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Non – Invasive Haemoglobin Measurement

P.M. Shivakumaraswamy, S.T. Veerabhadrappa, Priyanka D, Srinidhi S K, Sonia K, Anika Anjani Gowda

Abstract: ***Haemoglobin is one of the main constituents in characterizing the physiological condition of a human body. Currently, invasive techniques which are being used, are not suitable for real-time continuous monitoring and also include delay. On the other hand, the non-invasive method of haemoglobin measurement ensures painless and continuous real-time monitoring. This paper discusses the method and technique involved in designing a prototype for the non-invasive measurement of haemoglobin.***

Keywords: ***Anaemia, Haemoglobin, Non-invasive, Photo-plethysmography, Polycythaemia, Spectrophotometry.***

I. INTRODUCTION

Haemoglobin is the protein constituent of red blood cells which contains iron. This protein component is responsible for the transportation of gases i.e. oxygen from lungs to several parts of the body and carbon-di-oxide back to the lungs.

haemoglobin is available in two forms:

1. Oxygenated Haemoglobin.
2. De-oxygenated Haemoglobin.

Measuring of Haemoglobin is essential for all individuals especially in underweight children, pregnant women. Deficiency in Haemoglobin leads to anaemia, the reduction of iron content in blood, which creates problems related to kidney and liver whereas higher levels of haemoglobin results in polycythaemia[2].

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***** Correspondence Author
P.M. Shivakumaraswamy, Professor in Electronics and Communication **Engineering** Department, JSS Academy of Technical Education, Bengaluru, Karnataka, India. Email: pmsk.swamy68@gmail.com
S.T. Veerabhadrappa, Associate Professor in Electronics and Communication Engineering Department at **JSS** Academy of Technical Education, Bengaluru, Karnataka, India. Email: veeru.st@gmail.com
Priyanka D, Student, Bachelor of Engineering, Department Of Electronics and Communication, JSS **Academy** Of Technical Education, Bengaluru, Karnataka, India. Email: priyankadp001@gmail.com
Srinidhi S K, Student, Bachelor of **Engineering**, Department Of Electronics and Communication, JSS Academy Of Technical Education, Bengaluru, Karnataka, India. Email: srinidhisk8059@gmail.com
Sonia K, Student, Bachelor of Engineering, Department Of Electronics and Communication, JSS Academy Of Technical Education, Bengaluru, Karnataka, India. Email: soniakathir@**gmail**.com
Anika Anjani Gowda, Student, Bachelor of Engineering, Department Of Electronics and Communication, JSS Academy Of Technical Education, Bengaluru, Karnataka, India. Email: anikaanjanigowda64@gmail.com\

The haemoglobin range of a healthy human is 13.5 to 17.5 g/dL for men and 12.0 to 15.5 g/dL for women[8]. According to the statistics of a survey conducted by the World Health Organisation, around 60% of the world's population is suffering from anaemia which exceeds 1.6 million. As per the Global Nutrition Report 2017, 51% of Indian women whose age is between 15 to 49 are anaemic.

There are two ways in measuring haemoglobin such as the invasive method, non-invasive method. Some of the invasive techniques are Hemoase, Cyanmeth, Copper sulphur gravimetric method. But for all of these invasive methods, a drop of blood is required and these samples are later analyzed by making use of one of the above methods. Also, extra care needs to be taken while performing these methods since there is a risk of infection. It takes a few hours to analyze blood samples and to obtain results by a trained laboratory staff followed by a pathologist to verify the obtained results[7].

A non-invasive method of haemoglobin measurement provides an easier way for continuous monitoring of haemoglobin. The non-invasive method provides pain-free and continuous monitoring. The results are obtained between 30 to 60 seconds, allowing immediate clinical assessments. Because of the advancement of technology and research, such as spectrophotometry, optoacoustic and transmission spectroscopy, many low cost and simple non-invasive technologies have emerged.

The non-invasive methods are based on the principles of Spectrophotometry and Beer-Lambert law[1]. Spectrophotometry conveys that each compound will absorb or emit radiations only in a particular range of wavelengths.

The principle of spectrophotometry involves transmitting light differentially based on their biochemical variables through the tissues and the blood. The other approach is photoplethysmography that is an analysis of changes in body volume. Different wavelengths of light measure the relative magnitude of photoplethysmographic signals at various times of the cardiac cycle [3].

Near Infra-Red(NIR) spectra can be acquired in three different modes of operation, which are the transmission, reflectance of diffusion and transflectance. Out of these three operation modes, two common modes are transmission and reflectance. The transmission type consists of the light source and the detector which is facing each other. Whereas in reflectance type, the light source and the detector are placed in the same plane. The wavelength of the NIR will penetrate deeply into the dermis, before the capillary blood vessels. After penetration of NIR to the skin's target area, the same part of the light will be absorbed in the tissues due to scattering and the remaining part of the light will be transmitted through the tissues [4].

The blood level of humans haemoglobin may be determined by the blood color. H Ranganathan et al. proposed a technique in which photographs of the blood samples were taken for analysis and were color-coded to obtain certain values. This method required skilled techniques but was risk-free of infection. Researcher Komal Bhatia et al. proposed a technique in which two thumb photographs are taken for non-invasive diagnosis of anaemia.

The photographs are initially taken without blood welling and then taken again with blood welling in the thumb. When comparing the two images, the change in blood color will be detected since the person's skin tone is nullified [6]. This non-invasive method requires skilled techniques to analyze the outcome.

Pulse oximetry is another commonly known, and considered to be the most successful non-invasive procedure. In hospitals, pulse oximetry is used for continuous monitoring of a patient's heart rate. Dr. Raid Salleem Ul-Baradie proposed that this method might be used to develop a non-invasive measuring device for Hb [6]. Another method suggested by researchers is Photoplethysmography [PPG], an optical method that can be used to detect changes in the blood volume of micro-vascular tissue beds. This approach is both easy and cost-effective. The author also discussed the use of PPG technique, which can be used to build in small pulse rate sensors [6]. Color analysis approaches are characteristic of the techniques discussed above, and the use of this approach can not be used to build portable systems. A simple low cost, compact and smart system can be built using pulse oximetry and PPG techniques that do not require any technician to work. Anyone can operate at any time, anywhere and at regular intervals can check the Hb concentration.

Although traditional (invasive) methods are accurate, they take longer to analyze, are expensive, painful and have the potential risk of biohazard exposure. Most traumas attacked patients seek non-operational treatment and undergo surgery only for continuous bleeding or dynamic (instability) variations of haemoglobin [10], which requires less time for monitoring in ICU. The use of continuous or spot-check non-invasive Hb monitoring methods allows these patients to be tracked continuously in real-time and to respond upon changes in Hb level.

II. METHODOLOGY

Haemoglobin is a powerful blood absorber with high absorption at 575–1100 nm. Haemoglobin is non-invasively measured using red blood cells' (RBC's) arterial pulse signal. The theory which has been suggested is based on Twersky's hypothesis, the formulation of which is based on the premise that the difference is negligible in the arterial diameter which is generated between the systolic and the diastolic periods.

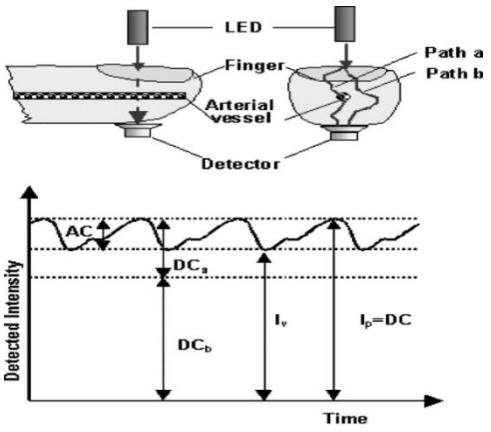


Figure 1: Device Prototype

$DC_a = f(r_a, r_f, \lambda)DC$ ..... (1)

$DC = DC_a + DC_b$ ..... (2)

Where,

r_a: Radius of the arterial blood flow

r_f: Radius of finger

λ: Incident light wavelength.

DC_a: path a's DC level

DC_b: path b's DC level

DC: Total transmitted DC level

One of the most important non-invasive tools for the assessment of human oxygen saturation is Pulse Oximetry. Whatever the reading's obtained from arterial blood gas examination i.e., arterial oxygen saturation(SaO_2) should not be necessarily the same as that of the reading's obtained from peripheral oxygen saturation (SpO_2). Both are fairly well associated that an accurate, quick, non-invasive, low-cost pulse oximetry procedure is useful for the calculation of oxygen saturation in clinical usage.

A sensor unit is placed over a foot on a thin part of the patient's body or usually a fingertip or earlobe in the case of an infant. This is the most common method in practice.

III. DESIGN OF HARDWARE

The sensor consists of emitter as LEDs with a canter wavelength of 660nm and 940nm. The reason for choosing these two wavelengths is that the absorbance of oxyhemoglobin at 660nm is greatly exceeded by the absorbance of deoxyhaemoglobin and absorbance of deoxyhaemoglobin at 940nm is greatly exceeded by absorbance of oxyhemoglobin. The upper shell of the finger probe contains these two LEDs and a single receiving photodiode is embedded at the lower shell of the finger probe/clip[1].

$$Ratio = \frac{ac\ voltage\ (red\ LED)}{ac\ voltage\ (IR\ LED)} \quad (3)$$

Output voltage increases linearly with the intensity of light. Output waves must be filtered to remove the DC component signal.

Both red and infrared light is passing through the capillaries to the photodetector. Excluding venous blood, flesh, bone, muscle, fat and nail polish, the system will continuously measure the increasing absorbance at every point of the wavelength, and it allows us to determine the absorbance due to the pulsation of the arterial fluid on its own. The absorption of light at the two wavelengths, as mentioned earlier, varies considerably between oxygen-charged blood and oxygen-free blood. Oxygenated haemoglobin absorbs more infrared light and allows more red light to pass through. Deoxygenated haemoglobin enables more visible light to pass through and more red light to be absorbed. The LEDs cycle in their process from one to the other, then switch off approximately thirty times per second, allowing the photodiode to respond independently to the red and infrared lights and also to adapt to the ambient light baseline. Firstly the amount of light transmitted i.e. not absorbed is measured and then the separate normalized signals are generated for each wavelength.

Such impulses fluctuate over time as the volume of arterial blood current decreases with every heartbeat. By removing total transmitted light from the transmitted light in each direction, the effects of other tissues are reversed to provide a coherent signal for pulsatile arterial blood. The ratio of the red-light measurement to the infrared light measurement is then measured by the processor that is it represents the ratio of oxygenated haemoglobin to deoxygenated haemoglobin and then converted to SpO_2 based on Beer-Lambert law.

The optical density of blood can be measured at both wavelengths using equation (4) mentioned below[2].

$$OD = \log\left(\frac{I_0}{I}\right) \quad (4)$$

The plethysmograph waveform is a combination of the full-wave reflecting the pulsatile signal. Which is generally used for the visual indicator of the pulse as well as the signal strength, and the quantitative ratio between the pulsatile and the baseline absorbance means perfusion index can be used to determine the perfusion.

IV. IMPLEMENTATION

Figure 2 shows the block diagram for haemoglobin analysis, involving two LEDs, i.e. 660 nm red led and 940 nm infrared led wavelength. The two LEDs are turned on and off at an interval of 250 ms using the microcontroller (ATMEGA320P).

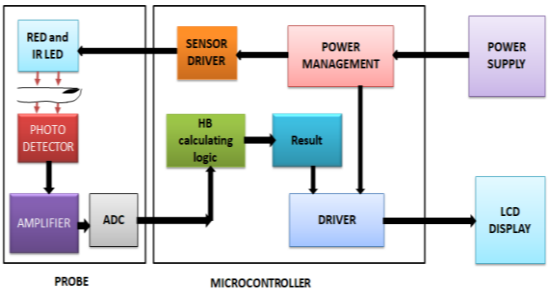


Figure 2: Block Diagram of noninvasive haemoglobin measurement

Further, when the finger is placed in the setup, the red and IR LEDs alternatively turn on and off for 250 ms as mentioned earlier. The time for which the finger is placed is approximately 60 seconds during which the intensity of red and IR LEDs obtained from the photodetector, I_1 and I_2 respectively are recorded. Based on the intensity values of red and IR LEDs obtained, Optical density (OD) can be calculated using the following equation[2];

$$OD = \log\left(\frac{I_{01}}{I_1}\right) + \log\left(\frac{I_{02}}{I_2}\right) \quad (5)$$

Where,

I_{01}- the intensity of red incident light.

I_{02}-the intensity of IR incident light.

I_1 – the intensity of red transmitted light.

I_2- intensity of IR transmitted light.

The haemoglobin is calculated using the below equation;

$$Hb = c_1 * OD^3 + c_2 * OD^2 + c_3 * OD + c_4 \quad (6)$$

Where, c_1, c_2, c_3 & c_4 are constant coefficients and are given as[2]

c_1= -1.173,

c_2= 19.28,

c_3= -102.8,

c_4 = 189.8.

Figure 3 shows the flow chart based on which the microcontroller is programmed to perform each task mentioned above with all the timing considerations. Finally, the value of haemoglobin, which is calculated by the above-mentioned procedure, will be displayed on an LCD.

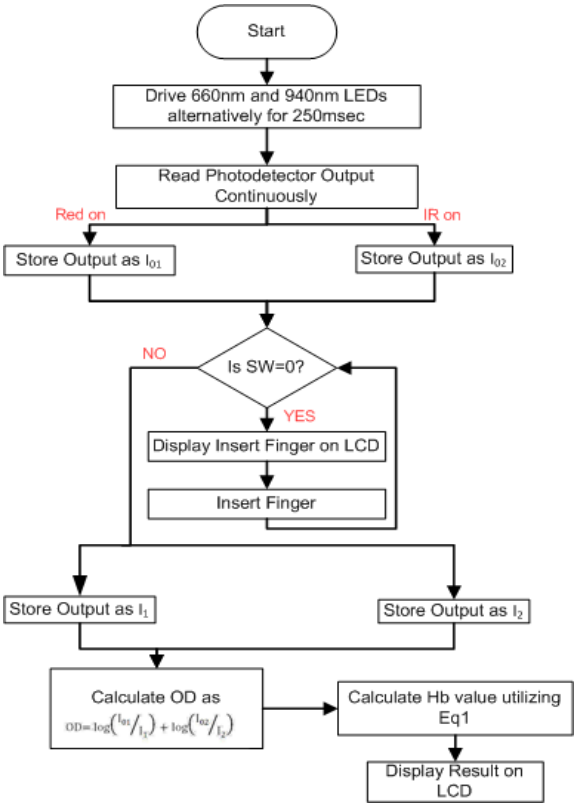


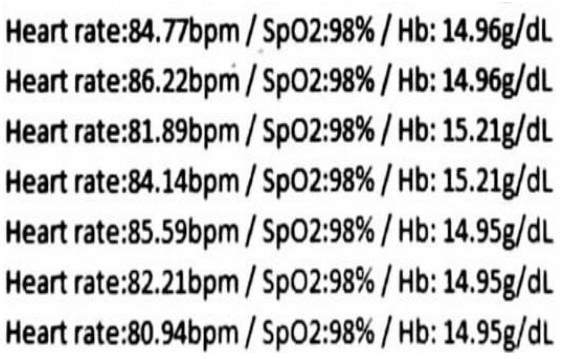
Figure 3: Flow Chart

V. RESULTS AND DISCUSSIONS

Figure 4 shows the results of three people obtained by measuring their Hb using the designed prototype for 60 seconds. Figure 4(a) reflects the results of a Male test case obtained when measured from the prototype which is 15.03±0.125 g/dL. The measured Hb value is very closed to the laboratory measurement (15.2g/dL). Figure 4(b) is the results of another Male test case obtained from the prototype which reads the Hb value of approximately 14.47±0.016 g/dL. The results of the same person when obtained from laboratory read as 14.9 g/dL.

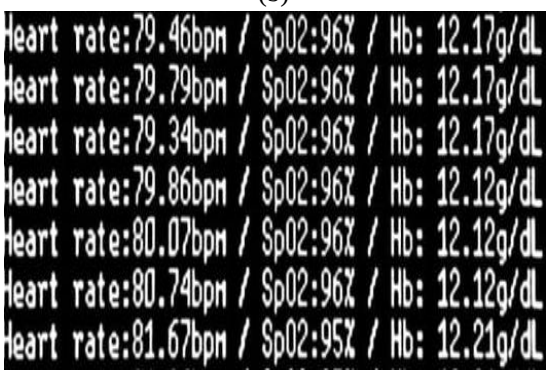
Figure 4(c) shows the results of a Female test case whose Hb values obtained from the prototype and laboratory are 12.15±0.035 g/dL and 12.02g/dL respectively.

From the above discussion, we can see the closeness of the results obtained from the designed prototype with that obtained from the laboratory.



(a)

(b)



(c)

Figure 4(a)(b)(c): Test Cases

VI. CONCLUSION

The results obtained from the designed prototype have shown a significant correlation with that obtained from the laboratory. Also, the Hb values are continuously measured in real-time with repeatability of which is the major advantage of the device Further research is required and test on more number of subjects to validate the results.

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AUTHORS PROFILE

P.M. Shivakumaraswamy obtained Bachelor of Engineering in Electronics & Communication Engineering in 1992 from GBDT College of Engineering, Davanagere. He obtained Masters in Digital Electronics in 1997 from BVB College of Engineering. He obtained PhD in 2017 from Anna Univeristy, CEG Campus, Chennai, India. He worked as Lecturer in Electronics and Communication Engineering Department from 1993 to 2000 at SJM Institute of Technology, Chitradurga. Since 2001 he has been Lecturer and at present Professor in Electronics and Communication Engineering Department, JSS Academy of Technical Education, Bengaluru, Karnataka, India.

S.T. Veerabhadrappa obtained a Bachelor of Engineering in Electronics & Communication Engineering in 1994 from The National Institute of Engineering, Mysore. He obtained Masters in Biomedical Engineering in 1998 from Manipal Institute of Technology, Manipal. He obtained Ph.D. in 2016 from Indian Institute of Technology (IIT), Delhi, India

He worked as Lecturer in Electronics and Communication Engineering Department from 1995 to 2000 at SJM Institute of Technology, Chitradurga. Since 2001 he has been Lecturer and at present Associate Professor in Electronics and Communication Engineering Department at JSS Academy of Technical Education, Bengaluru, Karnataka, India.

Priyanka D, Final Year undergraduate student, Bachelor of Engineering, Department Of Electronics and Communication, JSS Academy Of Technical Education, Bengaluru, Karnataka, India.

Srinidhi S K, Final Year undergraduate student, Bachelor of Engineering, Department Of Electronics and Communication, JSS Academy Of Technical Education, Bengaluru, Karnataka, India.

Sonia K, Final Year undergraduate student, Bachelor of Engineering, Department Of Electronics and Communication, JSS Academy Of Technical Education, Bengaluru, Karnataka, India.

Anika Anjani Gowda, Final Year undergraduate student, Bachelor of Engineering, Department Of Electronics and Communication, JSS Academy Of Technical Education, Bengaluru, Karnataka, India.