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## Non-invasive haemoglobin measurement among pregnant women using photoplethysmography and machine learning

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Abstract. Estimation of haemoglobin(Hb) using non-invasive methods has caught wide interest among researchers all over the globe. Among the various devices and methods adopted for non-invasive haemoglobin (SpHb) measurement, prediction of SpHb using PPG can provide earlier and faster diagnosis. The primary objective and motivation of this study is to assess the efficiency and effectiveness of SpHb monitoring among pregnant women using PPG and generalized linear regression technique. PPG signal was acquired from pregnant women with prior consent and Hb was predicted from the time-domain attributes of PPG. Hb value as calculated by the invasive lab methods was compared with the predicted SpHb value. The absolute bias between the SpHb predicted and Hbref was 0.73 g/dL (SD 0.62). To analyse and evaluate the performance of the proposed word, correlation coefficient between SpHb and Hb<sub>lab</sub>, was calculated using IBM SPSS software.

Keywords: Photoplethysmography, PPG, non-invasive, haemoglobin, machine learning, linear regression.

#### **1. Introduction**

Haemoglobin (Hb) measurement is one of the most frequently prescribed laboratory tests. Haemoglobin test is performed during usual physical examination or when there is a sign of RBC disorder person such as anaemia or polycythaemia [1], [2]. Hb test is usually the first and foremost test performed before any blood transfusions. Hb test is generally performed by invasive methods i.e., by drawing blood using fingerstick method followed by analysis in the laboratory. Even though, the invasive traditional method of Hb calculation is accurate and considered as the golden standard, it has its own undesirable facts such as delay in getting results, pain to the patient, possible exposure to infections and the lack of continuous monitoring in needed situations. Non-invasive Hb prediction (SpHb) can very well overcome the above said limitations to a greater extent.

SpHb monitoring has caught the interests of numerous academicians and researchers as it allows the ability to continuously visualise Hb level in an accurate, and non-invasive procedure. Followed by numerous researches and studies, many devices were developed and approved by FDA for noninvasive haemoglobin monitoring such as NBM 200, Radical Pulse CO-Oximeter by Masimo Corp. But there are varied arguments with respect to the accuracy of these devices under varied population settings, especially among pregnant women [4-6]. Several technologies and methods are used and developed by researches all over the globe for SpHb prediction and monitoring [7-15]. One such method is to measure SpHb from the statistical features of photoplethysmograph signal and machine

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learning technique [3]. The study was carried out on 33 healthy subjects using various machine learning techniques and a very good correlation was found between the Hb-laboratory value (Hb<sub>lab</sub>) and predicted Hb value (SpHb).

The main objective of the work is to evaluate the effectiveness of calculating SpHb among the pregnant women using Photoplethysmograph (PPG) and regressive machine learning technique. Previously a work was conducted by us for evaluating the effectiveness of calculating SpHb among the paediatric population using Photoplethysmograph (PPG) and regressive machine learning technique [4].

#### 2. Methodology

#### 2.1. PPG Signal Collection

The study was conducted on 47 pregnant women who are in earlier stage of their pregnancy i.e, from weeks 6 to 15. The data collection of PPG signal of Pregnant women was done in Sree Abirami Hospital (P) Ltd, Coimbatore after obtaining the ethical clearance from the hospital ethical committee . A formal consent was obtained after explaining the procedure to the subjects before data acquisition. Subjects aged between 20 to 33 years were enrolled. The subject information was recorded in a spreadsheet of MS Excel. The Plethysmograph transducer sensor and v7Labchart software of AD Instruments were used for PPG signal collection and recording.



Figure 1. Study flow

The sensor was placed as guided in the manual i.e., in the forefinger of left arm of the pregnant women. PPG signal from the subjects was acquired for a 15 period sample followed by venous blood sample collection by a trained professional. The pulse signal was recorded for a time duration of 15s from each subject. Flow of the study work is shown in Figure 1. Initially 60 pregnant women were contacted in the hospital. Out of which 47 subjects were enrolled for participation with prior consent received. It included subjects aged between 20 to 33 with a mean (m) age of 26 and standard deviation (SD) of 3.7. The remaining 13 subjects were excluded due to lack of co-operation and inability to receive proper PPG signal.

#### 2.2. SpHb calculation

The pulse signal was acquired using v7Labchart and their information was recorded in an excelsheet containing subject data. Along with original signal, derivatives of signal were also recorded in the Labchart software, which were exported to MATLAB for further processing and analysis. Although the signals obtained using Powerlab kit are mostly clean i.e., without baseline wandering and added noise, denoising using wavelets was performed to eliminate the other insignificant noises. Seven time-domain attributes as featured in [3] were found from the PPG signal and its derivatives. The selected attributes were trained using curve fitting tool in MATLAB. The selected seven features of PPG signal were given as input to the regression model with Hb<sub>lab</sub> as target output. Linear model type as used in [3] was incorporated. The SpHb values predicted using the linear regression model and its

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corresponding  $Hb_{lab}$  were taken for subsequent study analysis. For the statistical understanding, Bland-Altman diagram,  $R^2$  analysis, t-test, dispersion diagram, and various linear and non-linear correlation coefficient were calculated and performed on IBM SPSS package. Figure 2. depicts the block diagram of the work performed in the study.



Figure 2.Block diagram of the work

#### 3. Results and discussion

After obtaining initial consent, 47 pregnant women were participated which includes pregnant women in week 6 to week 16. Mean age of female subjects was 26 varying from 20 to 33 with standard deviation (Std.Dev) of 3.7. The average Hb<sub>lab</sub> obtained was 12.6 g/dL varying from 11 to 14 g/dL with Std.Dev of 0.89. The average SpHb obtained was 12.93 g/dL varying from 10.3 to 13.4 g/dL with Std.Dev of 1.33. The Hb<sub>lab</sub> calculated and the predicted SpHb levels are given in Table 1.

Subject	Age	Weeks	Hb <sub>lab</sub> (g/dL)	SpHb (g/dL)	Hb <sub>bias</sub> (g/dL)	Absolute Error (g/dL)	Squared Error
1	26	6	12.5	14.1	1.6	1.6	2.56
2	30	9	13.1	13.6	0.5	0.5	0.25
3	27	13	11.1	11.3	0.2	0.2	0.04
4	20	6	11.7	10.4	-1.3	1.3	1.69
5	28	11	11.5	11.9	0.4	0.4	0.16
6	33	8	12.1	13.3	1.2	1.2	1.44
7	25	16	13.7	13.3	-0.4	0.4	0.16
8	32	12	13.1	14.2	1.1	1.1	1.21
9	25	10	13.3	14.9	1.6	1.6	2.56
10	21	7	13.6	15.7	2.1	2.1	4.41
11	22	13	13.5	13.2	-0.3	0.3	0.09
12	24	13	13.6	13.7	0.1	0.1	0.01
13	24	12	14	14	0	0	0
14	32	14	13.7	13.9	0.2	0.2	0.04
15	23	10	11.2	11.3	0.1	0.1	0.01
16	27	6	12.5	12	-0.5	0.5	0.25
17	24	12	11.4	12.2	0.8	0.8	0.64
18	20	15	13	13.9	0.9	0.9	0.81
19	25	13	12.5	12.9	0.4	0.4	0.16
20	29	7	14	14	0	0	0
21	28	7	12.9	13.1	0.2	0.2	0.04
22	26	13	13.2	12.8	-0.4	0.4	0.16
23	32	12	12.2	12.8	0.6	0.6	0.36
24	31	10	11	10.3	-0.7	0.7	0.49
25	24	8	13.6	15.4	1.8	1.8	3.24
26	28	13	12.6	10.6	-2	2	4
27	29	11	11.3	12.3	1	1	1
28	21	12	12	12.6	0.6	0.6	0.36
29	22	8	12.9	123	-0.6	0.6	0.36

Table 1. Hblab recorded Vs Predicted SpHb

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Subject	Age	Weeks	Hb <sub>lab</sub> (g/dL)	SpHb (g/dL)	Hb <sub>bias</sub> (g/dL)	Absolute Error (g/dL)	Squared Error
30	21	7	13.1	14.7	1.6	1.6	2.56
31	23	16	11.4	11.9	0.5	0.5	0.25
32	24	10	12.5	12.2	-0.3	0.3	0.09
33	27	15	13.8	14.7	0.9	0.9	0.81
34	22	13	13.4	13.4	0	0	0
35	26	14	12.2	11.8	-0.4	0.4	0.16
36	33	12	11.8	11.8	0	0	0
37	20	7	12.1	12.2	0.1	0.1	0.01
38	22	11	14	13.4	-0.6	0.6	0.36
39	24	8	11.7	13	1.3	1.3	1.69
40	26	10	11.6	11.8	0.2	0.2	0.04
41	28	15	12.2	12.7	0.5	0.5	0.25
42	29	14	11.4	10.9	-0.5	0.5	0.25
43	24	7	13.1	15	1.9	1.9	3.61
44	23	16	13.5	13.5	0	0	0
45	22	15	13	11.2	-1.8	1.8	3.24
46	29	14	13	14.6	1.6	1.6	2.56
47	23	9	12.5	12.9	0.4	0.4	0.16

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For evaluating the performance, Mean Abs. Error (MAE), Mean Squared Error (MSE), Root Mean Squared Error (RMSE) were calculated as given in the following formula. In the given mathematical formula, Bj depicts the Hb<sub>lab</sub> level and  $B_j$  depicts the predicted SpHb level.

$$MAE = \frac{1}{n} \sum_{j=1}^{n} |B_j - B'_j|$$
$$MSE = \frac{1}{n} \sum_{j=1}^{n} (B_j - B'_j)^2$$
$$RMSE = \sqrt{MSE}$$

MAE, MSE and RMSE value of 0.73 g/dL, 0.91 g/dL and 0.95 g/dL was found between Hb<sub>lab</sub> and SpHb prediction.  $R^2$  value of 0.534 was shown alongside Pearson correlation coefficient of 0.731, Kendall's correlation coefficient of 0.56 and Spearman's correlation coefficient of 0.757. Dispersion plot with  $R^2$  is plotted in Figure 3. Poor correlation coefficient value between SpHb and Hb<sub>lab</sub> is observed implying unsatisfactory SpHb prediction.



Figure 3. Dispersion diagram

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The above Figure 3 depicts the dispersion diagram drawn between SpHb and Hblab. A regression value of 0.534 was obtained which shows quite unsatisfactory results on prediction of SpHb among pregnant women.

One sample t-test is performed with a desired fact that all the SpHb predictions were similar to Hblab i.e., by assuming null-hypothesis which calculated the confidence interval which is tabulated in Table 2.

Table 2.	One	Sample	t-test
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Testvalue = 0							
	t-static	Degree of freedom Sig Difference(Mean) 95% Confidence Interval			lence Interval		
					Lower	Upper	
Hb <sub>bias</sub>	2.28	46	0.03	0.3	0.011	0.028	

To analyse the similarity and correlation between  $Hb_{lab}$  and SpHb, Bland-Altman analysis was done with average of Hb levels on x-coordinate and Hb<sub>bias</sub> on y-coordinate as shown in Figure 4.



Figure 4. Bland altman plot

To analyse whether the predicted level of SpHb fits within the expected agreeable boundary, the upper (ULA) and lower limit of agreement (LLA) is plotted which are calculated as follows.

 $ULA = Mean Hb_{bias} + (1.96*Std.Dev of Hb_{bias})$ 

$$LLA = Mean Hb_{bias} - (1.96*Std.Dev of Hb_{bias})$$

The bland-altman plot is shown in figure for which the ULA and LLA is 1.47 and -2.09 respectively which indicates the 95% confidence limits. It can be observed that majority of the Hbdata points are caved towards the average bias line of -0.31.

#### 4. Conclusion

Coefficient of Determination  $R^2$  value of 0.53 shows quite satisfactory Hb with average bias of - 0.31g/dL. However, proposed study was conducted on pregnant women who are in their early stage of pregnancy. One limitation of the study is that it did not include any anaemic subjects. The smallest accounted Hb value in the work is 11 g/dL. So, it can be concluded that Hb prediction using plethysmograph and generalised linear regression indicates satisfactory similarity for hemoglobin levels higher than 10 g/dL. Better feature optimization for pregnant population might decrease the difference between predicted SpHb and actual Hb<sub>lab</sub>. Further investigation of the method for anaemic population is needed for further validation of the method with a larger database.

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