ECE 253, Homework 3

Due: Wednesday October 26, 2022 by 11:59pm

The first two problems should be done using Matlab, and the last two should be done by hand. Submit your homework electronically in Canvas on Gradescope. Everything can be uploaded as one PDF file– include your answers to each question and your Matlab code (cut and paste it in). Include your full name and PID.

1) **Chromaticity Diagrams**

The text file called cie contains color matching functions in the XYZ coordinate system. The format of the file is `wavelength X Y Z` from 380 nanometers to 780 nanometers. You can read it in using:

```
load cie -ascii
```

For this problem we ask you to include your plots as well as of your Matlab commands and interpretations.

(a) On one graph, plot the color matching functions, $X(\lambda), Y(\lambda), Z(\lambda)$. On another graph, plot the xy chromaticity diagram. Connect the "line of purples" on your diagram.

(b) In lecture 11, the conversion from the CIE RGB space to CIE XYZ space is given by the following linear transformation:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.49000 & 0.32000 & 0.2 \\ 0.17697 & 0.81240 & 0.01063 \\ 0 & 0.01 & 0.99000 \end{bmatrix} \begin{bmatrix} R_C \\ G_C \\ B_C \end{bmatrix}$$

Inside the xy chromaticity diagram for CIE XYZ space, plot the triangle that corresponds to the color gamut of the CIE RGB spectral primary system. You should use this 3x3 linear transformation to transform the coordinates in one system to the other system.

(c) The conversion from the CIE XYZ space to the NTSC receiver primary system R_N, G_N, B_N is given by the following linear transformation:

$$\begin{bmatrix} R_N \\ G_N \\ B_N \end{bmatrix} = \begin{bmatrix} 1.910 & -0.533 & -0.288 \\ -0.985 & 2.000 & -0.028 \\ 0.058 & -0.118 & 0.896 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

The Society of Motion Picture and Television Engineers (SMPTE) made its own receiver primary color coordinate system. The conversion from the CIE XYZ space to the SMPTE receiver primary system R_S, G_S, B_S is given by the following linear transformation:

$$\begin{bmatrix} R_S \\ G_S \\ B_S \end{bmatrix} = \begin{bmatrix} 3.508 & -1.741 & -0.544 \\ -1.069 & 1.977 & 0.035 \\ 0.056 & -0.197 & 1.051 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

Suppose there existed two sets of phosphors which exactly corresponded to the NTSC and SMPTE primaries. Inside the xy chromaticity diagram, plot the two triangles that correspond to the color gamuts of these two sets of phosphors. Does it appear that the NTSC or SMPTE primaries provide a larger gamut?

(d) On a separate plot of the xy chromaticity diagram, plot the triangle that corresponds to the color gamut of the CIE RGB spectral primary system, in which the monochromatic spectral primaries (Red=700nm, Green=546.1nm, Blue=435.8nm) were used for the original color matching experiment. In part (b), we already did this by using a 3x3 linear transformation to go between the CIE XYZ and CIE RGB color systems. However, in this part you should do this (in an approximate way) by directly using the data in the cie file.

2) **Contrast and saturation enhancement for color images**

Read the image PeopleWalking.jpeg into Matlab. It is of size 500 by 1110. If the image is called ”im”, you can break it into RGB color planes as follows:

```
>> r = im(:,:,1);
>> g = im(:,:,2);
>> b = im(:,:,3);
```

You can convert the RGB planes to HSI and back again using the routines rgb2hsi.m and hsi2rgb.m which are based on the formulation from Gonzalez and Woods (except that we keep the angles in radians, not degrees).

```
>> [h,s,i] = rgb2hsi(r,g,b);
```

The rgb2hsi routine expects inputs in the range of 0 to 255; check to be sure that your input ranges are correct. The h,s,i outputs from it are between 0 and 1. After processing in the HSI domain, you can convert back using hsi2rgb to obtain new RGB color planes For hsi2rgb.m, the h,s,i inputs must be between 0 and 1. The r,g,b outputs, however, are not necessarily restricted to the range 0–255.

(a) Use Matlab’s histeq command to equalize the intensity plane ”i”. Convert back to RGB using hsi2rgb.m. Then if the new color planes are called rHE, gHE, bHE you can put them together into a color image using:

```
imHE = reshape([rHE gHE bHE], 500, 1110, 3);
```

Provide your equalized image. Where do you see shifts in hue arising in the histogram equalized image? Give an explanation for why they occur in specific regions of the image.

(b) Going back to the HSI color planes before doing equalization, now we will try enhancing the saturation of this picture. First try creating a new saturation plane as newS = sqrt(s). How does the image look? Explain what you see. In particular, what happens to the woman's white hair and white shirt, and why does this happen?

(c) See if you can obtain more visually pleasing saturation enhancement results. Try one other transformation function of your choice on the saturation plane. Provide your image, a plot of your transformation function, and discussion of results.

3) **Change of Reference White**

We are given tristimulus values T_1, T_2 and T_3 for a color C. The tristimulus values are relative to a reference white W_1. In other words, for our color, the tristimulus values are given by

$$T_1(C) = \frac{A_1(C)}{A_1(W_1)}$$

$$T_2(C) = \frac{A_2(C)}{A_2(W_1)}$$

$$T_3(C) = \frac{A_3(C)}{A_3(W_1)}$$

You may interpret the A's as power knob settings in the color matching experiment. What would the new tristimulus values $\hat{T}_1$, $\hat{T}_2$, and $\hat{T}_3$ be for our color C in a coordinate system that uses the same primaries but uses a reference white W_2? Derive your expression in terms of the tristimulus values in the original coordinate system. So your expression for the $\hat{T}$'s should involve only T's and no A's.

4) **Adding Colors**

In some color system, color C has tristimulus values T_1, T_2 and T_3. Its chromaticity coordinates are $t_1 = 0.1$ and $t_2 = 0.1$. Let W denote the reference white for the color system. We form an additive mixture of colors: $A = \frac{1}{2}(C + W)$. (Note: The color A is in this problem has nothing to do with the A's in the previous problem. Here, A represents a color.)

a) What are the tristimulus values (call them $R, G,$ and B) for color A? What are the chromaticity coordinates for A? (Call them r and g.)

b) Within the chromaticity diagram, consider the line segment that goes from the chromaticity coordinates for C to the chromaticity coordinates for W. Show that color A is represented on the chromaticity diagram by a point on that line segment.