Design And Implementation of Pulse Oximatry Based Computer System.

Ahmed A. Radhi
Al-Ma'moon University College
Computer Engineering Techniques Department

Abstract:

For patients at risk of respiratory failure, it is important to monitor the blood oxygen saturation of such individuals to ensure proper perfusion of blood in their systems. Preferably this information should be received on a continuous basis. Both of these objectives can be reached via the non−invasive method of pulse oximetry. This is currently used in hospital/clinical settings. The purpose is to create a clinical diagnostic system which takes a few physiologically relevant signals and transmits them to a computer.

تصميم و تنفيذ مقياس الأوكسجين و نبضات القلب باستخدام نظام الحاسوب

م.م احمد علي راضي
قسم هندسة تقنيات الحاسبات
كلية المأمون الجامعة

المستخلص:

من المهم مراقبة نسبة الأوكسجين في الدم بالنسبة للمرضى المصابين بعجز التنفس، لضمان تزويدهم بدم مؤكسج بشكل كافٍ. و من المفضل أن تستلم هذه المعلومة بشكل مستمر. و هذه النتائج يمكن الحصول عليها بطريقة غير تداخلية و هي pulse oximetry .المستخدمة بالمستشفيات. الهدف من البحث هو بناء نظام تشخيصي يأخذ القليل من الإشارات الفزيولوجية وينقلها الى الحاسب.

1. Introduction

The first "pulse oximeter" to measure oxygen content in humans was built in the 1930's. However, these devices were not able to distinguish between the different types of blood within the finger including: arterial, venous and capillary blood. It was also then realized that the light transmitted through
the finger is attenuated by the arterial blood, but also by venous and capillary blood, skin (whose absorption properties will vary from person to person, due to different pigmentations) and by other tissues (such as muscle and bone) [Dr. Neil,lec.5,p.1]. In the 1970's, Hewlett−Packard created a device which tried to combat this problem by transmitting light at more than two wavelengths. They had developed a multi component model of the ear, and it was composed of up to 8 light absorbing substances (such as Hb and HbO2, skin, other tissues etc...). However, due to the high cost of the instrumentation along with the need for measurements at many (eight) different wavelengths caused it be very impractical and it never found regular clinical use [Scharf J. and Athan S., p.230].
There are physiological causes for hypoxia, one of which is due to complications during anesthesia. During anesthesia, there can be many factors that can occur to induce the onset of hypoxia. They include: low cardiac output, pulmonary edema, pulmonary embolism, airway obstruction, and endobroncial intubation among others.
[http://www.cbc.ca/news/background/healthcare/familydoctors.html].

2. Theoretical Background

There are many theoretical principles that are fundamental to understand how we can use pulse oximetry in order to obtain a signal relevant to physiological function. However, due to the many different fields involved, we will limit this discussion to only the pertinent details that are necessary in order to understand pulse oximetry. Hemoglobin is the oxygen carrying molecule of the blood and blood consists of millions of these molecules. It can also exist in two forms: oxidized (or oxygenated) Hemoglobin denoted HbO2 and reduced hemoglobin denoted Hb. Approximately 99% of oxygen is bound to hemoglobin in red blood cells. Oxygen saturation denoted SaO2 refers to the ratio of oxygenated hemoglobin to the total concentration of hemoglobin, or simply:
SaO2 = [HbO2] / [total concentration of hemoglobin] ……(1)

This SaO2 is normally given as a percentage, and for a healthy individual is > 91% (on average however is around > 97%).
Due to the optical properties of both HbO2 and Hb at 500nm-1000nm, it is possible to measure oxygen saturation. We do this by measuring transmitted light (through the tissue, normally finger or earlobe) at two different wavelengths. Making the assumption that the transmission of light through the arterial bed is influenced only by the relative concentrations of oxygenated and reduced hemoglobin and their absorption coefficients at the two wavelengths, light intensity will decrease logarithmically according to Beer−Lambert's law. Using these principles, we can obtain an expression for the ratio of the intensity of light transmitted at two different wavelengths given by:

$$R = \log10(I1) / \log10(I2) \quad \ldots\ldots (2)$$

Where I1 is the intensity of light at λ1 (wavelength 1) and I2 is the intensity of light at λ2 (wavelength 2). Once we know the absorbance coefficients of HbO2 and Hb at the two wavelengths, we can find the oxygen saturation via the following formula: [http://www.engr.wisc.edu]

$$SaO2 = (\alpha r2R - \alpha r1) / [(\alpha r2 - \alpha o2)R - (\alpha r1 - \alpha o1)] \quad \ldots\ldots\ldots\ldots (3)$$

Where:

- **αr1 is the absorption coefficient of Hb at wavelength 1**
- **αr2 is the absorption coefficient of Hb at wavelength 2**
- **αo1 is the absorption coefficient of HbO2 at wavelength 1**
- **αo2 is the absorption coefficient of HbO2 at wavelength 2**
- **R is the ratio from equation 2**

The wavelengths of transmitted light through the tissue, is chosen to be at 660nm (red light) and 940nm (Infrared light). These are the most practically used values, due to the fact that light at this wavelength is least attenuated by body tissues (tissue and pigmentation absorb blue, green and yellow light).
Traditional pulse oximetery is done using a red LED and a infrared LED. The light is partly absorbed by hemoglobin, which differ depending on weather the hemoglobin is saturated or unsaturated with oxygen. The light then passes through the finger and into a photo detector Figure(1). By calculating the absorptions at the different wavelengths, the amount of hemoglobin, which is oxygenated, can be computed. This method of pulse oximetry has been practiced using extremities of the body such as fingers, toes, and earlobes. For neonatal purposes the pulse oximeter is used on the

palm of the hand or the foot. [Sweta Sneha and Upkar Varshney, p.35]

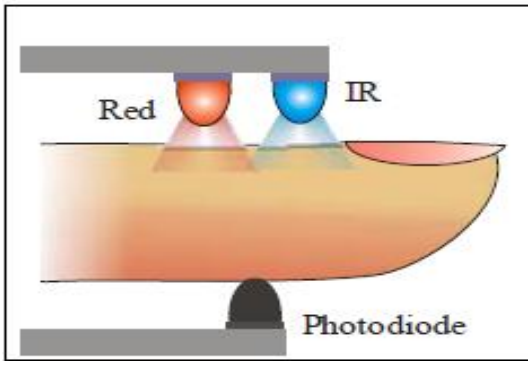
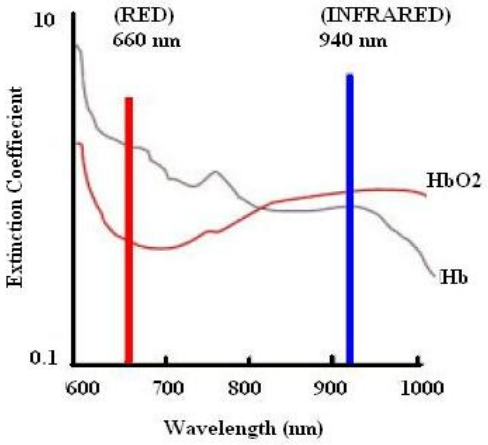


Fig.(1): Basic idea of a pulse oximeter of haemoglobin at red and infrared wavelength.

Oxyhaemoglobin refers to oxygen carrying haemoglobin and deoxygenated haemoglobin refers to non oxygen carrying haemoglobin. If all haemoglobin molecules bonded with an oxygen molecule (O2), the total body of haemoglobin is said to be fully saturated (100% saturation). When haemoglobin unloads the oxygen molecule to tissue cells at capillary levels, the saturation progressively decreases and the normal venous saturation is about 75%. The normal saturation level is said to be between 87-97%.
[College of Family Physicians of Canada,p.579]
The two wavelengths are chosen for the reason that deoxygenated haemoglobin has a higher absorption at around 660nm and at 910m oxygenated haemoglobin has the higher absorption.
The oxygenated haemoglobin allows red light to transmit through and absorbs more infrared light while the deoxygenated haemoglobin allows infrared to transmit through and absorbs more red light. Usually a finger is placed between the source (LEDs) and the receiver (photodiode) acting as a translucent site with good blood flow. Once these absorption levels are detected from the finger the ratio of absorption at different wavelengths can be obtained. [http://medicalreporter.health.org]



3. The Signal

In pulse oximetry, only the part of the signal which is related to the inflow of arterial blood at that segment is used for the calculation of oxygen saturation. When light at these wavelengths (IR and red) is transmitted through the tissue it gives a pulsatile signal as is shown in figure 1. This signal varies with time in relation to the heart beat. Therefore, the heart rate of an individual can be extracted from this signal, (heart rate = frequency of signal). This is also useful when designing our system, as it gives us an idea of the frequency content of our signal.

Fig.(3): Pulsatile signal obtained when IR or red light is transmitted through the finger.

From figure (3) the signal is a pulsating one, whose frequency is related to the individual's heart rate. From this, we can extract the necessary information, which in our case will be the voltage measurements at any given time from this outputted signal. This voltage measurement relates to the intensity of the transmitted light and can be implemented into equation 2 and 3 in order to find our

oxygen saturation reading. The signal in figure (3) however is just one example of a pulsating signal can be obtained .
[Medical Instrumentation, ch.10, p.453]

4. Design of Pulse Oximetry Instrumentation

A pulse oximetry works on the principles of light transmittance/absorbance, therefore a photo emitter (LED circuitry) will be needed to emit light through the area of interest (finger) and a photodetector (phototransistor/photodiode) in order to convert this transmitted incident light into an electrical signal, that this electrical signal will be a current that corresponds to light intensity (the higher value of current, the greater light intensity is). However, since we wish to work with voltages as opposed to currents, convert this current into a corresponding voltage will be needed. This can be easily accomplished via a current-to-voltage convertor. This design can then give us an output signal that corresponds to a pulsatile signal which we can use to extract the oxygen saturation reading.
The light intensity detected by photodiode depends, not only on the intensity of the incident light, but mainly on the opacity of the skin, reflection by bones, tissue scattering, and the amount of blood in the vascular bed. The pulse oximetry will generate a digital switching pulse to drive the red and infrared LED's in the sensor alternately at a converter repetition rate of approximately 1KHz. Timing circuits are used to supply, approximately 50 µs pulses to the red and IR LED drivers at the repetition rate of 1 kHz, as shown in Figure(4) (a frequency of 1 kHz is suitable because such a frequency is well above the maximum frequency present 3 in the arterial pulse). High-intensity light outputs can be obtained with the IR LED with currents of up to 1A over a low duty cycle.

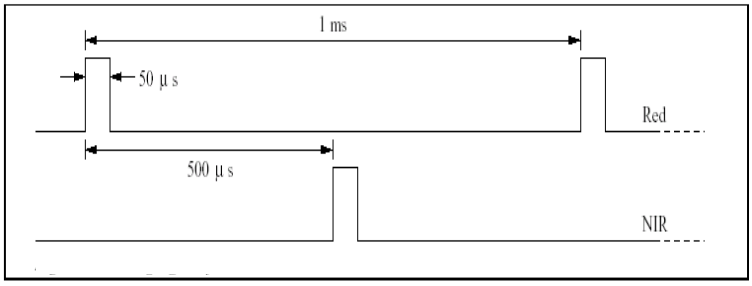


Fig.(4): Signal Processing Circuit

The reflected light enters the Signal Processing Circuit at photo detecter. Current is provided in accordance to the amount of reflected light absorbed by the P-N junction in the photo detector and is converted to a voltage in the Current - Voltage Converter, which also acts as a low-pass filter intended to remove various high frequency signals, yet possesses a high enough DC that allows all frequencies from the reflected light to pass through.
The above described can be depicted via the following block diagram, which shows the LED circuitry, photo detector circuitry, and the current-to-voltage converter, each represented by a block, (note that there are two of these systems, one for the red LED and one for the IR LED):

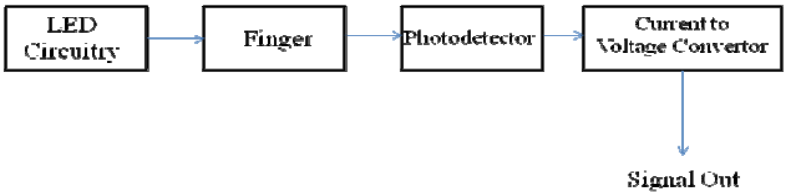


Fig.(5): Initial design of the pulse oximeter

4.1 Timing circuit

The timing circuit can be built around the 555-timer integrated circuit. From the data sheet for this i.c, it can easily be worked out that the circuit given in Figure (6) can be configured, for example by setting *C* = 22 nF, *Ra* = 56kΩ and *Rb* = 3.3kΩ, to give a 50 µs pulse approximately every millisecond, as intended.

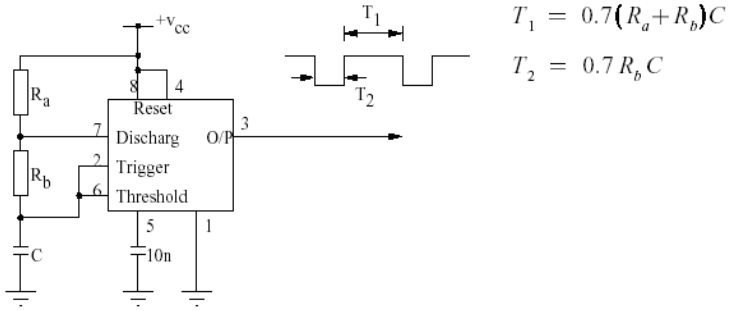


Fig.(6):Generating the timing pulses for pulse oximetr

4.2 Pulsing the Light Output from the LEDs

The output from the LED can be pulsed by connecting an n-channel enhancement-mode MOSFET across it as is shown in Figure (7). The pulses from the output pin of the 555 timer (pin 3) are taken to the gate of the transistor. The FET needs to be an enhancement-mode MOSFET for it to be turned fully off and on by the gate pulses. The MOSFET chosen for this task should also be capable of handling the maximum current flowing through the LED.

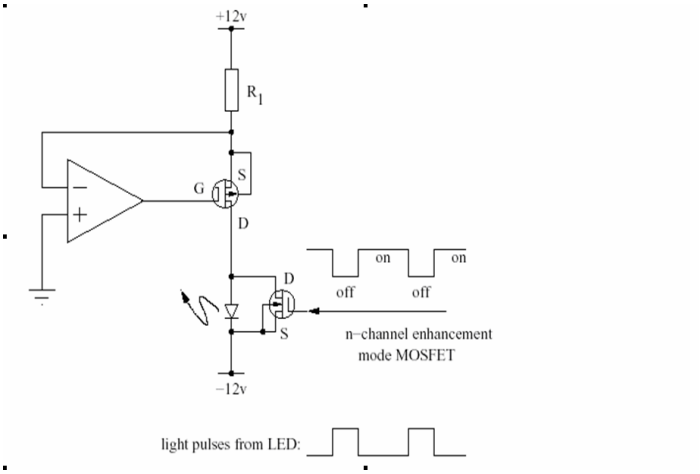


Fig.(7): Pulsing the LED

4.3 Receiver Circuit

The simplest solid-state optical detector is the photodiode. Photodiode detectors normally operate with reverse bias applied to the p-n junction (photoconductive mode). When light falls on the junction region of the photodiode, an electron-hole pair is created; under the influence of the junction (or built-in) field, the hole is swept towards the p-material and the electron towards the n-material. The resulting light current is seen as a large increase in the reverse current. For the purposes of signal amplification, the photocurrent must be transformed into a voltage with moderate output impedance; this is achieved with the circuit shown in Figure (8), the op-amp being configured as a current-to-voltage converter. Because of the high junction resistance of the reverse-biased photodiode, the op-amp should be a FET type with very high input impedance. Since the

negative input of the op-amp acts like a virtual ground, the output voltage of the circuit is
***vo = -I RL*. A very large feedback resistance may be used, values as high as several tens of M□Ω being typical in practice.**

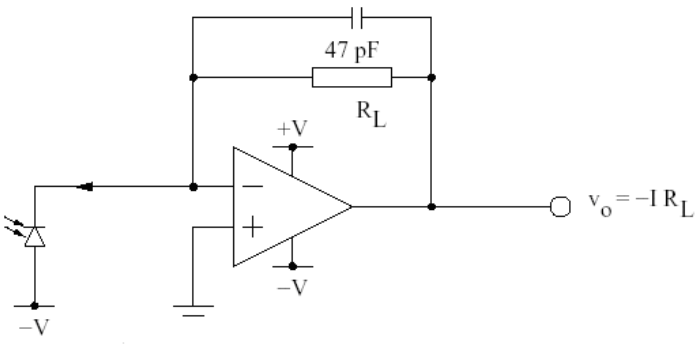


Fig.(8): Photodiode current-to-voltage converter circuit.

5. Connecting the Pulse Oximatry to the Computer System

In this paper, the pulse oximatry connected to the computer system via parallel port (LPT). The parallel port consists of a three interfacing ports the data port which is an 8-bit port used to transfer data from the computer, the control port which is a 4-bit bidirectional port, and status port which is a 5-bit input port.
Figure (9) shows the block diagram of the interfacing circuit.

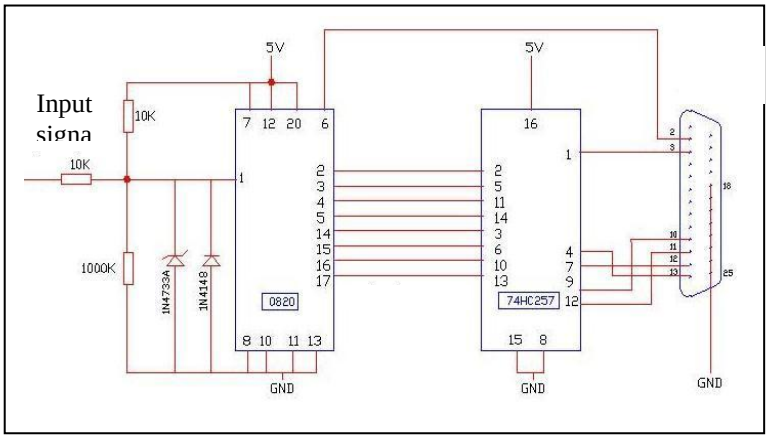


Fig.(9): interfacing circuit

Figures (10),(11), and (12) represents the result of three different peoples. The calculations were done by referring to equation 3. These results are tabulated in the table(1).

Fig.(10): software output of pulse oximatry of person 1

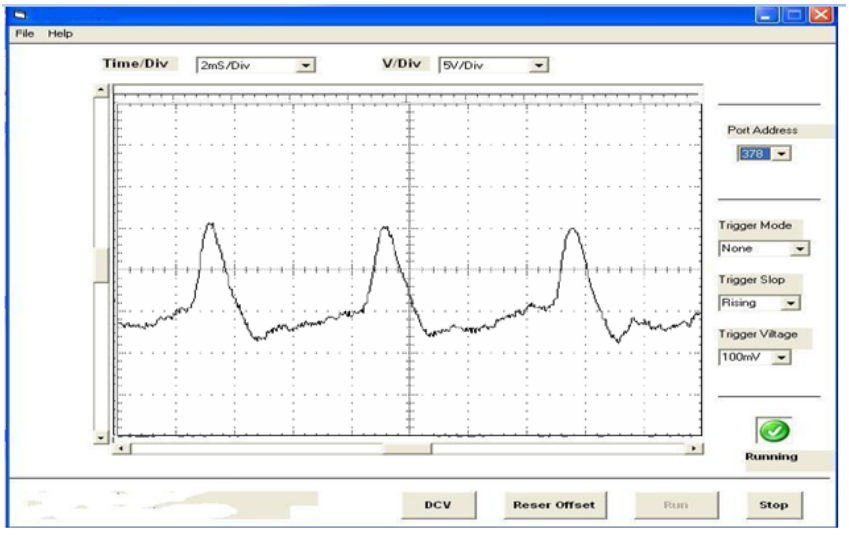


Fig.(11): software output of pulse oximatry of person 2

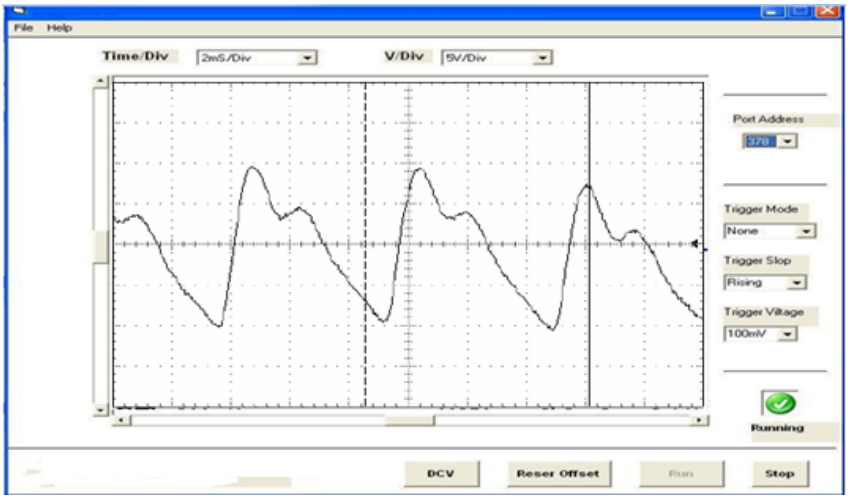


Fig.(12): software output of pulse oximatry of person 3

Table (1)
Voltage readings for each person as well as the oxygen saturation in %

Person	Voltage reading(V)	Oxygen Saturation%
1	1.29	93.2
2	1.10	91.4
3	1.95	96.35

6.Conclusions

This research deals with the implementation (specifically hardware implementation) of the blood oxygen monitor by using computer system.

In conclusion, in this paper have shown and proven with implementation design that a pulse oximeter signal can be obtained using transmission of light through the finger, which then can be processed by the necessary circuitry, We have seen that the results of our implementation our successful due to the fact they give us a 96.35 % oxygen saturation reading (knowing that a healthy individual has an oxygen saturation reading of > 91 %).

7. References

[1] Dr. Neil Townsend. *Medical Electronics.*Michaelmas Term, 2001.

[2] Scharf J. and Athan S. "Digital Capture of Pulse Oximetry Waveforms", *IEEE,* 93, 230-232, 1993.

[3] "Family Doctors" Internet: http://www.cbc.ca/news/background/healthcare/familydoctors.html, [April 3, 2009].

[4] Assistant Professor. Urs Utzinger," Pulse Oximeter Laboratory", http://www.engr.wisc.edu, 2002

[5] Sweta Sneha and Upkar Varshney. "A wireless ECG monitoring system for pervasive healthcare", *International Journal of Electronic Healthcare,* Volume 3, pg. 32 – 50, 2007.

[6] College of Family Physicians of Canada, "Public opinion poll on physician wait time" [Decima Research poll conducted for the College] Mississauga, Ont: College of Family Physicians of Canada; v.53(3): pg.579–580 , March 2007.

[7] Starfield B."The importance of primary care to health", Internet: http://medicalreporter.health.org/tmr0699/importance_of_primary_care_to_he.htm, 1999 [April 3 2009].

[8] Medical Instrumentation: Application and Design Edited by John Webster. John Wiley. and Sons, 1998. Chapter 10: page 453, 470-472