Noninvasive Sensor Technology for Total Hemoglobin Measurement in Blood

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***Abstract*—Anemia is a globally dreaded health hazard. To reduce the complications due to anemia, Hb level needs to be measured. There are number of methods available for estimating Hb value in blood. Current methods require an invasive and painful needle stick to draw a blood sample. Then it is sent to a laboratory for analysis, with results reported back to the physician later, potentially resulting in diagnosis and treatment delay. There is a requirement for simple method suitable in rural settings. Hemoglobin in blood exhibits the optical properties such as absorption, Transmission and reflection of photons in various proportions based on the wave length of photons .In this discussion photons at appropriate wave lengths (740nm and 805nm) are pumped into the skin on the finger where it is optically least resistant and the Transmitted photons from the Hb content of the blood are received at a photo detector which converts them into electrical signal. Then received signal strength can be calibrated in terms of Hb content in blood. An instrument which is working on this optical property exhibited by Hb is designed. 100 real-time samples are collected at clinical Laboratory; results are compared with standard methods. Early results are encouraging.**

***Index Terms*—Estimation of Hemoglobin in Blood, Transmission and reflections of photon at varies wave length, Fingertip Pulse oxmetry**

I. INTRODUCTION

WHO regularly publishes health statistics in respect of various countries. One single major health concern is anemia that affects more than 60% of the population in developing countries.

Anemia, one of the most common blood disorders, occurs when the level of healthy red blood cells (RBCs) in the body becomes too low. Worldwide over 2 billion people affected by anemia, mainly women and children. While the extent of affliction is negligible in developed world, it is alarming in developing countries. In pregnancy, it is associated with premature births, low birth weight of babies and prenatal and maternal mortality [1]. Anemia can be a result of drop in Hb level in blood, which in turn can be due to deficiency of Iron, Vitamin B12 or Folic acid. Of these, anemia due to Iron deficiency is normally prevalent. Iron in Hb is responsible for carrying Oxygen from the lungs to various parts of body through blood. So, reduction in Iron level will result in reduced Oxygen carrying capacity of blood, which can have adverse effect on the health of the individual.

For combating such a dreaded health condition as anemia, estimation of the level of Hb in one's blood is essential. There are different methods of evaluation of Hemoglobin in blood. These are documented and dealt in detail by World Health Organization (WHO) [2]. The practice in rural area for evaluation of Hb has been to use either pallor test or filter paper test or Sahli method. In the only non-invasive method, namely the pallor test, the color of the patient's conjunctiva is observed and guess is made regarding the level of Hb in blood. As can be appreciated, in these methods, the Hb level is guessed and it is subjective. It also does not give the value of Hb in precise and crisp form.

Some of the other methods for evaluation of Hb in one's blood are Copper sulfate method, Hematocrit method by centrifuge, Lovibond type comparator method. Grey wedge photometer method, Hemocue method and cyanmethemoglobin method. In these methods blood is drawn from the patient and is used to evaluate Hb using different reagents and some equipment. The operation of these sophisticated equipment's to evaluate Hb requires well-trained and experienced technician. Sometimes they may also be expected to use hazardous chemicals. These tests themselves may be unaffordable by the patients, especially in developing countries

Different methods used for evaluation give the results with varying accuracy and the values are generally not repeatable. The values obtained from different laboratories vary from each other. Of all the methods that are available for anemia detection, Cyanmethemoglobin method is considered to be the most reliable and accurate method. This calls for about 2 cc of blood to be drawn from the patient and be mixed with deadly chemicals such as Cyanide for analysis. This is the most standard method recommended by WHO [2]. This standardized, accurate testing method is costlier. So, we have a requirement to find a simple noninvasive method for estimation of Hb in blood.

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II. Current Approach

The optical property of Hb products can be used to develop a noninvasive method for Hb estimation. Here, different transmission, absorption and reflection levels of light with different wavelengths by Hb products are considered.

It is found that Hb is available in blood as various components such as Oxyhemoglobin (HbO_2 or oxygenated Hemoglobin), Hemoglobin (Hb, also known as reduced Hb), Carboxyhemoglobin (HbCO) and methemoglobin. Of these, HbO_2 and Hb are main forms that are available in blood. The other forms are available only in traces [3].

Hb absorbs oxygen readily and becomes a loose component of HbO_2 in the lungs. Ferrous iron in Hb is not oxidized though oxygen is accommodated [3]. The reaction is freely reversible. The reversible reaction is as shown (1)

$$Hb + O_2 \leftrightarrows HbO_2 \quad (1)$$

HbO_2 is mainly available in arteries and Hb is available in veins. In capillaries, both the forms are available. For ascertaining the level of Hb in one's blood, it is important that the levels of HbO_2 and Hb in a particular volume of blood are considered, as these forms are available together. The total availability of Hb in blood is the combination of availability of HbO_2 and Hb. So, for an accurate measurement of Hb in blood. It is necessary to measure Hb in either form (HbO_2 or Hb).

It is found that HbO_2 and Hb have different absorption characteristics. The absorption, transmission and scattering of light by Hb products are wavelength dependent. The variation of molar extinction coefficient of light by Hb products with wavelength is given in Fig. 1. Molar extinction coefficient can be converted into absorption coefficient simply by multiplying the same by 2.303. The most noticeable differences between absorption spectrum of HbO_2 and Hb are found between 550 to 800 nm. This phenomenon led to the development of oximetry based on the differential light absorption of oxygenated and deoxygenated blood. In the present approach that is similar to the practice in pulse oximeter, it is decided to measure the amount of light transmitted through skin, tissues and blood at the fingertip for estimation of Hb in blood

Human skin is characterized by variable concentration of melanin. Melanin and hemoglobin strongly absorb light in the ultraviolet (UV) and visible ranges and they present low absorption in the near-infrared range [4]. Almost complete absorption of light takes place up to a wavelength of 550 nm by HbO_2 and up to a wavelength of 700 nm by Hb. The light absorption is the minimum at the wavelength of 603 nm for HbO_2. Hb and HbO_2 absorb equal quantity of light at the wavelength (isosbestic) of 805 nm. These optical features are used in the estimation of Hb using light sources. Based on above theory a reflection type optical sensor was designed by National Cardiovascular center, Research institute, Osaka, Japan for continuous measurement of both hemoglobin content (Hb) and oxygen saturation (OS) of whole blood

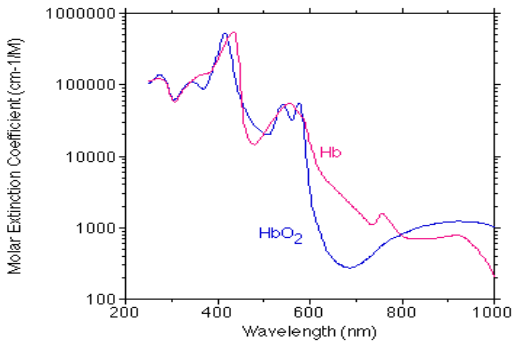

Figure 1. Molar extinction coefficient of light by Hb products with Wavelength

The emission wave length of LED was 665 and 795 nm [5]. But it has the limitation of observing the reflected light in different levels. Technology in this area is continuing to improve with clinical introduction of noninvasive hemoglobin measurement [6]

In our present approach, the assumption made is that the fingertip is considered to be a slab made-up if skin, tissues and blood. The blood is considered to be uniform in its composition. The lower wavelength light is absorbed and only a fraction of light is reflected at the skin surface. The higher wavelength light is transmitted at the skin and tissue surface. The amount of transmitted light is dependent on the Hb concentration of blood. As the amounts of Hb in the blood sample increases, more absorption takes place and less energy is transmitted and vice-versa. The extent of penetration is also dependent on the Hb concentration in blood. Modified Beer's law forms the basis of defining the extent for penetration of light energy into the fingertip. Modified Beer's law describing the light propagation through a slab of tissue [7] is given in (2)

$$I(\lambda, L) = I_0(\lambda)\, e^{\{-[\mu_s(\lambda) + \mu_a(\lambda)]\, L\}} \quad (2)$$

$\mathbf{I_0(\lambda)}$ is the incident light energy
$\boldsymbol{\mu_s(\lambda)}$ is the scattering coefficient
$\boldsymbol{\mu_a(\lambda)}$ is the absorption coefficient
$\boldsymbol{\lambda}$ is the wavelength of light
L is the distance of penetration

Observing from a standard area, the Hb concentration in blood defines the amount of light energy that is received from the fingertip. So, the Hb concentration that is specified here is the combination of concentrations of HbO_2 and Hb as the blood is expected to have both the forms at the capillaries where we measure. Taking a cross-section of fingertip, the concentrations of HbO_2 and Hb play a role in the amount of light transmitted for a specific amount of light irradiated to the surface.

If we consider the anatomy of the finger, typically the fingertip will have a network of arteries and veins. There are also capillaries. The capillaries are the end of the arteries and the beginning of the veins. The capillaries run longitudinally under the nail bed and in the pulp on

the palmer side of finger. In the fingertip, they form a mesh of capillaries as in the injected skin capillaries as shown in Fig. 2.

So, it is seen that the light energy penetrates skin to a depth depending on the wavelength of the source and the concentration of Hb and other ingredients of blood.

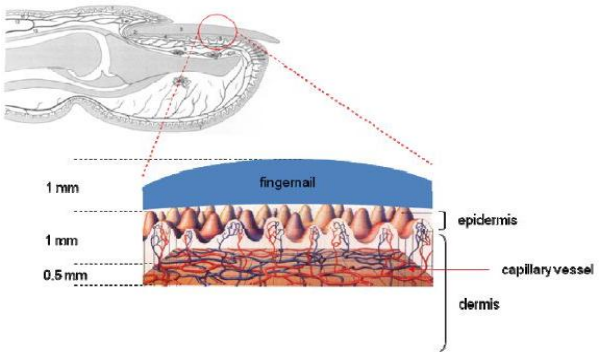

Figure 2. Characterization of skin tissues at finger

Different wavelengths of the light energy are expected to be transmitted, absorbed and reflected by varying degrees. The precision of noninvasive optical measurement of the concentration changes in oxy, de-oxy, and total-hemoglobin depends on wave length [8]. Based on the optical characteristics described earlier, light sources at wavelengths of 741 nm, and 805 nm are chosen. The strength of the transmitted light is measured as a voltage level after detection. The source and sensor assembly is shown as per the arrangement shown in Fig. 3.

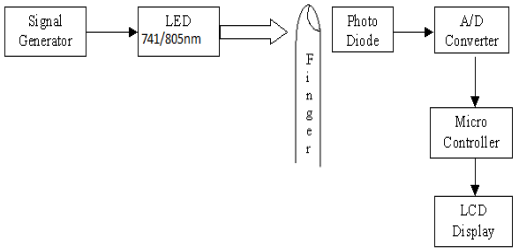

Figure 3. Block diagram of Optical Measuring setup

Irrespective of the wavelength approximately 5 to 7% of the incident light on the skin is reflected back to the environment [9]. At the wavelength of 741 nm, a portion of the light that has penetrated the skin is scattered and a portion of it is absorbed [10]. The absorption level is decided by the extent of population of Hb in blood. So, the strength of the transmitted light gives an indication of the amount of total Hb (reduced and oxygenated Hb) present in blood.

III. Proposed Optical Experimental Setup

The experimental setup includes a set of light sources at the wavelengths of 741 nm and 805 nm. There is a signal generator that drives the light sources by a 300 Hz square wave 5 V peak to peak. The transmitted light energy is received with a photo diode. The demodulated signal from the photodiode is amplified and converted in to digital signal by analog to digital converter. Processing of the signal is done through microcontroller. The basic block diagram of the whole setup is shown in Fig. 3 and the circuit diagram is shown in the Fig. 4.

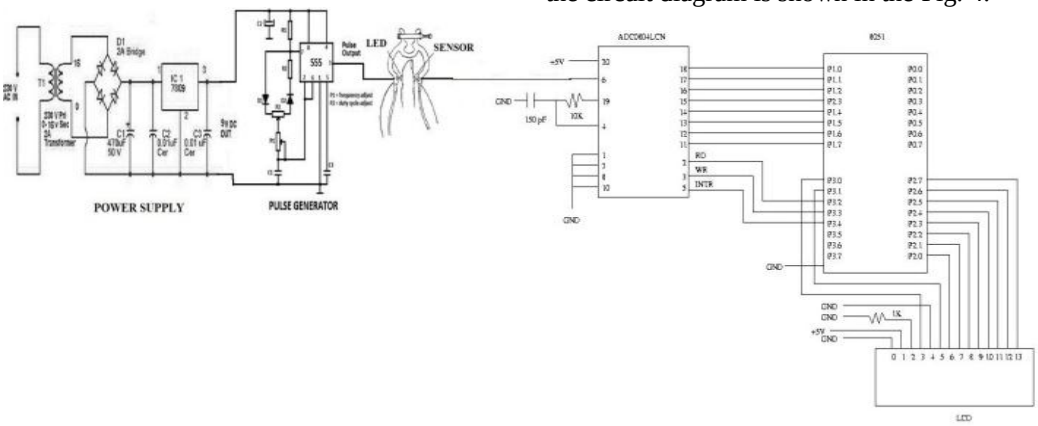

Figure 4. Circuit diagram of the setup

Transmitter sources are expected to radiate 4.0mw (741) & 6.5mw (805) so that the complete fingertip can be penetrated for more accurate results. At the wavelength of 741nm as the light that has penetrated the skin and tissues would have been partially absorbed by Hb products. The absorption level is decided by the extent of population of Hb in blood .At the wave length of 805nm, a portion of the light that has penetrated the skin is scattered and a portion of it is absorbed. Again the absorption level is decided by the extent of population of Hb in blood. So the strength of the transferred light gives an indication of the amount of total Hb(reduced and oxygenated) present in blood.

For each sample the Hb level measured in cynamethemoglobin method is stored in the system. The received signal from the photo diode is compared with the stored value. The system is calibrated with a number of samples for better accuracy.

Digital LCD display unit of the system is for providing the easier indication. This display made after analyzing the received signal from both the sources for over 30 seconds. The necessary calculations are made within the system and the Hb level is displayed as XX.X g/dL

IV. Result and Discussions

The experiment is conducted for 100 people in various ages. The population had persons with anemia and normal people. They have Hb in their blood in varying degrees. Out of these 100, the first 50 samples are used for calibrating the setup. Their Hb is measured using the standard cyanmethemoglobin method first. The information is recorded, then the optical setup is used to measure the Hb level and using the already recorded standard measurement data, the readings are calibrated. The readings of the balance 50 persons are verified for accuracy.

The Bland Altman plot as shown Fig. 5 is used to compare the results between the cyanmethemoglobin method and optical method.

The X axis shows the mean of results from two methods and the Y axis represents the difference in percentage between the results from two methods. The plot is done for only few selected samples and it can be seen that all readings shows a maximum variation of only 2%. It has been indicated that there is a large difference between the results obtained using the standard method and other methods. But our method the difference in the results is minimized.

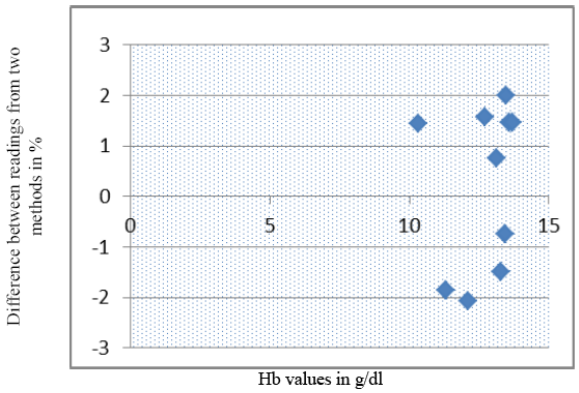

Figure 5. Bland Altman Plot for comparison of results

V. Conclusions

The ability to noninvasively measure the hemoglobin levels is a promising advance in technology. It has the potential to decrease medical costs and enable expedient clinical decision-making by reducing the need for costly, time consuming, and potentially painful blood draws that allow only intermittent and delayed measurements .This method is the simplest method with acceptable accuracies. Efforts are being taken by the authors to develop a hand held instrument that can be utilized to collect the samples for calibration. Once perfected, this scheme of evaluation of Hb in blood can be used extensively as the method is simple, non-invasive, easily portable, and easily operable and does not require services of experienced and skilled technicians

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