# Digital WHO Hemoglobin Color Scale: Analysis and Performance

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***Abstract*—Anemia is a public health problem that affects populations in both rich and poor countries. The World Health Organization recommends hemoglobin (Hb) color scale (HCS) to estimate the level of Hb in low resource settings where lab facilities are not available. Our aim is to investigate if the subjectivity associated with the use of HCS in estimating Hb level can be reduced by image processing techniques. It is proposed to take an image of a drop of blood under controlled conditions and then estimate the Hb value of the blood using an image processing algorithm trained on HCS. In the first part of the paper, the protocol for taking the images by a camera is standardized and established. In the second part of the paper, on a set of 20 healthy volunteers, the Hb value of their blood is estimated by the proposed method and compared with their reference Hb value. The correlation between the estimated Hb values and reference Hb values is 0.8. This result on a small dataset is encouraging and shows that color image analysis of blood can be used to estimate Hb.**

***Keywords - hemoglobin estimation; color image analysis; WHO HCS; nearest neighbor.***

## I. INTRODUCTION

Anemia is a condition characterized by inadequate red blood cell volume and a low concentration of hemoglobin (Hb) in the blood. Anemia, which has multiple causes, such as iron deficiency, chronic blood loss, and hemolysis, is a prevalent health problem affecting an estimated 2 billion people, or approximately 30% of the world's population. The most common cause of anemia worldwide is iron deficiency, which is often exacerbated by parasitic infections [1].

In most developing countries, anemia in pregnancy makes a very high contribution to maternal mortality and morbidity. An Hb concentration of < 11.0 g/dl is commonly taken as an indication of anemia in pregnancy. Successful management of anemia in pregnancy depends on accurate and acceptable methods of detecting anemia, assessing its severity and monitoring response to treatment. In pregnant women with mild-to-moderate anemia, timely treatment is likely to prevent the development of more severe anemia and thus reducing the need for blood transfusion which has its own associated risks. Moreover, prevention of severe anemia has direct benefits for both mother and child [2].

A few of the adverse effects of anemia in pregnant women include substantial reduced working capacity, increased susceptibility to infections and prolonged recovery, cardiac complication, respiratory complications, premature births, still births, low birth weight babies and high perinatal mortality. Anemia in children leads to reduced exercise capability, slower growth, impaired neurological and cognitive development, delayed wound healing and increased risk of dying [3].

In absence of lab facilities in a clinical setup, following are the two most common methods for Hb estimation: a) for invasive Hb estimation, the World Health Organization (WHO) Hemoglobin Color Scale (HCS) is a standard tool recommended by the WHO to estimate Hb [4], and b)for the non-invasive Hb estimation, clinicians usually examine the pallor to categorize the level of anemia into three broad categories, viz, mild, moderate and severe [5]. Both approaches require prior training, and suffer from subjectivity associated with the estimation.

Color analysis by digital photography of blood for estimating Hb value has been tried before. Ranganathan and Gunasekaran [6] used a sample of blood, then smeared it on a glass plate to prepare a slide and used color analysis to estimate Hb value using artificial neural networks. They used a standard method designed by them to capture the smeared images. AlZahir and Donker [7] used a novel regression based model for detecting anemia using color microscopic blood images and showed good results in classification of anemia but did not estimate Hb. In this paper, we have extensively studied the behavior of WHOHCS and tried to come up with an algorithm to estimate Hb based on the digital photograph of WHO HCS.

The rest of the paper is organized as follows: In Section II, the WHO HCS and its usage is described. The basic characteristics of HCS when digitized by taking a digital photograph are explained in Section III. The important protocols for taking an image of HCS and a blood sample are established through experimental analysis in Section IV. In Section V, the database and the results of Hb estimation (by the proposed method) on a set of 20 volunteers are discussed. The conclusions of this study, its limitations and the future directions are discussed in Section VI.

## II. WHO HCS

WHO's HCS is a simple and effective medical device for accurate estimation of hemoglobin levels at 4, 6, 8, 10, 12 and 14 g/dl, respectively (Figure 1). WHO HCS has already been validated in a few studies [8][9][10]. The device is simple to use, and the usage process is as follows:

 

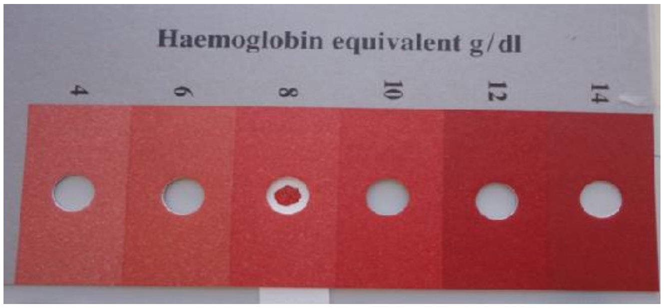


Figure 1. Camera photograph of WHO HCS with blood sample.

- Place a drop of blood on the test strip provided.
- Wait for about 30 seconds.
- Immediately match the color of the stain against all the hues on the scale. The closest match is estimated as the Hb value of the blood.

As shown in Table I, this estimation process indicates whether the patient is anemic, and if so, the severity of anemia in clinical terms. This method of estimating Hb value cannot track minor changes in Hb during treatment, but rather assist in the management of any patient with suspected anemia, for example, to decide whether a patient may require a blood transfusion, a blood count, be referred for laboratory tests or to a hospital or clinic for treatment.

TABLE I. WHO HCS IN CLINICAL TERMS.

| **Severity of anemia in clinical terms by WHO HCS** | |
|---|---|
| ***Hb value (gm/dl)*** | ***Severity of anemia*** |
| 14 | Healthy |
| 12 or more | Not anemic |
| 8-11 | Mild to moderate anemia |
| 6-7 | Marked anemia |
| 4-5 | Severe anemia |
| Less than 4 | Critical |

In this paper, we have made an attempt to digitize the WHO HCS, and used it with a digital photograph of a drop of blood to estimate the Hb value of the blood using an image processing algorithm.

## III. CHARACTERISTICS OF HCS

Each Hb level image from a scanned image of WHO HCS was cropped to understand whether the clusters of each Hb value are distinct and can be used for predicting the Hb value (of the blood) from an image of a drop of blood taken by a camera.

Figure 2 reveals that Red is most discriminatory at higher Hb levels (14 and 12) whereas Green does a better job in distinguishing lower Hb levels. The histograms of Blue are similar to that of the Green but are less discriminating. RGB color space was considered for image analysis. We also tried HSI (Hue, Saturation, Intensity), YCbCr (Y is luma component, Cb and Cr are the blue-difference and red-difference chroma components), Lab (L is lightness, a and b are the color opponent dimensions) and I1I2I3 (Ohta's color space) color spaces [11] for initial analysis and found that RGB color space gives monotonicity in the Hb levels of WHO HCS. The RGB cube of a scanned image of the HCS is shown in Figure 3. It is clear from the figure that each Hb level forms a distinct cluster and the clusters are orderly arranged such that monotonicity is maintained, that is, clusters of 4, 6, 8, 10, 12 and 14 are arranged such that cluster of 4 is followed by 6, 6 is followed by 8, and so on in the RGB space. The aim was to compute the Euclidean distance between the cluster of blood and cluster of each Hb value, with the assumption that the nearest cluster would be closest to the actual Hb value of the blood.

In the subsequent experiments, we found out that the following factors are responsible for displacement of the clusters obtained from WHO HCS.

- Distance: With the variation of distance between the camera and the HCS, the clusters move such that the monotonicity gets disturbed.
- Resolution: The change in the resolution of the camera from 2 Megapixel (MP) to 14 MP also changes the placement of the clusters.
- Illumination: The monotonicity is disturbed with the variation in illumination.
- Angle: The angle at which the photograph is taken also changes the distance between each cluster and the monotonicity of clusters.

## IV. STANDARDISATION OF PROTOCOL

After conducting various experiments with the HCS, we designed a standard protocol where the factors responsible for the movement of the clusters mentioned above are controlled to an extent. We have tried to come up with a standard where the inter cluster distance (ICD) is high and the monotonicity between the different clusters of HCS is maintained.

### *A. Effect of distance between HCS and camera and resolution of the camera*

Images of the HCS were captured from 10 cm, 20 cm, and 30 cm and at a distance from where the camera screen is spanned by the preview of the HCS (approximately 7.5 cm). The megapixels settings of the camera were 2 MP and 5 MP. All the images were captured in natural light. The clusters are plotted in RGB color space (Figure 3) and mean to mean ICD is calculated (Table II). It is observed that the distance of the camera for a linear distribution of the clusters of Hb values should be less than 10 cm. Even at 10 cm, camera with 2 MP fails to maintain the linearity of clusters whereas 5 MP camera just about maintains the linearity with the ICD between Hb values of 8 and 10 being very small. Therefore, a good setting would be a camera distance of around 7.5 cm and the camera's megapixel setting of 5 MP where linearity is maintained and ICD is high.

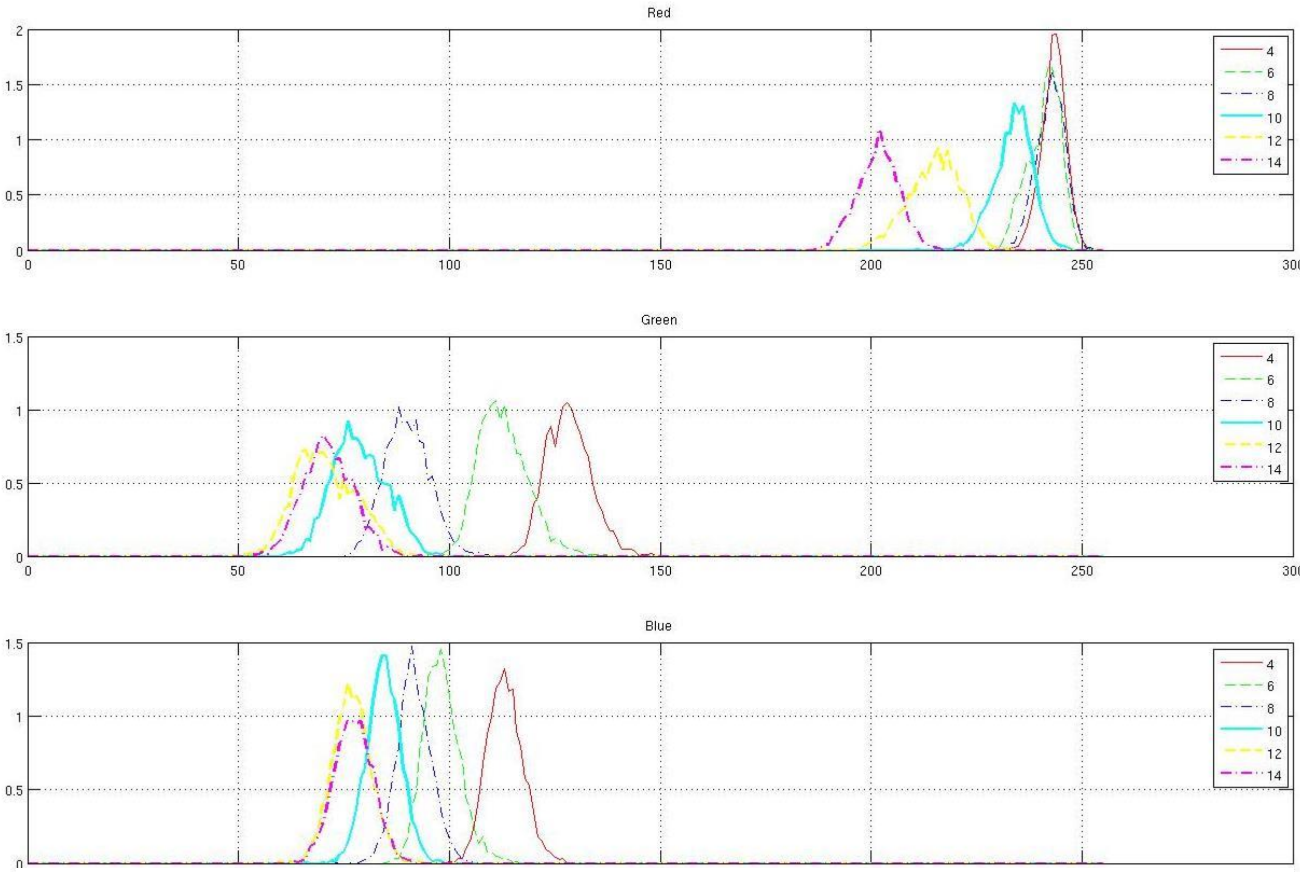


Figure 2. Histogram of RGB features for different values of Hb from HCS.

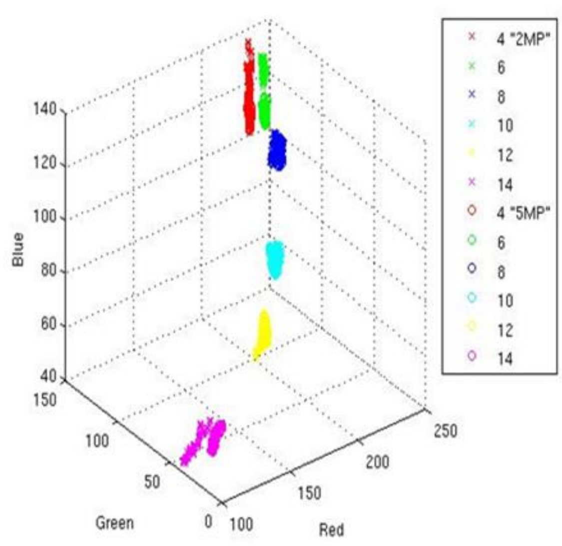


Figure 3. Distance between the camera and the HCS is approximately 7.5 cm (camera screen spans the preview of the HCS). Camera's MP settings are 2 MP and 5 MP.

### B. *Effect of Illumination*

In the following experiments, images of HCS were captured by the camera placed at a distance of 7.5 cm and the camera's megapixel setting at 5 MP. All the images were captured in natural light. When taking the photograph, the lux value near the scale was measured. It needs to be noted that it is an adhoc setting where the lux value was not controlled, that is, whatever value was there, it was just recorded. The clusters were plotted in RGB color space and mean to mean ICD is calculated (Table III). Detailed experimentation for different types of light under controlled condition was not conducted. The experiments revealed that in low light conditions (low lux value), the clusters of different Hb values overlap.

Moreover, in low light conditions, the clusters are not ordered according to their Hb values. For example, cluster of Hb value 14 is between the clusters of Hb value 4 and 6. Similarly, the cluster of Hb value 12 is between clusters of Hb value 6 and 8. This change in cluster position is highly undesirable for Hb estimation using WHO HCS. Illumination above 500 lux in natural outdoor light gave high ICD between the clusters of different Hb values of the HCS.

TABLE II. ICD WITH VARIATION IN CAMERA SETTINGS.

| ICD | Resolution – 2 MP and Distance - 7.5 cm | | | | | |
|---|---|---|---|---|---|---|
| | *4* | *6* | *8* | *10* | *12* | *14* |
| *4* | 0 | 11.43 | 31.79 | 75.16 | 111.79 | 170.09 |
| *6* | 11.43 | 0 | 34.45 | 79.35 | 117.51 | 177.98 |
| *8* | 31.79 | 34.45 | 0 | 45.04 | 83.86 | 147.07 |
| *10* | 75.16 | 79.35 | 45.04 | 0 | 40.04 | 107.24 |
| *12* | 111.79 | 117.51 | 83.86 | 40.04 | 0 | 69.09 |
| *14* | 170.09 | 177.98 | 147.07 | 107.24 | 69.09 | 0 |
| **ICD** | **Resolution – 2 MP and Distance – 10 cm** | | | | | |
| | *4* | *6* | *8* | *10* | *12* | *14* |
| *4* | 0 | 62.43 | 131.54 | 119.55 | 165.54 | 204.95 |
| *6* | 62.43 | 0 | 69.63[a] | 58.77 | 104.19 | 146.46 |
| *8* | 131.54 | 69.63 | 0 | 16.95 | 38.43 | 88.92 |
| *10* | 119.55 | 58.77 | 16.95 | 0 | 54.88 | 105.69 |
| *12* | 165.54 | 104.19 | 38.43 | 54.88 | 0 | 52.37 |
| *14* | 204.95 | 146.46 | 88.92 | 105.69 | 52.37 | 0 |
| **ICD** | **Resolution – 2 MP and Distance – 20 cm** | | | | | |
| | *4* | *6* | *8* | *10* | *12* | *14* |
| *4* | 0 | 41.49 | 112.31 | 109.2 | 138.98 | 139.9 |
| *6* | 41.49 | 0 | 72.02 | 68.82 | 99.47 | 102.09 |
| *8* | 112.31 | 72.02 | 0 | 6.19 | 28.04 | 34.61 |
| *10* | 109.2 | 68.82 | 6.19 | 0 | 31.83 | 38.77 |
| *12* | 138.98 | 99.47 | 28.04 | 31.83 | 0 | 14.1 |
| *14* | 139.9 | 102.09 | 34.61 | 38.77 | 14.1 | 0 |
| **ICD** | **Resolution – 5 MP and Distance - 7.5 cm** | | | | | |
| | *4* | *6* | *8* | *10* | *12* | *14* |
| *4* | 0 | 27.49 | 54.57 | 87.41 | 134.85 | 151.21 |
| *6* | 27.49 | 0 | 27.42 | 60.20 | 108.21 | 125.04 |
| *8* | 54.57 | 27.42 | 0 | 33.18 | 82.39 | 99.91 |
| *10* | 87.41 | 60.20 | 33.18 | 0 | 50.11 | 68.29 |
| *12* | 134.85 | 108.21 | 82.39 | 50.11 | 0 | 18.72 |
| *14* | 151.21 | 125.04 | 99.91 | 68.29 | 18.72 | 0 |
| **ICD** | **Resolution – 5 MP and Distance – 10 cm** | | | | | |
| | *4* | *6* | *8* | *10* | *12* | *14* |
| *4* | 0 | 33.81 | 124.63 | 134.57 | 168.39 | 211.36 |
| *6* | 33.81 | 0 | 92.13 | 101.98 | 136.89 | 182 |
| *8* | 124.63 | 92.13 | 0 | 10.72 | 46.38 | 97.44 |
| *10* | 134.57 | 101.98 | 10.72 | 0 | 39.03 | 91.88 |
| *12* | 168.39 | 136.89 | 46.38 | 39.03 | 0 | 53.75 |
| *14* | 211.36 | 182 | 97.44 | 91.88 | 53.75 | 0 |
| **ICD** | **Resolution – 5 MP and Distance – 20 cm** | | | | | |
| | *4* | *6* | *8* | *10* | *12* | *14* |
| *4* | 0 | 25.95 | 88.06 | 101.14 | 129.93 | 159.42 |
| *6* | 25.95 | 0 | 64.26 | 77.3 | 107.39 | 138.21 |
| *8* | 88.06 | 64.26 | 0 | 13.28 | 43.84 | 76.4 |
| *10* | 101.14 | 77.3 | 13.28 | 0 | 32.12 | 65.59 |
| *12* | 129.93 | 107.39 | 43.84 | 32.12 | 0 | 33.81 |
| *14* | 159.42 | 138.21 | 76.4 | 65.59 | 33.81 | 0 |

a. Note that ICD is a symmetric matrix. The second element of the matrix is the distance from mean of the Hb level cluster '4' to the mean of Hb level cluster '6' and so on. The entries underlined in red show change in monotonicity which is reflected in ICD.

## C. Angle

For all the above experiments, the HCS was kept right below the camera. So, the angle was fixed at nearly 90°. In order to understand the effect of angle, the images of HCS were captured in the outdoor light at an angle of 60° and 90°. In both the cases, 5 MP camera setting was used and distance for image taken at 90° angle was 7.5 cm. So, the distance between the HCS and the camera would have changed slightly for image taken at 60°.The clusters were plotted in RGB color space and mean to mean ICD is calculated (Table IV). There is a change in linearity between Hb value 8 and Hb value 10 when the HCS is captured at an angle of 60°. Even the ICD has decreased significantly.

TABLE III. ICD WITH VARIATION IN LUX.

| ICD | Lux - 136, Resolution – 5 MP and Distance - 7.5 cm | | | | | |
|---|---|---|---|---|---|---|
| | *4* | *6* | *8* | *10* | *12* | *14* |
| *4* | 0 | 12.49 | 22.56 | 23.41 | 12.01 | 23.05 |
| *6* | 12.49 | 0 | 14.20 | 17.25 | 16.48 | 32.40 |
| *8* | 22.56 | 14.20 | 0 | 4.60 | 21.70 | 41.70 |
| *10* | 23.41 | 17.25 | 4.60 | 0 | 21.79 | 42.02 |
| *12* | 12.01 | 16.48 | 21.70 | 21.79 | 0 | 20.48 |
| *14* | 23.05 | 32.40 | 41.70 | 42.02 | 20.48 | 0 |
| **ICD** | **Lux - 271, Resolution – 5 MP and Distance - 7.5 cm** | | | | | |
| | *4* | *6* | *8* | *10* | *12* | *14* |
| *4* | 0 | 11.74 | 25.25 | 23.26 | 36.10 | 49.84 |
| *6* | 11.74 | 0 | 15.65 | 12.87 | 38.68 | 55.23 |
| *8* | 25.25 | 15.65 | 0 | 6.31 | 51.41 | 69.12 |
| *10* | 23.26 | 12.87 | 6.31 | 0 | 45.73 | 63.84 |
| *12* | 36.10 | 38.68 | 51.41 | 45.73 | 0 | 19.38 |
| *14* | 49.84 | 55.23 | 69.12 | 63.84 | 19.38 | 0 |
| **ICD** | **Lux - 469, Resolution – 5 MP and Distance - 7.5 cm** | | | | | |
| | *4* | *6* | *8* | *10* | *12* | *14* |
| *4* | 0 | 12.86 | 29.14 | 52.90 | 88.11 | 104.69 |
| *6* | 12.86 | 0 | 17.65 | 43.68 | 83.01 | 101.98 |
| *8* | 29.14 | 17.65 | 0 | 27.94 | 71.27 | 92.95 |
| *10* | 52.90 | 43.68 | 27.94 | 0 | 45.94 | 70.21 |
| *12* | 88.11 | 83.01 | 71.27 | 45.94 | 0 | 26.28 |
| *14* | 104.69 | 101.98 | 92.95 | 70.21 | 26.28 | 0 |
| **ICD** | **Lux - 534, Resolution – 5 MP and Distance - 7.5 cm** | | | | | |
| | *4* | *6* | *8* | *10* | *12* | *14* |
| *4* | 0 | 17.88 | 37.14 | 69.21 | 110.32 | 131.41 |
| *6* | 17.88 | 0 | 20.36 | 54.76 | 99.59 | 124.07 |
| *8* | 37.14 | 20.36 | 0 | 36.44 | 84.33 | 112.14 |
| *10* | 69.21 | 54.76 | 36.44 | 0 | 49.85 | 81.32 |
| *12* | 110.32 | 99.59 | 84.33 | 49.85 | 0 | 35.01 |
| *14* | 131.41 | 124.07 | 112.14 | 81.32 | 35.01 | 0 |

TABLE IV. ICD WITH VARIATION IN ANGLE OF TAKING PHOTOGRAPH.

| ICD | Angle - 60°, Resolution – 5 MP and Distance - 7.5 cm | | | | | |
|---|---|---|---|---|---|---|
| | *4* | *6* | *8* | *10* | *12* | *14* |
| *4* | 0 | 34.57 | 88.58 | 85.99 | 112.46 | 114.96 |
| *6* | 34.57 | 0 | 54.77 | 52.37 | 79.78 | 83.48 |
| *8* | 88.58 | 54.77 | 0 | 4.17 | 27.26 | 34.38 |
| *10* | 85.99 | 52.37 | 4.17 | 0 | 30.23 | 37.14 |
| *12* | 112.46 | 79.78 | 27.26 | 30.23 | 0 | 10.21 |
| *14* | 114.96 | 83.48 | 34.38 | 37.14 | 10.21 | 0 |
| **ICD** | **Angle - 90°, Resolution – 5 MP and Distance - 7.5 cm** | | | | | |
| | *4* | *6* | *8* | *10* | *12* | *14* |
| *4* | 0 | 27.49 | 54.57 | 87.41 | 134.85 | 151.21 |
| *6* | 27.49 | 0 | 27.42 | 60.20 | 108.21 | 125.04 |
| *8* | 54.57 | 27.42 | 0 | 33.18 | 82.39 | 99.91 |
| *10* | 87.41 | 60.20 | 33.18 | 0 | 50.11 | 68.29 |
| *12* | 134.85 | 108.21 | 82.39 | 50.11 | 0 | 18.72 |
| *14* | 151.21 | 125.04 | 99.91 | 68.29 | 18.72 | 0 |

## D. Timing Significance

To understand the importance of time difference between the instance when a blood drop is placed on the strip and the instance when the photo of the blood drop is taken, we did a few experiments directly with the blood. To study whether the RGB values of the blood change with time, the photographs of a blood sample (placed on the filter strip) were taken at 20s, 30s, 40s and 60s after being placed on the

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filter strip. The variation in RGB values of blood with time (30s-60s) was found to be less than 5%.

## V. DATABASE AND RESULTS

In a volunteer study, with 5 MP camera setting and distance between HCS and camera being 7.5 cm and HCS right below the camera (Angle - 90°), the image of the blood with the HCS was taken in outdoor light, as shown in Figure 1. The timing of taking photograph was delayed since as per the WHO HCS protocol, the Hb had to be estimated by 2 physicians using WHO HCS after waiting for 30s. The timing of the photograph was kept constant around 60s after the prick (as mentioned in Section Timing Significance, the difference in RGB values between an image taken at 30s and 60s is less than 5%). 20 samples were collected in this volunteer study.

As this was a volunteer study in an office setting, the volunteers had typically high reference Hb values. The Hb value was measured through Sahli's method. The estimation of the Hb value using WHO HCS was done by two physicians and these Hb values were also noted down. It is worth mentioning that HemoCue AB is used as a reference in many Hb studies. However, we could not procure HemoCue AB due to its conflict of interest with Philips. We compared our results with Sahli's method which is widely used in India and many other developing countries such as Indonesia.

A portion of each Hb level and blood sample is cropped from the image for each volunteer. As the scale behavior might have changed for each volunteer due to illumination change, for each image the WHO HCS levels and blood sample were taken for analysis. A part of the database with results is shown in Table V.

TABLE V. THE DATABASE AND RESULTS. THE LAST TWO COLUMNS ARE THE ESTIMATED HB USING OUR APPROACH.

| ***Sahli's method*** | ***Physicians judgment using WHO HCS*** | | ***Average Hb*** | ***EucRGB*** | ***EucRGB(interpolated)*** |
|---|---|---|---|---|---|
| | ***1*** | ***2*** | | | |
| 12.5 | 12 | 12 | 12.17 | 12 | 12.95 |
| 10.8 | 12 | 10 | 10.93 | 10 | 10.95 |
| 10.0 | 9 | 11 | 10.00 | 12 | 11.24 |
| 9.8 | 8 | 9 | 8.93 | 10 | 10.37 |
| 12.0 | 13 | 12 | 12.33 | 12 | 12.96 |
| 9.6 | 10 | 11 | 10.20 | 10 | 10.93 |
| 9.8 | 8 | 10 | 9.27 | 10 | 10.43 |

In Table V, 'Average Hb' is the average of Hb values by Sahli's and physicians' interpretation of blood sample while using WHO HCS. Since Sahli's method also suffers from subjectivity of human vision and interpretation, we considered the 'Average Hb' for reference; this is expected to reduce the bias and give better estimate as compared to estimate by any of the individual reference method. The last two columns show the results of our approach. The means of the Hb level and blood were plotted in RGB color space, and Euclidean distance measure was used to find the nearest neighbor. The nearest neighbor Hb value in RGB color space for each sample is documented in the column 'EucRGB' of Table V. 'EucRGB(interpolated)' is calculated using the distance of the mean of blood with the Hb values. For example, if the Hb value of blood falls between clusters of Hb value 12 and 14, Euclidean distance between "cluster of Hb value 12 and blood" and "cluster of Hb value 14 and blood" is calculated, and these distances are used for linear interpolation.

'Average Hb' value of each subject and means of red and green channels from the cropped blood sample of each subject (from the image of blood) are plotted in Figure 4. The Hb value for each subject is on the X-axis with mean of Red and Green channels in the Y-axis and Z-axis respectively. Two strong natural clusters are observed suggesting that the Hb value above 12.5 can be easily distinguished from the Hb values below 12.5 by the information present in the red and green channels.

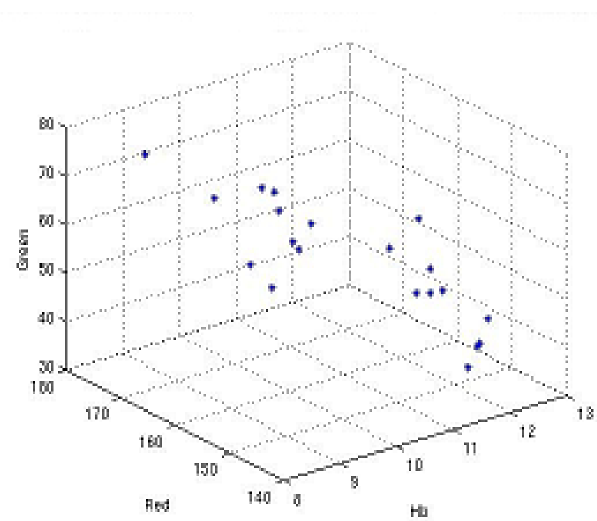


Figure 4. Mean of Red, Green values of only the blood sample images with Hb value( by taking 'Average Hb'). It clearly shows two natural clusters.

Pearson's product-moment correlation coefficient between various methods used in this study to estimate Hb is shown in Table VI. It is observed that the estimation from the algorithm ('EucRGB (interpolated)') has a correlation coefficient of 0.80 with the average Hb value. This is the highest correlation between any of the two methods studied in this paper (the correlation of 0.85 between 'Average Hb' and other methods which were used to derive 'Average Hb' needs to be discounted since it is going to be high by design).

Bland-Altman plots [12] comparing 'Average Hb' value and estimation of algorithm ('EucRGB (interpolated)') is shown in Fig. 5. It shows that the algorithm overestimates the Hb values near 12-13 Hb levels and 10-11 Hb levels, whereas in 10-11 Hb levels the algorithm underestimates Hb values.

TABLE VI. CORRELATION BETWEEN VARIOUS METHODS OF ESTIMATION AND OUR APPROACH.

| Method | Pearson's product-moment correlation coefficient | | | | | |
|---|---|---|---|---|---|---|
| | ***Sahli's*** | ***Physician 1*** | ***Physician 2*** | ***Average Hb*** | ***EucRGB*** | **EucRGB (interpolated)** |
| ***Sahli's*** | 1 | 0.54 | 0.64 | 0.85 | 0.46 | 0.55 |
| ***Physician 1*** | 0.54 | 1 | 0.59 | 0.85 | 0.61 | 0.76 |
| ***Physician 2*** | 0.64 | 0.59 | 1 | 0.85 | 0.74 | 0.73 |
| ***Average Hb*** | 0.85 | 0.85 | 0.85 | 1 | 0.70 | 0.80 |
| ***EucRGB*** | 0.46 | 0.61 | 0.74 | 0.70 | 1 | 0.73 |
| ***EucRGB(interpolated)*** | 0.55 | 0.76 | 0.73 | 0.80 | 0.73 | 1 |

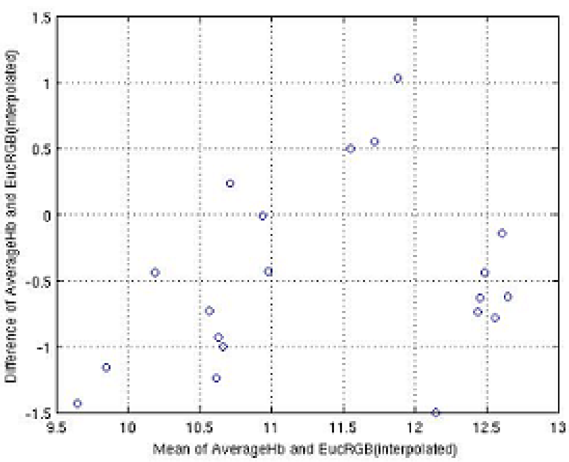


Figure 5. Bland-Altman plots for comparison of 'Average Hb' value and estimation from algorithm ('EucRGB interpolated').

## VI. CONCLUSIONS, LIMITATIONS AND FUTURE DIRECTIONS

In this paper, the important protocols for taking an image of HCS and a blood sample for estimating Hb value of the blood are established through experiments. The results show that there is a high correlation (0.8) between color of blood and its Hb value. Though the results are encouraging, the database is limited and has typically high values of Hb.

The three methods (Sahli's and judgment of physicians using WHO HCS) which were used for comparison with the estimate of the algorithm (Tables V and Table VI) have high subjectivity associated with them. So there is a need for an objective measure. In addition, this whole study was conducted in the natural light and there was no control on illumination conditions. Though the results presented in this paper on a small dataset are encouraging, the same results need to be replicated in controlled artificial light to make the system usable anytime and anywhere. One of the methods to achieve this is to mimic natural light using artificial lights.

Despite all attempts to standardize the protocol of data collection, there were illumination changes in the outdoor condition. This might have affected the RGB values of the blood samples. Gray balancing and various other color constancy algorithms in computer vision can be applied to improve the performance of the algorithm.

Fig. 4 suggests that the image of the blood sample on the filter strip (without validation of observation through WHO HCS) is enough and can be used to estimate the Hb value by using machine learning algorithms. However, we need a much larger dataset to develop this data driven approach.

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