HPC: Homework Exercise 2.6.1

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1 Introduction

In this assignment, we have to perform white balance and chromatic adaptation on given images. This allows us to transform images from source color (X_S, Y_S, Z_S) to destination color (X_D, Y_D, Z_D). But this transformation (M) depends on the source reference white and the destination reference white. The destination reference white is usually D65 but we don't always know the source reference white. So to estimate source reference white we are to implement three different methods in this assignment. Once we have the source reference white and destination reference white we can feed it to a chromatic adaptation algorithm to perform the transformation. In this assignment, I have used two different chromatic adaptation algorithms namely; Von Kries and CAT02.

$$\begin{pmatrix} X_D \\ Y_D \\ Z_D \end{pmatrix} = [M] \begin{pmatrix} X_S \\ Y_S \\ Z_S \end{pmatrix}$$

2 Pre-processing

Before performing chromatic adaptation, the input image must be manipulated to fit the requirements for the methods. Firstly, when the image is read, it must be changed to double and scaled to [0,1] range. Then the image must be transformed from sRGB color space to XYZ. For this I have created a function 'sRGB2XYZ'. To transform an image from sRGB to XYZ, it is first linearized and then transformed to XYZ using the following equations. Where C_{sRGB} are the R, G, and B values. The resulting XYZ values are also scaled to [0,1] range.

$$C_{linear} = \begin{cases} \frac{C_{sRGB}}{12.92} & \text{if } C_{sRGB} \leq 0.04045 \\ \frac{C_{sRGB}+0.055}{1+0.055} & \text{otherwise} \end{cases}$$

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

3 Source Reference White Estimation Methods

3.1 Method 1

To estimate source reference white using method 1, I created a function 'method1' that takes as input image in XYZ color space. In this method, the input image is transformed from XYZ color space to cone-response color space (LMS) using the equation given below.

$$\begin{pmatrix} L \\ M \\ S \end{pmatrix} = \begin{pmatrix} 0.4002 & 0.7076 & -0.0808 \\ -0.2263 & 1.1653 & 0.0457 \\ 0 & 0 & 0.9182 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

Then for each LMS response, an achromatic channel response is computed using the expression below. The LMS response that gives the maximum achromatic response is considered to be the source reference white. We can obtain the XYZ values from the input image at the same index as the LMS that gave maximum A. Figure 1 shows the achromatic response of an image.

$$A = 2L + M + \frac{1}{20}S$$

Figure 1: Achromatic response

3.2 Method 2

Another method to estimate source reference white in an image was to manually select a white point in the image. For this, I created a function 'method2' that takes as input an image in XYZ color space and the file name of the image. The function uses if/else conditions to find which image is being used and then selects XYZ from the given image at pre-defined coordinates. To determine these pixel coordinates, I opened each image in paint and noted the coordinates of the white pixel.

3.3 Method 3

Another method to estimate source reference white in an image is to assume that the average color data of the image is gray. For this method, I created a function 'method3' that takes as input image in sRGB color space. In this method I have taken the average of each channel in the image and then converted the average RGB to XYZ using 'sRGB2XYZ' function. Then I used these average XYZ to compute chromaticity coordinates using the equations below.

$$x_{av} = \frac{X}{X+Y+Z}$$
$$y_{av} = \frac{Y}{X+Y+Z}$$

Lastly, the chromaticity of the average color ($x_a v$,$y_a v$) along with luminance of a perfect white (Y=100) were used to compute the tristimulus values of the source reference white as given below.

$$X = \frac{x_{av}}{y_{av}}Y$$
$$Z = \frac{(1 - x_{av} - y_{av})}{y_{av}}Y$$

4 Chromatic Adaptation Methods

4.1 Von Kries

Once we have the source and destination reference white we can apply Von Kries for chromatic adaptation of the image from source color (X_S, Y_S, Z_S) to destination color (X_D, Y_D, Z_D) using transformation (M) that depends on the LMS response of source and destination reference white Lindbloom (2006). For this I have created a function 'vonKries' that takes as input the image in XYZ color space, source reference white estimated using methods discussed in the previous section, and destination reference white which is usually D65 and gives as output the corrected image in XYZ color space scaled to [0,1].

$$\begin{pmatrix} X_D \\ Y_D \\ Z_D \end{pmatrix} = [M] \begin{pmatrix} X_S \\ Y_S \\ Z_S \end{pmatrix}$$

[M] is given by the equation below. Where (L_D, M_D, S_D) is the cone-response of the destination reference white and (L_S, M_S, S_S) is the cone-response of the source reference white.

$$[M] = [M_A]^{-1} \begin{pmatrix} L_D/L_S & 0 & 0 \\ 0 & M_D/M_S & 0 \\ 0 & 0 & S_D/S_S \end{pmatrix} [M_A]$$

Where, $[M_A]$ and $[M_A]^{-1}$ are defined as:

$$[M_A] = \begin{pmatrix} 0.4002400 & 0.7076000 & -0.0808100 \\ -0.2263000 & 1.1653200 & 0.0457000 \\ 0.0000000 & 0.0000000 & 0.9182200 \end{pmatrix}$$

$$[M_A]^{-1} = \begin{pmatrix} 1.8599364 & -1.1293816 & 0.2198974 \\ 0.3611914 & 0.6388125 & -0.0000064 \\ 0.0000000 & 0.0000000 & 1.0890636 \end{pmatrix}$$

4.2 CAT02

Another chromatic adaptation method is CAT02 Wikipedia (2023). For this, I have created a function 'CAT02' that takes as input the image in XYZ color space, source reference white estimated using methods discussed in the previous section, and destination reference white which is usually D65 and gives as output the corrected image in XYZ color space scaled to [0,1]. The input image in XYZ color space is transformed to LMS cone-response color space using M_{CAT02} transformation matrix which is given below.

$$\begin{pmatrix} L \\ M \\ S \end{pmatrix} = M_{CAT02} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

$$M_{CAT02} = \begin{pmatrix} 0.7328 & 0.4296 & -0.1624 \\ -0.7036 & 1.6975 & 0.0061 \\ 0.0030 & 0.0136 & 0.9834 \end{pmatrix}$$

Once in LMS, the white point can be adapted to the desired degree by choosing the parameter D which is the degree of adaptation it can be set to zero for no adaptation and unity for complete adaptation (color constancy) so I decided to set it to unity. The adapted LMS are given by the equation below.

$$L_c = \left(\frac{Y_w L_{wr}}{Y_{wr} L_w} D + 1 - D \right) L$$

$$M_c = \left(\frac{Y_w M_{wr}}{Y_{wr} M_w} D + 1 - D \right) M$$

$$S_c = \left(\frac{Y_w S_{wr}}{Y_{wr} S_w} D + 1 - D \right) S$$

where parameters with w in subscript indicate source reference white and wr in subscript indicate destination reference white. Lastly, we transform the adapted LMS cone-response to XYZ color space using the equation below.

$$\begin{pmatrix} X_c \\ Y_c \\ Z_c \end{pmatrix} = [M_{CAT02}]^{-1} \begin{pmatrix} L_c \\ M_c \\ S_c \end{pmatrix}$$

5 Results

5.1 Method 1

(a) Original (b) Von Kries (c) CAT02

Figure 2

(a) Original (b) Von Kries (c) CAT02

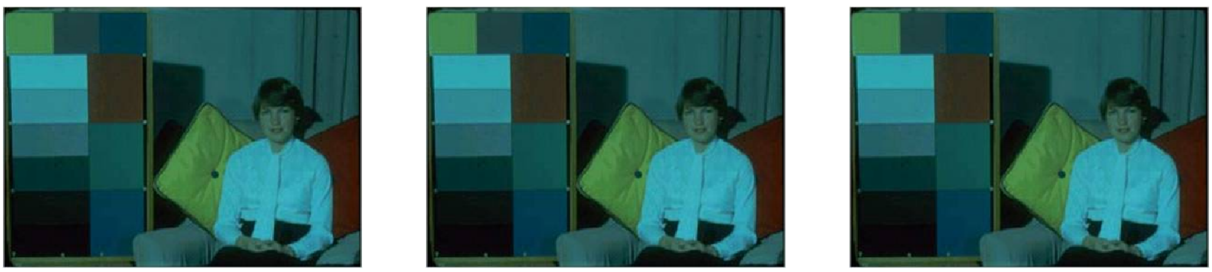
Figure 3

(a) Original (b) Von Kries (c) CAT02

Figure 4

(a) Original (b) Von Kries (c) CAT02

Figure 5



(a) Original (b) Von Kries (c) CAT02

Figure 6


(a) Original

(b) Von Kries

(c) CAT02

Figure 7


(a) Original

(b) Von Kries

(c) CAT02

Figure 8


(a) Original

(b) Von Kries

(c) CAT02

Figure 9


(a) Original

(b) Von Kries

(c) CAT02

Figure 10

5.2 Method 2


(a) Original

(b) Von Kries

(c) CAT02

Figure 11


(a) Original


(b) Von Kries


(c) CAT02

Figure 12


(a) Original


(b) Von Kries


(c) CAT02

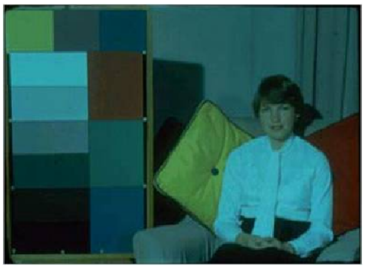
Figure 13

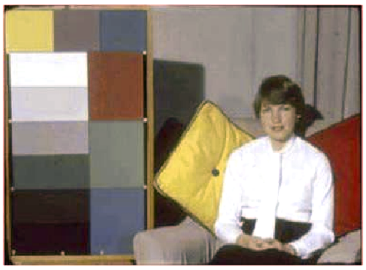

(a) Original


(b) Von Kries


(c) CAT02

Figure 14


(a) Original


(b) Von Kries

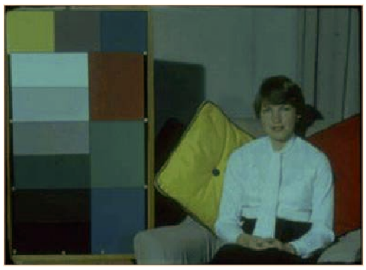

(c) CAT02

Figure 15


(a) Original


(b) Von Kries


(c) CAT02

Figure 16

(a) Original

(b) Von Kries

(c) CAT02

Figure 17

(a) Original

(b) Von Kries

(c) CAT02

Figure 18

(a) Original

(b) Von Kries

(c) CAT02

Figure 19

5.3 Method 3

(a) Original

(b) Von Kries

(c) CAT02

Figure 20

(a) Original

(b) Von Kries

(c) CAT02

Figure 21

(a) Original

(b) Von Kries

(c) CAT02

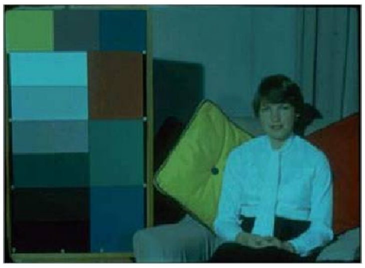
Figure 22

(a) Original

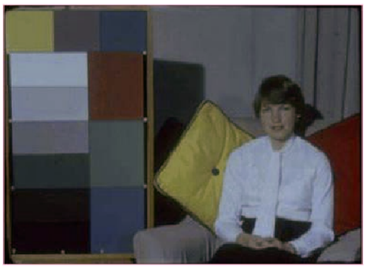
(b) Von Kries

(c) CAT02

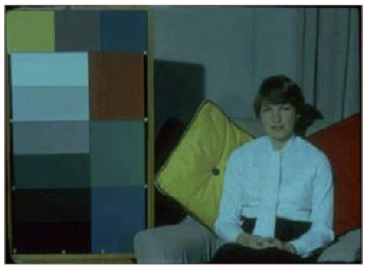
Figure 23



(a) Original



(b) Von Kries



(c) CAT02

Figure 24

(a) Original

(b) Von Kries

(c) CAT02

Figure 25

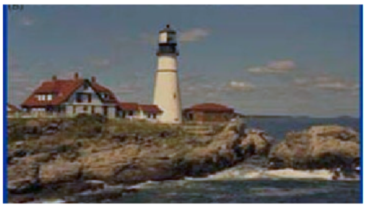
(a) Original

(b) Von Kries

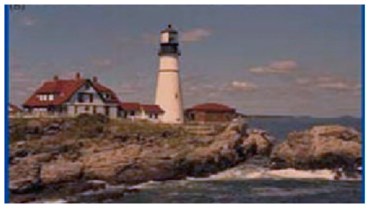
(c) CAT02

Figure 26

(a) Original



(b) Von Kries



(c) CAT02

Figure 27

(a) Original

(b) Von Kries

(c) CAT02

Figure 28

6 Analysis

From the results shown in the previous section, we can conclude that method 1 has shown poor results. We can notice no improvement in the white balancing of figure 6, 7, and 9. While in method 2 and method 3 we can notice a significant improvement in the white balancing of the same images shown in 15, 16, 18, and 24, 25, 27. If we compare the results of method 2 and method 3 in figures 16 and 25 respectively we can conclude that method 3 had better performance than method 2. We can also notice that in method 2 the resulting white-balanced images are a bit overexposed for e.g. if we compare white-balanced images of method 2 and method 3 in figure 15 and 24 respectively. We can conclude that amongst all three methods to estimate source reference white method 3 has shown to given better results.

References

Lindbloom, B. (2006, November 10). *Chromatic adaptation.* http://www.brucelindbloom.com/index.html?Eqn_ChromAdapt.html.

Wikipedia. (2023). *Ciecam02.* https://en.wikipedia.org/wiki/CIECAM02. ([Online; accessed 2-April-2023])