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 Penzcek, 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 ΔE^*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.

A full recording of the meeting is available at http://www.npes.org/Portals/0/standards/2014-04-09%2009.59%20ICC%20MIWG_%20Medical%20Photography%20measurement%20analysis.wmv

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

Camera Color Error Analysis Flow

The CIELAB color difference ΔE_{ab} was determined by comparing the LAB values embedded in digital images to spectroradiometer data.

Camera

Camera image data

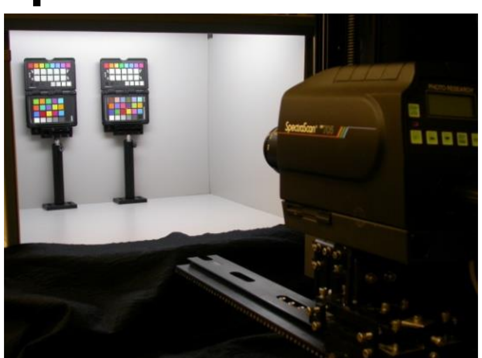
RGB → CIE XYZ @ sRGB → External correction → CIE LAB

Perceived color

CIE LAB ↓

ΔE Color Difference

Spectroradiometer



Spectra → CIE XYZ @ sRGB → CIE LAB ↑

Spectroradiometer data

Reference Color Analysis

Spectral measurements were taken with a precision spectroradiometer of each color patch to determine it reference CIELAB color.

Spectroradiometer measurement

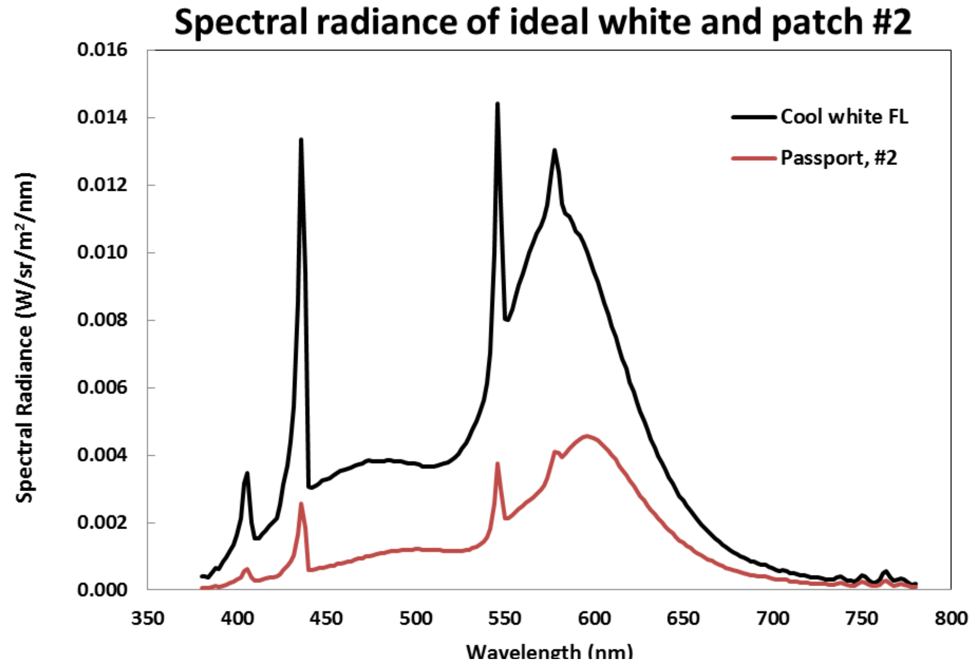
Spectroradiometer data flow

Spectra → CIE XYZ @ sRGB → CIE LAB

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



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

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

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

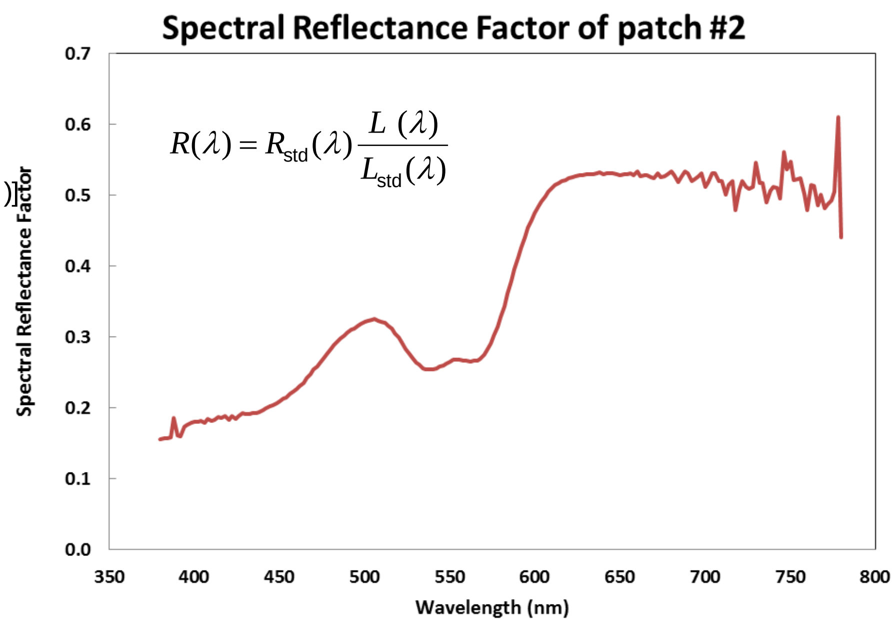
$$k = 100 \Big/ \int_{\lambda} E_{\mathrm{D65}}(\lambda)\bar{y}(\lambda)d\lambda$$

$$L^* = 116\times f(Y/Y_{\mathrm{n}}) - 16$$

$$a^* = 500\times[f(X/X_{\mathrm{n}}) - f(Y/Y_{\mathrm{n}})]$$

$$b^* = 200\times[f(Y/Y_{\mathrm{n}}) - f(Z/Z_{\mathrm{n}})]$$

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



Reference CIELAB Calculation

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

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

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

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

where $k = 100 \Big/ \int_{\lambda} E_{\mathrm{D65}}(\lambda)\bar{y}(\lambda)d\lambda$

The CIELAB values are then calculated by:

$$L^* = 116 \times f(Y/Y_{\mathrm{n}}) - 16$$

$$a^* = 500 \times [f(X/X_{\mathrm{n}}) - f(Y/Y_{\mathrm{n}})]$$

$$b^* = 200 \times [f(Y/Y_{\mathrm{n}}) - f(Z/Z_{\mathrm{n}})]$$

where

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

Using the following values for D65:
Xn= 0.95047
Yn= 1.0
Zn= 1.08883

NIST

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

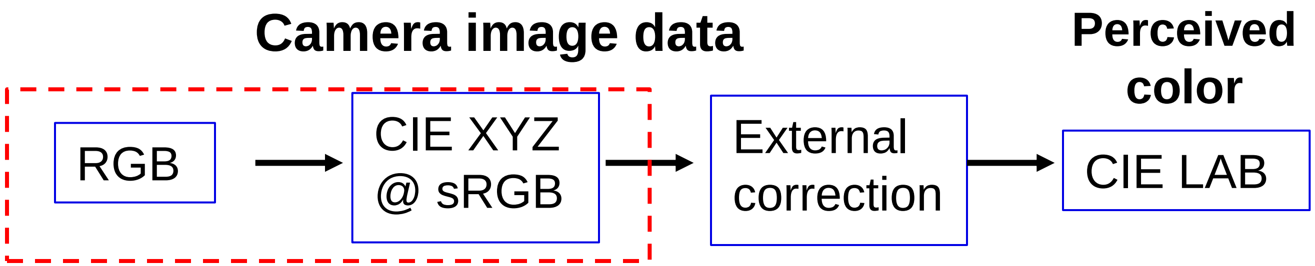
CIELAB values with D65 white:

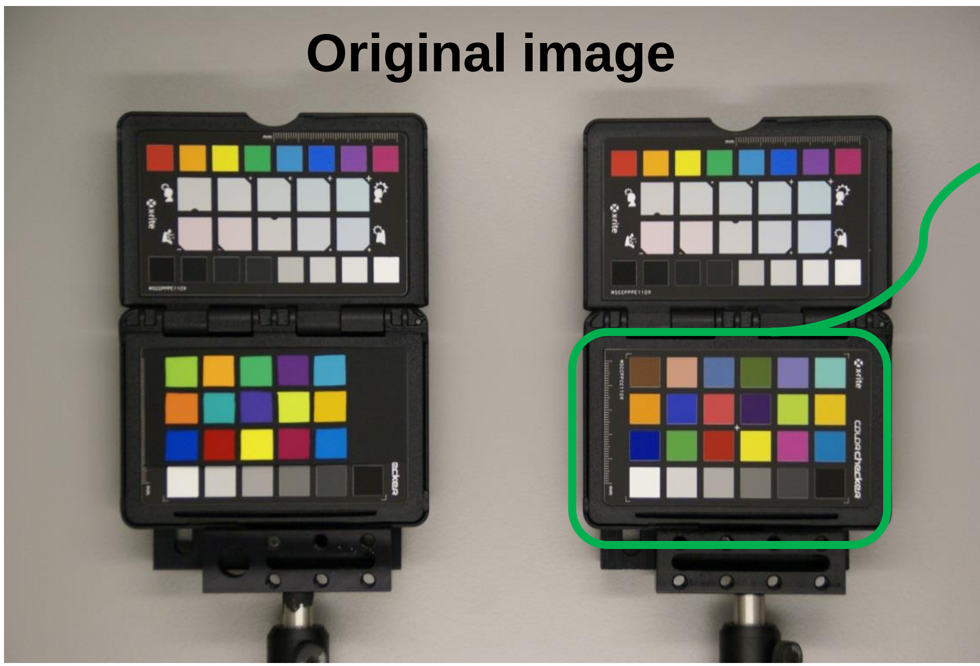
L*= 64.2

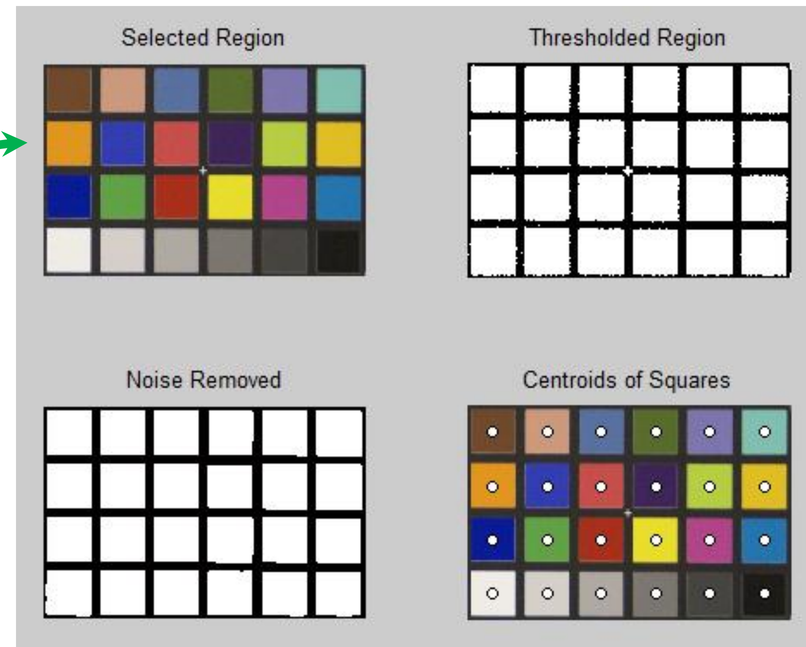
a*= 14.5

b*= 16.1

Color Data Extraction from Image File







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.

MATLAB software adapted from B. Tannenbaum webinar, Color image processing, July 10, 2007. http://www.mathworks.com/matlabcentral/fileexchange/15552-color-image-processing-webinar-files

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,

$$R'_{sRGB} = \frac{R}{255}$$
$$G'_{sRGB} = \frac{G}{255}$$
$$B'_{sRGB} = \frac{B}{255}$$

If R'_{sRGB}, G'_{sRGB}, B'_{sRGB} ≤0.04045,

$$R_{sRGB} = R'_{sRGB}/12.92$$
$$G_{sRGB} = G'_{sRGB}/12.92$$
$$B_{sRGB} = B'_{sRGB}/12.92$$

If R'_{sRGB}, G'_{sRGB}, B'_{sRGB} >0.04045,

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

Then calculate tristimulus values,

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.4124 & 0.3576 & 0.1805 \\ 0.2126 & 0.7152 & 0.0722 \\ 0.0193 & 0.1192 & 0.9505 \end{bmatrix} \begin{bmatrix} R_{sRGB} \\ G_{sRGB} \\ B_{sRGB} \end{bmatrix}$$

XYZ to CIELAB Calculation

Used procedure in CIE 15.2 (Colorimetry) to calculate the CIELAB values from the tristimulus XYZ values.

The CIELAB values are then calculated by:

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

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

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

Using the following values for D65:
Xn= 0.95047
Yn= 1.0
Zn= 1.08883

where

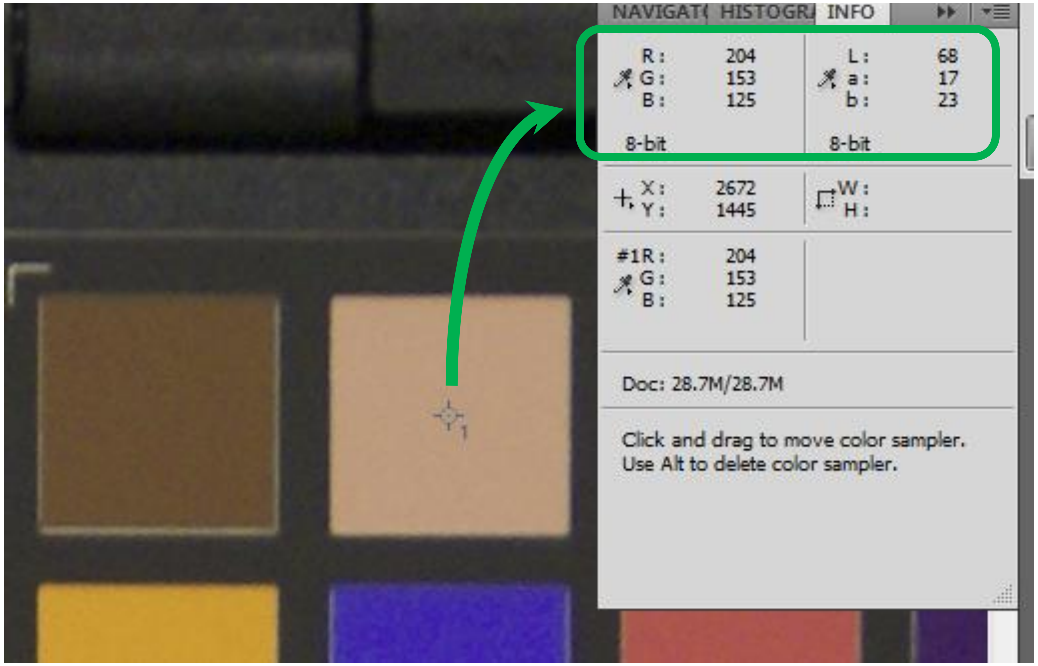
$$f(t) = \begin{cases} t^{1/3} & t > (6/29)^3 \\ \frac{1}{3}\left(\frac{29}{6}\right)^2 t + \frac{16}{116} & \text{otherwise} \end{cases}$$

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

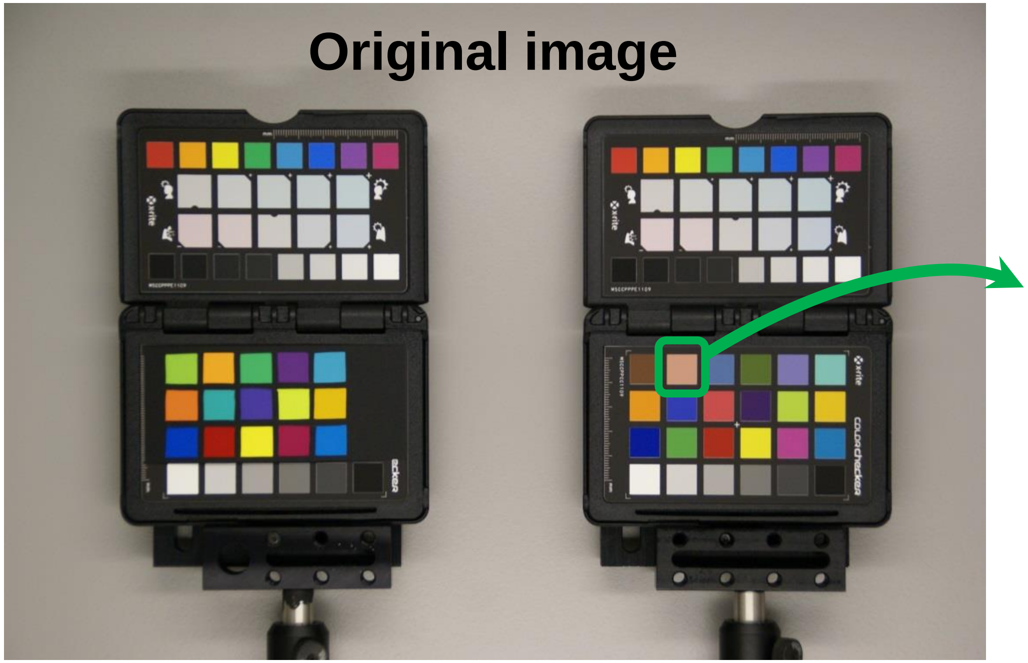
This corresponds well the values extracted using Matlab.

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:

$$\Delta E_{ab} = \sqrt{\left(L_2{}^* - L_1{}^*\right)^2 + \left(a_2{}^* - a_1{}^*\right)^2 + \left(b_2{}^* - b_1{}^*\right)^2}$$



For the flesh tone example:

$L^*_1 = 64.2$
$a^*_1 = 14.5$
$b^*_1 = 16.1$

$L^*_2 = 67.3$
$a^*_2 = 15.4$
$b^*_2 = 21.9$

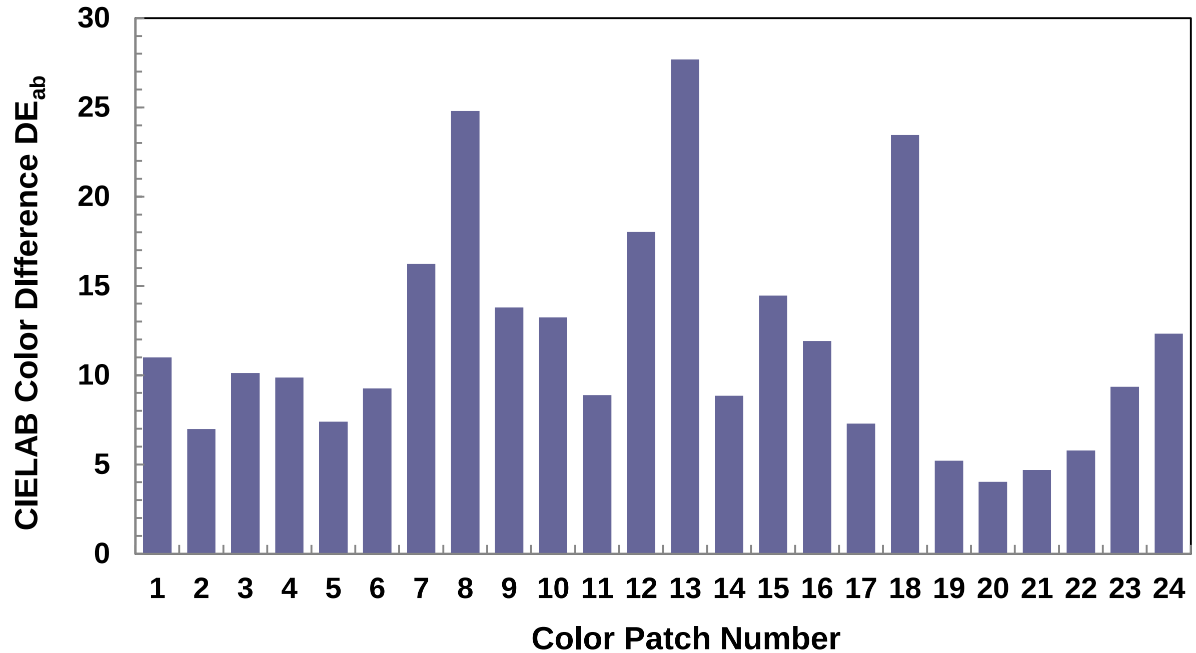
Therefore,

$\Delta E_{ab} = 6.7$

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



I. Gibson and P Green, Implementing Colour Appearance and Local Adaptation in Digital Photography, Proc. ICIS 2010

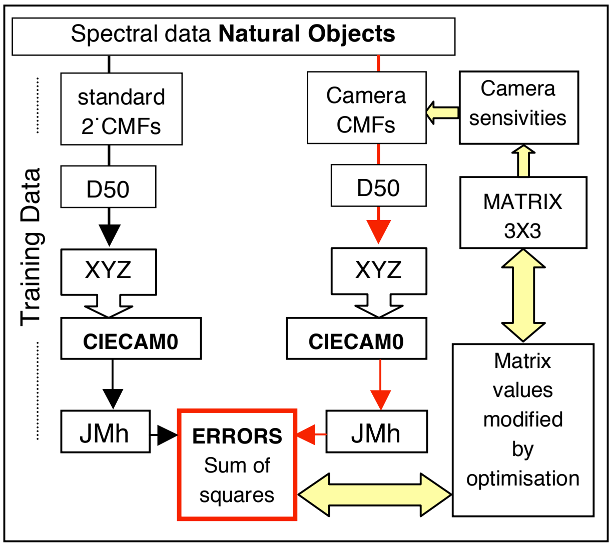


Figure 4 showing matrix optismation method

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 *La* is calculated from the image specific exposure, aperture and ISO settings, *La* 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 La for each of the above illuminants.

The example matrix shown in Table 1. is calculated for D50, *La* 781 cd/m2, *Yb* 20 and 'average' surround with the associated table of errors.

	R	G	B
X	0.717370848	0.214559415	0.032211208
Y	0.310217076	0.871240275	-0.181457352
Z	-0.001483855	-0.008537715	0.834946179

Natural Object Colors	5nm bandpass		
Deltas	L*a*b*	JCh	JMh
Avg	1.00	1.05	1.16
Max	5.46	5.72	6.39

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 *Xw, Yw, Zw* and *La* 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 *Yb* 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 *La* 30cd/m^2 ,*Yb* 20, white point of D65 and a 'Dim' surround and calculated from the appearance coordinates of JMh.

XYZto 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 a 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.

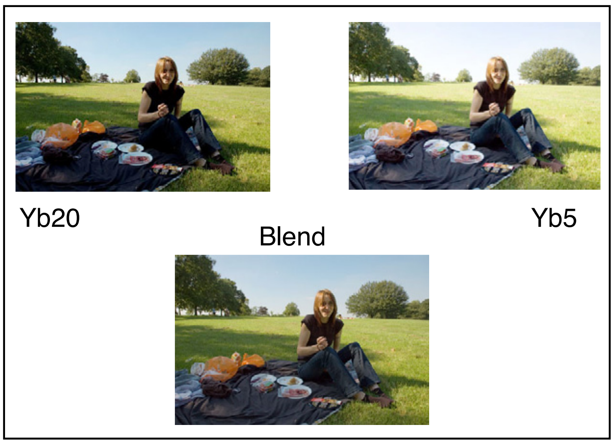


Figure 5. The same image was processed twice through CIECAM02 then blended in Photoshop®.

The setting that will be changed is the averaged luminance of the background *Yb*. This will be set to *Yb*=20 cd/m^2 for the first image to be processed as