SMARTPHONE PULSE OXIMETRY DEVICE – A REVOLUTIONARY HEALTHCARE SYSTEM

THIẾT BỊ ĐO NỒNG ĐỘ OXY TRONG MÁU CÓ KẾT NỐI VỚI SMARTPHONE – BƯỚC CẢI TIẾN TRONG CHĂM SÓC SỨC KHỎE

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Abstract - Smartphone is increasingly popular with many integrated functions; therefore it is widely used in the daily life. In addition, the Microcontroller becomes cheaper and consumes less power. This will allow us to develop a low cost portable Pulse Oximeter System interface with Smartphone for patients and old people to control their health everywhere and everytime. This paper presents a system includes a Smartphone and a portable device which implemented preprocessing algorithms such as Led switching controller, noise filter and DC tracking, data processing and transfer data through Smartphone by Bluetooth connecting. In Smartphone, the software was constructed with many functions to enable the users to manipulate it easily. Our device had been compared with the machines now using at C-hospital with high accuracy.

Key words - Pulse Oximeter; Smartphone; Medical devices; SpO2;

Tóm tắt - Điện thoại thông minh đang ngày càng phổ biến với nhiều chức năng tích hợp, do đó nó được sử dụng rộng rãi trong cuộc sống hàng ngày. Ngoài ra, các vi điều khiển trở nên rẻ hơn và tiêu thụ ít điện năng hơn, điều này sẽ cho phép chúng ta phát triển một thiết bị có chi phí thấp gồm hệ thống Oximeter kết nối với điện thoại thông minh cho bệnh nhân và người già để kiểm soát sức khỏe của họ ở khắp mọi nơi và mọi lúc. Bài báo này giới thiệu một hệ thống này bao gồm một điện thoại thông minh và thiết bị di động mà thực hiện các thuật toán tiền xử lý như Led chuyển đổi bộ điều khiển, bộ lọc tiếng ồn và DC theo dõi, xử lý dữ liệu và truyền dữ liệu thông qua điện thoại thông minh kết nối bằng Bluetooth. Trong điện thoại thông minh, phần mềm được xây dựng với nhiều chức năng để giúp người dùng có thể dễ dàng thao tác. Máy đo sẽ được so sánh với hệ thống đang được sử dụng tại bệnh viên C với độ chính xác cao.

Từ khóa - Điện thoại thông minh; nồng độ oxy; SpO2; mạch; y tế.

1. Introduction

The common situation is that in most of the traffic accidents, patients died before being transferred to the hospital, due to the delay in the initial status diagnosis. In most of the traffic accidents, victims have died before being transferred to the hospital due to the delay of the initial status diagnosis, In addition, the patients with medical history of cardiovascular disease often have abnormal symptoms while sleeping. In this paper, we provide a portable medical device not only to monitor online the old people's oxygenation but also to help doctors make clear decisions in a short time. This device can also be connected to the Smartphone through Bluetooth to monitor the customer's health status and give warnings by sending messages, email or calling relatives when the accident happens.

One Pulse Oximeter is a rapid noninvasive measurement of arterial oxygen saturation and cardiac pulse using simple light emitter diodes (LED) and sensor application. There are two types of pulse oximetry: the transmission type and reflection type [8]. Now, most of commercial products are in transmission type while reflection pulse oximetry devices are still on-going researches. The light sources are transmitted through a body part to a light receiver in opposite side to determine blood oxygen saturation and the heart beating. Smartphone is becoming cheaper with many integrated y functions as well as have widely screen will help the user can interact easily. The combination between Smartphone and medical device is going to become widely applying in the future. With rising of medical expenses and the number of doctors that do not meet with increasing number of medical services demands, this device could be a solution for families or hospitals [2].

Figure 1. *Examples of portable pulse oximeter system by smartphone*

According to the previous paper [9], a simple and uncompleted system was established without Smartphone connection. So that in the following sections, we will review the principle of the transmission pulse oximeter to understand the mechanism of calculating the blood oxygen saturation and cardiac pulse from sensor with LED, infrared LED (IR) and optoelectronic sensor. Then in the third section, we provide draft of a pulse oximeter system based on low power MCU to implement a portable device. Next, we also describe the building software on the smartphone to connect and interact with the device. Conclusion and future research will also be included in the paper.

2. Principle of Pulse Oximeter

The typical pulse oximetry configuration on a finger shown in the figure 2 has two different wavelength light sources: Red Led with 660nm wavelength and IR Led with 910nm wavelength, with a photo-detector in opposite positions. Pulse oximetry is based on fractional change in light transmission during an arterial pulse at two different wavelengths [8].

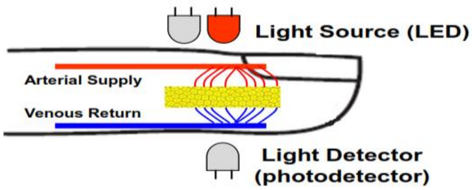


Figure 2. *Typical finger pulse oximeter with two wavelength light sources emitted*

When only one light source is active, the incident light is the summary of transmitted light, absorbed light, scattered light and reflection light on the finger. Each wavelength light source has different light absorbance on different thickness of skin, color, tissue, bone, blood, and other material of the body part being illustrated in figure 3

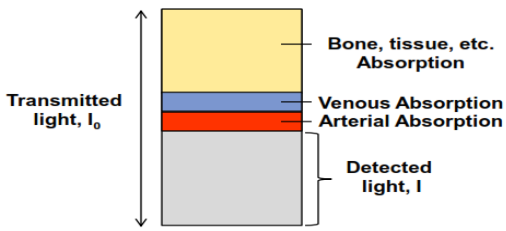


Figure 3. *Absorption of bone, tissue, venous, arterial for light source*

According to the Beer-Lambert law, the absorbance (A) of the wavelength light source with a molar absorptivity (ϵ) is directly proportional to both the concentration (c) and path length (l) of the absorbing material: A = ϵcl. Actually, there are four difference components: oxy hemoglobin in the blood (concentration c_o, molar absorptivity ϵ_o, and effective path length l_o), "reduced" deoxyhemoglobin in the blood (concentration c_r, molar absorptivity ϵ_r, and effective pathlength l_r),specific variable absorbance that are not from the arterial blood (concentration c_x, molar absorptivity ϵ_x, and effective pathlength l_x), and all other non-specific sources of optical attenuation, combined as A_y, which can include light scattering, geometric factors, and characteristics of the emitter and detector elements. The total absorbance at the two wavelengths can then be written [1]:

$$
\begin{aligned}
A_{i1} &= \epsilon_{01} c_0 l_0 + \epsilon_{r1} c_r l_r + \epsilon_{x1} c_x l_x + A_{y1} \\
A_{i2} &= \epsilon_{02} c_0 l_0 + \epsilon_{r2} c_r l_r + \epsilon_{x2} c_x l_x + A_{y2}
\end{aligned}
\quad (1)
$$

During a cardiac pulse, the absorbances that are not from the arterial blood and other non-specific sources of optical attenuation have constant values. we assume that two blood pathlength changes are equivalent, the ratio R of thyme rate change of the absorbance at wavelength 1 to that at wavelength 2 can be reduced in the below equation.

$$R = \frac{dA_{i1}/dt}{dA_{i2}/dt} = \frac{-d\log(I_1/I_0)/dt}{-d\log(I_2/I_0)/dt} = \frac{(\Delta I_1/I_1)}{(\Delta I_2/I_2)} = \frac{\epsilon_{01} c_o + \epsilon_{r1} c_r}{\epsilon_{o2} c_o + \epsilon_{r2} c_r} \quad (2)$$

Where I_1, I_2 are light intensity of received lights from photo detector and I_o is light intensity of emitted light. In this case, I_o can be removed because it does not change in time rate. Because the oxygen saturation is calculated by equation $S = c_o/(c_o + c_r)$ so that we can rewrite it in terms of the ratio of R as in the following equation [9]:

$$S = \frac{\epsilon_{r1} - \epsilon_{r2} R}{(\epsilon_{r1} - \epsilon_{o1}) - (\epsilon_{r2} - \epsilon_{o2})} \quad (3)$$

Where ϵ_{r1}, ϵ_{r2}, ϵ_{o1}, ϵ_{o2} are hemoglobin extinction coefficient variations with wavelength. The values are illustrated in the following table 1.

Wavelength (nm)		Extinction Coefficient			
			Hb		HbO_2
RED	60	ε_{r1}	0.81	ε_{o1}	0.08
IR	40	ε_{r2}	0.18	ε_{o2}	0.29

Table 1. *Hemoglobin extinction coefficient variation with wavelength*

This method has a disadvantage that Log computation is difficult (but can use linear approximation look-up tables etc). In oximetry, it is assumed that a hemolyzed blood sample consists of a two-component homogenesous mixture of Hb and HbO2 and that light absorbance by the mixture of these components is additive. However, other variables in the biological media such as bone, skin, tissue, muscle and blood also scatter light. The absorption of light also depends on both skin thickness and color. Therefore, Beer-Lambert's Law is unable to account for all of these variables. Actually, experiments proved that the method is not accurate when SaO2 <85%. Empirically, we had found a normalization technique as given in equation (1).

$$(R/IR) = \frac{(AC_R/DC_R)}{(AC_{IR}/DCI_R)} \quad (4)$$

When we control the DC component of Red light equal IR light then we minimalist R/IR ratio as equation

$$(R/IR) = \frac{AC_R}{AC_{IR}} \quad (5)$$

We can find SpO2 by equation SpO2 = 110 – 25*R and R can find by relationship of red R/infrared (IR) numeric ratio value to arterial oxygen saturation as figure 4

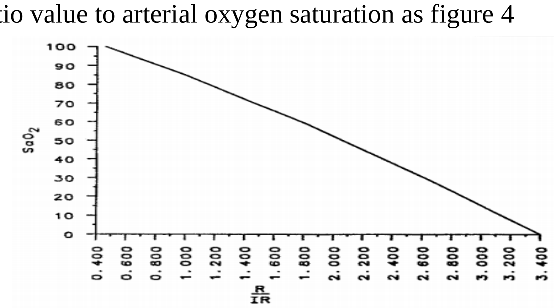


Figure 4. *Relationship of red R/infrared (IR) numeric ratio value to arterial oxygen saturation (SaO_2)*

3. Pulse Oximeter Portable Device Interact with Smartphone

This section proposes a design of a low cost and portable pulse oximeter based on microcontroller of Texas Instruments, MSP430 consuming low power. The MSP430 have analog devices such as op-amp, Analog Digital

Converters (ADCs), Digital to Analog Converters (DACs) therefore, this system not need use external ADCs and DACs and our system become smaller. The system is presented in figure 6. This system is supported by external circuits to preprocessing signal, amplifier, noise filter and the LED gain controller circuit. To support calculate SpO2 and cardiac pulse, the system control DCs component of two light wavelength are equal. Therefore, the system needs a DCs tracking to automatic LED gain controller to response immediately to the input signal. In addition, the system has a module of bluetooth to connect and interact with smartphone.

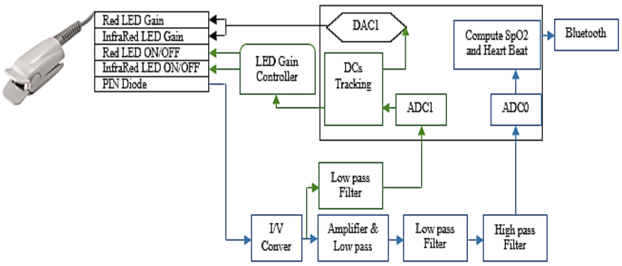


Figure 5. *Block diagram of the system pulse oximeter*

4. Implement

Amplifier and noise filter: A simple circuit Current-to-Voltage Converter in figure 6 was used to convert the current receiver from photo-detector in pulse oxymetry probe to the voltage signal. These signals always exist of high frequency noises from fluorescent lights or radio waves [5].

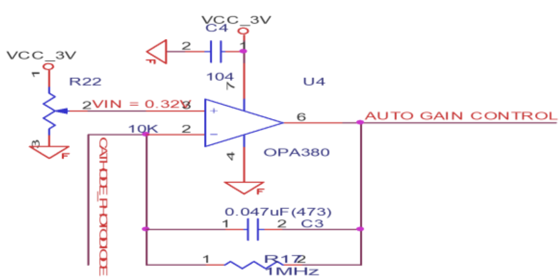


Figure 6. *Simple circuit Current to Voltage Converter*

The system was divided into two components. The first component, the signal was filtered low pass noise by Sallen-key filter. This signal was taken to input ADC1 of MSP430 to tracking DCs component to automatic LED gain controller.

The second component, the signal was filtered by high pass RC filter to remove DCs component, retaining only ACs component. This high pass filter was designed to have cut-off frequency $f=1/(2\pi RC)=0.16$ Hz. This signal was taken to input of a Pre-Amplifier combine low pass filter.

Microcontroller: To design a portable device then MSP430FG4618 was chosen because it consumes low power with 1.8-3.3V. In addition, MSP430 have two ADCs and DACs that is convenient to sampling data without external circuits [7]. On the smartphone, software was building to display results of SpO2 and heart beating. This software was constructed based on Android platform with support tools as Java Eclipse environment and SDK.

5. Result and Discussion

After designing schematic of each component, the electronic device was implemented and tested carefully. The output signal of circuit Current to Voltage Converter has waveform being illustrated in figure 7.

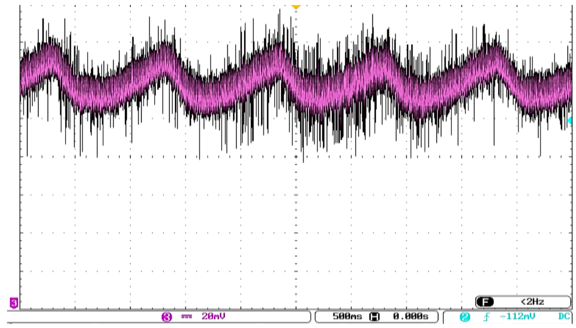


Figure 7. *The output waveform of Current to Voltage Converter*

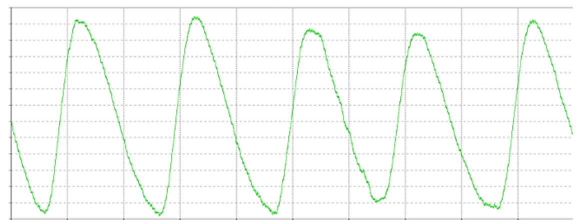
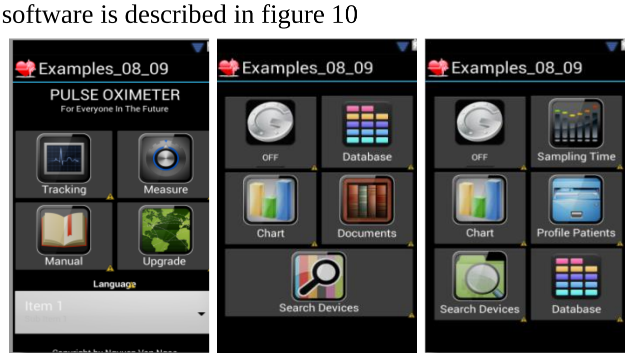


Figure 8. *The output waveform of stage Pre-Ampifiler*

Figure 8 shows us that the simple low pass filter worked well in removing most of high frequency noises and Pre-Amplifier original signal with the gain 11. However, signal after the low pass filter still contained the interference noise and this noise was removed completely after the two Sallen-key filters as illustrated in figure 9.

Figure 9. *The ouput waveform of Sallen-key high pass filter*

Figure 9 shows us that two Sallen-key filter works well in removing most of the interference noise. The output signal of each light wavelength was taken to input ADC0 of MSP430 to sampling data and calculate SpO2 and heart beat. For the software of this system [6], the interface of software is described in figure 10



(a) (b) (c)

Figure 10. *Interface of software include 3 main layout*

Figure 10a is the cover of software with the main functions allowing us to choose mode to measure or track. We can also use such languages as Vietnamese, French and English. In addition, the software can upgrade to new version without charging. When you touch the Measure button then you will go to the measure mode, as showed in figure 10b to measure each patient one time, and the results are saved to database and send email to the doctors or relatives. Further, we can see data chart of each patient every weekend and every month. When you touch the Tracking button then you will go to the tracking mode as illustrated in figure 10c, to track the patient in the evening when they go to sleep. This mode also has a function to alarm patient when accidents happens such as very high heart beating.

This system was checked in the C-hospital, Danang City and from table 2; the results show that it is as accurate as current machines. That means this system can be applied popularly not only for hospital but also for individual purposes.

Type	**Trial**	**SpO2** (%)			**Heart Rate** (Beats/Min)		
		1	**2**	**3**	**1**	**2**	**3**
Machine in hospital	Tester A	98	98	98	89	82	80
Test Machine	***Tester A***	***96***	***94***	***97***	***89***	***82***	***80***
Machine in hospital	Tester B	98	98	98	79	80	83
Test Machine	***Tester B***	***95***	***98***	***96***	***66***	***75***	***67***

Table 2: *The comparison of accuracy between two types of machines*

In the last stage of the project, analyzing power consumption of the systems is the most important work that enable the system to be commercialized. The product should be 95% more accurate than compared to the common commercial product. The first selected communication type using this system is Bluetooth, because it is popular in most of the mobile phones or laptops. That helps us build software in Android mobile to transmit old people's oxygen status to doctor or relatives through GSM/GPRS/3G/the Internet.

6. Conclusion

This paper proposed a completed method to design and implement a Pulse Oximetry portable device using MSP4304618. In this method, the system can give automatic LED gain control through DCs tracking inside MSP430. Therefore the system doesn't depend on the changes of the environment. In the future, Smartphone will be widely used in life, therefore the combination between Smartphone and a medical instrument could revolutionize the healthcare system when medical expenses are rising and the number of doctors does not catch up with the demand for medical services.

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