Measuring and Analyzing the Human Pulse Signal Using an Electrical Model and the MATLAB

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ABSTRACT

Human health is a critical issue to monitor and diagnose, through analyzing data extracted from Bio-signals (Arterial Blood Pressure, Heart Rate, Body Temperature, Oxygen Concentration in Blood, and Sugar Level in Blood….). This paper introduces simple techniques to measure, analyze, and display some of these Bio-signals. A Pulse Oximeter device was designed , then the output signals were entered to the PC using a suitable USB cable , and with the help of the software tools specifically MATLAB codes ,these signals where analyzed using Signal Processing Toolbox. Finally the analyzed results and the input data were displayed on the PC screen using the Graphical User Interface (GUI) tool in MATLAB, enabling the user to interact with a mini easily used screen.

Keywords: Digital Oscilloscope, Heart rate, Infrared signal, Oxygen saturation,

1. INTRODUCTION

Bio-signals Analysis is being recently an important field of research, since human health care is considered to have the priority in man's life. Blood oxygen content is now considered the 5th vital sign, joining: temperature, respiratory rate, heart rate and blood pressure [1]. 30 years ago, the only practical assessment of a patient's oxygenation was by the presence or absence of cyanosis. The introduction of the first blood gas analyzers in the late 1950's rapidly revolutionized medical practice [2]. Until recently, measurement of arterial blood oxygen saturation required the direct sampling of arterial blood, which though not difficult was invasive and potentially risky.

Pulse oximetry technology was available in 1930's but was limited in its use, as it was cumbersome and bulky. It became widely available only in the 1980's with advances in the Light Emitting Diode (LED), microprocessors, optical plethysmography and spectra-photometry [3]. Recently Pulse oximetry provides a simple, non-invasive, portable and inexpensive method to continuously monitor oxygen saturation and heart rate with accepted accuracy.

An exercise pulse oximeter measures the level of oxygen in human blood during exercise and is a useful tool for serious athletes and people with health problems. For example, athletes routinely engaging in vigorous exercise, particularly at high altitudes, may wear pulse oximeters to ensure adequate oxygenation. Those with respiratory illnesses or recovering from surgery, meanwhile, may find wearing an exercise pulse oximeter during exercise useful for monitoring oxygen levels.

In newborns it is important to provide the oxygen saturation (SpO2), besides temperature, pulse, respiration and blood pressure. It is a useful adjunct in the assessment of response to resuscitation and an important measurement to aid in titration of oxygen therapy in newborns. It can act as apnea monitor (indicating bradycardia and desaturation).

This device helps clinician in noninvasive arterial oxygen saturation monitoring, pulse rate monitoring.

The common indications for pulse oximetry includes measuring oxygenation in infants suffering from hypoxia, apnea, cardio-respiratory disease, Broncho-pulmonary dysplasia, etc. Also to monitor response to therapy during resuscitation, and monitoring side-effects of therapy.

A simple implementation of basics in pulse oximeter using Red, IR, and photodiodes was accomplished in this project. After processing electrical signals in the built design the resulted data were analyzed in MATLAB and displayed using the GUI window.

2. SUBJECT

The transfer of oxygen from the lungs to the tissue cells is carried out mainly by the hemoglobin molecules in the red blood cells. The total oxygen content in blood includes the hemoglobin-bound oxygen (97%–98% of the total oxygen content) and the oxygen dissolved in plasma [04].

The level of arterial hemoglobin oxygenation is assessed by oxygen saturation in arterial blood (SaO_2) (Equation.1), which is the ratio of oxygenated hemoglobin concentration [HbO_2] to total hemoglobin concentration in the blood ([HbO_2] + [Hb])

$$SaO2 = [HbO2]/([HbO2] + [Hb]) \quad (1)$$

Hemoglobin bound to oxygen is called oxygenated hemoglobin (HbO_2). Hemoglobin not bound to oxygen is called deoxygenated hemoglobin (Hb).

The oxygen saturation is the ratio of the oxygenated hemoglobin to the hemoglobin in the blood, as defined by the Equation 2.

$$Oxygen\ saturation = C\ (HbO2)\ /\ C\ (HbO2) + C(Hb) \quad (2)$$

SaO_2 has the same value throughout the arterial system, since oxygen is extracted from the blood only in the capillaries. The concentration of dissolved oxygen in arterial blood is measured by arterial oxygen partial pressure (PaO_2). SaO_2 increases as PaO_2 increases in an S-shaped curve, the dissociation curve, which depends on blood temperature, acidity level, and the concentration of several substances in the blood.

Typical values of PaO_2 for adults at sea level range between 80 and 100 mmHg and those of SaO_2 between 96% and 98%. Because of the gradual slope of the upper part of the dissociation curve, a change of PaO_2 from 100 to 70 mmHg under normal conditions only results in a decrease of SaO_2 from 97% to 92%. With regard to venous blood, the normal range of oxygen saturation is 70%–80%, and oxygen partial pressure varies in the range of 40–50 mmHg [05].

Pulse Oximeter is a noninvasive method that enables rapid measurement of the oxygen saturation of hemoglobin in arterial blood. It can rapidly detect changes in oxygen. Also is defined as the measurement of the amount of oxygen dissolved in blood, based on the detection of Hemoglobin and Deoxyhemoglobin.

Two different light wavelengths are used to measure the actual difference in the absorption spectra of HbO_2 and Hb. The bloodstream is affected by the concentration of HbO_2 and Hb, and their absorption coefficients are measured using two wavelengths 660 nm (red light spectra) and 940 nm (infrared light spectra) [06] ,as shown in Figure .1

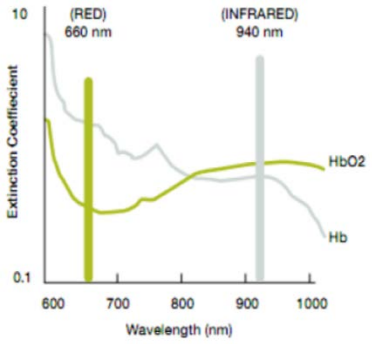


Fig.1 Hemoglobin Light Absorption Graph

Deoxygenated and oxygenated hemoglobin absorb different wavelengths. Deoxygenated hemoglobin (Hb) has a higher absorption at 660 nm and oxygenated hemoglobin (HbO_2) has a higher absorption at 940 nm.

After the transmitted red (R) and infrared (IR) signals pass through the measuring site and are received at the photodetector, the R/IR ratio is calculated. The R/IR is compared to a "look-up" table (made up of empirical formulas) that convert the ratio to a SpO_2 value.

Most manufacturers have their own look-up tables based on calibration curves derived from healthy subjects at various SpO_2 levels. Typically, a R/IR ratio of 0.5 equates to approximately 100% SpO_2, a ratio of 1.0 to approximately 82% SpO_2, while a ratio of 2.0 equates to 0% SpO_2.

3. Mathematical Model

A mathematical model for the P.O Pro begins by considering light at two wavelengths, l_1 and l_2 passing through tissue and being detected at a distant location. At each wavelength the total light attenuation is described by four different component absorbencies: oxyhemoglobin in the blood (concentration C_0, molar absorptivity a_0, and effective path length L_0).

Reduced deoxyhemoglobin in the blood (concentration C_r molar absorptivity a_r and effective path length L_r,), specific variable absorbencies that are not from the arterial blood (concentration C_x molar absorptivity a_x and effective path length L_x), and all other non-specific sources of optical attenuation, combined as Ay 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 in Equation 3 :

$$\begin{cases} A_{\lambda_1} = a_{o_1} C_o L_o + a_{r_1} C_r L_r + a_{x_1} C_x L_x + A_{y_1} \\ A_{\lambda_2} = a_{o_2} C_o L_o + a_{r_2} C_r L_r + a_{x_2} C_x L_x + A_{y_2} \end{cases} \quad (3)$$

The blood volume change due to the arterial pulse results in a modulation of the measured absorbencies. By taking the time rate of change of the absorbencies, the two last terms in each equation are effectively zero, since the concentration and effective path length of absorbing material outside the arterial blood do not change during a pulse as in Equation 4.

$$\frac{d(C_X L_X)}{dt} = 0 \quad (4)$$

All the nonspecific effects on light attenuation are also effectively invariant on the time scale of a cardiac cycle in Equation 5:

$$\frac{dA_y}{dt} = 0 \quad (5)$$

Since the extinction coefficients are constant, and the blood concentrations are constant on the time scale of a pulse, the time-dependent changes in the absorbencies at the two wavelengths can be assigned entirely to the change in the blood path length ($\frac{dL_0}{dt}$ *and* $\frac{dL_\gamma}{dt}$).

The functional oxygen saturation is given by Equation 6:

$$S = C0/(C0 + Cr)$$
$$\text{And} \quad IS = Cr/(C0 + Cr) \qquad (6)$$

The oxygen saturation can then be written in terms of the ratio R as follows in 7:

$$S = \frac{a_{r1} - a_{r2} R}{(a_{r1} - a_{01}) - (a_{r2} - a_{02}) R} \qquad (7)$$

The above equation provides the desired relationship between the experimentally determined ratio R and the clinically desired oxygen saturation S. LEDs are not monochromatic light sources, typically with bandwidths between 20 and 50 nm, and therefore standard molar absorptivity's for hemoglobin cannot be used directly in the above equation.

Also, the simple model presented above is only approximately true; for example, the two wavelengths do not necessarily have the exact same path length changes, and second-order scattering effects have been ignored. Consequently the relationship between S and R is instead determined empirically by fitting the clinical data to a generalized function of the Equation 8.

$$S = (k1 - k2R)/(k3 - k4R) \qquad (8)$$

A typical empirical calibration for R versus S is shown in Figure 2, together with the curve that standard molar absorptivity's would predict. In this way, the measurement of the ratio of the fractional change in signal intensity of the two LED's is used along with the empirically determined calibration equation to obtain a beat-by-beat measurement of the arterial oxygen saturation in a perfused tissue - continuously, noninvasively, and to an accuracy of a few percent [07] .

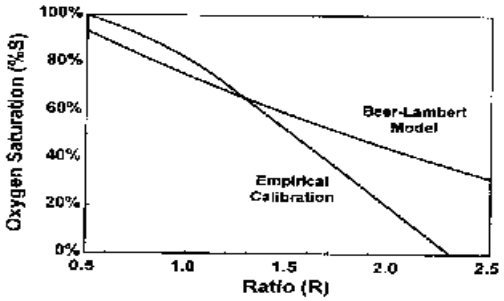


Fig. 2 Empirical calibration for R versus S

4. ELECTRICAL DESIGN AND IMPLEMENTATION

The basic optical sensor of a noninvasive pulse oximeter consists of both red and infrared LED's with peak emission wavelengths of 660 nm and 940 nm respectively, and a silicon photodiode. The Photodiode used has a broad range of spectral responses that overlaps the emission spectra of both the red and infrared LED's as shown in Figure.3.

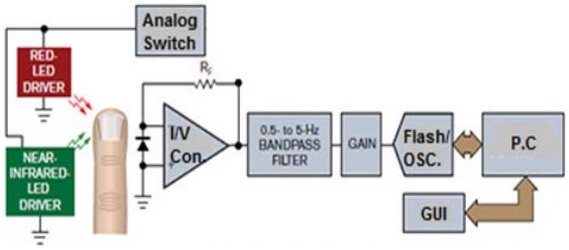


Fig.3 Pulse Oximeter Block Diagram.

The light intensity detected by the photodetector 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 .

If both light sources are pulsed, a single photodetector can be used in the probe, since silicon devices are responsive to light having visible and IR wavelengths. Analog switch used to pulses to the red and IR LED drivers.

This design will drive the red and infrared LED's in the sensor alternately. The transmitted light detected by the photodiode is amplified and converted to a voltage using an op-amp configured as a current-to-voltage converter.

The outputs from these circuits are then filtered with a band-pass filter (with 0.5 Hz and 5 Hz cut-off frequencies) in order to remove primarily the dc component but also high frequency noise. The resulting signals thus represent the cardiac-synchronous information in the waveforms and these are further amplified before they are converted to digital format for subsequent analysis by the Oscilloscope and the PC.

The outputs are shown at the screen of the digital oscilloscope as seen in Figure.3, and saved in the flash memory for farther analysis in the PC.

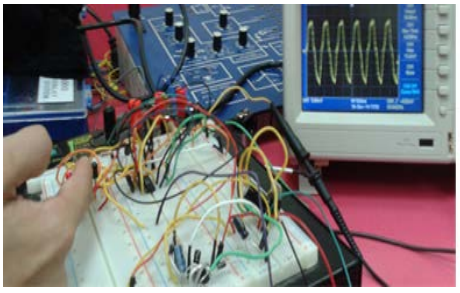
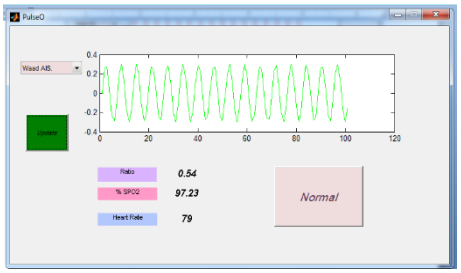


Fig.4. Output signal saved in OSC.



5. RESULTS AND ANALYSIS

The pulse oximeter measures a ratio of transmitted red and infrared light intensities, and relate this to reference table of empirical oxygen saturation values. In the case of this particular study, the Pulse oximeter will deal with absorbed instead of reflected red and infrared light intensities. The data used for calibration processes are usually obtained from healthy adults breathing hypoxic gas mixtures [07].

The used data for calculating the desired slope referred to IR and red waveform samples of 612 volunteers, the down slope and up slope values are defined to be, respectively, the difference between the middle point and the last and first points, scaled by a factor of 25.5. So the used equation to calculate the percentage of oxygen saturation is shown in Equation 9.

$$\%S = -25.5\,(R - 0.5) + 98.255.1 \quad (9)$$

From the experimental signals approved by the American Society for Microbiology, Red (R) and infrared (IR) scaled alternating current (AC) signals at arterial oxygen saturation (SaO_2) of 0%, 85% and 100%. The numeric value of the red-to-infrared (R/IR) ratio can be easily converted to SaO_2 [08].

Also the heart rate for this study is calculated from the measured signal, and it equals the number of pulses per minute Equation 10.

$$Heart\ Rate = 60 * Signal\ Frequency \quad (10)$$

Using the implemented circuit in this project, the resulted data where shown in a digital oscilloscope. The output signals were fairly close to American Society for Microbiology results.

The measured and saved signals for both Red and IR diodes were entered to the software (MATLAB), and analyzed using the previously discussed equations. The GUI window then displays the resulted SPO_2 and the calculated Pulse per minute value as shown in Figure 5, Figure 6.

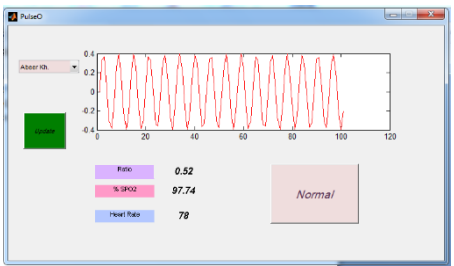


Fig.5 volunteer1 result.

Fig.6 volunteer2 result.

6. CONCLUSION

A pulse oximeter is a medical device that indirectly monitors the oxygen saturation of a patient's blood instead of the blood oxygen being measured directly through a blood sample. The pulse oximeter also measures a person's heart rate. Including in the operating room, emergency room, recovery room and intensive units' pulse oximeter is a basic devise to be present. A healthy person will normally have a reading of at least 95% saturation. The wavelengths and the infrared technology recognizes the differences between oxygenated blood and deoxygenated blood and then calculates the ratio between the two. A simple circuit is implemented in the lab and the resulted data is displayed on the digital oscilloscope screen and saved in a flash memory. This data is then entered to the MATLAB workspace and analyzed. The GUI is used to display the data and the results.

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REFERENCES

[1] Stedman's Medical Dictionary for the Health Professions and Nursing. 5th ed. Lippincott Williams & Wilkins, Baltimore, MD; 2005.

[2] Milliken G. A.The oximeter: an instrument for measuring continuously oxygen saturation of arterial blood in man. Rev. Sci. Instr.131942434444.

[3] L. Nicolai, Uber Sichtbarmachung, Verlauf und Chemische Kinetik der Oxyhemoglobinreduktion im Lebenden Gewebe, Besonders in der Menschlichen Haut, Arch. Gesamte Physiol. 229: 372 (1932).

[4] Michel CC. The transport of oxygen and carbon dioxide by the blood. In Respiratory Physiology, ed Guyton AC, Widdicombe JG, Baltimore: University Park Press, pp 67–104, 1974.

[5] Piiper J, Scheid P. Diffusion limitation of O2 supply to tissue in homogeneous and heterogeneous models. Respir Physiol 85: 127–36, 1991.10.1016/0034-5687(91)90011-7.

[6] Mendelson Y and Kent J C 1989 Variations in optical absorption spectra of adult and fetal hemoglobins and its effect on pulse oximetry IEEE Trans. Biomed. Eng. 36 844–8.

[7] Tabbutt S, Ramamoorthy C, Montenegro LM, Durning SM, Godinez RI, Kurth CD, Steven JM, Spray TL, Wernovsky G, Nicolson S: Impact of inspired gas mixtures on pre-operative infants with hypoplastic left heart syndrome (HLHS) during controlled ventilation (abstract). Circulation 2000; 102 (suppl II): II-469Tabbutt, S Ramamoorthy, C Montenegro, LM Durning, SM Godinez, RI Kurth, CD Steven, JM Spray, TL Wernovsky, G Nicolson,

[8] Bardy SL, Briegel A, Rainville S, Krell T. 2017. Recent advances and future prospects in bacterial and archaeal locomotion and signal transduction. J Bacteriol 199:e00203-17.