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Non-Invasive Optical Sensor for Hemoglobin Determination

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Abstract

Hemoglobin (Hb) is an important component of red blood cells. This paper presents an optical non-contact technique that provides Hb concentration measurement. The absorption coefficient of blood differs at different wavelength this fact is used to calculate the optical characteristics of blood. In this newly developed system, absorption of light by oxygenated and deoxygenated hemoglobin is measured at two wavelength 660nm and 940nm. The particular wavelength of light is obtained from red and IR LED. Constant current circuit is designed to drive the LEDs. Transmitted light through an area of skin on finger was detected by a photodiode. Ratio of red to 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-blood, hemoglobin, infrared, LED, noninvasive, optical method

1. Introduction

Hemoglobin (Hb) is the most vital component in human blood, and is responsible for transporting oxygen from the lungs to the rest of our body. It is composed of a protein, called globin, and an iron containing compound called heme. Hemoglobin level is an important clinical parameter for assessing anemia in both chronic and acute conditions, and is among the most commonly performed blood tests. If Hb concentration falls below normal, this is called anemia. Anemia is a condition in which the Hb concentration in the blood drops below a defined level, resulting in a reduced oxygen-carrying capacity of red blood cells. In its severe form, anemia is associated with fatigue, weakness, dizziness and drowsiness, and may lead to death [1].

Currently, invasive methods are used to measure the Hb concentration, whereby 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 pulsatile changes of blood volume in tissue can be observed by measuring the transmission or reflection 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]. A wholly 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].

This newly developed optical sensor system uses two wavelengths of light 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) in the range of 600nm to 1400nm. The detector detects the light transmitted through the finger. In order to achieve mathematical conversion from detected light intensity at different wavelengths to hemoglobin concentration, extinction coefficients of hemoglobin, ε , is used. The Hb sensor developed for this research is fully integrated into a wearable finger clip.

2. Experimental Methods

Presently clinically used methods are Spectrophotometry, Hemoglobincyanide and conductivity based method for measurement of hemoglobin. Howerever in this method 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.

A. System Overview

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

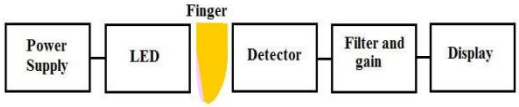

Figure1. Block diagram of hemoglobin measurement system

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 in the range from 600nm -1400nm. 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). Upon interaction with the tissue the transmitted light is detected non-invasively by photo diodes.

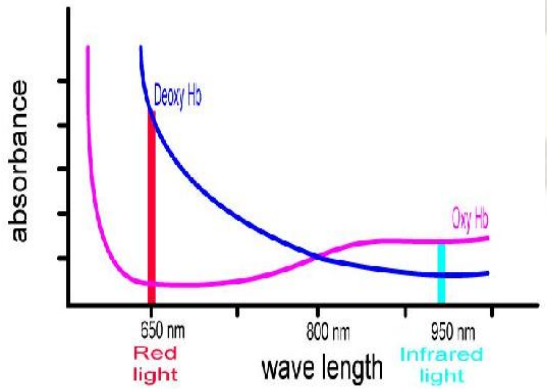

Figure2. Absorption spectra of oxy- and deoxyhemoglobin

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].

B. 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:

$$0D = Log(I_0/I) = \varepsilon cL \qquad (1)$$

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.

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

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

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

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

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

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

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].

5. 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, CRO. Figure3 is a schematic representation of hemoglobin measurement.

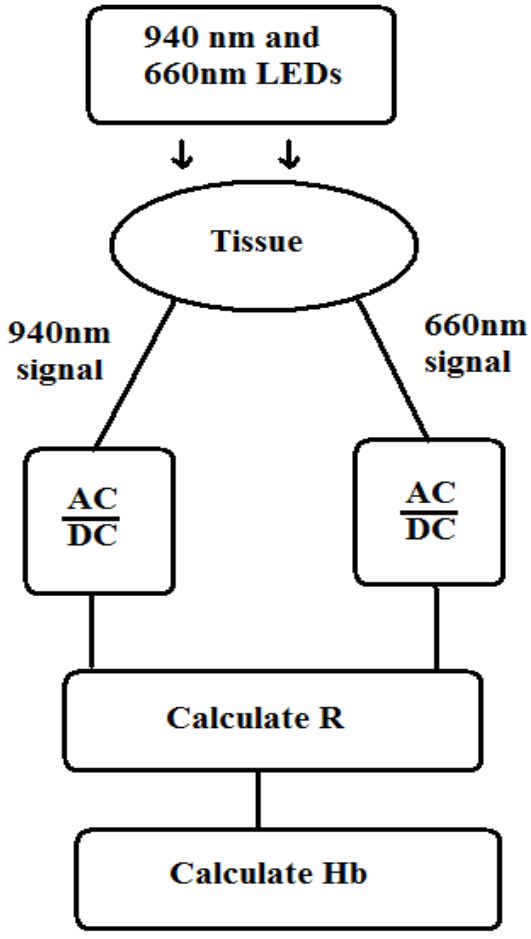

Figure3 Schematic representation of hemoglobin measurement sensor system

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 [9]. These LEDs are installed in the upper shell of a finger clip. 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℃.

6. 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. Voltage observed as follows:

Source wave length 660nm:

Age	Output voltage
10 years	0.5v
35 Years	0.6v
32 years	0.59v
50 years	0.54v

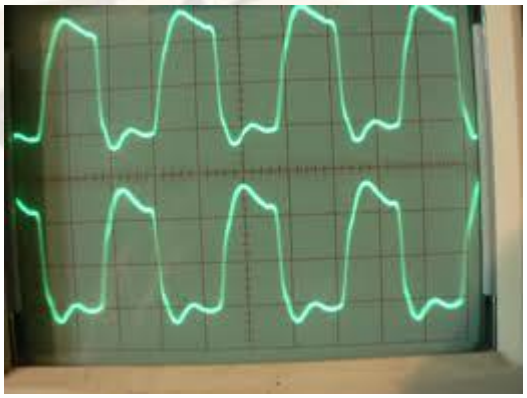

Figure4 PPG signal at 660nm LED

Source wave length 940nm:

Age	Output voltage
10 years	0.58v
35 Years	0.63v
32 years	0.63v
50 years	0.58v

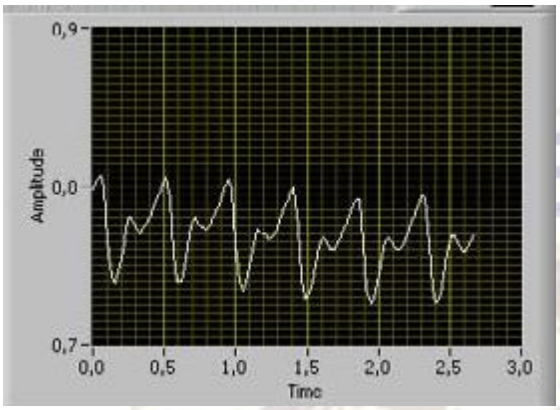

Figure5 PPG signal at 940nm LED

DC component is extracted from signal and AC signal is proportional to hemoglobin. Sensor probe is tested on various subjects from different age group and it is observed that AC signal is proportional to hemoglobin measure using conventional method.

7. 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 some subjects and the results are promising.

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