Medical Photography task force
Teleconference
9 April 2014 • 11:00 (EST)

The meeting was called to order at 11:00 am (EST) by Craig Revie, chair of MIWG, with the following attendees:

- Pinky Bautista
- James Chang
- John Dalrymple
- Max Derhak
- Susan Farnand
- Michael Flynn
- Phil Green
- Tyler Keay
- Olga Konovalova
- Tom Lianza
- Andy Masia
- John Penczek
- Craig Revie
- Thomas Schopf
- Christye Sisson
- Yves Vander Haeghen
- Hong Wei
- Dave Wyble
- Masahiro Yamaguchi

After self-introductions and a check of the sound quality Mr. Revie outlined future meeting plans and summarised the goal of the meeting as reviewing the measurement and calibration procedures for medical photography.

John Penczek, the leader of the Medical Photography activity in ICC MIWG, presented his work on analysis of camera errors [see attached]. He clarified that he had used telespectroradiometers rather than spectrophotometers to measure reflectance as these were available in his lab. Patch averaging had been done to extract single RGB values for each colour patch, but no noise reduction had been performed. It was noted that illumination uniformity and target positioning were potential variables in such photography.
It was felt that rendering to D65 introduced an additional source of error, and this was scene content dependent. The scene white cannot easily be determined, and this can play a large role in the rendering.

It was suggested that the automatic white balance might be adequate for some outdoor environments, but can give poor results for indoor lighting. The automatic white balance is sensitive to the scene content.

Phil Green showed results from a student project [see attached] which used a different camera characterization method and achieved an accuracy around 1.0 CIELAB \(\Delta E^*_{ab}\). He agreed to draft a description of a procedure to convert camera RGB to scene colorimetry. It was noted that a number of vendors provide software to do this, both using conventional ICC input profiles and DNG-based profiles.

Tom Lianza reported that X-Rite make a book of flesh tone colour samples, and undertook to provide a reference.

Yves Vander Haeghen presented some results [see slides in meeting recording] which showed differences between camera sRGB colorimetry and measurements which were of a similar order to those reported by John Penczek – a median of 8-10 DE and a maximum of around 30. A calibration procedure reduced the errors to a median on 1.0 in CIEDE2000, using a LUT + matrix approach. He agreed to consider whether a description of the procedure can be made available to the group.

It was agreed that there was a need to invite medical photography practitioners to participate, particularly in determining accuracy requirements. Christye Sisson will provide contacts in the US and at Cardiff University.

Craig Revie closed the meeting at 12:30pm and thanked the participants.


**Action items from the meeting:**

- **MIWG-14-23** Provide draft description of camera characterization procedure (Green)
- **MIWG-14-24** Provide reference to X-Rite flesh tone colour samples (Lianza)
- **MIWG-14-25** Consider providing a description of the calibration procedure (Vander Haeghen)
- **MIWG-14-26** Provide medical photography contacts in US and U. Cardiff (Sisson)
CIELAB Color Difference Analysis for Digital Color Photography

John Penczek
NIST & Univ. Colorado, Boulder

ICC Medical Imaging Task Force
Medical Photography Teleconference
April 9, 2014
Outline

- Measurement methodology
- Reference color measurements and analysis
- Extracting image color data and analysis
- Color error analysis
The CIELAB color difference $\Delta E_{ab}$ was determined by comparing the LAB values embedded in digital images to spectroradiometer data.
Spectral measurements were taken with a precision spectroradiometer of each color patch to determine its reference CIELAB color.

Spectroradiometer data flow

Spectra → CIE XYZ @ sRGB → CIE LAB

Spectroradiometer measurement

Controls:
- Measure spectra of each color patch for a given position (centered or side-by-side) or lighting conditions (daylight FL, cool white FL, or incandescent).
- Maintain position and lighting configuration for digital photography.
- Use white reflectance standard as a reflection reference.
- Measure average color in center of each patch.
- Use motorized motion stages for position repeatability.
Example Reference Spectra

\[ X = k \int_{\lambda} R(\lambda) E_{D65}(\lambda) \bar{x}(\lambda) d\lambda \]

\[ Y = k \int_{\lambda} R(\lambda) E_{D65}(\lambda) \bar{y}(\lambda) d\lambda \]

\[ Z = k \int_{\lambda} R(\lambda) E_{D65}(\lambda) \bar{z}(\lambda) d\lambda \]

\[ k = \frac{1}{\int_{\lambda} E_{D65}(\lambda) \bar{y}(\lambda) d\lambda} \]

\[ f(t) = \begin{cases} 
  t^{1/3} & \text{if } t > (6/29)^3 \\
  \frac{1}{6} (\frac{29}{6})^2 t + \frac{16}{116} & \text{otherwise}
\end{cases} \]

\[ L^* = 116 \times f(Y/Y_n) - 16 \]

\[ a^* = 500 \times [f(X/X_n) - f(Y/Y_n)] \]

\[ b^* = 200 \times [f(Y/Y_n) - f(Z/Z_n)] \]

\[ R(\lambda) = R_{std}(\lambda) \frac{L(\lambda)}{L_{std}(\lambda)} \]

Spectral Radiance of ideal white and patch #2

Spectral Reflectance Factor of patch #2
Reference CIELAB Calculation

The spectral reflectance factor $R(\lambda)$ of each color patch is used to calculate the normalized tristimulus values:

$$X = k \int_{\lambda} R(\lambda) E_{D65}(\lambda) \bar{x}(\lambda) d\lambda$$

$$Y = k \int_{\lambda} R(\lambda) E_{D65}(\lambda) \bar{y}(\lambda) d\lambda$$

$$Z = k \int_{\lambda} R(\lambda) E_{D65}(\lambda) \bar{z}(\lambda) d\lambda$$

where

$$k = \frac{100}{\int_{\lambda} E_{D65}(\lambda) \bar{y}(\lambda) d\lambda}$$

The CIE94 values are then calculated by:

$$L^* = 116 \times f\left(\frac{Y}{Y_n}\right) - 16$$

$$a^* = 500 \times \left[ f\left(\frac{X}{X_n}\right) - f\left(\frac{Y}{Y_n}\right) \right]$$

$$b^* = 200 \times \left[ f\left(\frac{Y}{Y_n}\right) - f\left(\frac{Z}{Z_n}\right) \right]$$

where

$$f(t) = \begin{cases} t^{1/3} & t > (6/29)^3 \\ \frac{1}{3}\left(\frac{29}{6}\right)^2 t + \frac{16}{116} & \text{otherwise} \end{cases}$$

Using the following values for D65:

$X_n= 0.95047$

$Y_n= 1.0$

$Z_n= 1.08883$
Example of Reference CIELAB Data

The following example shows the CIELAB values measured by a spectroradiometer of one color patch for a x-Rite Passport color target in a lightbooth under cool white fluorescent (CWF) illumination.

Original scene

Normalized tristimulus values for CWF:
\[ X_{n,cwf} = 0.3699 \]
\[ Y_{n,cwf} = 0.3341 \]
\[ Z_{n,cwf} = 0.1210 \]

Norm. tristimulus values corrected to D65:
\[ X_{n,D65} = 0.3554 \]
\[ Y_{n,D65} = 0.3307 \]
\[ Z_{n,D65} = 0.2485 \]

CIELAB values with D65 white:
\[ L^* = 64.2 \]
\[ a^* = 14.5 \]
\[ b^* = 16.1 \]
Color Data Extraction from Image File

Camera image data

- **RGB** → **CIE XYZ @ sRGB** → **External correction** → **CIE LAB**

Original image

Software was used to crop the area of interest, identify the centroids of each color patch, extract the average RGB and XYZ tristimulus values over 21x21 pixels, than calculate the LAB values of each patch for a D65 whiter point.

RGB to XYZ Calculation

Used procedure in IEC 61966-2-1 (sRGB) to calculate the tristimulus XYZ values from raw RGB values.

For 8-bit RGB values,

\[
R'_{\text{sRGB}} = \frac{R}{255} \\
G'_{\text{sRGB}} = \frac{G}{255} \\
B'_{\text{sRGB}} = \frac{B}{255}
\]

If \( R'_{\text{sRGB}}, G'_{\text{sRGB}}, B'_{\text{sRGB}} \leq 0.04045 \),

\[
R_{\text{sRGB}} = \frac{R'_{\text{sRGB}}}{12.92} \\
G_{\text{sRGB}} = \frac{G'_{\text{sRGB}}}{12.92} \\
B_{\text{sRGB}} = \frac{B'_{\text{sRGB}}}{12.92}
\]

If \( R'_{\text{sRGB}}, G'_{\text{sRGB}}, B'_{\text{sRGB}} > 0.04045 \),

\[
R_{\text{sRGB}} = \left[ \frac{R'_{\text{sRGB}} + 0.055}{1.055} \right]^{2.4} \\
G_{\text{sRGB}} = \left[ \frac{G'_{\text{sRGB}} + 0.055}{1.055} \right]^{2.4} \\
B_{\text{sRGB}} = \left[ \frac{B'_{\text{sRGB}} + 0.055}{1.055} \right]^{2.4}
\]

Then calculate tristimulus values,

\[
\begin{bmatrix}
X \\
Y \\
Z
\end{bmatrix} = \begin{bmatrix}
0.4124 & 0.3576 & 0.1805 \\
0.2126 & 0.7152 & 0.0722 \\
0.0193 & 0.1192 & 0.9505
\end{bmatrix} \begin{bmatrix}
R_{\text{sRGB}} \\
G_{\text{sRGB}} \\
B_{\text{sRGB}}
\end{bmatrix}
\]
Used procedure in CIE 15.2 (Colorimetry) to calculate the CIELAB values from the tristimulus XYZ values.

The CIELAB values are then calculated by:

\[
L^* = 116 \times f \left( \frac{Y}{Y_n} \right) - 16
\]
\[
a^* = 500 \times [f \left( \frac{X}{X_n} \right) - f \left( \frac{Y}{Y_n} \right)]
\]
\[
b^* = 200 \times [f \left( \frac{Y}{Y_n} \right) - f \left( \frac{Z}{Z_n} \right)]
\]

Using the following values for D65:
- \(X_n= 0.95047\)
- \(Y_n= 1.0\)
- \(Z_n= 1.08883\)

where

\[
f(t) = \begin{cases} 
  t^{1/3} & \text{if } t > (6/29)^3 \\
  1 - \frac{29}{6} t + \frac{16}{116} & \text{otherwise}
\end{cases}
\]

Same calculation as for the reference data.
Validation with Commercial Software

The Matlab values were confirmed by manually measuring the color values of a patch using commercial image viewing software (Photoshop).

Using color sampler tool in Photoshop

This software calculates the CIELAB values using a D50 white point. Can use Bradford chromatic adaption transform for D65 white point.

\[ L^* = 67.4 \]
\[ a^* = 15.4 \]
\[ b^* = 22.1 \]

This corresponds well the values extracted using Matlab.

\[ L^* = 67.3 \]
\[ a^* = 15.4 \]
\[ b^* = 21.9 \]
CIELAB Color Difference

The CIELAB color difference between the reference data \((L^*_{1}, a^*_{1}, b^*_{1})\) and camera data \((L^*_{2}, a^*_{2}, b^*_{2})\) was calculated by:

\[
\Delta E_{ab} = \sqrt{(L^*_{2} - L^*_{1})^2 + (a^*_{2} - a^*_{1})^2 + (b^*_{2} - b^*_{1})^2}
\]

For the flesh tone example:
\(L^*_{1} = 64.2\)
\(a^*_{1} = 14.5\)
\(b^*_{1} = 16.1\)
\(L^*_{2} = 67.3\)
\(a^*_{2} = 15.4\)
\(b^*_{2} = 21.9\)

Therefore,
\[\Delta E_{ab} = 6.7\]
Camera Color Error Dependence on Color

Image color error of the x-Rite Passport color target taken with a Digital SLR camera under cool white fluorescent lighting conditions.

Passport Color Chart

![Passport Color Chart](image)

![Graph showing CIELAB Color Difference DE_ab](image)

Output Format:

Camera Color Error Dependence on Color

Image color error of the x-Rite Passport color target taken with a Digital SLR camera under cool white fluorescent lighting conditions.

Passport Color Chart

![Passport Color Chart](image)

![Graph showing CIELAB Color Difference DE_ab](image)
This method produces a white balanced appearance optimized matrix.

As most of the images in the project were captured in daylight conditions, the matrices were calculated using five reference scene illuminants: C, D50, D55, D65 average daylight and D75 typical ‘north sky’ [11].

As \( L_a \) is calculated from the image specific exposure, aperture and ISO settings, \( L_a \) varied from 3025 cd/m\(^2\) (bright scene), 1936 cd/m\(^2\) (sunny scene), 781 cd/m\(^2\) (sun/shade scene) to 113 cd/m\(^2\) (shady scene). Matrices were calculated using the four values of \( L_a \) for each of the above illuminants.

The example matrix shown in Table 1. is calculated for D50, \( L_a \) 781 cd/m\(^2\), \( Y_b \) 20 and ‘average’ surround with the associated table of errors.

<table>
<thead>
<tr>
<th></th>
<th>R</th>
<th>G</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>0.717370848</td>
<td>0.214559415</td>
<td>0.032211208</td>
</tr>
<tr>
<td>Y</td>
<td>0.301270767</td>
<td>0.871240275</td>
<td>-0.181457352</td>
</tr>
<tr>
<td>Z</td>
<td>-0.001483855</td>
<td>-0.008537715</td>
<td>0.834946179</td>
</tr>
</tbody>
</table>

Table 1 Optimised Matrix and associated errors derived from a characterisation using a 5nm bandpass.

Image CIEXYZ to CIECAM02

In order to convert the image through the forward model of CIECAM02, input parameters were selected. The illuminant white point \( X_w, Y_w, Z_w \) and \( L_a \) are the same as used in the optimized matrix for the device RGB to CIEXYZ image conversion. Accurate adopted white point estimation is crucial if CIECAM02 is to perform accurately. Rather than develop algorithms for illuminant estimation, it was decided to use the camera estimates ‘as shot’. Hordley (2006) has reviewed the developments of research in this area [12].

The background luminance \( Y_b \) is set to an arbitrary value of 20 and the surround is selected to be ‘average’ which assumes complete adaptation in daylight.

CIECAM02 to XYZ

The premise of using CIECAM02 was to convert from Scene Appearance direct to Output Appearance in effect using the appearance processing to perform the rendering to output-referred. This route was chosen so that algorithms could be assessed quickly.

The output viewing conditions will be that of a standard sRGB monitor. The viewing parameters will be \( L_a \) 30cd/m\(^2\), \( Y_b \) 20, white point of D65 and a ‘Dim’ surround and calculated from the appearance coordinates of JMh.

XYZ to sRGB

The next stage is to convert to sRGB. As the whitepoint input to the reverse model is D65, no further chromatic adaptation is required. The file was assigned a sRGB profile prior to viewing and then compared with the sRGB JPEG produced by the camera.

Local Adapation.

A digital camera however does not have the ability to adapt to local contrast differences in a scene as does the human visual system. Due to the linear response and the dynamic range of the sensor, in a high dynamic scene (e.g. a sunny day) it can only expose correctly for either the highlights or the shadows, but not both at once. The auto exposure system settles for an optimum that produces reasonable highlights and shadows, even so the latter still tends to be on the dark side.

The approach taken to address this problem is to process the image through CIECAM02 twice at different settings and then blend through a mask defining the shadow areas Figure 5.