment results revealed that the proposed PPG signal acquisition sensor could acquire high quality PPG signals.

2. Methods and Materials

2.1 The Light Source and Photodetector Separation Determination

Unlike the transmission mode, to design a reflective PPG sensor, the source-detector separation which is a function of the effective detection depth should be first determined. Human tissue is a strongly scattering media, in which the photon will propagates along random path, as shown in Fig. 1, which presents a photon trajecting randomly from the source to detector. Because the scattering coefficient is much larger than absorption coefficient for most human tissue, when the scattering length is much smaller than the tissue geometric dimensions, most of the photons will be scattered repeatedly before escaping outside the tissue surface [23]. Although the paths of different photons propagating in the highly scattering human tissue could not be the same, the statistic trajectory of the photons between the emitter and detector conforms to a banana-shape, as is shown in Fig. 2 [28, 29]. The detection depth varies with the source-detector separation which will be optimal when the corresponding penetration depth just reaches the bottom of the interested matter layer [30].

In order to determine the source-detector separation, we need to understand the process of the photons propagating in the tissue. There are two methods to study this issue: one is based on the diffusion theory [29], the other is the based on the Monte Carlo simulation. The diffusion theory is appropriate provided that the photons propagate in the homogeneous tissue media, and the relationship between the source-detector separation and detection depth is approximated as:

$$z \approx \frac{d\sqrt{2}}{4} \tag{1}$$

where z represents the detection depth, d is the source- detector separation.

In this study, the Monte Carlo simulation which simulates the photons propagating in the multi-layered media will be utilized to determine the source-detector separation. In the simulation, the tissue is modeled as a three-layer media including epidermis, dermis and blood layers. To mimic the different oxygenation states of the blood, we take the method as presented in [31], two extreme states (100% oxygenated blood and 100% deoxygenated blood) are considered in the Monte Carlo simulation process. Thus, when the light effective penetration depth just reaches the bottom of the blood layer, the detector located according to the corresponding source-detector separation will receive the most discrepant light intensity between the two blood oxygenation states. The source-detector separation corresponding to the most discrepant received light intensity is the optimal spacing. The optical parameters needed in the Monte Carlo simulation are shown in Table 1. All the parameters are selected around the wavelength of 940nm.

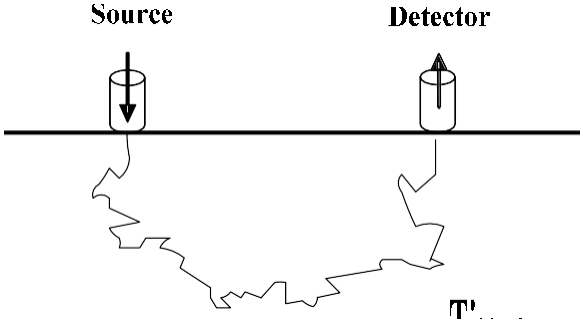

Figure 1. A random propagation path of a photon in tissue.

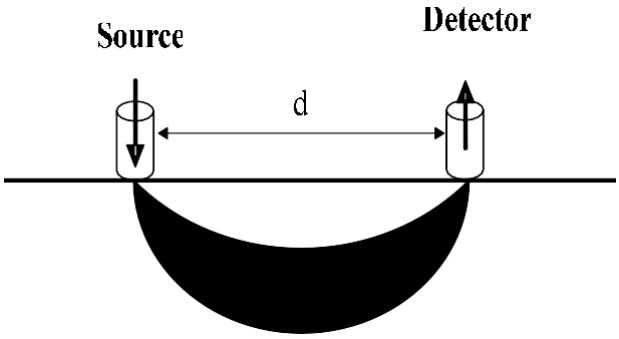

Figure 2. The banana-shaped light propagation envelop.

Table 1. The Optical Parameters Used In The Monte Carlo Simulation

	Tissue	Refrac- tive indices n	μa (cm^{-1})	μs (cm^{-1})	Aniso- tropy g	Thick- ness (cm)
Layer1	Epidermis	1.5	5.86	170	0.85	0.01
Layer2	Dermis	1.37	0.56	90	0.9	0.2
Layer3	Oxygenated blood	1.37	2.84	505	0.9922	0.1
	Deoxygenated blood	1.37	1.68	668	0.9922	

After 10^6 times Monte Carlo simulations, the curves of two extreme blood oxygenation states that the intensity decays with source-detector separation increase are obtained, as is shown in Fig. 3, in which, the x-coordinate represents the source-detector separation (d), and the y-coordinate represents the reflected light intensity. In Fig. 3, the most discrepant reflected light intensity between the two blood oxygenation states corresponds to about 0.3-0.4 cm source-detector separation, which provides a guidance for the reflective PPG sensor design.

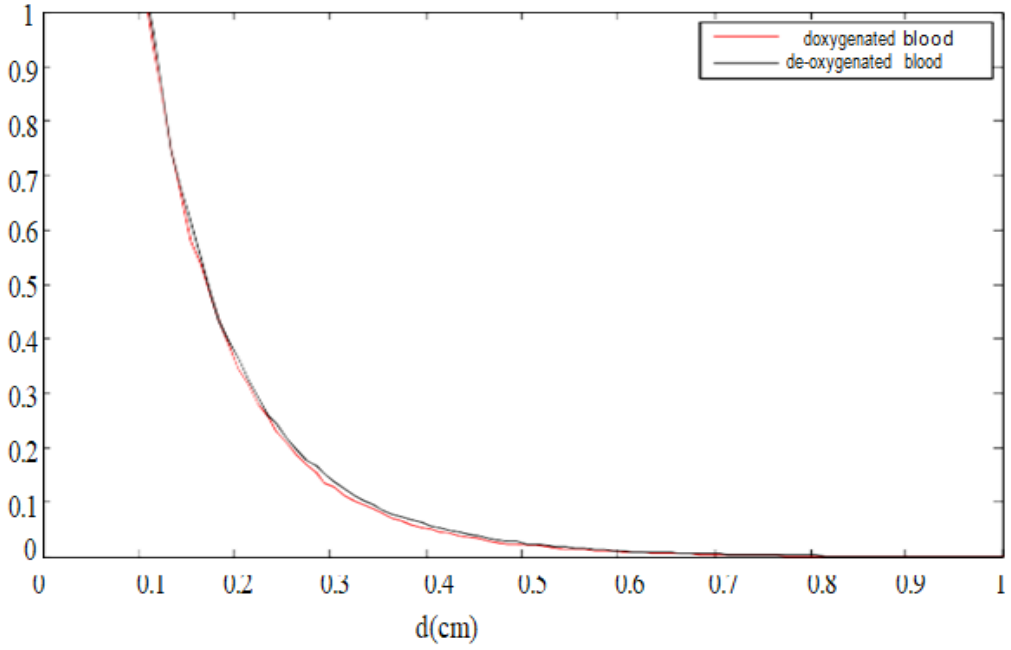

Figure 3. The curves that irradiance decays with source-detector separation increase of two oxygenation states.

2.2 PPG Sampling Module

The principle block diagram of the PPG sampling hardware module is shown in Fig. 4. The LED driver module and signal disposal module traditionally use the discrete electronic component, which will not only consume considerable power but also bring more noise (such as thermal noise) into the signal during processing. In order to avoid these disadvantages, the hardware system design will be simplified by using the integrated chip. In this way, only another mi-

cro-controller will be used in the design, as is shown in Fig. 5, which presents the whole PPG sampling hardware system module. A high processing capability and low power consumption micro- controller (MSP430F5529) is used here.

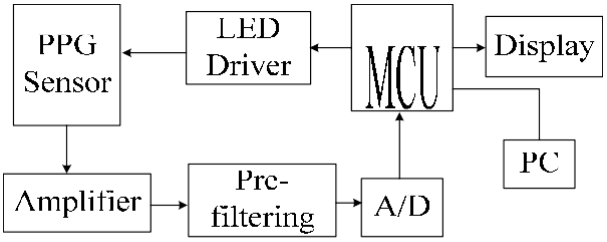

Figure 4. The principle block diagram of PPG sampling hardware module.

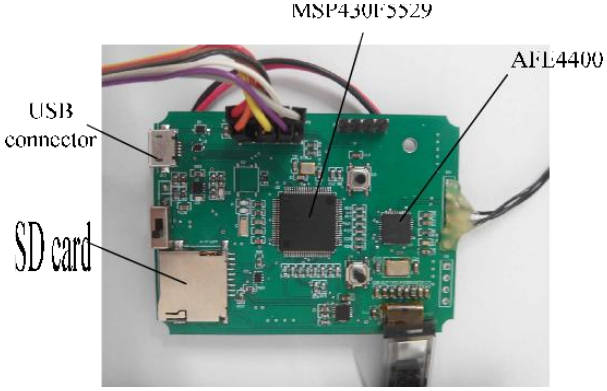

Figure 5. The whole PPG sampling hardware system module.

3. Conclusions

This paper presented a reflective mode PPG sensor which consists of a photodiode and four light sources surrounding the photodiode. The Monte Carlo simulation was used to determine the source-detector separation. The high-quality captured PPG signals from five different measurement sites testified the efficacy of the developed PPG sensor.

References

[1] A. Johansson, P. A. Oberg and G. Sedin. "Monitoring of heart and respiratory rates in newborn infants using a new photoplethysmographic technique," J Clin Monit Comput, vol. 15, pp. 461-467, 1999.

[2] R. A. Payne, C. N. Symeonides, D. J. Webb, and S. R. Maxwell. "Pulse transit time measured from the ECG: an unreliable marker of beat-to-beat blood pressure," J. Appl. Physiol., vol. 100, pp.136-41, 2006.

[3] M. Azabji Kenfack, F. Lador, M. Licker, C. Moia, E. Tam, C. Capelli, et al. "Cardiac output by Modelflow method from intra-arterial and fingertip pulse pressure profiles," Clin. Sci., vol. 106, pp. 365-369, 2004.

[4] M. Orini, M. D. Pelaez-Coca, R. Bailon, and E. Gil. "Estimation of spontaneous respiratory rate from photoplethysmography by cross time- frequency analysis," in Computing in Cardiology, 2011, pp. 661-664.