TNM059 – Grafisk teknik
Lab 3 – Färg

DEL 3 Laboration

Färg

Denna laboration innehåller ett antal uppgifter som ska lösas med hjälp av MATLAB. Era svar ska skrivas i dokumentet *Lab_3.3_Laboration_Svar.docx*, där ni dessutom infogar erforderliga bilder.
För att spara bilder, använd MATLAB-funktionen ***imwrite*** eller ***imsave***. Se till att spara bilderna i ett okomprimerad format, som *.tif* eller *.png*. Spara svarsdokumentet som *.pdf* innan ni lämnar in det på Lisam.
För uppgifterna i detta dokument behöver ni inte lämna in några m-filer, men vi rekommenderar starkt att ni sparar era experiment i en m-fil, ifall ni behöver gå tillbaka och rätta till något senare. Ibland kan ni återanvända era koder i senare uppgifter.
Alla bilder och funktioner som ni kommer att behöva finns på Lisam under *Kursdokument/Labbar/Lab3/files* och kan även nås via fliken *Laborationer* på kurssidans vänstermeny. Eftersom den här laborationen ursprungligen skrevs på engelska, kommer vi att behålla språket, men ni får gärna skriva era svar på svenska.

IMPORTANT: The first thing to do is to read the theory described in theory document (called **TheoryDocument_Lab3.pdf**), "Basic Color Science", thoroughly. **Without knowledge of that theory, the computer exercises will be useless**! Then you should be able to solve the preparation exercises and write the code ***spectra2xyz***.

1) Working with Spectral Power Distribution

In this assignment, we examine how to calculate tristimulus values from a spectral power distribution. Also, metamerism is going to be visualized. First, load some necessary variables available in the file *spectra.mat* and show their variable names: (In the document for part 2, i.e. ***spectra2xyz***, the necessary variables included in this file are described)

> *load spectra*
> *who*

Plot the *xyz* color matching functions with Matlab command:

> *plot(wavelength, xyz)*

Check that their appearance on the screen is similar to Fig. 1.2 in the theory document. Notice that the vector wavelength is a vector representing the visible wavelength interval 380:5:780 (nm), and the first, second and third columns in the matrix *xyz* include $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ functions, respectively.

1.1.

Calculate the white point of **CIED65**, by using your code ***spectra2xyz***, which was supposed to be written prior to this lab (part 2). When you call this function to calculate the white point of the illuminant: what should the parameter ***reflectance*** be and why? (**Hint:** read the first paragraph on page 66 in the course book (kompendium)). What values do you obtain, and do they agree with the values in Section 1.2 on the top of page 4 (second row) in the theory document? **If they don't agree**, then your code is not correct. Fix your code before you continue!
Write your answers in the answer document.

1.2.

Now plot the two reflectance functions *R1* and *R2*, for example by ***plot(wavelength, R1)*** for *R1* and similarly for *R2*. As you can see they differ quite a lot. Compare with the spectrum in Fig. 1.1 in the theory document and try to predict the colors of the two objects. Calculate the XYZ tristimulus values of the two objects, both illuminated with CIED65 (using your pre-written code ***spectra2xyz***). Write your answers in the answer document.

1.3.

Now we are going to change the illumination to a fluorescent lamp, representative of the three-band type. The emission is mainly concentrated to three narrow bands in the spectrum, designed to occur around wavelengths of approximately 435, 545, and 610nm. This kind of lamps tends to increase the saturation of most colors, making it attractive for some purposes, such as lighting goods in stores. However, the appearance of some colors can be somewhat distorted, so it is less suitable for critical evaluation of colors in general.
Change the illumination to *f11* (the CIE code for the lamp described above) and once again calculate the tristimulus values. Write your answers in the answer document.

1.4.

What has happened, and what is the term for the phenomenon? Write your answers in the answer document.

1.5.

Convert the four XYZ values to RGB values of the screen by using the transformation described in Eq. 1.9 and 1.10 (the prewritten function ***myxyz2rgb*** does that). Use the *help* command to see how you are supposed to call this function.
Create a color map of the four calculated RGB values, project the values into the monitor's color gamut, and create an image, which displays the four colors (two colors from assignment 1.2 and two colors from assignment 1.3):

```
> map=[r1 g1 b1; r2 g2 b2; ...];
> map=min(1,max(0,map));
> image([1 2; 3 4])
> colormap(map)
```

Insert this figure in the answer document.

Explain in what way the colors changed when switching to *f11*. What has happened to the white point in the xy chromaticity diagram when changing the light source? (**HINT:** look at **uppgift 3** in the preparation part of this lab). Towards which hue ("färgnyans eller kulör") has it moved? Does that show in the colors?

Now after you have done these assignments, answer the following questions.

1.6.

Explain briefly what color matching functions ($\bar{x}(\lambda)$, $\bar{y}(\lambda)$ and $\bar{z}(\lambda)$) are and what they represent. (**HINT:** Read pages 2 and 3 in the theory document and/or Section 6.3.1 in the course book)

1.7.

Explain why the CIEY-value of a light source is always equal to 100 by referring to Equation 1.4 in the theory document. (**HINT:** Read the beginning of page 66 in the course book)

2) Dot-on-Dot and Dot-off-Dot Halftoning

To know the exact color of an area of a halftone image, it is important to know if the halftone dots of the different inks are mainly on top of each other, or next to each other. There is a large difference between the two extreme cases—maximum overlap or minimum overlap. Let us now consider two printing colors: cyan and magenta. We wish to create a 50% blue. As blue is constructed by both cyan and magenta, it is natural to use 50% cyan coverage and 50% magenta coverage. Then the two extreme cases are (see also Fig. 2.1):

- **Left:** The two inks do not overlap at all, leaving no unprinted area. This is referred to as **dot-off-dot** printing.
- **Right:** The two inks are completely on top of each other, leaving 50% of the paper unprinted. This is referred to as **dot-on-dot** printing.

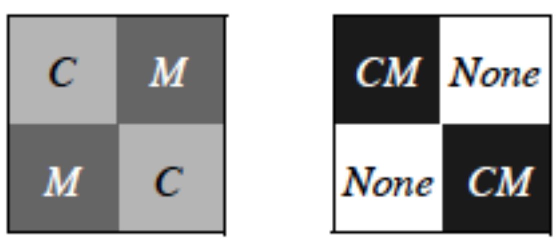

Fig 2.1: *The two extreme cases when creating blue by using 50% cyan and 50% magenta. Left: off-dot, and right: on-dot.*

2.1.

The following values have been measured, using the white point corresponding to *D65*:

Ink	X	Y	Z
None	80.43	84.00	96.50
Cyan	25.84	42.52	80.88
Magenta	37.36	18.44	27.52
Cyan & Mag.	7.40	5.74	40.36

Now use these values in Neugebauer's equations (Section 1.5 in the theory document) and calculate the perceived colors in the two extreme cases described earlier: (**HINT:** look at **uppgift 1** in the preparation part of this lab. **Just notice** that in the preparation assignment, for the sake of simplicity, you used other XYZ-values. In this assignment, though, you are supposed to use the XYZ-values in the above table). Write your answers in the table in the answer document.

2.2.

Convert the six XYZ values (i.e. the CIEXYZ values for None, Cyan, Magenta, Cyan & Mag., dot-off-dot and dot-on-dot) to RGB, create a color map, and show an image with these six colors, in the same manner as described earlier in Section 1.5. Insert your figure in the answer document. Is there a noticeable difference between dot-on-dot and dot-off-dot? For example, which one is darker? Why?

2.3.

You have now used the function ***myxyz2rgb*** a couple of times to convert color coordinates from RGB to XYZ. Could you use this function in all applications? Is this function device independent? (**HINT:** Think first about whether the RGB color system is device independent or dependent, as well as the XYZ color system. If one of them is device dependent and the other one independent, will the transformation from one of them to the other one be *independent* or *dependent* on the device?)

3) Color Halftoning According to Demichel

Read the CMYK-image called *halftone.tif* into MATLAB by:

> *[C, M, Y, K]=tiffread('halftone');*

Use the pre-written function *cmyk2rgb* to convert **C**, **M**, **Y**, and **K** to an **RGB** image, and display it:

> *[R, G, B]=cmyk2rgb(C, M, Y, K);*
> *imshowrgb(R, G, B)*

Each of the four-color channels can be displayed by for example:

> *imshow(C)*

The image is a halftoned version of the color constructed by: 30% cyan, 40% magenta, 50% yellow, and 10% black (Notice that these are exactly the same coverages being used in **uppgift 4** in the preparation part of this lab). The four binary matrices C, M, Y and K have the size 512×512 pixels. Because they are binary, logical operations may be performed on them. This fact can be used when calculating the fractional area covered with certain inks. For example, the fractional area covered with cyan and magenta, but not yellow or black is:

> *sum(sum(C & M & ~Y & ~K))/512^2*

3.1.

We are not going to use the whole image. Rather, we are going to choose a centered partition of size 256×256, for example:

> *C1=C(129:384,129:384);*

Do correspondingly for the other three channels. Then calculate the fractional coverages using the pre-written function ***Demichel_test***, for the sixteen possible ink combinations in four-color printing. Write the results in the table in the answer document in column 2, marked Test 1.
Try also to simulate misregistration by translating the choice of partition by ten to twenty positions in any direction, for one or several of the four matrices. For example, to shift 10 positions (pixels) downwards in the cyan channel, instead of *C1* above, you can use:

> *C2=C(139:394,129:384);*

Once more calculate the fractional coverages with the new matrices and write the results in the table in the answer document in column 3, marked Test 2. Describe also which channels and how many pixels and in each direction, you chose to simulate misregistration.

3.2.

In the preparation assignments (uppgift 4) in this lab, you already used Demichel's equations to approximate the fractional coverage for all 16 different ink combinations, which you wrote in column 1 in the table in the answer document. Now, compare column 1, 2 and 3 in this table. Are Demichel's equations a good model of the reality? Does it work reasonably well even when misregistration occurs?

3.3.

Notice that the four printing colors in the color halftone (*halftone.tif*) had different angles. What would have happened in case of misregistration if all the four printing colors had had the same screen angle? Would Demichel's equation be applicable? Why not? (**HINT:** read Section 7.3.1 in the course book)

4) Color Adjustment in CIELAB

Here, we are going to study how to adjust some color attributes of a CIELAB image, such as lightness, contrast, hue, and saturation. This kind of color manipulation is commonly performed in image processing software like Photoshop. Here we are going to perform these manipulations mathematically in Matlab, using the CIELAB color space. Read the image called *Butterfly.tif* by:

> *[R, G, B]=tiffread('Butterfly');*
> *imshowrgb(R ,G, B)*

When manipulations are made in CIELAB, one has to remember that the color gamut of the monitor limits what is possible to display. As an example: if colors are made extremely saturated, then most of the colors will have to be projected back into the monitor's color gamut to be displayed, yielding a distortion.

4.1.

Begin by converting the RGB image to CMYK, by using the pre-written ***rgb2cmyk*** function. Display them simultaneously. This is the kind of monochromic images that will be individually halftoned with different screen angels.

```
> [C, M, Y, K]=rgb2cmyk(R,G,B);
> figure(1)
> imshow(C)
> figure(2)
> imshow(M)
> figure(3)
> imshow(Y)
> figure(4)
> imshow(K)
```

The images seem inverted. Why is that the case? Refer to how the images will be used in the printing and halftoning processes. Look for example at the K image. What happens in the regions where K is light, and what happens in the regions where K is dark, when this image is printed. The same is valid for the other three channels as well. Answer in the answer document.

4.2.

Convert the image from RGB to CIELAB.

```
> [L, a, b]=myrgb2lab(R,G,B);
```

Test what happens if the values of L are translated up or down.

```
> [R2, G2, B2]=mylab2rgb(L+20, a, b);
> imshowrgb(R2, G2, B2)
> figure
> [R3, G3, B3]=mylab2rgb(L-20, a, b);
> imshowrgb(R3, G3, B3)
```

Insert these two images in the answer document and describe what attribute (among lightness, contrast, hue, and saturation) has been changed.

4.3.

Change sign for all **a***-values. Compare to Fig. 1.5 in the theory document. Then set all **a***-values to zero and predict what will happen (see the commands below). Were you right? Insert these two images in the answer document and describe what attribute (among lightness, contrast, hue, and saturation) of the color do we change when switching sign of **a*** or **b***.

> *[R2, G2, B2]=mylab2rgb(L, -a, b);*
> *[R2, G2, B2]=mylab2rgb(L, 0, b);*

4.4.

Now, scale the **a***- and **b***-values. Insert these two images in the answer document and describe what color attribute (among brig lightness, contrast, hue, and saturation) is now affected.

> *[R2, G2, B2]=mylab2rgb(L, 0.5*a, 0.5*b);*
> *[R2, G2, B2]=mylab2rgb(L, 3*a, 3*b);*

5) Light sources, CIEXYZ and CIELAB

In this part of the lab you are given three light sources, *CIED65*, *Tungsten60W* and *plank90K*, which are the ones that differ most among the light sources plotted in Figure 1.8 in the theory document.

5.1.

Calculate the CIEXYZ values of the white point for these three light sources (by your pre-written code ***spectra2xyz***) and convert them to RGB as you did before and show them on the screen by the function ***showRGB***. Insert this figure in the answer document. Observe that ***showRGB*** can take and show a number of RGB-values simultaneously (read the help text in the function). Are the colors of these three light sources what you expected? (**HINT:** look at the characteristic of these three light sources in Figure 1.8 in the theory document)

5.2.

The matrix *chips20* include the reflectance spectra for twenty different objects. Use the function ***showRGB_20*** to display the color of these twenty objects under the three light sources discussed above. Three windows will be opened and without looking at the code try to figure out which window corresponds to which light source. Insert these figures in the answer document and write which one of these three figures corresponds to which one of the three light sources.

As discussed in the course book and the theory document, one of the main advantages of the CIELAB color system to CIEXYZ is that the former one is a perceptually uniform color system, meaning that there is a correlation between the Euclidean distance between color coordinates and their perceptual color difference. The following equation is one of the equations used to obtain the color difference between two colors (L_1, a_1, b_1) and (L_2, a_2, b_2) in the CIELAB space:

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

5.3.

The function ***plot_deltaE*** plots the ΔE_{ab} color difference for the twenty objects in *chips20* under the three different illuminations. Use this function and study the plot and explain why the color differences between the color of the objects under **Tungsten** and **plank90k** are larger than those under the other two pairs of light sources. (**HINT:** look at the characteristic of these three light sources in Figure 1.8 in the theory document)

The rest of this lab is aimed at focusing on another advantage of CIELAB to CIEXYZ color system.

The function ***plot_XYZ*** plots the CIEXYZ values of the three light sources along with the CIEXYZ values of the twenty objects under these three light sources. The white points of the light sources are shown using **black circle (o)**, **red circle (o)** and **blue circle (o)** for *CIED65*, *Tungsten60W* and *plank90K*, respectively. The twenty objects under *CIED65*, *Tungsten60W* and *plank90K* are shown using **black (x)**, **red (*)** and **blue (+)**, respectively.

5.4.

First, notice that the light sources have different locations in the CIEXYZ space. However, all light sources have the same Y-value. What is this value? (You already answered this in assignment 1.7).

5.5.

Observe now the location of the twenty objects under these three illuminations in the CIEXYZ space. Notice that you can rotate the scene to see the positions more clearly. How do they move in XYZ-space when the illumination is changed? Do you agree that, when the illumination is changed, we get completely different positions in the XYZ space?

The function ***plot_Lab*** plots the CIELab values of the three light sources along with the CIELab values of the twenty objects under these three light sources. The white points of the light sources are shown using **black circle (o)**, **red circle (o)** and **blue circle (o)** for *CIED65*, *Tungsten60W* and *plank90K*, respectively. The twenty objects under *CIED65*, *Tungsten60W* and *plank90K* are shown using **black (x)**, **red (*)** and **blue (+)**, respectively.

5.6.

First, notice that you only see one light source (one black circle), meaning that all light sources have the same coordinate in the CIELAB space. What is the CIELab values of light sources and why? (**HINT:** Look at Equation 1.13 in the theory document and try to figure out the value of L, a and b if the X, Y and Z values correspond to the white point of a light source (which are denoted by Xn, Yn and Zn). You can also look at the explanation on page 76 in the course book)

5.7.

Observe now the location of the twenty objects under these three illuminants in CIELAB space. Notice that you can rotate the scene to see the positions more clearly.

How do they move when the illumination is changed? Do you agree that the position of each object in CIELAB color space is much more independent of the illumination compared to CIEXYZ color space?

5.8.

Discuss at least two differences between CIEXYZ and CIELAB. (**HINT:** read for example the beginning of Section 6.4.3 in the course book for one difference. For the second difference look at assignments 5.4 and 5.7 above)