Adaptive Pulse Oximeter

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What is a Pulse Oximeter? (B)

- Medical device that can read your heart rate and blood oxygen saturation.
- First steps in diagnosis and checkups
- Used to monitor oxygen saturation for administering external oxygen supply
- Minimally invasive method
Why do we care? (B)

- Pulse oximeters are minimally invasive
  - Blood draws are the only alternative

- Relatively cheap

- Very basic to manufacture/ Basic parts

- Very simple to use with adequate precision (exceptions)
Key Flaw in the pulse ox (B)

- Calibrated for lighter skin tones
- People with darker skin pigmentation get imprecise readings
- Gives readings that get artificially higher the darker the pigmentation
- Differences at key wavelength of 680 nm
What does this mean? (B)

- Pulse Ox used to administer external oxygen
- Overestimate in Pulse Ox means under administering external oxygen in darker skinned patients
- Many other medical uses for pulse oximeters including diagnosis is disrupted by this
- Creates racial disparities in healthcare quality
Our Idea (B)

- Calibrate the standard Pulse Ox for every patient
- Includes a color sensor to detect skin pigmentation of subject
- Use some sort of regression method to extrapolate a calibration curve to 680nm
- Use a few wavelengths at points where Hb and HbO2 are close
Methods: Goal For Data Acquisition (B)

- Sample a diverse set of people (different skin tones)
- Limitation: no reliable way to gather control data
  - Pulse oximeters are imprecise (as mentioned before)
  - Only alternative is to draw blood, we don't have that equipment
- Theoretical model of the spectra of patient solely from color data
- Proceed to build a model regardless, with only color data.
Breakdown of Sensor and Modules Used (B)
Feather M0 Microcontroller (B)

● As data logger and microcontroller
● Why we made the swap
  ○ Integrated SD card slot saved space
  ○ Small form factor compared to mega 2560
  ○ Support for an external lithium battery
● Difficulties
  ○ Not always straightforward to adapt code
  ○ Took time getting used to reset button
  ○ Required different board firmware (took us a while to figure out)
● Once difficulties were fleshed out the feather was great!
MAX30102 Pulse Oximeter (SparkFun) (B)

- Large, but similar in size to the Color Sensor
- Pulse sensor, SpO2 detection (blood oxygen)
- NOTE: this pulse ox uses reflectance
  - Clamp pulse oxes use transmittance through finger.
- BUT: our method is adaptable
  - Reflectance is inverse of transmittance
- We can apply calibration parameter to this
TFT Display (B)

- Provide a simple way to display data
- Large enough to display all sorts of things
- Colorful so it’s easy on the eyes
- Not much else. We thought it’d be interesting.
AS7341 Color Sensor (B)

- By far, most important.
- We use only 3 wavelengths
- Chose this one for its flexibility
- Small form factor
- Integrated white LED (pretty good)
- Caveat: glaring green LED onboard
  - Disrupts color readings (baffling inclusion)
- We removed the green LED
Sensor on AS7341 (B)

- F1(405-425nm)
- F2(435-455nm)
- F3(470-490nm)
- F4(505-525nm)
- F5(545-565nm)
- F6(580-600nm)
- F7(620-640nm)
- F8(670-690nm)
Spectral Range of AS7341 (B)
Typical Light Absorption of Skin (B)
Prototype Pulse Ox
Device Design

- Two separate units
- Feather M0 and TFT in display case
- Spo2 and colorimeter in ergonomic finger holder
Display

- Contains Feather M0 and TFT Display

- Access to SD card, micro usb port, and reset button
Challenges

- Opening for USB port slightly out of place

- Opening for SD card too small to access
Finger Holder

- Based on existing pulse oximeters
- Maintains constant pressure on spo2 sensor
- Colorimeter at a distance from finger to avoid saturation
Challenges

- Opening for spo2 sensor was too small and would not sense the finger
- Colorimeter LED too bright, saturated the sensor
- Posts used to fasten pcb boards were too brittle
Data Collection

● Attempted to test front and back of finger to determine correlation between skin pigmentation and spo2 readings

● Inaccurate spo2 when testing back of finger

● Instead used select wavelengths to plot skin color absorption and compared the plots in an attempt to find a way to calibrate the pulse oximeter
- Used 590, 555, and 415 nm wavelengths to plot melanin absorption
- 590 nm and 555 nm wavelengths were the best indicators of different skin colors
- Found line of best fit for the data points
- Compared slope in an attempt to calibrate the pulse oximeter
Discussion: Calculation Method Limitations (B)

- Regression relies on extrapolation.

- Lack of control data means we can’t be sure how exactly absorption of skin changes with pigmentation at different wavelengths.

- Dark skin may have details we can’t see or predict at lower wavelengths.

- Without control (blood draws), we can’t know for sure.
Code

- Pulse Oximeter
- Spectrometer
- Data Collection
- Calibration
Pulse Ox

- **Heart Rate - Zero Crossing**

- **SpO2**

\[
R = \frac{AC_{\text{red}}}{DC_{\text{red}}} \frac{AC_{\text{ir}}}{DC_{\text{ir}}}
\]

\[
SpO_2 = a \cdot R^2 + b \cdot R + c
\]

\[
a = 1.5958422
\]

\[
b = -34.6596622
\]

\[
c = 112.6898759
\]
Calibration Methods
### Table 2. Examples of Mean L*, a*, and b* Values for the Six Groups of Skin Color

<table>
<thead>
<tr>
<th>Skin color type</th>
<th>ITA°</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very light</td>
<td>&gt;55</td>
<td>74.5 ± 1.5</td>
<td>3.7 ± 0.5</td>
<td>14.5 ± 0.7</td>
</tr>
<tr>
<td>Light</td>
<td>55–41</td>
<td>68.8 ± 0.5</td>
<td>7.0 ± 0.6</td>
<td>17.4 ± 0.5</td>
</tr>
<tr>
<td>Intermediate</td>
<td>41–28</td>
<td>63.3 ± 0.4</td>
<td>7.4 ± 0.5</td>
<td>18.7 ± 0.5</td>
</tr>
<tr>
<td>Tan</td>
<td>28–10</td>
<td>57.5 ± 0.3</td>
<td>10.1 ± 0.6</td>
<td>20.2 ± 0.5</td>
</tr>
<tr>
<td>Brown</td>
<td>10 to −30</td>
<td>47.0 ± 0.9</td>
<td>10.4 ± 0.5</td>
<td>18.3 ± 0.6</td>
</tr>
<tr>
<td>Dark</td>
<td>&lt;−30</td>
<td>35.5 ± 0.7</td>
<td>8.8 ± 0.4</td>
<td>11.6 ± 0.6</td>
</tr>
</tbody>
</table>

**Mean values ± SEM**

**Abbreviations:** CIE, Commission Internationale de l’Eclairage; ITA°, individual typology angle; SCI, specular component included; SEM, standard error of the mean.

CIE L*, a*, and b* values were measured for 135 photoprotected skin samples with variable pigmentation. The L*, a*, and b* values were classified into six skin color groups according to their ITA°. L*a*b* parameters were measured with a spectrophotometer (Datacolor Check) using D65, 10°, SCI, d/8° (Del Bino and Bernerd, 2013, and personal communication).
\[
X = \frac{1}{N} \sum \bar{x}_i S_i I_i \Delta \lambda
\]

\[
Y = \frac{1}{N} \sum \bar{y}_i S_i I_i \Delta \lambda
\]

\[
Z = \frac{1}{N} \sum \bar{z}_i S_i I_i \Delta \lambda
\]

\[
N = \sum \bar{y}_i I_i \Delta \lambda
\]

\[
f_x = \begin{cases} 
\frac{3\sqrt{\bar{x}_r}}{\kappa_x r + 16} & \text{if } \bar{x}_r > \epsilon \\
\frac{116}{116} & \text{otherwise}
\end{cases}
\]

\[
f_y = \begin{cases} 
\frac{3\sqrt{\bar{y}_r}}{\kappa_y r + 16} & \text{if } \bar{y}_r > \epsilon \\
\text{otherwise}
\end{cases}
\]

\[
f_z = \begin{cases} 
\frac{3\sqrt{\bar{z}_r}}{\kappa_z r + 16} & \text{if } \bar{z}_r > \epsilon \\
\text{otherwise}
\end{cases}
\]

\[
x_r = \frac{X}{X_r}
\]

\[
y_r = \frac{Y}{Y_r}
\]

\[
z_r = \frac{Z}{Z_r}
\]

\[
L = 116 f_y - 16
\]

\[
a = 500 (f_x - f_y)
\]

\[
b = 200 (f_y - f_z)
\]

\[
\epsilon = \begin{cases} 
0.008856 & \text{Actual CIE standard} \\
216/24389 & \text{Intent of the CIE standard}
\end{cases}
\]

\[
\kappa = \begin{cases} 
903.3 & \text{Actual CIE standard} \\
24389/27 & \text{Intent of the CIE standard}
\end{cases}
\]


