



# Towards development of portable instantaneous smart optical device for hemoglobin detection non invasively

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## Abstract

Nowadays, large number of anaemia cases can be seen especially in women and children. It is caused due to low haemoglobin level in blood. Mostly conventional methods are used to calculate haemoglobin level. These methods involve pricking of human body with needle and sending blood sample to laboratory for further analysis which results in delay and chances of infection increases. This research work is aimed at designing a instantaneous non invasive small, portable and low cost device to determine hemoglobin value in blood which makes it completely mobile. The prototype is based on transmittance type PPG sensor having LEDs and photo detector. The developed prototype capability for hemoglobin detection is validated on 8 subjects by comparing its results with laboratory type digital calorimeter. As a result, the response of prototype has been proved with mean absolute error of 0.7 having a small bias of 0.1 g/deciliter (g/dl) with all data points lie within 95% limits. This shows good agreement and perfect correlation between developed prototype and standard instrument.

**Keywords** MATLAB · Non invasive · Pulse co-oximetry · PPG sensor

## 1 Introduction

Anaemia is caused due to low volume of red blood cells in body. It is affecting human beings worldwide in developing as well as developed countries. As per the statistics given by WHO, 60% of population in developing countries is affected by this problem. Globally 1.6 million are estimated to be suffered from anaemia. Mostly, anaemic symptoms appear in children and pregnant women [1]. Main reason of anaemia is the deficiency of nutrients in diet. Table 1 gives normal range of hemoglobin value in healthy body.

Anaemia can be measured using invasive and non-invasive methods by detecting hemoglobin (Hb) in blood. Invasive methods includes Cyanmethemoglobin, Copper

sulphate etc. and these are traditional methods used in laboratories and hospitals [3]. In these methods, expensive reagents are used for chemical processes to read out the final concentration value. To complete its process accurately, experienced technicians are required. Unlike invasive techniques, non invasive techniques role is simple to find hemoglobin level in blood and are of special interest. Big advantage of non invasive measurement is that it is painless and risks of infection are very less [4, 5].

## 2 Related work

Detecting colour of blood is the most basic invasive technique for analyzing hemoglobin in blood. Ranganathan et al. developed this technique to analyze the blood samples by applying the computational models based on neural networks [6]. In this, authors derived relationship between the colour coded values of samples and hemoglobin; measured by using cyanmethemoglobin method.

Priyanka Gupta et al. compare Hb of female subjects aged between 11 and 18 years using direct and indirect

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**Table 1** Normal range of Hemoglobin level in healthy body [2]

Normal range of hemoglobin level in healthy body in grams per deciliter (g/dL)	
Male	13.8 to 17.2
Female	12 to 15.1
Newborn	14 to 24
Infant	9.5 to 13

methods [7]. For direct measurement, blood is sampled into Drabkin's solution and in indirect method filter paper is eluted in Drabkin's solution. Then the absorptions were read at 540 nm wavelength for Hb measurements. The study reveals that a correction factor is required to estimate more accurate Hb levels successfully and to establish agreement more studies can be undertaken. Nowadays, researchers and scientists are putting their efforts to design PPG based low power, low cost optical techniques to measure hemoglobin. Using this technique D. Fricke and other researchers developed a diagnostic model of blood flow [8]. In this, authors designed human circulatory system and observed optical properties of human blood using absorption, transmission and scattering in 400–1700 nm wavelength range by online spectrometer measurements. The results were validated using Blood Gas Analyzer (BGA). Authors observed changes in the absorption levels of carboxyhemoglobin which results in false alarms in oximetry. Jae et al. studied Near Infrared Spectroscopy (NIRS) on tissues and derive extinction coefficients of hemoglobin [9]. This approach utilises 650–900 nm wavelength of NIR light to quantify concentration of hemoglobin. Authors claimed variation of 20% in hemoglobin concentration based on differences in extinction coefficient of hemoglobin.

Edward Jay et al. presented a method to measure blood hemoglobin non invasively through mobile phone

application “HemaApp” using various light sources [10]. In first experiment authors use common LED's found in smart phones and in second experiment, incandescent light source is used. Finally, in third experiment both LED's setup and incandescent light augments the smartphone. Authors estimate the blood hemoglobin level from the analysis of colour of blood by passing the light from the source through patient's finger. The device was tested on 31 patients and has yielded a correlation of 0.82 with gold standard blood test. This system lacks in validating the haemolysed and non haemolysed hemoglobin.

Pulse oximetry is the most recent commercially available technology that uses multi wavelength technology for measurement of methemoglobin, total hemoglobin, carboxyhemoglobin and blood oximetry parameters non-invasively. Wearable PPG sensors are also becoming popular for many past years. Devices designed using photoplethysmography concept are small, light weight and wearable. It consists of infra red LEDs and photo detectors to measure heart rate non invasively. This technology is reliable, low cost and very simple to develop. Toshio Tamura et al. briefly presented the past and present of wearable photoplethysmographic sensors and recent developments in this field [11]. Another researcher uses this technology to develop smart phone based heart rate and portable cuffless blood pressure measurement device for continuous monitoring [12, 13]. Srinivasam et al. diagnosed anaemia by taking pictures of thumbs. Here, authors clicked pictures of thumb with and without welling and analyze the blood colour from both pictures [14].

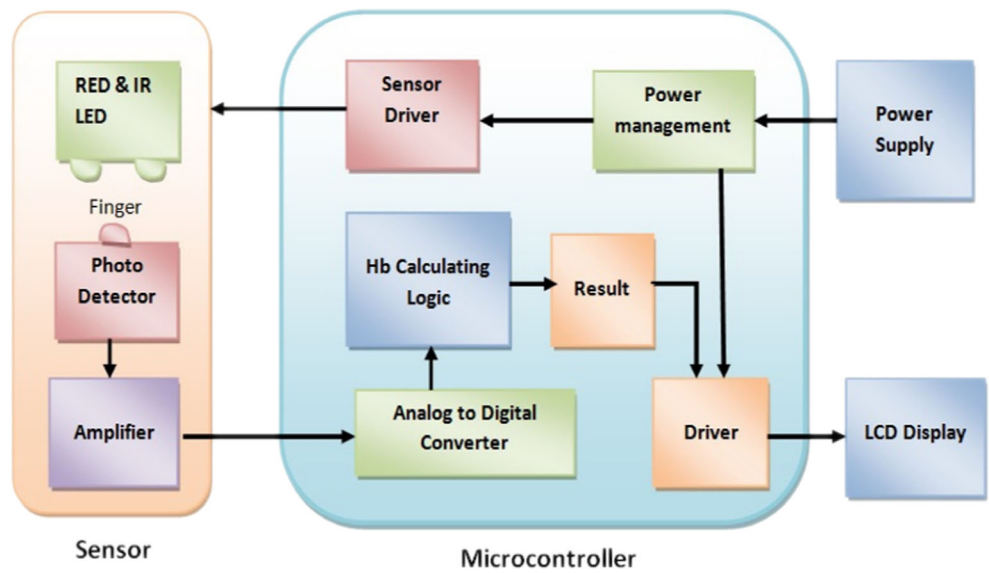
As compared to non invasive technology, invasive methods are very painful and the available invasive techniques cannot be used for designing portable systems. Table 2 gives the summary of studies by comparing non-invasive pulse co-oximeters to laboratory co-oximeters [15–20].

Probir Kumar Sarkar et al. developed point of care based Hb detection device using non contact spectroscopic

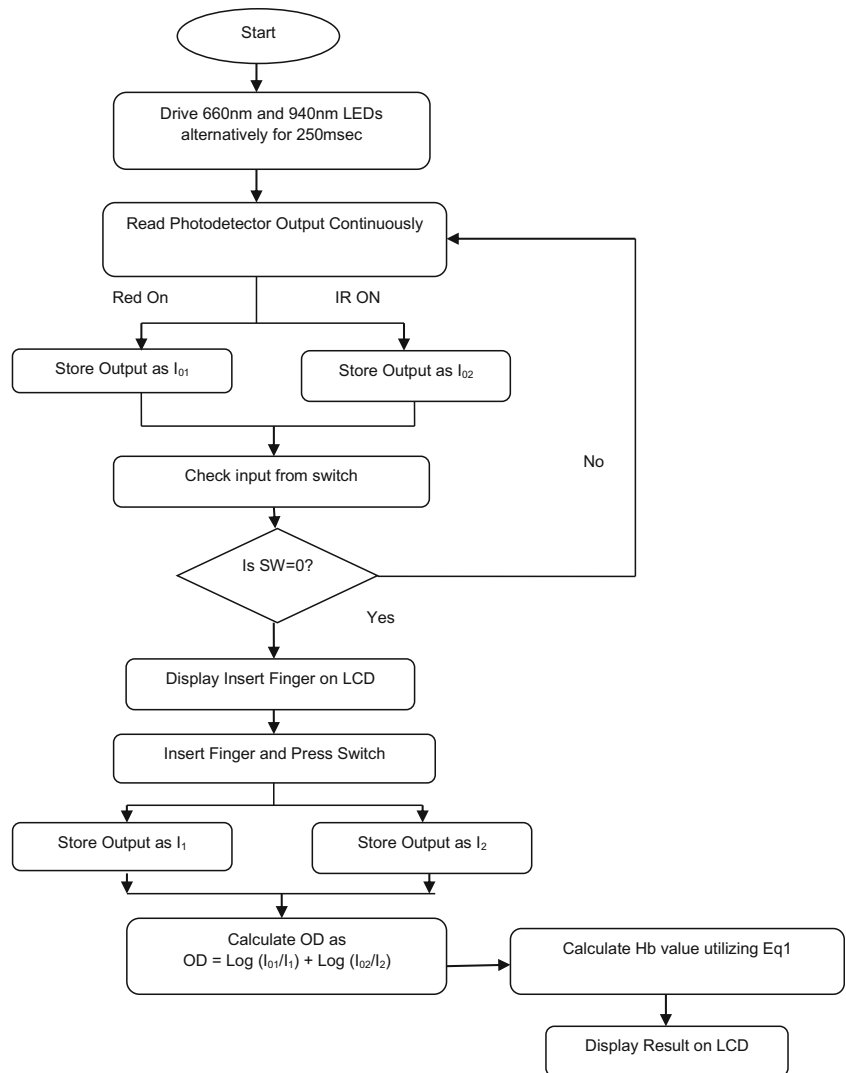
**Table 2** Summary of studies comparing noninvasive pulse co-oximeters to laboratory co-oximeters

Author	Device	Principle	Standard	Precision (g/dL)	Bias (g/dL)	Sensor placement/ Measurement location
Allard [15]	Masimo Radical	Pulse Co-oximetry	Radiometer ABL 820	0.92	−0.15	Finger
Macknet [16]	Prototype pulse Co-oximeter	Pulse Co-oximetry	Radiometer ABL 735	1.28	−0.11	Finger
Macknet [17]	Prototype Pulse Co-oximeter	Pulse Co-oximetry	Radiometer ABL 735	0.74	0.146	Finger
Torp [18]	Maximo Pulse Co-oximeter	Pulse Co-oximetry	Nova Biomedical pHox Plus	0.8	0.2	Finger
Lamhaut [19]	Masimo Radical 7	Pulse Co-oximetry	Hb Lab- unknown	1.11	0.26	Finger
Hadar [20]	NBM 200	Occlusion Spectroscopy	LH-750 Beckman coulter gold standard	0.86	0.1	Right and Left Thumb

**Fig. 1** Developed system block diagram



**Fig. 2** Flow chart of microcontroller programming



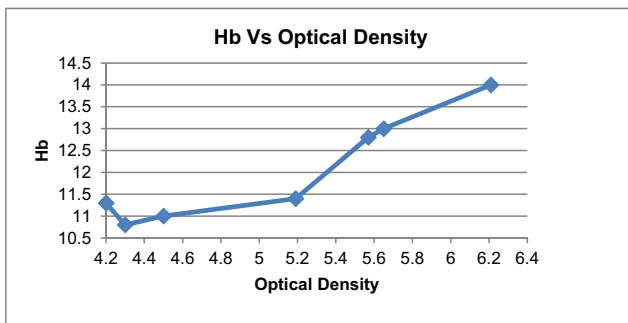


Fig. 3 Validation plot acquired using curve fit tool

technique [21]. In this device authors measure the Hb from the blood flowing in the bulbar conjunctiva of human eye vascular bed. The wavelength of spectroscopic LED's range from 430 to 700 nm and optical fibre is attached for transmission and collection of scattered light. Labview software in PC used to process the spectral response collected in spectrograph via USB connection and Hb level of patient is displayed. Since light is exposed to the conjunctiva of eye, the subject has to open the eyelids for longer time and need to blink otherwise there may be interference in scattered light which affects the Hb readings. The developed prototype is calibrated by comparing the readings with standard automated haematology analyser.

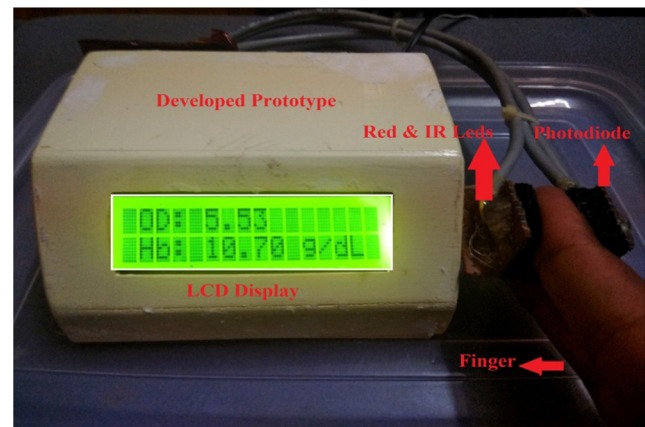


Fig. 5 Hb and optical density (OD) value displayed on developed prototype LCD

Number of other commercial devices are available for bedside monitoring in hospitals (like Radical-7, Rad-87) and for onspot applications (Rad-57, Pronto). From the above study a large discrepancy was reported between the results obtained from non-invasive measurement method and laboratory measurements. Thus there is a need to design a simple, smart, portable low cost device which can operate without need of technician.

### 3 System hardware and software description

All the commercially available devices are very costly and can only be seen in large hospitals and are not available in laboratories/homes for personal monitoring. Even today, the Hb test is performed using conventional techniques which require the pricking for blood sample. Using pulse oximetry and PPG techniques a simple, low cost, small and smart device can be designed which will not need any technician to operate. Anyone could be able to operate it anytime, anywhere and the person suffering from problem of low Hb level can check the Hb after regular intervals.

Figure 1 shows the block diagram of developed prototype hardware for hemoglobin measurement. It requires two LEDs i.e. red led of 660 nm and infrared led of 940 nm wavelength. These two wavelengths are selected because at 660 nm wavelength absorbance of deoxyhemoglobin is greater than the absorbance of oxyhemoglobin whereas at 940 nm wavelength absorbance of oxyhemoglobin greatly exceeds the absorbance of deoxyhemoglobin. Both leds are switched ON and OFF alternatively for a short interval of 250 msec through the I/O pins of microcontroller for measurements. The sensor is designed in transmittance mode with RED & IR LEDs fitted on upper part of the finger

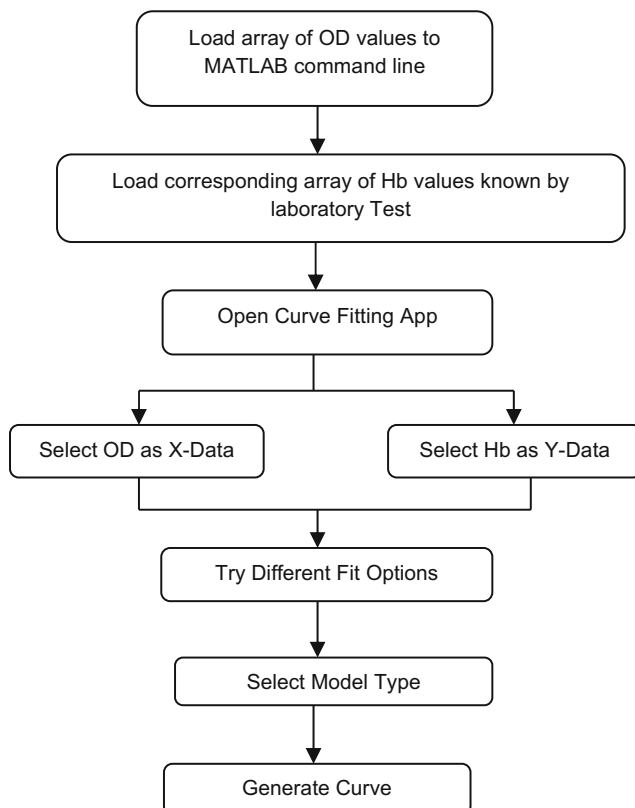


Fig. 4 Flow chart to find relationship in MATLAB

**Fig. 6** **a** Reading displayed on colorimeter **(b)** Clinical report showing Hb level



clip and photo diode (OPT101) on the lower part. The index finger is inserted into the designed probe for Hb detection process.

The light transmitted through finger fall on the photodiode and the output of the photodiode is fed to the analog pin of microcontroller (Atmega328P) for analog to digital conversion after amplification. The microcontroller is programmed as per flowchart in Fig. 2 to calculate the Hb value using the Eq. 1 and is gives as:

$$Hb = p1 * OD^3 + p2 * OD^2 + p3 * OD + p4 \tag{1}$$

Where p1, p2, p3, p4 are the constant coefficients and are given as:

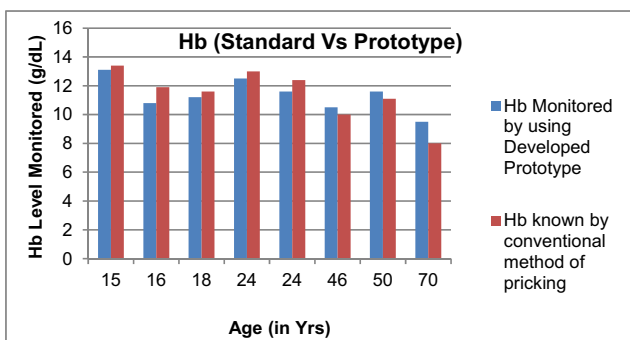
$$p1 = -1.173, p2 = 19.28, p3 = -102.8, p4 = 189.8$$

Optical Density is calculated as

$$OD = \text{Log} \left( \frac{I_{01}}{I_1} \right) + \text{Log} \left( \frac{I_{02}}{I_2} \right)$$

where,

$I_{01}$  and  $I_{02}$  is intensity of Red and IR incident light



**Fig. 7** Graphical representation of hemoglobin

$I_1$  and  $I_2$  is intensity of Red and IR transmitted light

As a standard calibration plot MATLAB curve fitting tool is used to derive the relation between the optical density and the Hb of a person by conventional method. The system is trained by taking 07 samples and a line is drawn passing through the points between optical density and Hb. The line further derives relationship between optical density and Hb and is given by Eq. 1. Figure 3 shows the validation plot obtained in curve fitting toolbox to protect against over fitting and goodness of fit. Flow chart for calculating relationship using MATLAB software curve fitting tool is shown in Fig. 4.

### 4 Experimental results

The developed prototype capability for Hb detection is validated on 8 subjects by comparing it with laboratory type digital calorimeter as standard instrument. Figure 5 shows the prototype LCD displaying Hb level determined using the developed prototype. Figure 6a shows the reading obtained while checking the Hb level and optical density of the same person in laboratory. The clinical report of the results obtained using colorimeter to determine the Hb level in laboratory is shown in Fig. 6b. In laboratory Hb is calculated using the following formula:

$$Hb = \text{Reading} * \frac{100 * 15}{36}$$

Here, Reading = 0.25

$$Hb = 0.25 * \frac{100 * 15}{36} = 10.42 \text{ gm/dl}$$

Figure 7 show the graphical representation of Hb values obtained using developed prototype and standard



**Table 3** Statistical analysis: prototype vs. standard instrument

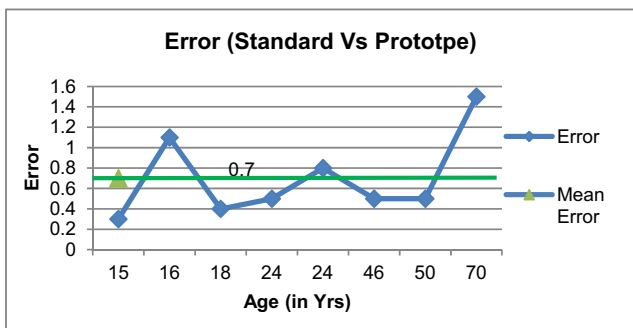
Parameter	Standard instrument		Developed prototype		Standard instrument vs developed prototype			
	Mean	Std dev	Mean	Std dev	MAPE	Coefficient of correlation	Bias	Mean absolute error
	11.42	1.75	11.35	1.13	6.65	0.914	0.1	0.7

instrument. Table 3 gives the interpretation and the statistical analysis in terms of mean, standard deviation, mean absolute percentage error, coefficient of correlation and bias. Figure 8 shows the graph plotted for error value obtained between the reading of developed prototype and actual reading known using conventional method used in laboratories. Mean absolute error value is 0.7 and is shown by a straight line in Fig. 8. It illustrates that the error obtained from individual reading is very close to the mean absolute error and the developed prototype results are very close to the standard instrument.

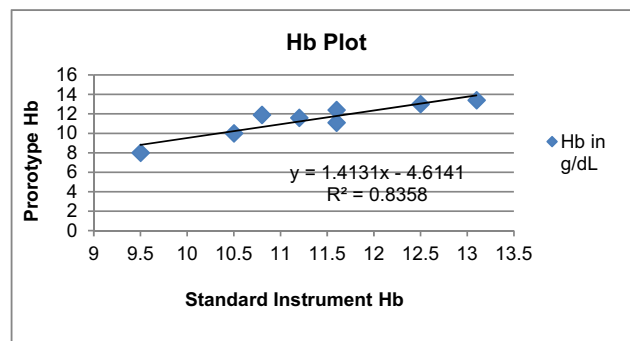
The data is further analyzed to find relation between the two Hb determination methods (non-invasive and conventional invasive method) and bias is calculated as the mean difference between both methods. The bias between the results obtained from two methods is 0.1. It shows that prototype measures 0.1 less than standard instrument in Hb level measurement which is very negligible and acceptable. Figure 9 shows the scatter plot of Hb by comparing the values obtained from developed prototype and standard instrument. Regression equation is given as  $y = 1.413x - 4.6141$  and data points in plot are very near to straight line which shows perfect correlation. R is the correlation coefficient and its value is 0.914 approaching towards one. It shows the strong relationship between both devices.

### 5 Conclusion and future scope

The developed prototype demonstrated the development of non invasive, small, simple and portable device using advanced technology for reliable measurement of Hb. It avoids the chances of arterial punctures caused due to wrong pricking and also reduces the chances of infection. This system can quickly identify the anaemia in patients required for instant clinical diagnosis anytime, anywhere. In this study, it is observed that the bias of device is 0.1 which is very less when compared to the conventional methods. It shows that 95% values of mean difference lie within  $\pm 1.96$  SD limits and has good degree of agreement with conventional method. Results obtained by developed prototype shows accuracy of 99.3% which very close to the actual Hb level determined by conventional methods in laboratories. The developed prototype show smaller deviation ( $\pm 1.03$ ) when compared to standard instrument ( $\pm 1.75$ ) and development cost of prototype is Rs. 2000/- (33\$) approximately which is also very less. The work done here can be further used for measurement of hemodynamic parameters like blood glucose monitoring non-invasively. For this a relationship need to be established between blood glucose level and the input signals. This work can



**Fig. 8** Error: Standard instrument vs prototype



**Fig. 9** Scatter plot of Hb measured with prototype and standard instrument, R: Correlation Coefficient=0.914, regression function  $y = 1.4131x - 4.6141$  for  $n = 8$

be further extended by transmitting the Hb and other parameters measured to the doctor using IoT and the device can be incorporated for significant advances in Wireless Body Area Networks (WBAN) or integrated with telemedicine monitoring systems for telehealthcare models.

### Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical approval** This article does not contain any studies with human participants or animals performed by any of the authors.

**Informed consent** Not applicable.

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