

Smartphone Based Photometric Hemoglobin Measurement

An abnormal hemoglobin concentration, e.g. anemia or polycythemia, is one of the most common disorders in humans and hemoglobin measurement is one component of the most commonly performed diagnostic test, the CBC (complete blood count). Hemoglobin is composed of four polypeptides and an iron-containing porphyrin, heme. One of heme's most distinctive physical properties is its Soret band, i.e. light absorption at a specific wavelength. Measuring the Soret band using the Lambert-Beers Law is routinely used to determine the hemoglobin concentration in blood. Light transmission through a sample has an equation of the form $I=I_0 \exp(-\alpha d)$ where I is the measured intensity I_0 is the initial intensity, α is the absorption and d is the distance. The quantity that changes is the absorption or concentration of hemoglobin. The data can be fit by a linear curve, though an logarithmic curve fits much better. (Taylor expansion of $\ln(x) = (x-1) - (x-1)^2/2 + \dots$)

i-calQ's biosensor technology uses a smartphone camera and flash, a disposable plastic capillary cuvette, and analyte-specific app to measure hemoglobin from a 3 microliter blood sample without the need to convert hemoglobin to a cyanide or sulfide derivative. The strip is filled with a drop of capillary blood, inserted into the i-calQ reader and imaged. The algorithm i-calQ has developed for hemoglobin measurement is embedded in the hemoglobin app (Figure 1). This image analysis algorithm performs the following steps:

1. The color image is converted into a color measurement by separating the image into its component color channels, red, blue, and green.
2. The measurement region is located by scanning a profile of the image (Figures 2). The average red channel pixel value is calculated within the measurement region. Next the average red channel pixel value for the exposure compensation region is calculated. Different camera exposures can give different readings for the same strip. The white part of the reader strip can be used as exposure compensation. (Figure 3)
3. The normalized pixel value is calculated from the measurement and exposure compensation values. This value is plugged into the equation with constants C_1 and C_2 . By taking samples with a known value of hemoglobin and using the measurement strips a calibration curve can be formed. The form of the curve is $P=C_1+C_2*\ln(\text{conc})$ where P is pixel value, C_1 and C_2 are constants, \ln is natural log (base e) and conc is the known concentration. Figures 4 and 5 are the normalized, measured pixel values versus known concentration. Figure 4 represents data generated by an iPhone 4 using an IOS operating system and Figure 5 shows data from a HTC smartphone using an Android operating system. A single curve fits both, however the curve coefficients differ based upon camera type, flash characteristics, and operating system. From this curve, an unknown sample can be measured, $U_c=\exp((P-C_1)/c_2)$ where U_c is unknown concentration, P is normalized pixel value, and constants C_1 and C_2 are from the previously determined calibration curve.
4. A displayed value of concentration is shown on the smartphone screen, with warnings if the measurement is outside an expected range $5 < \text{concentration (gms/dl)} < 25$. The results can be saved on the phone, printed, or transmitted via the internet or by SMS. Decision support to interpret the results and recommend additional evaluation and treatment can be included in the app.



Figure 1
Analyte Specific Apps
Folder Showing Hemoglobin

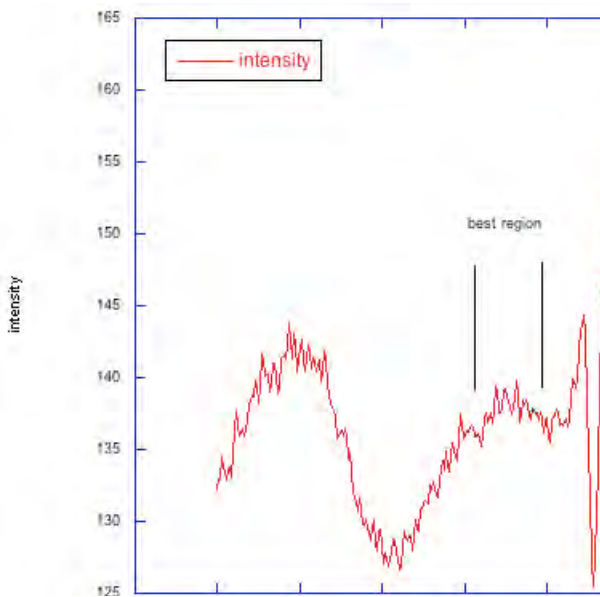


Figure 2
Image Analysis App Showing
Measurement and Compensation
Regions

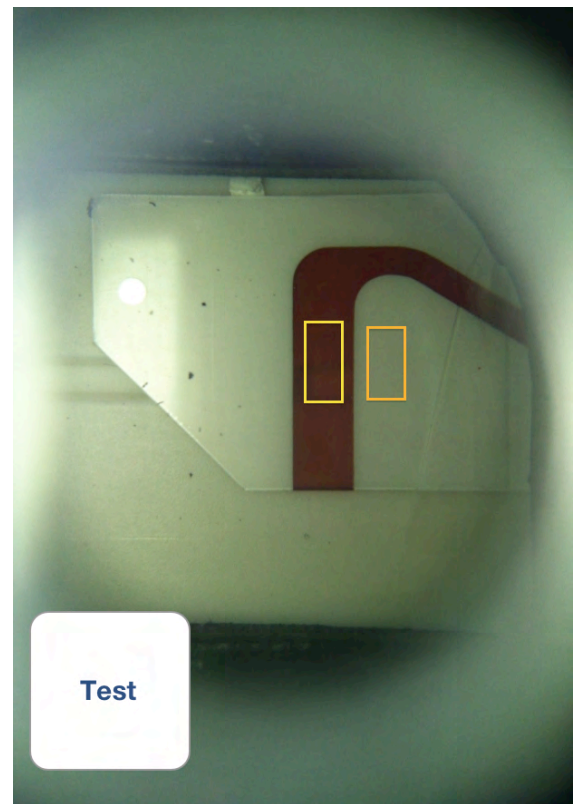


Figure 3
Image Analysis App Showing
Measurement and Compensation
Regions

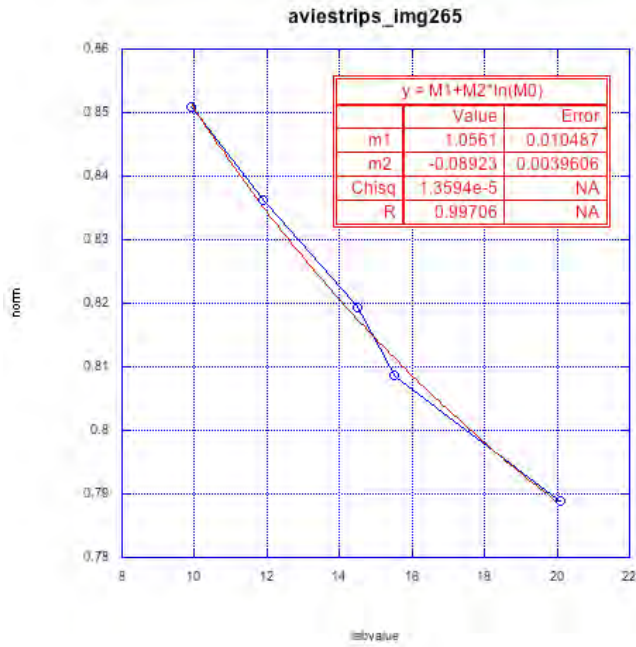


Figure 4
Hemoglobin Standard Curve
Using iPhone 4 and IOS Operating
System

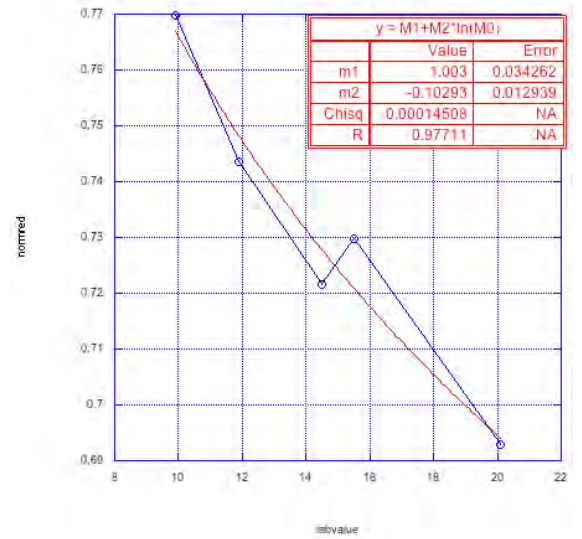


Figure 5
Hemoglobin Standard Curve Using
HTC Smartphone and Android
Operating System