INVESTIGATION OF DIGITAL COLOUR IMAGES

H. Ziemann[a], D. Grohmann[b]

[a] FB3, Anhalt University of Applied Sciences, 06846 Dessau, Germany, hziemann@afg.hs-anhalt.de
[b] Gropius-Institute, 06846 Dessau, Germany, grohmann@afg.hs-anhalt.de

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ABSTRACT:

Investigations were carried out for available digital image B,G,R data aiming at the derivation of a colour difference measure for the same scene areas imaged in several overlapping images of a photogrammetric bloc. The images were transformed first into the CIE XYZ tristimulus colour space and then into the approximately uniform CIE L*a*b* colour space using both, the known relative spectral sensitivity curves for each of the colour images and the colour matching functions for the 2º normal CIE observer. Colour differences ΔE for overlapping image areas within a photogrammetric bloc were determined. The results show that the ΔE values within the strip of photographs are relatively small while those to the neighbouring strip are significantly larger as can also be recognized by visual inspection of the images. As the colour transformations require the spectral characteristics of the light source, the effect of a change in illuminating light can be simulated.

1. INTRODUCTION

The human visual system is an excellent colour difference detector; however, even professionals are unable to exactly describe observed differences. It is desirable to describe observed colour differences with a single number. This number is known as ΔE; however, the symbol is used for a number of differently defined and therefore not identical measures. The CIE recommends e.g. three different ways, CIE 1976, CIE 1994 and CIE 2000. All of these require CIE L*a*b* colour coordinates.

As test material were available system-calibrated original B, G, R images of two overlapping models of digital images with approximately 60% forward-lap and 30% side-lap taken over a village at about 6:00 pm. The images were transformed first into the X, Y, Z colour space and afterwards into the CIE L*a*b* colour space. Gruber point patches were defined analogue to geometric evaluation procedures, and representative colour value derived.

This paper presents reviews of the colour transformations RGB to XYZ and XYZ to CIE L*a*b* and back, the determination of colour differences within the CIE L*a*b* space and the possibility of chromatic adaptation of images.

2. COLOUR TRANSFORMATION RGB⇒CIE XYZ

Colour images with the monochrome partial images R, G and B can be transformed into the CIE space if the spectral response of the sensors is known for the partial images, using the following set of equations:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \mathbf{M} \cdot \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

$$M = \begin{pmatrix} X_r & X_g & X_b \\ Y_r & Y_g & Y_b \\ Z_r & Z_g & Z_b \end{pmatrix} \circ \left[\begin{pmatrix} X_r & X_g & X_b \\ Y_r & Y_g & Y_b \\ Z_r & Z_g & Z_b \end{pmatrix}^{-1} \cdot \begin{pmatrix} X_w \\ Y_w \\ Z_w \end{pmatrix} \right]^T$$

$$Y_{b,g,r} = 1$$

$$X_{b,g,r} = x_{b,g,r} \cdot \frac{Y_{b,g,r}}{y_{b,g,r}}$$

$$Z_{b,g,r} = \left(1 - x_{b,g,r} - y_{b,g,r}\right) \cdot \frac{Y_{b,g,r}}{y_{b,g,r}}$$

The letters R, G and B represent the grey values scaled between 0 and 1 for the partial images. The indices r, g and b describe the colour properties of the respective partial images. The multiplication symbol "∘" indicates a scalar product.

The colour property values for each partial image are calculated as follows:

$$X_{b,g,r} = \frac{\sum_{\lambda=380nm}^{830nm} r_{b,g,r}(\lambda) \cdot \overline{x}_2(\lambda)}{\sum_{\lambda=380nm}^{830nm} \overline{y}_2(\lambda)}$$

$$Y_{b,g,r} = \frac{\sum_{\lambda=380nm}^{830nm} r_{b,g,r}(\lambda) \cdot \overline{y}_2(\lambda)}{\sum_{\lambda=380nm}^{830nm} \overline{y}_2(\lambda)}$$

$$Z_{b,g,r} = \frac{\sum_{\lambda=380nm}^{830nm} r_{b,g,r}(\lambda) \cdot \overline{z}_2(\lambda)}{\sum_{\lambda=380nm}^{830nm} \overline{y}_2(\lambda)}$$

$$x_{b,g,r} = \frac{X_{b,g,r}}{X_{b,g,r} + Y_{b,g,r} + Z_{b,g,r}}$$

$$y_{b,g,r} = \frac{Y_{b,g,r}}{X_{b,g,r} + Y_{b,g,r} + Z_{b,g,r}}$$

where $r_{b,g,r}(\lambda)$ represent the relative spectral sensitivity values and the bared values $x_2(\lambda)$, $y_2(\lambda)$, $z_2(\lambda)$ the CIE colour matching functions of the 2° normal observer.

It is common to graphically present CIE XYZ co-ordinates as a section through the colour space; the result is known as CIE xy diagram. It is derived using the formulas:

$$x = \frac{X}{X+Y+Z}$$
$$y = \frac{Y}{X+Y+Z}$$

3. COLOUR TRANSFORMATION XYZ⇒CIE L*a*b*

One of the disadvantages of the CIE XYZ colour space is the largely varying size of colour difference vectors as a function of location within that space. A number of attempts have been undertaken to find a solution to the problem. Although not implemented after a trial period of 12 years as CIE ISO standard, the CIE L*a*b* colour system is widely used today.

CIE XYZ co-ordinates are transformed into CIE L*a*b* co-ordinates as follows:

$$L^* = 116 \cdot f_y - 16$$
$$a^* = 500 \cdot \left(f_x - f_y\right)$$
$$b^* = 200 \cdot \left(f_y - f_z\right)$$

with

$$f_x = \begin{cases} \sqrt[3]{x_r} & \text{für } x_r > \varepsilon \\ \dfrac{\kappa \cdot x_r + 16}{116} & \text{für } x_r \leq \varepsilon \end{cases}$$

$$f_y = \begin{cases} \sqrt[3]{y_r} & \text{für } y_r > \varepsilon \\ \dfrac{\kappa \cdot y_r + 16}{116} & \text{für } y_r \leq \varepsilon \end{cases}$$

$$f_z = \begin{cases} \sqrt[3]{z_r} & \text{für } z_r > \varepsilon \\ \dfrac{\kappa \cdot z_r + 16}{116} & \text{für } z_r \leq \varepsilon \end{cases}$$

and

$$\varepsilon = \tfrac{216}{24389} \approx 0,00887$$
$$\kappa = \tfrac{24389}{27} \approx 903,29630$$

and also

$$x_r = \frac{X}{X_{LQ}}$$
$$y_r = \frac{Y}{Y_{LQ}}$$
$$z_r = \frac{Z}{Z_{LQ}}$$

It is important to note that the spectral characteristics of the light source are needed to perform the transformation.

4. COLOUR DIFFERENCE DEFINITIONS

The human visual system is an excellent colour difference detector; however, even professionals are unable to exactly describe observed differences. It is desirable to describe observed colour differences with a single number. This number is known as ΔE; however, the symbol is used for a number of differently defined, and therefore not identical, measures. The CIE recommends e.g. three different ways, CIE 1976, CIE 1994

and CIE 2000. All of these require CIE L*a*b* colour coordinates. The following auxiliary values

$$\Delta L = L_2 - L_1, \ \Delta a = a_2 - a_1 \text{ and } \Delta b = b_2 - b_1$$

led to a first definition:

CIE 1976: $\Delta E^2 = (L_2 - L_1)^2 + (a_2 - a_1)^2 + (b_2 - b_1)^2$.

This colour difference definition proved to be unsatisfactory in both, graphic and textile industries und was improved. Further following additional auxiliary values were introduced:

$$C_1^2 = a_1^2 + b_1^2, \ C_2^2 = a_2^2 + b_2^2, \ \Delta H^2 = \Delta a^2 + \Delta b^2 - \Delta C^2,$$
$$K_C = K_H = 1, \ S_L = 1, \ S_C = 1 + K_1 C_1^2, \ S_H = 1 + K_2 C_2^2;$$

in addition, the following two sets of constants were defined:

$$K_1 = 0,045, \ K_2 = 0,015, \ K_L = 1 \text{ for the graphic industry and}$$
$$K_1 = 0,048, \ K_2 = 0,014, \ K_L = 2 \text{ for the textile industry}$$

to defined a new colour difference:

CIE 1994: $\Delta E^2 = (\Delta L/(K_L S_L))^2 + (\Delta C/(K_C S_C))^2 + (\Delta H/(K_H S_H))^2$.

In this definition, ΔH represents a hue difference, ΔC a chroma difference and ΔL a luminance difference. The definition from 1994 appears to be for two specific groups only. A further definition requiring a further increased number of auxiliary values known as CIE 2000 will not be given here in detail.

It was decided to use the definition from 1976 for the investigation.

5. TEST IMAGES

As test material were available system-calibrated original B, G, R images of two overlapping models of digital images with approximately 60% forward-lap and 30% side-lap taken over a village on 14th July 2003 at about 6:00 pm. For the time of exposure a colour temperature of ~ 3500K was assumed for an

attempt to correct the image appearance towards images taken at about noon, see below. The images were transformed first into the X, Y, Z colour space and afterwards into the CIE L*a*b* colour space. Gruber points were defined analogue to geometric evaluation procedures; each point consisted of a patch of approximately 80 pixels. The values for those pixels were averaged to obtain a representative colour value. The following figure is an assembly of those four images with indicated "Gruber point" areas (red for points only in images of a single strip; blue for points in the overlapping area of the two strips)

6. COLOUR DIFFERENCE RESULTS

The results were determined as differences to the average for the same Gruber point. The following tables show first the results for a point located in model A/B of a single strip, and then for a point located in the two models A/B and C/D within the overlap area of two strips:

Image	L	a	b	ΔL'	Δa'	Δb'	ΔE
A	66.27	18.51	34.17	1.34	0.30	0.66	1.5
B	68.94	19.11	35.50	-1.34	-0.30	-0.66	1.5

Image	L	a	b	ΔL'	Δa'	Δb'	ΔE
A	69.14	2.25	16.52	-11.19	-0.27	-2.46	11.5
B	70.55	2.63	16.27	-12.60	-0.65	-2.50	12.9
C	43.85	1.82	10.86	14.10	0.16	3.21	14.5

The results show that the ΔE values within the strip of photographs are relatively small while those to the neighbouring strip are significantly larger. The numerical results are also recognized by visual inspection of the images. The differences indicate that the major contribution to the increase ΔE in the case of the overlapping models results from a difference ΔL', i.e. a luminance difference between the two strips.

7. COLOUR TRANSFORMATION CIE L*a*b* $\Rightarrow$ XYZ

The spectral characteristics of the light source must also be taken care of in the reverse transformation from CIE L*a*b* to XYZ colour co-ordinates:

$$X = x_r \cdot X_{LQ}$$
$$Y = y_r \cdot Y_{LQ}$$
$$Z = z_r \cdot Z_{LQ}$$

with

$$x_r = \begin{cases} f_x^3 & \forall f_x^3 > \varepsilon \\ \dfrac{116 \cdot f_x - 16}{\kappa} & \forall f_x^3 \le \varepsilon \end{cases}$$

$$y_r = \begin{cases} \left(\dfrac{L+16}{116}\right)^3 & \forall L > \varepsilon\kappa \\ \dfrac{L}{\kappa} & \forall L \le \varepsilon\kappa \end{cases}$$

$$z_r = \begin{cases} f_z^3 & \forall f_z^3 > \varepsilon \\ \dfrac{116 \cdot f_z - 16}{\kappa} & \forall f_z^3 \le \varepsilon \end{cases}$$

and

$$f_x = \frac{a}{500} + f_y$$

$$f_z = f_y - \frac{b}{200}$$

$$f_y = \begin{cases} \dfrac{L+16}{116} & \forall y_r > \varepsilon \\ \dfrac{\kappa \cdot y_r + 16}{116} & \forall y_r \le \varepsilon \end{cases}$$

using the same constants ε and κ as before.

7. CHROMATIC ADAPTATION OF IMAGES

One possible implication could be a change of the characteristics of the light source according to the time difference for the adjacent strips in order to decrease ΔE values of adjacent strips. A method called chromatic adoption is used to linearly transform between reference and destination light source. Parameters were calculated from the tri-stimulus colour co-ordinates of the two sources. A first step transforms the CIE X, Y, Z colour coordinates to a so-called "cone response domain", a second step scales the colour vectors within this domain, and a third step transforms the modified values back to tri-stimulus colour space. Three different definitions can be found in the literature for the cone response functions, CIE XYZ, von Kries and Bradford; the latter was first published in 1986 and has since been refined by Lam and Rigg (Hunt, 1975). It is considered the best method and is e.g. used in Adobe Photoshop.

The transformation of colour image data between two sets of CIE XYZ co-ordinates for different light sources is as follows:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_Z = \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_R^T \cdot M$$

$$\begin{pmatrix} \rho_R \\ \gamma_R \\ \beta_R \end{pmatrix} = \begin{pmatrix} X_R \\ Y_R \\ Z_R \end{pmatrix}^T \cdot M_A$$

$$\begin{pmatrix} \rho_Z \\ \gamma_Z \\ \beta_Z \end{pmatrix} = \begin{pmatrix} X_Z \\ Y_Z \\ Z_Z \end{pmatrix}^T \cdot M_A$$

$$M = M_A \cdot \begin{bmatrix} \frac{\rho_Z}{\rho_R} & 0 & 0 \\ 0 & \frac{\gamma_Z}{\gamma_R} & 0 \\ 0 & 0 & \frac{\beta_Z}{\beta_R} \end{bmatrix} \cdot M_A^{-1}$$

where the matrix M has different definitions such as

CIE XYZ:

$$M_A = M_A^{-1} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

von Kries:

$$M_A = \begin{bmatrix} 0,40024 & -0,22630 & 0,00000 \\ 0,70760 & 1,16532 & 0,00000 \\ -0,08081 & 0,04570 & 0,91822 \end{bmatrix}$$

$$M_A^{-1} = \begin{bmatrix} 1,859936 & 0,361191 & 0,000000 \\ -1,129382 & 0,638812 & 0,000000 \\ 0,219897 & -0,000006 & 1,089064 \end{bmatrix}$$

Bradford:

$$M_A = \begin{bmatrix} 0,8951 & -0,7502 & 0,0389 \\ 0,2664 & 1,7135 & -0,0685 \\ -0,1614 & 0,0367 & 1,0296 \end{bmatrix}$$

$$M_A^{-1} = \begin{bmatrix} 0,986993 & 0,432305 & -0,008529 \\ -0,147054 & 0,518360 & 0,040043 \\ 0,159963 & 0,049291 & 0,968487 \end{bmatrix}$$

The definition by Bradford was first published by the CIE in 1986 and further developed by Lam and Rigg; it is used in the given form since 1996, considered at present as best available method and used e.g. in Adobe Photoshop.

An image used in [Ziemann & Grohmann, 2006] was transformed from 6500K over 4500K to 2500K to show resulting colour changes; e.g. the greenish areas become increasingly bluish tinted.

8. SUMMARY AND CONCLUSIONS

Digital colour images were transformed from the R,G,B colour space to the CIE XYZ colour space and from there to the CIE L*a*b* colour space to determine colour differences ΔE in a space where equal colour differences are represented be vectors of approximately equal length. Colour differences were determined for overlapping areas of a small bloc of digital images, and the differences were found to be significantly larger between the two strips then within the two strips.

As the CIE L*a*b* colour space requires the introduction of a defined light source, the attempt was undertaken to perform a chromatic adaptation of colour images be introducing two different light sources; all light sources were defined by colour temperature. This process also required the reverse transformations, that is from CIE L*a*b* to CIE XYZ and from CIE XYZ to R, G, B, which were successfully applied on an available digital aerial image.

9. REFERENCES

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