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Method for Non-invasive Hemoglobin Determination

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ABSTRACT

Hemoglobin is the iron containing metalloprotein responsible for the transport of oxygen present in the red blood cells (RBC) so it plays an important role in the existence of the homo-sapiens on earth. Its deficiency as well as surplus both are harmful and give rise to disease like Anemia and Polycythemia respectively. It can be measured non-invasively as well as invasively. This paper presents the data acquisition through sensor system with monitoring of photoplethysmography (PPG) waves at two wavelengths for the assessment of hemoglobin concentration non-invasively. PPG signal and key variables have been obtained using LabVIEW. For compensating for the water present in the blood, wavelength selection has been done at two Isobestic point including compensation of water. Recorded data has been analyzed the relation between hemoglobin and the PPG value. This paper also focuses on the development of algorithm for the prediction of the hemoglobin non-invasively. Graphical user Interface based on LabVIEW is developed for better human-computer interaction.

Keywords:*Hemoglobin (Hb)Concentration, Anemia, Polycythemia, Invasive, Non-invasive, Isobestic Point, Photoplethysmography (PPG).*

I. INTRODUCTION

Hemoglobin (Hb) is a metalloprotein present in red blood plasma cells. It plays an important role in transporting the essential amount of oxygen through the blood. It is an iron containing protein in human body responsible for the transfer of oxygen from lungs to body tissue through blood. Hemoglobin assessment is one of the most important tests for assessing anemia, blood donors during the donor interview process and at the time of surgical operations of patient. Anemia affects around 2 billion people worldwide and has become one of the main public health problems in developing countries.

Anemia is most common complication in pediatric intensive care units (PICU) and it representsup to 74% of hospitalized patients [1]. Anemia result in blood loss due to acute traumatic hemorrhages in the postoperative period of critical patients, in particular due to cardiac or traumatological surgery, repeated blood extractions, chronic disorders, Iron and other deficiency disorders, hepatic dysfunction or disseminated intravascular coagulation, among others.Anemia also affects work capacity, immunity, accelerated/rapid heartbeat, pale skin and headache. It also +affects the fetus, that is,low birth weight, intrauterine growth retardation/delay and increased fetal and neonatal mortality [2, 3].

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WHO has shown that the incidence of iron deficiency anemia (IDA) in pregnant women is 14% in developed countries and 51% in developing countries [4]. The risk of anemia increases with respect to the time devoted to pregnancy [5].An observational prospective study was made in Spain, 2016, comparing core laboratory Hb measurement (Lab-Hb) as the gold standard versus transcutaneous hemoglobin monitoring (SpHb) to determine the accuracy and usefulness of noninvasive continuous hemoglobin (Hb) monitoring in critically ill patients at risk of bleeding, concluded that, the more serious the patient's condition, the greater the blood loss due to blood draws [6].

Therefore, the evaluation of hemoglobin is essential.Blood sampling technique can be very sore (painful) and could be cause of blood loss due to unnecessary removal of blood. Invasive technique takes time and gives delayed value of hemoglobin. Immediate approximation of hemoglobin is necessary which creates requirement of online monitoring. Hemorrhage is a major cause of preventable death secondary to traumatic injury [7, 8]. In the invasive method, blood is taken from the patient and subsequently analyzed. In addition to the discomfort of taking blood samples, a further disadvantage of this method is the delay between blood collection and analysis. That does not allow monitoring of the patient in real time in critical situations.

Bleeding is one of the main causes of preventable death to traumatic injuries. Diagnosis often requires multiple blood samples, which are psychologically stressful in pediatric patients. A non-invasive method allows continuous pain-free monitoring of the patient with the least risk of infection and replaces invasive laboratory measurements[9]. Non-invasive monitoring provides oxygen saturation for continuous and rapid evaluation. The non-invasive solution is significantly safer than the invasive method and eliminates potential contamination and biological risk. It is precise, fast and easy to use, which allows non-professional personnel to perform accurate diagnostics and allows for mobile operation in rural areas and guarantees lower costs. Near-infrared spectroscopy (NIRS) is becoming a widely used research technique to measure oxygenation in a non-invasive way in human blood [10].

This paper focuses on the development of an algorithm by which the hemoglobin can be determined using a non-invasive method. The property of absorbance of RBC and water present in the blood is used for the determination of the hemoglobin. The calculation is done at some Isobestic points of the hemoglobin concentration. Absorbance of light at 810nm and 1300nm wavelength is determined and the analysis of the absorbance with the cycle of systole and diastole of the heart is done forfinding the hemoglobin concentration in blood.

II. METHODOLOGY

Described method is based upon the dual wavelength pulse oximeter principal. Near Infrared (NIR) technology with Photoplethysmography (PPG) signals is used for analysis in dual wavelength pulse oximeter. According to the principal of pulse oximeter, light has been passed through fingertip and detector has been placed at the receiving side to receive transmitted signals from the finger for calculating oxygen saturation in the body.

SELECTION OF WAVELENGTH

According to the principal of pulse oximeter, concentration of oxygenated (HbO_2) and deoxygenated (HHb) blood values are required for estimation of oxygen saturation present in the body. Oxygen saturation is not directly proportional to the hemoglobin concentration and cannot define hemoglobin by relating with oxygen

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saturation. Therefore, thereis a need to take different wavelength values of light source from pulse oximeter. Hemoglobin concentration can be calculated at Isobestic point. Absorption coefficient of oxygenated and deoxygenated hemoglobin values are same at the Isobestic point. Two Isobestic points with absorption spectra at 810nm and 1300nm are selected as it gives a clear picture about the hemoglobin concentration.Reason behind this selection of values is one can directly relate oxygen saturation value with hemoglobin value. For the purpose of this investigation the wavelength was selected as 810 nm. Hemoglobin concentration can be measured at these Isobestic points where an equation can be derived including concentration of water According to the assumption that red blood cells are mainly filled with water, the absorption coefficient of blood is similar to a solution consisting Hb, HbO_2, and plasma and the absorption of Hb and HbO_2 is indisguisable to the absorption of water above 1200 nm. For the system to able to isolate the presence of water in the blood it is necessary to select a second wavelength in this region which is outside the traditional optical diagnostic window. Selection of 1300nm wavelength gives minimum distance between absorption coefficient of water and Isobestic point. Therefore, the measurement has been performed at 810 nm and 1300 nm.

SYSTEM DESIGN

Light emitting diodes of wavelength 810 nm and 1300 nm are used for passing light through finger. Photodiode converts the incident light into equivalent current where major factor is its responsivity in ampere/watt. Selection of photodiode depends upon the selection of the light emitting source since the peak wavelength of light emitting source should come under the range of photodiode. Placement of light emitting source and photodiode is also important because the angle of incident of light emitting source affects the output current of the photodiode. Transimpedance amplifier is a current to voltage converter used to convert output current generated by the photodiode to the voltage. This voltage can be used to extract and display key variables. These variables will be used to get hemoglobin value with the help of software based on principle of pulse oximetry.

In the first part of the experiment, finger probe is used which have two LEDs of 810nm and 1300nm at the one side of the probe and have one amplified detector at the receiving or opposite side of the detector. Light is made to pass through finger and unique PPG signals are collected by detector, which are used to calculate hemoglobin in blood.

Basic components of system design are Light Emitting Diodes, Photodiode, Transimpedance Amplifier, and Signal Processing unit using LabVIEW as shown in fig 1. LEDs and Photodiode are attached in the finger probe. Photodiode is also attached with an amplification unit using Transimpedance configuration. This unit makes an amplified photodetector section which is directly connected with personal computer to perform signal processing using LabVIEW software.

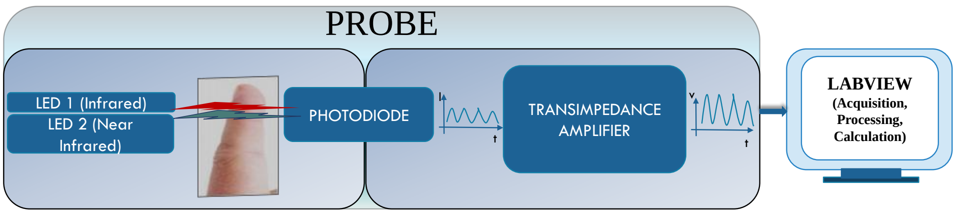

Figure 1 Block Diagram of System Design for saving and calculating the PPG signalby using finger probe in LabVIEW

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III. EXPERIMENTAL SETUP

The main aim of the work is to make an instrument to measure hemoglobin in human body noninvasively. The design of experiment includes selection of light emitting source, probe design and electronic circuit or an amplified detector that includes transimpedance amplifier and filter. Selection of light emitting source with peak wavelength is important to calculate significant parameters.

Light emitting diodes (LEDs) of peak wavelength of 810nm (Aluminum gallium arsenide) and of 1300nm (Indium gallium arsenide phosphide) are used as light source.LEDs having wavelength of 810nm and 1300nm are connected on the upper part of the probe and an amplified detector at the other opposite end. When the light is made to pass through finger with the help of two different light emitting diodes simultaneously, some light will be absorbed by the blood in tissues and some light is transmitted. Transmitted light is received by photodiode. According to the working principle of photodiode, light is converted in electrical signal. This current consists of AC as well as DC components which will create some noise in signal. The signal should be between 0.5Hz to 5Hz[11]. Therefore, amplified photodetector is used to remove DC components in signal obtained. At the end, a low pass filter is used to remove unwanted signal. Hardware Setup is shown in fig 2.

LEDs of 810nm and 1300nm are used as source in sensor. In this set up we can easily recognize signals of 810nm but it is quite difficult to see proper signal pattern of wavelength at 1300nm as IR signals penetrates more through skin so few signals can be captured. For observation of proper signals amplification is required. This difficulty has been overcome by an amplifier and filter.

Photodiode converts the incident light into equivalent current signal where the major factor is its responsivity in ampere/watt. Selection of photodiode depends upon the selection of the light emitting source. Peak wavelength of light emitting source should come under the range of photodiode. Placement of light emitting source and photodiode is also important because the angle of incidence of light from the sourceaffects the output at photodiode thus disturbing the output current from the photodiode.

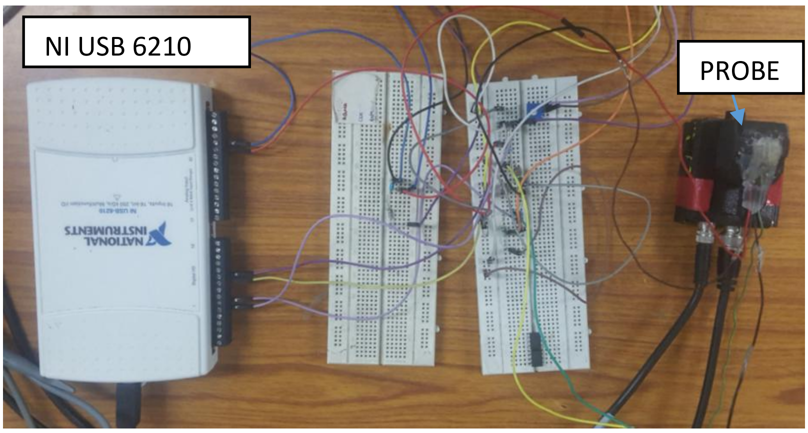

Figure 2 Hardware set up of the system

Transimpedance amplifier is a current to voltage converterwhich converts the output current generated by the photodiode to the voltage. This voltage signal can be utilizedfor extracting the essential feature of blood and display key variables. These variables are used to get hemoglobin value with the help of software program

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developed on the principle of pulse oximetry. According to proposed method, the research work can be divided into two main parts (a) the system design (b) data acquisition of signal.

IV. NON-INVASIVE HEMOGLOBIN MONITORING SYSTEM

FINGER PROBE

A finger probe is developed with two LEDs i.e. RED is of 810nm and IR is of 1300nm and also an amplified photodetector for collecting the data. With the help of this probe we can pass the light through skin and get signals for data acquisition. Placement of LEDs and photodetector are opposite to each other as shown in fig3. Finger is placed between LEDs and detector.

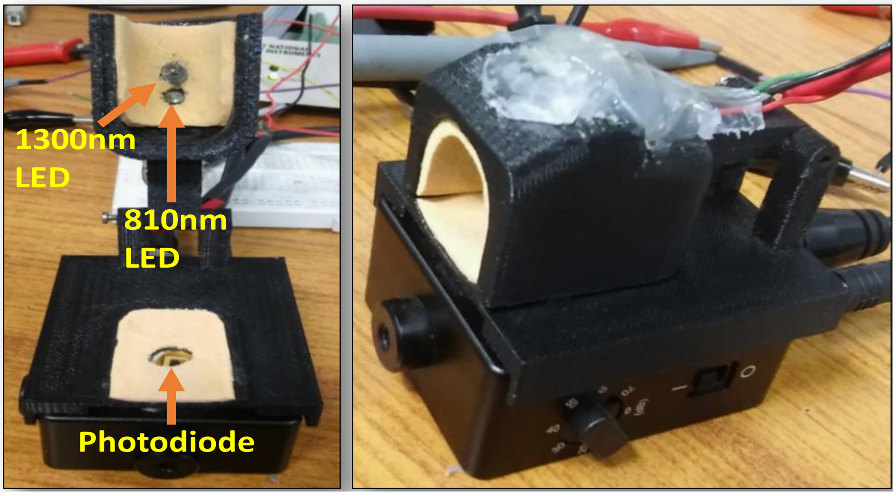

Figure 3 Finger Probe for collecting PPG signal

The circuitry of probe is shown in Fig. 4. When photodiode generates an equivalent current for incident light of LED1/LED2, the output current of the photodiode is converted into an amplified voltage level using transimpedance amplifier configuration. Amplified PPG signal is acquired and recorded with the help of LabVIEW for further processing and calculating of key parameters.

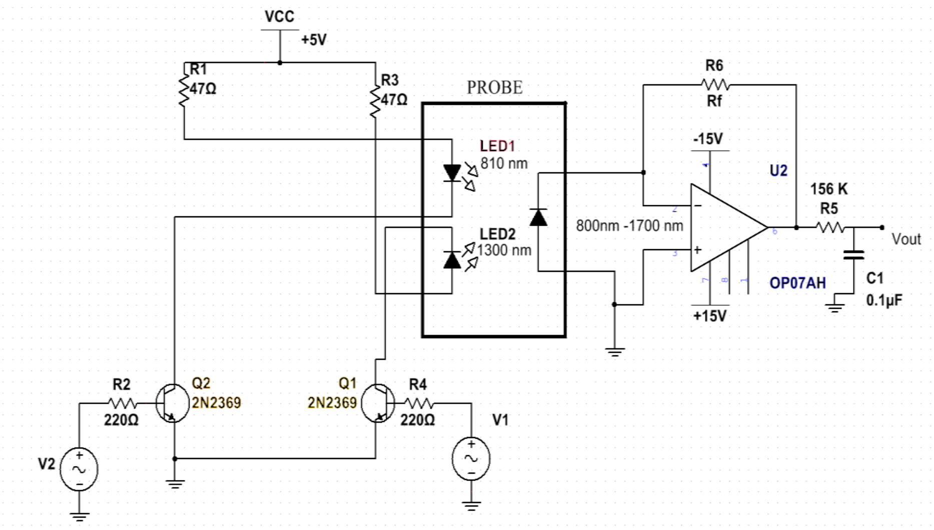

Figure 4 Schematic of Probe for Non-Invasive Hemoglobin Monitoring System

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Once the signals are obtained with respect to the wavelengths of 810 nm and 1300 nm the data acquisition has been done by software on LabVIEW through VI for acquisition and processing of data [12]. Signals coming from the amplifier are connected to NI USB-6210. The compact DAQ system is connected to a PC and signal processing and visualization of data is programmed in LabVIEW.

V. FLOWCHART TO SAVE THE DATA

Flowchart for acquiring the PPG signal, switching of LED, recording, saving and analyzing the acquired signal using LabVIEW with the help of NI USB-6210 model.

Initially, before running the program, finger is inserted into the probe. Thereafter some details of the patient are required to be filled in, that is, name, age, weight, gender and height, in the front panel of LabVIEW. After that, the recording switch mode is selected for whether the recording is fixed timed recording (FTR) or continuous recording (CR). Then the program is run. After the PPG signal is captured clearly, the recording is switched ON and respective mode of recording (FTR/CR) is saved in the Microsoft Excel file with the help of write to measurement function in LabVIEW.

In CR mode, recording is performed that is entered into the "insert time/time to record" block mentioned in front panel of LabVIEW. After saving the data for a fixed time, the recording is stopped. However, the program runs for the visualization of signal and key variablestill its execution. However, in FTR mode, recording is performed only for a fixed time. The flow for acquiring the data is shown in figure 5.

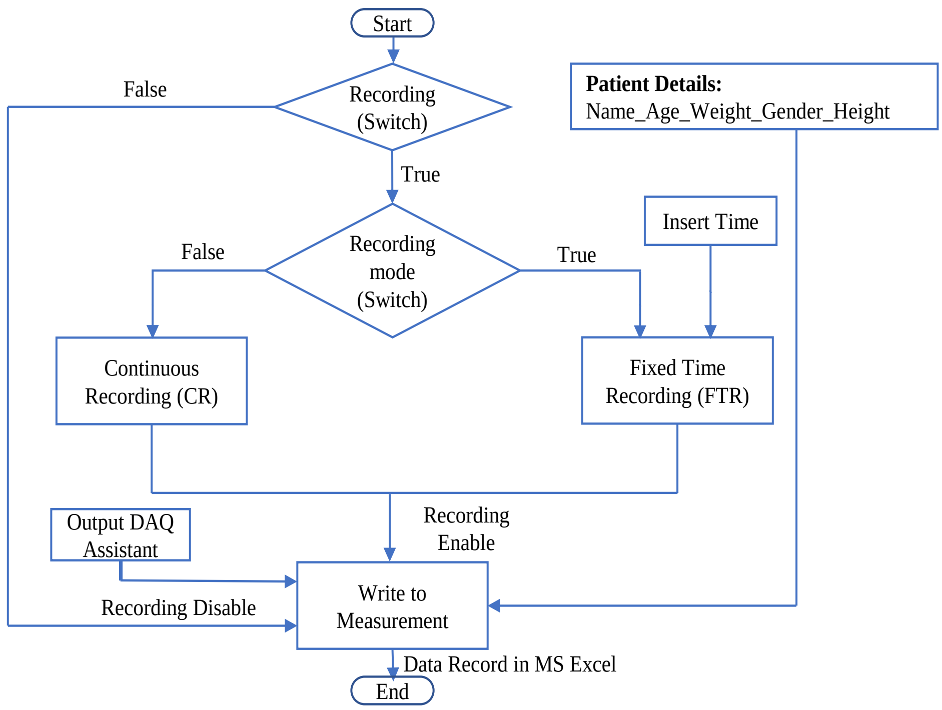

Figure 5 Flow chart for Switching, Recording and Saving the PPG Signal

VI. DATA SAVING

The data is saved in Microsoft Excel file with respect to time and voltage for selected number of samples in DAQ assistant tool with the help of Write to Measurement function in LabVIEW as shown in fig.8. For finding the accurate time in seconds for recording the data, data is taken for different time periods i.e. for 5 seconds and

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for 10 seconds. The number of average peaks vary from 4 to 6 for 5 seconds data depending upon beats per minute of a person or selected number of samples. The saved data for switching of 10 seconds time period are shown in fig.6. The number of average peaks vary from 8 to 14 for 10 seconds data depending upon beats per minute of a person or selected number of samples.

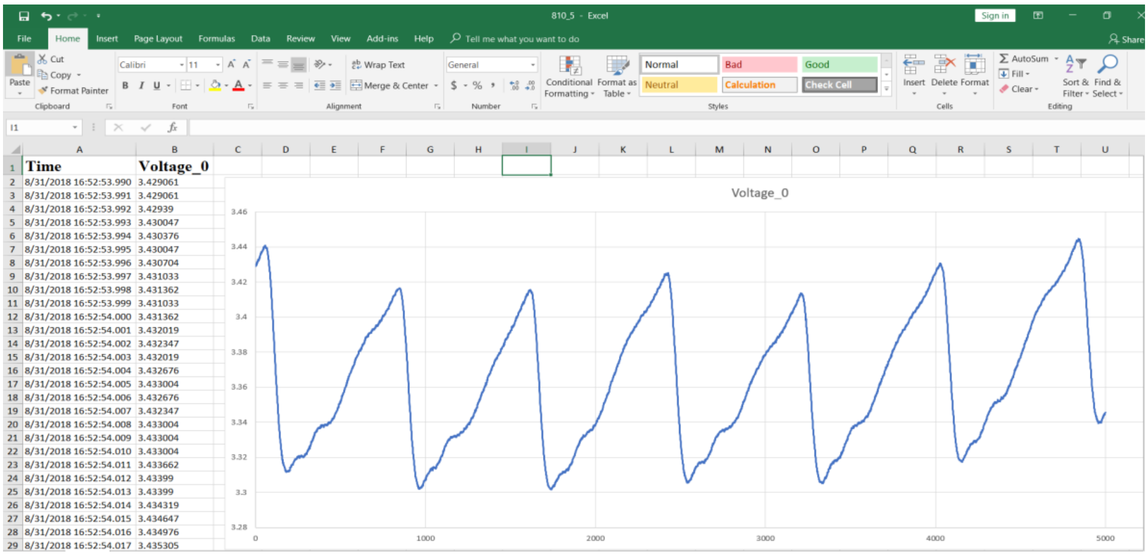
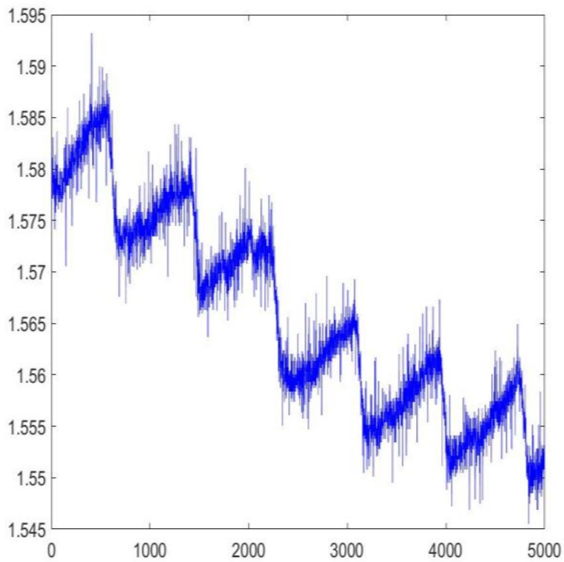


Figure 6 Saved data in Excel by switching

NOISE RDUCTION IN PPG SIGNALS

The data saved in Excel which was acquired by LabVIEW from the switching of LEDs consisted of noise. Therefore, MATLAB coding has been done as shown in fig. 7 (a) and 7 (b) for smoothing of the noisy PPG signals, so as to find out the maximum peaks and minimum peaks of the acquired PPG data. The sampling rate of the data has to be determined before filtering out the noisy signals.



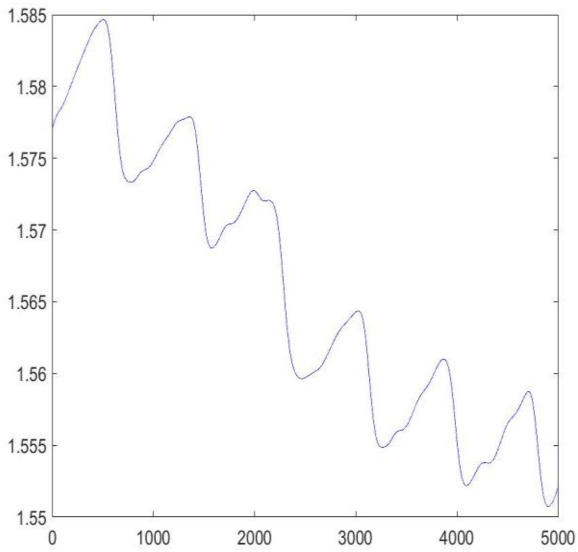


Figure 7 (a) Graph of Recorded Output Signal in Excel

Figure 7 (b) Graph of Filtered Signal

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The data from LabVIEW setup taken non-invasively by using probe setup as shown in figure 8. The data is recorded to findout the algorith to calculate the hemoglobin concentration using PPG signal non-invasively and compare the relation with the invasive technique.

Figure 8 Recording of PPG data

The Hemoglobin value measured by invasive traditional method are shown in table 1. Details of a subject as shown in table 1 are taken for hemoglobin and different parameters of a subject. The parameters like, gender,age, weight, height, blood group and birth, born and bought-up place of a patient are taken into consideration for finding out the relation between these parameters with the hemoglobin value.

Table 1 Subject's details along with invasive hemoglobin (Hb) values with sampling through technique

S. No.	Gender	Age	Weight	Height	Hb (g/dL)	Blood Group	Place
1	Female	25	63	5.1	12.8	B^+	Uttrakhand
2	Male	29	84	5.7	14.9	AB+	Darbhanga,
3	Male	21	92	5.8	17.4	-	Hyderabad
5.	Male	51	62.5	5.2	11.8	B+	-
6.	Male	23	60	5.7	17.8	O^+	-
7.	Male	24	70	5.9	13.9	O+	-
8.	Male	21	88	5.11	16.3	B+	Hyderabad
9.	Male	22	71	5.10	15.8	B+	Hyderabad
10.	Male	36	60	5.6	11.9	O+	Odisha
11.	Female	25	60	5.4	11.6	O+	Delhi
12.	Male	26	58	5.5	14.7	B+	-
13.	Male	53	65	5.5	13.1	AB^+	Uttar Pradesh
14.	Female	24	59	5.4	12.5	O+	Assam
15	Male	23	70	5.6	13.1	AB+	Mohali

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16.	Male	28	70	5.6	17.5	-	Greater Noida
17.	Male	29	79.5	5.8	16.3	O--	Chandigarh
18.	Male	36	63.4	5.9	16.5	B-	Chandigarh
19	Male	47	87	5.11	14.5	O-	Punjab
20	Female	23	61	5.6	12.7	B+	Maharashtra
21	Female	20	63	5.1	13.3	A+	Rajasthan
22	Female	26	46.1	5.6	11.5	O+	Haryana
23	Male	26	71	5.9	18.3	B+	Uttar Pradesh
24	Female	25	75	5.3	12.6	B+	Uttar Pradesh
25	Male	24	95	5.9	14.6	B+	West Bengal
26	Female	26	70	5.3	12	B+	Punjab
27	Female	23	61	5.4	10.2	O+	Maharashtra
28	Male	22	78	6	14	AB+	Maharashtra
29	Male	29	67	5.7	14.7	A+	Madhya Pradesh
30	Female	23	54	5.3	10.5	B+	Rajasthan
31	Female	23	48	5.4	12.4	AB+	Chandigarh
32	Male	27	66	5.8	17.5	O+	West Bengal
33	Male	25	82	5.85	15.6	B+	Haryana
34	Female	25	39	5	11.6	A+	Himachal
35	Male	26	72	5.7	16.8	A+	Himachal

The average hemoglobin value of the given 35 recordings is 14 g/dL (10g/dL to 18 g//dL) of 27 average age. The analysis has done for finding out the algorithm to calculate hemoglobin noninvasively and to find out the PPG-based correlation of Near-Infrared/Infrared spectroscopy for hemoglobin measurement.

VI. RESULTANALYSIS

A PPG signal recorded by LabVIEW setup is shown in fig.9. Maximum and minimum peaks of recorded PPG signal are also shown in fig.9.

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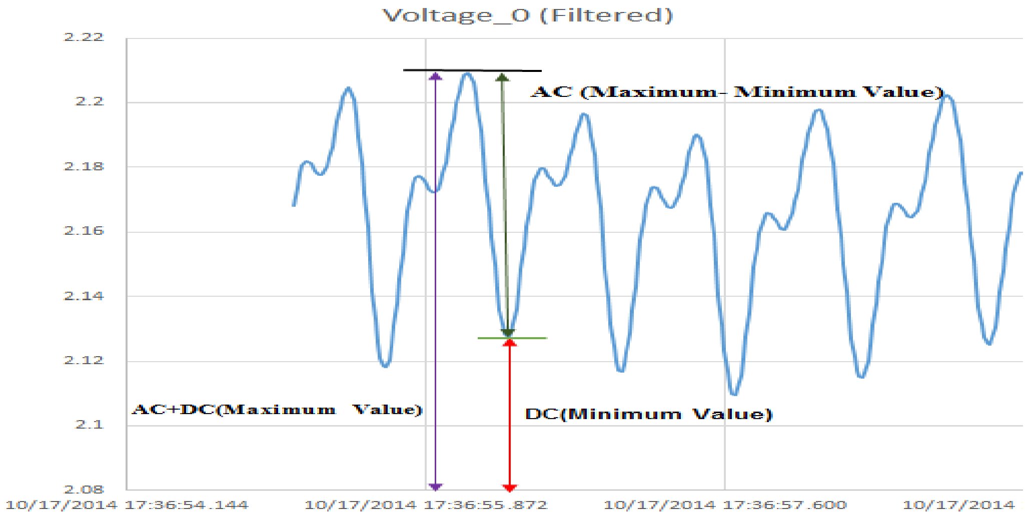

Figure 9 Typical pulse wave obtained with the Non-invasive Hemoglobin sensor system

Detailed analysis is done by using these maximum- minimum peaks as shown in fig.9 and the total absorbance values of a PPG signal.Data of different subjects are recorded. The average peaks for 10 second data are around 8 to 14 depend upon the human beats per minute (BPM) are recorded. The procedure used for manual analysing the data as described below:

Step 1: Write maximum and minimum peaks of an individual PPG signal

Step 3: a) Calculation of Average [(AC+DC)/DC] of an individual PPG signal

b) Calculation of Average (ΣAC)

c) Total Absorbance of a PPG signal

d) Calculation of Ratio of $[(AC+DC)/DC]_{810\ nm}$ and $[(AC+DC)/DC]_{1300\ nm}$

(e) Average $[(Max.-Min.)_{810\ nm} / (Max.-Min.)_{1300\ nm}]$ - First take Max.-Min. of both the LEDs and take division value of both for 810 nm and 1300 nm

(f) Ratio of Ratios = $[(I_{(AC+DC}/I_{DC})_{810\ nm} / (I_{(AC+DC}/I_{DC})_{1300\ nm}]$

According to research, the value of hemoglobin concentration can be related to the absorbance and AC-DC components of the PPG signal. Study related to absorbance of the light by blood parameters in human finger has given the relation of hemoglobin concentration. Therefore, analysis has to be done based on absorbance to find out the relation between invasively measured Hb and non-invasively measured Hb for there is no earlier research is recorded. Analysis based on absorbance has been carried out.Some analysis are done using Coding. MATLAB coding discussed below has been employed to identify the relation between recorded PPG values with invasively taken hemoglobin values and conventional method in g/dL.

CODING

MATLAB coding has been developed for analysing the recorded data in MS Excel. Before applying any coding, the values of some recording parameters are required like the number of samples, rate and recording time etc.Coding has been done for analysis purpose to find out the relation between hemoglobin (Hb) and algorithm to relate the hemoglobin value.Some MATLAB algorithms are:

1. Coding for reducing Noise

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2. DC Shift Algorithm – Algorithm to calculate mean of incoming PPG signal.
3. Algorithm to find mean of AC, DC, AC-DC with DC shift of recorded PPG signal.
4. Algorithm for calculating the mean value of maximum peaks, minimum peaks and (max-min) peaks without DC shifter.
5. Algorithm to calculate mean ratio of minimum peak and maximum peak.
6. Algorithm to calculate mean ratio of (maximum-minimum) peak and maximum peak.
7. Algorithm to calculate mean ratio of (maximum-minimum) peak and minimum peak.
8. Algorithm to calculate Root Mean square (RMS).

VII. RESULTS AND DISCUSSION

The value of Ratio of (Absorbance) $_{810\ nm}$ and (Absorbance) $_{1300\ nm}$is calculated and its relationship with Hb in g/dL is determined as shown in table 2 and in table 3.

Table 2Ratio of (Absorbance) $_{810\ nm}$ and (Absorbance) $_{1300\ nm}$for high Hb values ranges from 18 g/dL to 13 g/dL

S. No.	Hb (g/dL)	Ratio Average (Absorbance)$_{810\ nm}$ /Average(Absorbance)$_{1300\ nm}$
1	18.3	1.348969348
2	17.8	1.461864021
3	17.5	1.917963814
4	17.5	2.085639983
5	16.5	2.515095152
6	16.3	2.848848417
7	15.8	2.992871431
8	15.6	3.122605986
9	15.1	2.923045209
10	14.7	2.987541364
11	13.1	3.308521167

The relation from the table 2 is shown in figure 10 between the Hb values and and Ratio Average (Absorbance) 810 nm /Average (Absorbance) 1300 nm for Hb ranges 18 g/dL to 13 g/dL.

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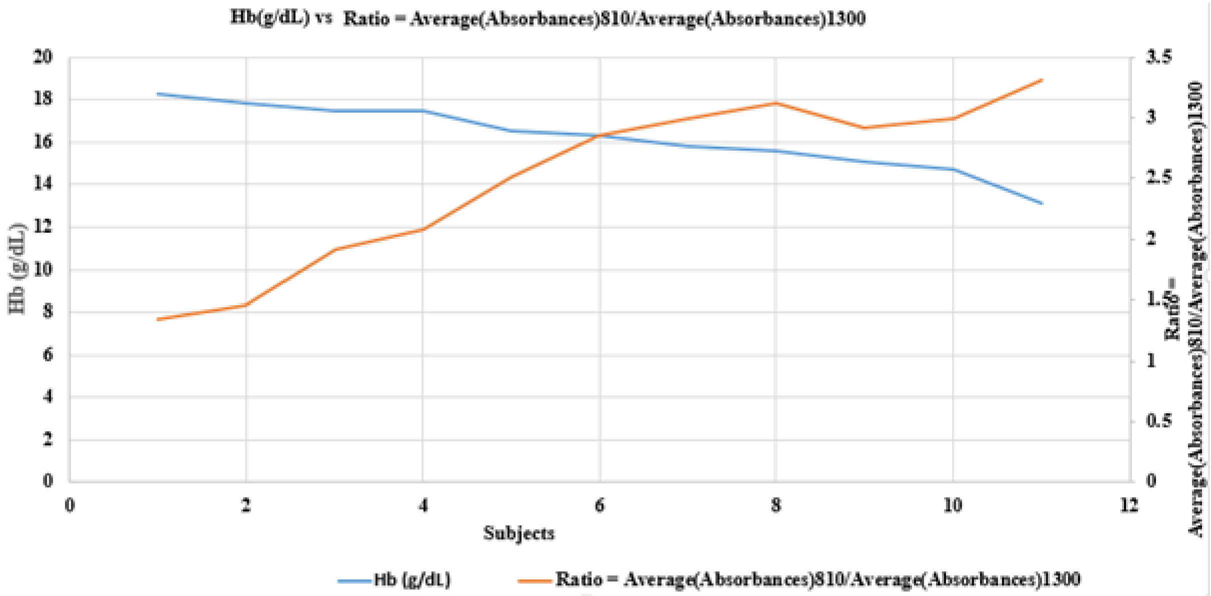

Figure 10 Hb (g/dL) vs Ratio Average (Absorbance) $_{810\ nm}$ /Average (Absorbance) $_{1300\ nm}$ for Hb ranges 18 g/dL to 13 g/dL

Fig. 10is showing an inversely proportional relationship. Thus it can be concluded that high hemoglobin range give the linear relationship. On the basis of this relationship, more data is analyzed for low Hb values as it is shows the positive relation for finding the hemoglobin value.

Table 3Ratio of (Absorbance) $_{810\ nm}$ and (Absorbance) $_{1300\ nm}$for Hb ranges from 13 g/dL to 10 g/dL

S. No.	Hb (g/dL)	Ratio Average (Absorbance)$_{810\ nm}$ /Average(Absorbance)$_{1300\ nm}$
1	13.3	1.020889268
2	12.9	1.404559638
3	12.6	1.582051483
4	12.5	1.950842848
5	12	1.565476476
6	11.6	1.821262732
7	11.5	2.321191284
8	10.5	2.390098879
9	10.2	2.076606838
10	10.2	2.076606838

The relation for the calculted values shown in table 3 is shown in figure 11. The values are calculated for hemoglobin values ranges from 13 g/dL to 10 g/dL.

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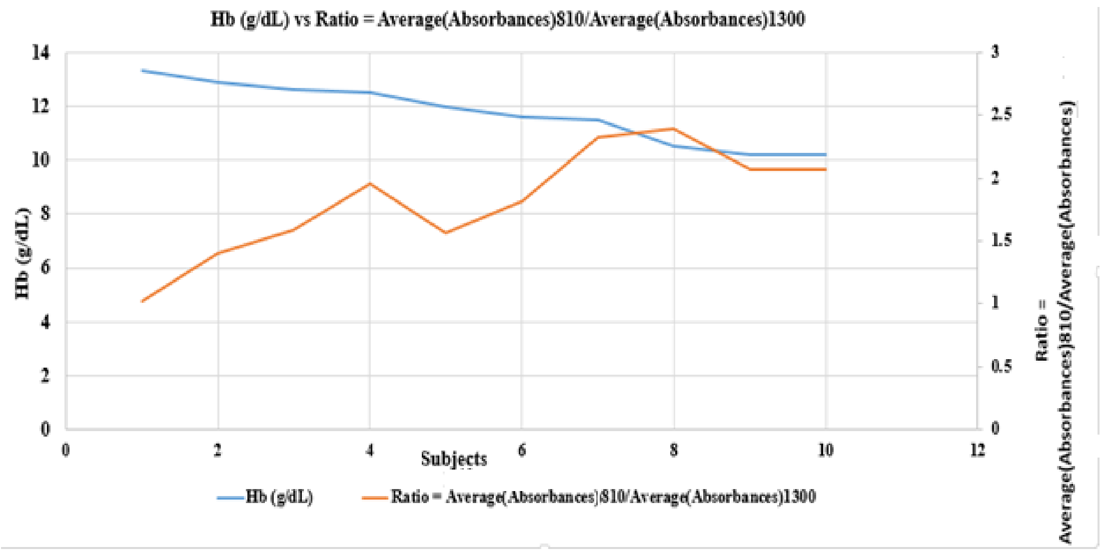

Figure 11 Hb (g/dL) vs Ratio [Average (Absorbance) $_{810\ nm}$ /Average (Absorbance) $_{1300\ nm}$]for Hb values ranges from 13 g/ dLto 10g/dL

Figure 11 is also showing the inversely proportional relation between the Hb and Ratio of (Absorbance) $_{810\ nm}$ and (Absorbance) $_{1300\ nm}$same as for high Hb values. But, the results are showing non-liner relation for the low Hb values after 11g/dL. Therefore, there is a need to research more on this given relation.

Conclusion drawn from fig. 10 and 11 shows that Hb parameter can be related through an absorbance ratio of 810 nm and 1300 nm. Under the analysis process from table 2 and table 3,it can be concluded that there is a need to study or modification in the probe or measuring method for accuracy as it is showing linear relation for high hemoglobin and non-liner relation for low hemoglobin ranges. The given relation in fig 10 and fig. 11 can be due to the gender or age factor. Therefore, more researches are required to check the relation between genders, age of a person with Hb for relating the Hb value with PPG. Mathematical analysis is done with finding ratio of 810 nm and 1300 nm for selected number of subjects which is tabulated in table 4 and relation between Hb (g/dL) and Ratio of absorbance of $(AC/DC)_{810\ nm}$and$(AC/DC)_{1300\ nm}$ is shown in fig. 12.

Ratios of AC/DC are calculated for 810 nm and 1300 nm for showing the relation with Hb g/dL which are taken from traditional methods. The calculated values for Ratio $(AC/DC)_{810\ nm}$ / $(AC/DC)_{1300\ nm}$ are shown in table 4.

Table 4 Selected data from table 6 for (AC/DC) $_{810}$/ (AC/DC) $_{1300\ nm}$

S.NO.	Hb(g/dL)	(AC/DC)810/(AC/DC)1300
1	17.8	3.228178663
2	17.5	3.110977315
3	16.3	2.310791407
4	15.6	2.403395439
5	14.6	2.241293086
6	12.5	2.166787926
7	11.9	2.158779201

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Table 4 has shown the calculated values for 7 subjects, as concluded relations from above fig 10 and in fig. 11. Which has shown linear relation for high hemoglobin values. Therefore, ratios are calculated for hemoglobin ranges from 18 g/dL to 12 g/dL. The relation for calculated values in table 4 is shown in fig. 12.

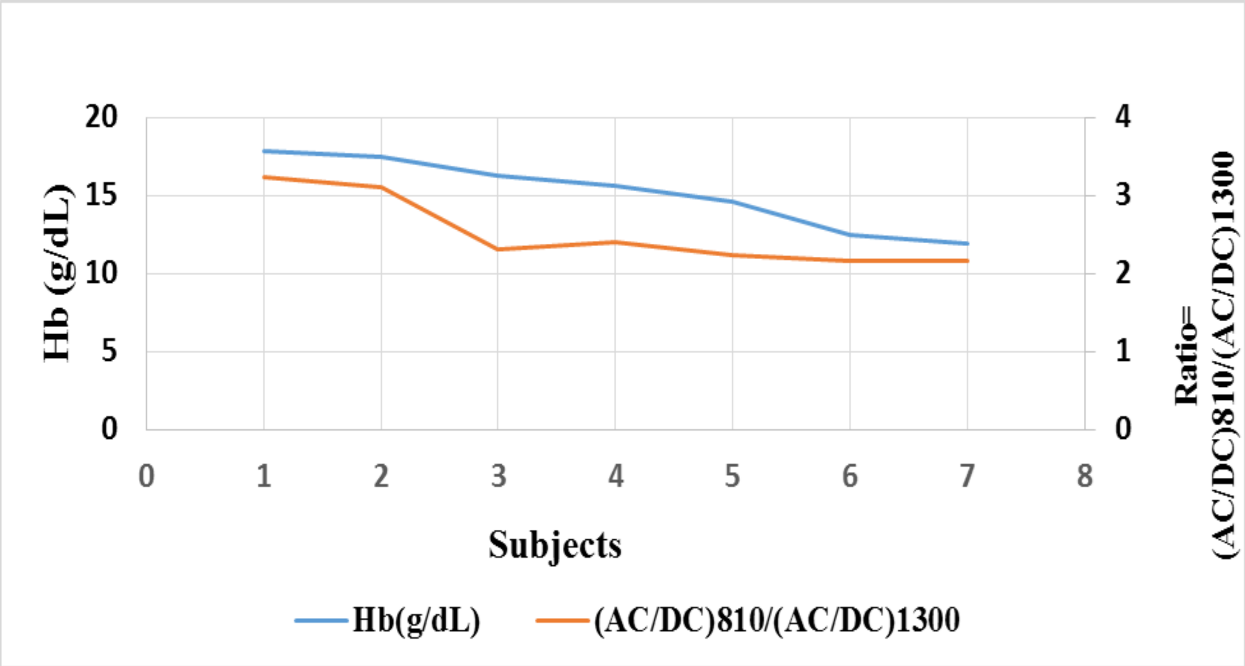

Figure 12 Hb (g/dL) vs Ratio $(AC/DC)_{810\ nm}$ / $(AC/DC)_{1300\ nm}$

Figure 12 showing the linear relation between Hb (g/dL) vs Ratio $(AC/DC)_{810\ nm}$ / $(AC/DC)_{1300\ nm}$. Thus hemoglobin values can be measure by calculating the ratio of arterial and nonartirial component through optical technique.

It can be deduced from figure 12 thatthe value at the 3rdsubject shows much difference with respect to Hb which is basically die to his old age as the age of the subject is 53. Similarly, other elder subjects has also shown much difference. Thus it can be concluded that the PPG signal or absorbance also depends upon the age and gender factor. Heart rate variability decreases with aging [13].

VIII. ANALYSIS DURING RECORDING OF PPG SIGNAL

- The amplitude of the absorbance of PPG signal depends upon the recording time for which the finger is kept in the probe.
- Placement of the finger and motion artifact causes problems while recording the PPG signal,as it adds noise to the signal. Therefore, when the PPG signal becomes stable, it should be recorded. Further refinement and modification in probe is required for signal acquisition to reduce the motion artifacts.
- With the research work, it can be deduced that 10 second recording is sufficient for analyzing the PPG signal.
- By using machine learning, such as, steepest addition methods, the relation between invasive and noninvasive hemoglobin values can be investigated further to find the correlation between the Hb values obtained through invasive and noninvasive methods.

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- Linear relationship has been found in limited range of Hb that is from 12.8 to 18.3 g/dL for wavelength of 810 nm and 1300 nm.
- Suitable pressure is required for the placement of finger on the probe for recording the uniform PPG signal. Therefore, further study is required on finding the appropriate pressure required on the finger through the probe during recording.
- It has been fouond that age factor is an important parameter for finding the hemoglobin value non-invasively. Since the heartbeat rate changes with the age.

IX. CONCLUSION

In this research work from the analysis of the results, it can be concluded that PPG based correlation of Near-Infrared/Infrared spectroscopy can be used for the measurement of hemoglobin. The hemoglobin value of a human can be measured noninvasively by computing the ration of AC and DC component of PPG signal of Near-Infrared and Infrared wavelengths. The Hb value can be related through finding the ratio of AC and DC component. However, there is a need to to determine this relation with human factors like gender, age etc. and with respect to the hemoglobin value which can be the future aspect of this research work.

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