Optical Sensor System for Hemoglobin Measurement

Rajashree Doshi [1], Anagha Panditrao [2]

[1] Department of Instrumentation and Control, Cummins College of Engineering for Women Pune University, India

ABSTRACT

For complete blood count Hemoglobin (Hb) is an essential parameter. This paper presents non invasive optical technique for Hb measurement. At different wavelengths absorption coefficient of blood differs this fact is used to measure the optical characteristics of blood. In this newly developed system, principle of pulse oximetry is used. Oxygenated and deoxygenated hemoglobin absorbs different amount of light at two wavelength 660nm and 940nm. Red and IR LED are used for these particular wavelengths. Transmitted light through an area of skin on finger was detected by a transimpedance amplifier photodiode. Ratio of pulsating to non pulsating component of both red and IR signal after normalization is calculated for determination of Hb. Signal acquisition by this method is totally noninvasive. The sensors assembled in this investigation are fully integrated into wearable finger clips.

KEYWORDS: *absorption of light, blood, hemoglobin, infra red, LED, noninvasive, optical method.*

I. INTRODUCTION

Hemoglobin (Hb) is usually measured as a part of the complete blood count from a blood sample. Hemoglobin plays important role for transporting oxygen from the lungs to the other peripheral tissue of body and exchange oxygen for carbon- dioxide and then carry carbon dioxide back to lungs where it is exchange for oxygen. Hemoglobin is made up of four protein molecules, called globulin chains; each globulin chain contains an important central structure called the heme molecule. Embedded within the heme molecule is iron that is vital in transporting oxygen and carbon dioxide in our blood. An iron contained in hemoglobin is responsible for the red color of blood. If Hemoglobin level crosses the critical limits then problem occurs such as anemia for low hemoglobin and polycythemia for high hemoglobin level. Several methods are used to measure total hemoglobin content in the blood. The most common methods utilize spectrophotometric analysis of light absorbance based on Beer-Lambert law. Other method takes advantage of the varying conductivities of blood at different concentrations of blood.

In Hemoglobincyanide method hemoglobin is chemically converted to form a cyanmethemoglobin which is having maximum absorption around 540nm wavelength. The hemoglobin concentration is determined from absorption. This technique is most broadly use in laboratory. In this invasive method to measure the Hb concentration, blood is ejected from the patient and subsequently analyzed. Apart from the discomfort of ejecting blood samples, an added disadvantage of this method is the delay between the blood collection and its analysis, which does not allow real time patient monitoring in critical situations. A noninvasive method allows pain free continuous on-line patient monitoring with minimum risk of infection and facilitates real time data monitoring allowing immediate clinical reaction to the measured data. Since the near infrared light was found to penetrate a great depth into biological tissues, near-infrared spectroscopy has been developed into a noninvasive method for biomedical sensing and clinical diagnosis. Oximetry, is well known as typical example of a near-infrared application in clinic, and can be used to noninvasive measure the oxygen saturation of human blood in-vivo [2]. The absorption of whole blood in the visible and near infrared range is dominated by the different hemoglobin derivatives and the blood plasma that consists mainly of water. It is well known that pulsating changes of blood volume in tissue can be observed by measuring the absorption of light through the blood volume. This diagnostic method is known as photoplethysmography (PPG) [3]. Aldrich et al. have reported on the ability to use NIR transmission through the fingertip at a single pseudoisosbestic wavelength (905 nm) coupled with a sonomicrometer to monitor pulsatile changes in the optical path length through the finger as well as correct for interpatient variation in finger diameter [4]. An optical method for direct measurement of Hb noninvasively was reported by Jeon et al., who used a 5-wavelength diode-emitting array, but this method requires more robust detection mechanisms [5].

In this newly developed optical sensor system two different wavelengths of light uses for the measurement of Hb concentration. This non-invasive optical measurement method is based on radiation of red and near infrared light, emitted by Light Emitting Diodes (LED) at particular wavelength of 660nm and 940nm. Transmitted light through an area of skin on finger was detected by a transimpedance amplifier photodiode. Ratio of pulsating to non pulsating component of both red and IR signal after normalization is calculated for determination of Hb. Signal acquisition by this method is totally noninvasive. The sensors assembled in this investigation are fully integrated into wearable finger clips.

II. EXPERIMENTAL METHODS

Cyanmeth is the standard method for laboratory determination of haemoglobin in blood samples. The test is usually done by dissolving 20 microliters of uncoagulated blood in 5 ml of Drabkins solution. Also different clinically used methods are Spectrophotometry, Hemoglobincyanide and conductivity based method for measurement of hemoglobin. However in these methods it is required to eject the blood sample from human body and then it is tested. It causes pain to the patient and results required are delayed. In the developed technique non contact optical sensor is developed for haemoglobin measurement.

2.1. System Overview

Basic block diagram of noninvasive hemoglobin measurement system are described in figure (1).

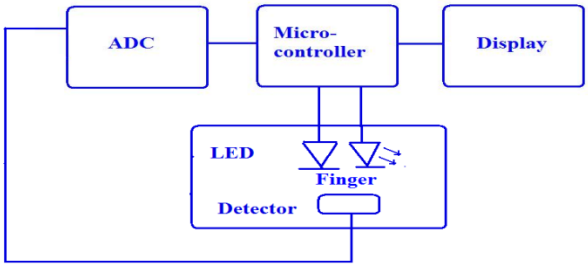


Figure1. Block diagram of hemoglobin measurement system

The non-invasive sensor systems allow a continuous measurement of the hemoglobin concentration, which is based on a pulse photometric measurement method. Thereby an area of skin on the fingertip is trans-illuminated by light which is emitted by LEDs of 660nm and 940nm. Figure (2) describe the absorption spectra for oxyhemoglobin and deoxyhemoglobin. The objective of the photometric devices described here is the non-invasive continuous measurement of heart circulation patterns and light absorbent blood components in the blood of the human finger. The arteries contain more blood during the systolic phase of the heart than during the diastolic phase, due to an increased diameter of the arteries during the systolic phase. This effect occurs only in arteries but normally not in veins. For this reason the absorbance of light in tissues with arteries increases during systole because the amount of hemoglobin (absorber) is higher and the light passes through a longer optical path length in the arteries. These intensity changes are called PPG-waves [6].

The time varying part allows the differentiation between the absorbance due to venous blood and bloodless tissue (DC part) and that due to the pulsatile component of the total absorbance (AC part). An electrical signal consisting of two components is generated by the photo detector receiving the LED emission. There is an invariant direct current (DC) component to the signal which represents ambient background light and transmission of light through invariant that is non pulsating tissues such as skin, bone and, to a certain extent, veins. The second component of the signal is an alternating current (AC) which represents varying transmission of light through the pulse varying tissues i.e. the arteries and capillaries. Both AC and DC components are affected by altered LED light intensity. Suitable wavelengths were selected for the analyses of relative hemoglobin concentration change. The principle of measurement is based on the fact of a substantial absorption/transmission difference of light in red and near infrared region between oxygenated [HbO_2] and reduced hemoglobin [HHb]. HHb is optically much denser to the red light (600 ~ 750 nm) than HbO_2. whereas the reverse is true in the near infrared region (900 ~ 1000 nm) [7].

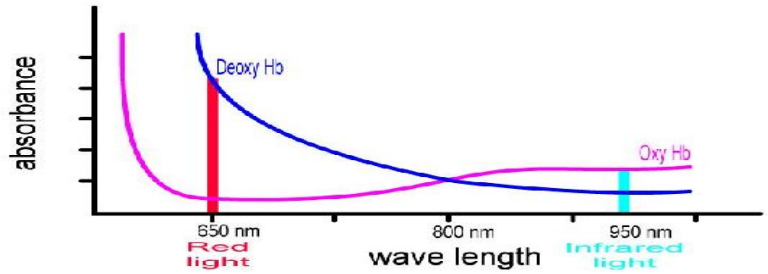


Figure2. Absorption spectra of oxy- and deoxyhemoglobin

2.2. Mathematical Implementation

Hemoglobin is a molecule in the red blood cells that has a role of delivering oxygen to tissue cells. Hemoglobin is composed of four heme groups and a protein group, known as a globin. For spectro- photometric experiments Beer-Lambert's law is utilized and developed the notation of absorbance to express light absorption as a function of hemoglobin concentration as given in equitation:

$$OD = Log(I_0/I) = \varepsilon cL \qquad (1)$$

Where OD is the optical density, I_0 is the light intensity of incident light, I *is* the light intensity of transmitted light, ε is the extinction coefficient of hemoglobin, c is the concentration of hemoglobin, and L is the length of light path through solution.

When the measured sample has a mixture of oxygenated and deoxygenated hemoglobin, equation (1) can be further expanded as,

$$OD^{\lambda} = \{\varepsilon^{\lambda}_{HHb}[HHb] + \varepsilon^{\lambda}_{HbO2}[HbO_2]\}\ L \qquad (2)$$

Where OD^{λ} is the optical density or absorbance at wavelength λ and εHHb (λ) and εHbO_2 (λ) are the extinction coefficients at wavelength λ for molar concentrations of deoxygenated hemoglobin, [HHb], and oxygenated hemoglobin, [HbO_2], respectively. By assuming light path L as 1cm. Both [HbO_2] and [HHb] can be determined by measuring the light absorbance at the two specific wavelengths, provided that the values for εHHb (λ) and εHbO_2 (λ) are known, as expressed below.

$$[HbO_2] = \frac{\varepsilon^{\lambda 2}_{HHb} OD^{\lambda 1} - \varepsilon^{\lambda 1}_{HHb} OD^{\lambda 2}}{L\left(\varepsilon^{\lambda 2}_{HHb}\varepsilon^{\lambda 1}_{Hbo2} - \varepsilon^{\lambda 1}_{HHb}\varepsilon^{\lambda 2}_{Hbo2}\right)} \qquad (3)$$

$$[HHb] = \frac{\varepsilon^{\lambda 2}_{Hbo2} OD^{\lambda 1} - \varepsilon^{\lambda 1}_{Hbo2} OD^{\lambda 2}}{L(\varepsilon^{\lambda 1}_{HHb}\varepsilon^{\lambda 2}_{Hbo2} - \varepsilon^{\lambda 2}_{HHb}\varepsilon^{\lambda 1}_{Hbo2})} \qquad (4)$$

It follows that changes in [HHb] and [HbO2] can be consequently given as

$$\Delta[HbO_2] = \frac{\varepsilon^{\lambda 2}_{HHb}\Delta OD^{\lambda 1} - \varepsilon^{\lambda 1}_{HHb}\Delta OD^{\lambda 2}}{L(\varepsilon^{\lambda 2}_{HHb}\varepsilon^{\lambda 1}_{Hbo2} - \varepsilon^{\lambda 1}_{HHb}\varepsilon^{\lambda 2}_{Hbo2})} \qquad (5)$$

$$\Delta[HHb] = \frac{\varepsilon^{\lambda 2}_{Hbo2}\Delta OD^{\lambda 1} - \varepsilon^{\lambda 1}_{Hbo2}\Delta OD^{\lambda 2}}{L(\varepsilon^{\lambda 1}_{HHb}\varepsilon^{\lambda 2}_{Hbo2} - \varepsilon^{\lambda 2}_{HHb}\varepsilon^{\lambda 1}_{Hbo2})} \qquad (6)$$

$$\Delta[Hb]total = \Delta[HHb] + \Delta[HbO_2] \qquad (7)$$

Where ΔOD^{λ} represents a change in optical density at the specific wavelength, λ, and equals log (IB/IT)**.** IB and IT correspond to light intensities measured under the baseline and transient conditions [8].

III. SENSOR DESIGN

The developed hemoglobin sensor system consist of a number of hardware modules, which include appropriate light sources, constant light intensity circuit, transimpedance amplifier, DSO microcontroller, and GUI. Figure.3 is a schematic representation of hemoglobin measurement. The sensor consist of emitter as LEDs, with centre wavelengths of λ_1 = 660nm, λ_2 = 940nm. These two wavelengths are selected because at 660nm wavelength absorbance of deoxyhemoglobin greatly exceeds the absorbance of oxyhemoglobin where as at

960nm wavelength absorbance of oxyhemoglobin greatly exceeds the absorbance of deoxyhemoglobin. These LEDs are installed in the upper shell of a finger clip.

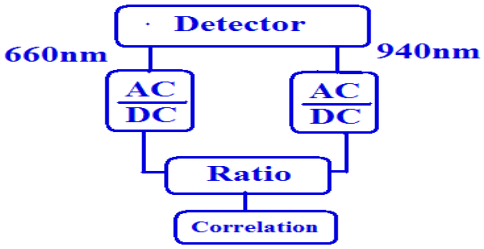
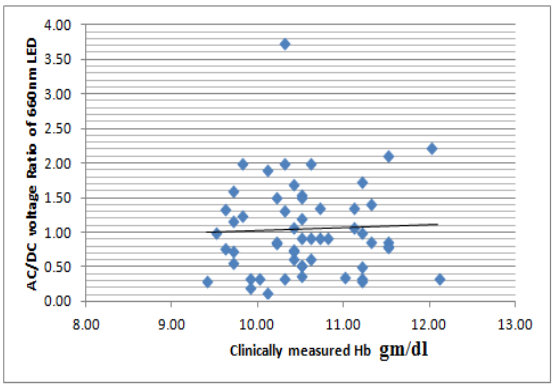


Figure3.Schematic representation of hemoglobin measurement sensor system

Source intensity should remain constant for this constant light intensity circuit is used. To detect the transmitted light OPT101 transimpedance amplifier is used as detector. The OPT101 is a monolithic photodiode with on-chip transimpedance amplifier. This single receiver photo diode is installed in the lower shell of the finger clip. The probe is placed to the patient's body usually on the finger. Red and infrared light is then emitted sequentially through the body tissue. The transmitted light is sensed by photodiode. Out-put voltage of photodiode increases linearly with light intensity. The amplifier is designed for single or dual power-supply operation, making it ideal for battery operated equipment. Integrated combination of photodiode and transimpedance amplifier on a single chip eliminates the problems commonly encountered in discrete designs such as leakage current errors, noise pick-up, and gain peaking due to stray capacitance. The 0.09 × 0.09 inch photodiode is operated in the photoconductive mode for excellent linearity and low dark current. The OPT101 operates from +2.7V to +36V supplies and quiescent current is only 120μA. It is available in clear plastic 8-pin DIP, and J-formed DIP for surface mounting. Temperature range is 0℃ to + 70℃.For digitalized this analog signal 40 pin pic 16f 877A microcontroller is used which is having inbuilt ten bit analog to digital converter. The microcontroller facilities software controlled and time multiplexed operation of light sources and receiver channels.



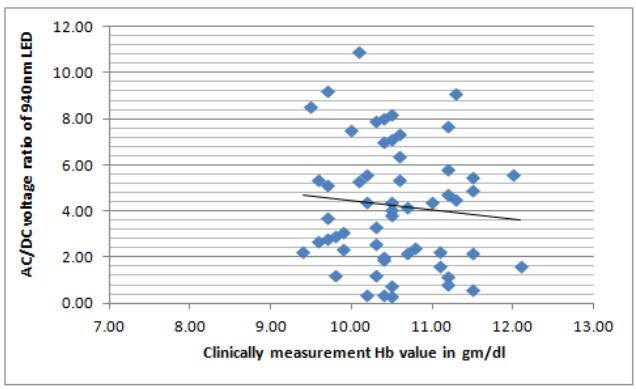


Figure4. Plot of clinically measured Hb vs. AC/DC ratio of 660nm LED and 940nm LED

IV. RESULTS AND DISCUSSION

An optical sensor is developed for measurement of haemoglobin by using wavelength 660nm and 940nm. Output signal are observed by sensor probe tested on various subject, and output voltage is measured also output waveform is observed on digital storage oscilloscope. A study with n=58 adult female in range of 18 to 20 year old has been performed to test the ability of this newly developed system to measure the hemoglobin content non invasive. The photometric measurements spanning 3 to 5 minutes for each subject and were store using microcontroller. Then clinically measured hemoglobin value vs. non invasively measured AC/DC ratio of 660nm wavelength are plotted as shown in figure 4. Similar graph of AC/DC ratio of 940nm and clinically measured Hb is plotted. The AC signal must be corrected for inter LED light intensity differences prior to their use for Hb calculation. The ratio of 660nm to that of 940nm is compare to clinically measured Hb value as shown in figure5.

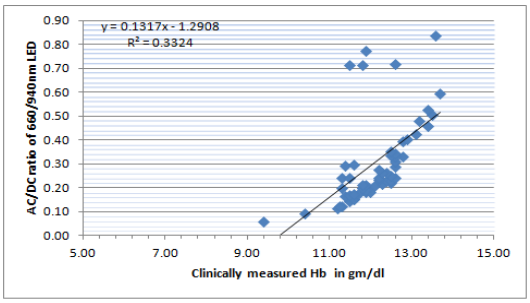


Figure5. Plot of clinically measured Hb vs.AC/DC ratio of 660nm/940nm LED

V. Conclusion

An optical non contact type sensor for hemoglobin measurement is developed. With the help of developed technique it is possible to measure hemoglobin with two wave length 660nm and 940nm. This developed technique is tested on 60 subjects and the result shows that the ratio values increases proportionally with haemoglobin. This show the capabilities of these selected wavelengths are promising for haemoglobin measurement.

ACKNOWLEDGEMENT

We would like to express sincere thanks to staff and faculty member of Instrumentation and Control department of Cummins College of Engineering for Women, Pune, India.

REFERENCES

[1] U. Timm, E. Lewis, D. McGrath, J. Kraitl, H. Ewald, "LED Based Sensor System for Non-Invasive Measurement of the Hemoglobin Concentration in Human Blood", IFMBE Proceedings Vol. 23, 825-28, 2008

[2] Suzaki, H.; Kobayashi, "Noninvasive measurement of total hemoglobin and hemoglobin derivatives using multiwavelength pulse spectrophotometry -In vitro study with a mock circulatory system" EMBS 28th Annual International Conference of the IEEE, 2006 .

[3] J.Kraitl, H. Ewald, U.Timm "Non-invasive measurement of blood components" IEEE fifth international Conference on Sensing Technology 2011.

[4] Aldrich TK, Moosikasuwan M, Shah SD, Deshpande KS. "Length-normalized pulse photoplethysmography:a noninvasive method to measure blood haemoglobin". Ann Biomed Eng 2002; 30:1291– 8.

[5] Jeon KJ, Kim SJ, Park KK, Kim JW, Yoon G."Noninvasive total hemoglobin measurement".J Biomed Opt 2002;7:45–50.

[6] Petrova, Prough, D.S.; Petrov, Brecht, "Optoacoustic technique for continuous, noninvasive measurement of total hemoglobin concentration: an in vivo study" IEMBS Volume: 1, 2004

[7] Jae G.Kim, Mengna Xia,and Hanali Liu "Extinction coefficient of hemoglobin for near-infrared spectroscopy of tissue" IEEE Eneineering in medicine and biology magazine 2005.

[8] Brecht, H.-P.; Petrov, "Noninvasive continuous optoacoustic monitor of total hemoglobin concentration" Engineering in Medicine and Biology Conference, Volume: 3, 2002