Color Differences Lab

By Max Shooster and Malcolm Zale

Team 4

In this project, we have developed functions to calculate CIELab values from XYZ tristimulus values, and deltaEab color differences from pairs of CIELab values. We then calculate CIELab values for the real, imaged, and matching color patches measured in previous labs, and calculate the deltaEab color differences between pairs of patches. Finally, we plot the differences to determine if the imaged and matching patches are within 2.5 deltaEab of the given real patch.

Contents

Steps 1 - 3

Modified the ref2XYZ function created in Project 3 so that it can simultaneously process multiple reflectance spectra.

```
function XYZ = ref2XYZ(refs, cmfs, illum)
%compute XYZ from durface reflectance factor(s), color matching functions,
%and illuminant spectral power distribution
%can handle multiple refs simultaneously
%Function written by Jim Ferwerda

%compute normalizing constant for each illuminant
k = 100./(cmfs(:,2)'*illum);

%compute xyz

XYZ = k.*cmfs'*diag(illum)*refs;

end
```

```
cie = loadCIEdata;
CC_spectra = load('ColorChecker_380-780-5nm.txt');
CC_XYZs = ref2XYZ(CC_spectra(:,2:25), cie.cmf2deg, cie.illD65);
```

Steps 4 - 5

Created an XYZ2Lab function to calculate the CIELab values of the patches in the ColorChecker chart.

```
function Lab = XYZ2Lab(XYZ, XYZn)
y = (XYZ(2,:))/(XYZn(2));
x = (XYZ(1,:))/(XYZn(1));
z = (XYZ(3,:))/(XYZn(3));

%determines f(y)
if y > 0.008856
    y = y.^(1/3);
else
```

```
    y = 7.787 .*y +16/116;
end

%determines f(x)
if x > 0.008856
    x = x.^(1/3);
else
    x = 7.787 .*x +16/116;
end

%determiens f(z)
if z > 0.008856
    z = z.^(1/3);
else
    z = 7.787 .*z +16/116;
end

L = 116* y -16;
a = 500*(x-y);
b = 200*(y-z);

Lab = [L; a; b];
end
```

```
XYZn_D65 = ref2XYZ(cie.PRD, cie.cmf2deg, cie.illD65);

%Calculate the LAB values
CC_Labs = XYZ2Lab(CC_XYZs, XYZn_D65);

%read in the names of the ColorChecker Patches
names = textread('ColorChecker_names.txt', '%s' , 'delimiter' , '|');

%print the formatted table
% header
fprintf('\t\t\t Color Checker XYZ and Lab values (D65 illuminant and 2deg. observer)');
fprintf (' \n Patch# \t\t X \t\t Y \t\t Z \t\t L* \t\ta* \t b* \t Patch Name');

%loop to print patch values
for i=1:size(CC_Labs,2)
   fprintf(' \n     %d\t\t    %9.4f \t    %9.4f\t   %9.4f\t   %9.4f\t  %9.4f %9.4f \t %s',...
       i,CC_XYZs(:,i), CC_Labs(:,i),names{i});
end
fprintf('\n\n');
```

Color Checker XYZ and Lab values (D65 illuminant and 2deg. observer)

Patch#	X	Y	Z	L*	a*	b*	Patch Name
1	11.5145	10.3819	7.1502	38.5192	12.4105	13.3086	Dark Skin
2	39.1346	36.5981	27.0564	66.9744	14.3293	17.3201	Light Skin
3	18.3488	19.6332	35.6470	51.4199	-1.6243	-21.6029	Blue Sky
4	11.1492	13.8551	7.4267	44.0244	-13.9633	21.7735	Foliage
5	25.8437	24.3868	45.6142	56.4730	11.5442	-24.6979	Blue Flower
6	31.7110	43.8600	44.8778	72.1348	-33.1015	3.1149	Bluish Green
7	37.1457	29.5592	6.5006	61.2720	32.4974	55.0590	Orange
8	13.8627	12.3179	39.3093	41.7169	14.4162	-42.8998	Purplish Blue
9	29.1328	19.8475	14.9941	51.6643	45.4684	13.3816	Moderate Red
10	8.5889	6.4569	15.4745	30.5371	23.7846	-24.1361	Purple
11	33.9174	44.1533	11.4297	72.3309	-26.0831	57.9482	Yellow Green
12	46.1864	42.4957	8.6771	71.2114	17.1873	64.2972	Orange Yellow
13	8.9183	6.4177	32.2736	30.4428	27.0237	-53.2773	Blue
14	15.0353	24.1079	9.6379	56.1956	-40.7711	35.3416	Green
15	19.3447	11.3576	5.5526	40.1763	51.9757	22.6886	Red
16	55.8457	58.9726	9.6411	81.2765	-0.5083	78.5745	Yellow

17	29.6768	19.3515	32.2626	51.0960	50.0036	-17.6531	Magenta
18	14.4138	19.9750	39.0008	51.8089	-25.6415	-25.1262	Cyan
19	87.8402	92.3781	95.6125	96.9746	0.0764	3.2618	White
20	57.9621	61.0426	65.4909	82.4016	-0.1330	0.8313	Neutral 8
21	35.2286	37.0414	40.2256	67.3081	0.0793	0.1249	Neutral 6.5
22	19.3492	20.4708	22.1545	52.3654	-0.5407	0.2370	Neutral 5
23	8.7646	9.2915	10.3188	36.5395	-0.5681	-0.5997	Neutral 3.5
24	3.2111	3.3763	3.9312	21.4922	0.0351	-1.4617	Black

Step 6

Modified data to account for dark colors.

```
%multiplies every value in CCXYZ by .02 to make them darker
dCC_XYZs = CC_XYZs.* 0.02;

%converts the darker XYZ values to LAB
dCC_Labs = XYZ2Lab(dCC_XYZs, XYZn_D65);

%Reprints the table from step 5
fprintf('\t\t\t Color Checker (Dark) XYZ and Lab values (D65 illuminant and 2deg. observer)');
fprintf (' \n Patch# \t\t X \t\t Y \t\t Z \t\t L* \t\t a* \t b* \t Patch Name');

%loop to print patch values
for i=1:size(CC_Labs,2)
    fprintf('\n     %d\t\t   %9.4f \t   %9.4f \t   %9.4f        %9.4f  \t   %9.4f%9.4f    %s ', ...
        i,dCC_XYZs(:,i), dCC_Labs(:,i),names{i});
end
fprintf('\n')
```

Color Checker (Dark) XYZ and Lab values (D65 illuminant and 2deg. observer)

Patch#	X	Y	Z	L*	a*	b*	Patch Name
1	0.2303	0.2076	0.1430	1.8756	1.3497	1.1882	Dark Skin
2	0.7827	0.7320	0.5411	6.6118	3.5645	3.6594	Light Skin
3	0.3670	0.3927	0.7129	3.5469	-0.2549	-4.0824	Blue Sky
4	0.2230	0.2771	0.1485	2.5030	-1.6543	2.1910	Foliage
5	0.5169	0.4877	0.9123	4.4057	2.1841	-5.4531	Blue Flower
6	0.6342	0.8772	0.8976	7.9237	-8.1725	0.8230	Bluish Green
7	0.7429	0.5912	0.1300	5.3401	7.4163	7.3474	Orange
8	0.2773	0.2464	0.7862	2.2253	1.7660	-7.4087	Purplish Blue
9	0.5827	0.3969	0.2999	3.5856	8.4137	1.8926	Moderate Red
10	0.1718	0.1291	0.3095	1.1665	2.0090	-2.4157	Purple
11	0.6783	0.8831	0.2286	7.9767	-6.5932	10.4831	Yellow Green
12	0.9237	0.8499	0.1735	7.6772	4.7497	10.7543	Orange Yellow
13	0.1784	0.1284	0.6455	1.1594	2.3094	-7.2337	Blue
14	0.3007	0.4822	0.1928	4.3553	-6.4542	4.7519	Green
15	0.3869	0.2272	0.1111	2.0518	7.0052	1.9492	Red
16	1.1169	1.1795	0.1928	10.6539	-0.1668	15.6107	Yellow
17	0.5935	0.3870	0.6453	3.4960	9.2456	-3.2019	Magenta
18	0.2883	0.3995	0.7800	3.6086	-3.7451	-4.9354	Cyan
19	1.7568	1.8476	1.9123	16.6889	0.0339	1.4214	White
20	1.1592	1.2209	1.3098	11.0279	-0.0447	0.2781	Neutral 8
21	0.7046	0.7408	0.8045	6.6918	0.0191	0.0301	Neutral 6.5
22	0.3870	0.4094	0.4431	3.6982	-0.0876	0.0384	Neutral 5
23	0.1753	0.1858	0.2064	1.6786	-0.0543	-0.0579	Neutral 3.5
24	0.0642	0.0675	0.0786	0.6100	0.0017	-0.0730	Black

Steps 7 - 8

Created a function DEab = deltaEab (Lab1, Lab2) that implements the deltaEab color difference metric. Then, tested the deltaEab function by calculating the deltaEab color differences between two sets of spectral data.

```
function DEab = deltaEab(Lab1, Lab2)
%DELTAEAB Implements deltaEab Color Difference Metric
DEab = sqrt((Lab2(1,:) - Lab1(1,:)).^2 + (Lab2(2,:) - Lab1(2,:)).^2 + (Lab2(3,:) - Lab1(3,:)).^2);
end
```

```
%Calculate deltaEab color differences between two datasets
%Calculate for illuminant D65
CC_sample = load('MetaChecker_380-780-5nm.txt');
CC_XYZsample = ref2XYZ(CC_sample(:,2:25), cie.cmf2deg, cie.illD65);
CC_Labssample = XYZ2Lab(CC_XYZsample, XYZn_D65);
Color_Differences_D = deltaEab(CC_Labssample, CC_Labs);

%Calculate for illuminant A
XYZn_A = ref2XYZ(cie.PRD, cie.cmf2deg, cie.illA);
CC_XYZsA = ref2XYZ(CC_spectra(:,2:25), cie.cmf2deg, cie.illA);
CC_LabsA = XYZ2Lab(CC_XYZsA, XYZn_A);
CC_XYZsampleA = ref2XYZ(CC_sample(:,2:25), cie.cmf2deg, cie.illA);
CC_LabssampleA = XYZ2Lab(CC_XYZsampleA, XYZn_A);
Color_Differences_A = deltaEab(CC_LabssampleA, CC_LabsA);

%Print out the data to stdout
fprintf('\n\t\t\t ColorChecker and MetaChecker Color Differences');
fprintf (' \n\n Patch # \t\t  DEab(D65) \t\t  DEab(illA)');
fprintf('\n')
for i=1:size(Color_Differences_A,2)
    fprintf('\n       %d\t\t %d \t\t %9.3f', ...
        i, Color_Differences_D(:,i), Color_Differences_A(:,i));
end
fprintf('\n')
```

```
                        ColorChecker and MetaChecker Color Differences

 Patch #                  DEab(D65)               DEab(illA)

       1                 2.597378e-07              22.636
       2                 1.136098e-07              22.178
       3                 1.055877e-07              32.275
       4                 1.904523e-07              28.232
       5                 3.979834e-07              25.937
       6                 1.326305e-07              29.487
       7                 8.581245e-08              17.309
       8                 1.453749e-07              27.241
       9                 1.665224e-07              12.210
       10                2.907378e-07              19.509
       11                1.560836e-07              22.623
       12                1.304694e-07              16.970
       13                1.083275e-07              20.083
       14                1.193293e-07              26.099
       15                6.707831e-08               7.053
       16                1.329748e-07              11.532
       17                6.468134e-09              10.690
       18                8.581325e-08              31.619
       19                2.660645e-07               2.545
       20                6.947658e-08              15.940
       21                1.846291e-07              28.926
       22                8.337354e-08              26.751
       23                3.667644e-07              20.574
       24                1.022093e-07              18.567
```

Step 9

Use XYZ2Lab and deltaEab functions to calculate CIELab values and color differences for real, imaged and matching color patches.

```
%import calculated XYZ values
% For 28.1 Patch
fileID = fopen('Calculated_Real.txt');
Values = textscan(fileID, '%f %f %f');
Real_Calc_vals_1 =  cell2mat(Values)';
Real_Calc_vals_1 =  Real_Calc_vals_1(1:3)';
fclose(fileID);
fileID = fopen('Calculated_Imaged.txt');
Values = textscan(fileID, '%f %f %f');
Imaged_Calc_vals_1 = cell2mat(Values)';
Imaged_Calc_vals_1 = Imaged_Calc_vals_1(1:3)';
fclose(fileID);
fileID = fopen('Calculated_Matching.txt');
Values = textscan(fileID, '%f %f %f');
Matching_Calc_vals_1 = cell2mat(Values)';
Matching_Calc_vals_1 = Matching_Calc_vals_1(1:3)';
fclose(fileID);

% For 28.2 Patch
fileID = fopen('Calculated_Real.txt');
Values = textscan(fileID, '%f %f %f');
Real_Calc_vals_2 =  cell2mat(Values)';
Real_Calc_vals_2 =  Real_Calc_vals_2(1:3,2);
fclose(fileID);
fileID = fopen('Calculated_Imaged.txt');
Values = textscan(fileID, '%f %f %f');
Imaged_Calc_vals_2 = cell2mat(Values)';
Imaged_Calc_vals_2 = Imaged_Calc_vals_2(1:3,2);
fclose(fileID);
fileID = fopen('Calculated_Matching.txt');
Values = textscan(fileID, '%f %f %f');
Matching_Calc_vals_2 = cell2mat(Values)';
Matching_Calc_vals_2 = Matching_Calc_vals_2(1:3,2);
fclose(fileID);


% Use XYZ2Lab function to calculate the CIELab values of patches from XYZ values
XYZn_D50 = ref2XYZ(cie.PRD, cie.cmf2deg, cie.illD50);
real28_1= XYZ2Lab(Real_Calc_vals_1, XYZn_D50);
imaged28_1 = XYZ2Lab(Imaged_Calc_vals_1, XYZn_D50);
matching28_1 = XYZ2Lab(Matching_Calc_vals_1, XYZn_D50);
real28_2= XYZ2Lab(Real_Calc_vals_2, XYZn_D50);
imaged28_2 = XYZ2Lab(Imaged_Calc_vals_2, XYZn_D50);
matching28_2 = XYZ2Lab(Matching_Calc_vals_2, XYZn_D50);

% Use deltaEab function to calculate color differences between each of the real patches and their corresponding image
d and matched patches
Color_Differences_28p1_Img = deltaEab(real28_1, imaged28_1);
Color_Differences_28p1_Mtch = deltaEab(real28_1, matching28_1);
Color_Differences_28p2_Img = deltaEab(real28_2, imaged28_2);
Color_Differences_28p2_Mtch = deltaEab(real28_2, matching28_2);

%Print out the data to stdout
fprintf('\n\t\t\t\t Calculated XYZ, Lab, and deltaEab values (w.r.t real patches)\n');
fprintf ('\n\t\t\t\t\t\t    Patch 28.1');
fprintf (' \n \t\tX \t\t Y \t\t Z \t\t L \t\ta \t\t b \t\t dEab');
fprintf('\n  %s\t %8f \t  %10f \t %10f \t % 10f \t % 10f \t %10f\n', ...
'real', Real_Calc_vals_1', real28_1);
fprintf('%s\t %8f \t  %10f \t %10f \t % 10f \t % 10f \t %10f\t\t%10f\n', ...
'imaged', Imaged_Calc_vals_1, imaged28_1, Color_Differences_28p1_Img);
fprintf('%s %8f \t  %10f \t %10f \t % 10f \t % 10f \t %10f\t\t%10f\n', ...
'matching', Matching_Calc_vals_1, matching28_1, Color_Differences_28p1_Mtch);
fprintf('\n')
```

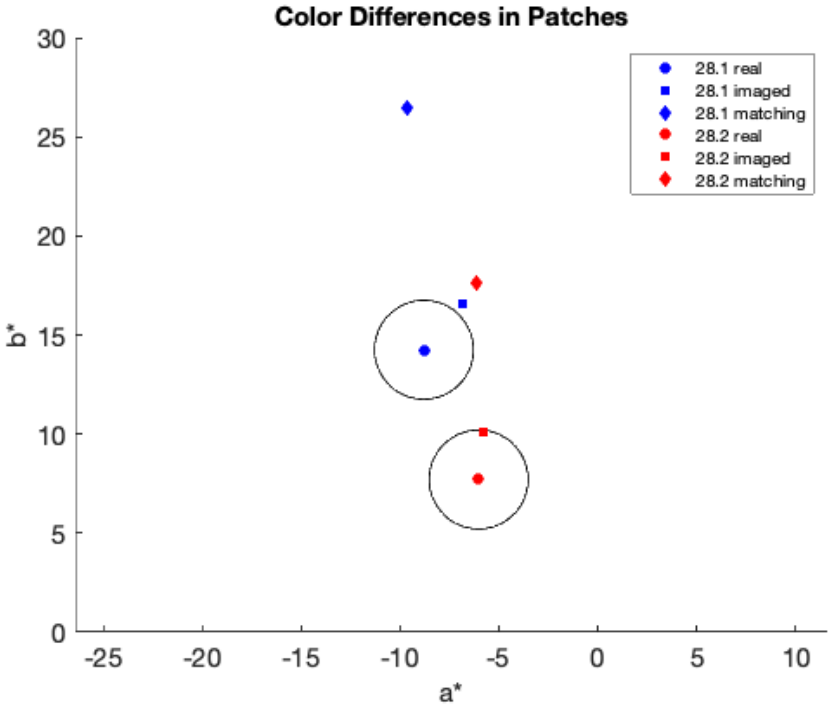
```
fprintf ('\n\t\t\t\t\t\t    Patch 28.2');
fprintf (' \n \t\tX \t\t Y \t\t Z \t\t L \t\ta \t\t b \t\t dEab');
fprintf('\n  %s\t %8f \t  %10f \t %10f \t % 10f \t % 10f \t %10f\n', ...
'real', Real_Calc_vals_2', real28_2);
fprintf('%s\t %8f \t  %10f \t %10f \t % 10f \t % 10f \t %10f\t\t%10f\n', ...
'imaged', Imaged_Calc_vals_2', imaged28_2, Color_Differences_28p2_Img);
fprintf('%s %8f \t  %10f \t %10f \t % 10f \t % 10f \t %10f\t\t%10f\n', ...
'matching', Matching_Calc_vals_2', matching28_2, Color_Differences_28p2_Mtch);

fprintf('\n')
```

```
                        Calculated XYZ, Lab, and deltaEab values (w.r.t real patches)

                                                Patch 28.1
                X                Y                Z                L                a                b              dEab
  real    34.220571        38.200633        23.121053        68.168226        -8.787131        14.250090
imaged    26.400970        29.155587        16.134726        60.918697        -6.865765        16.540437         7.8
41748
matching 43.516594         48.631933        23.090876        75.221771        -9.665823        26.468334        14.1
35419


                                                Patch 28.2
                X                Y                Z                L                a                b              dEab
  real    27.817479        30.457476        21.066850        62.046954        -6.023040         7.692642
imaged    17.062978        18.820423        11.789882        50.476444        -5.820089        10.062507        11.8
12457
matching 31.462863         34.413566        18.994412        65.289518        -6.155802        17.587961        10.4
13894
```

Step 10

Visualize the color differences between the real, imaged, and matching patches.

```
figure;
hold on;
% Adjust the font size of the graph
set(gca,'FontSize',15)
centers1 = [real28_1(2), real28_1(3)];
centers2 = [real28_2(2), real28_2(3)];
viscircles(centers1, 2.5, 'Color','k', 'LineWidth', 1);
viscircles(centers2, 2.5, 'Color','k','LineWidth', 1);
plot(real28_1(2), real28_1(3), 'ob', 'LineWidth', 1, 'MarkerFaceColor', 'b');
plot(imaged28_1(2), imaged28_1(3), 'sb', 'LineWidth', 1, 'MarkerFaceColor', 'b');
plot(matching28_1(2), matching28_1(3), 'db', 'LineWidth', 1, 'MarkerFaceColor', 'b');
plot(real28_2(2), real28_2(3), 'or', 'LineWidth', 1, 'MarkerFaceColor', 'r')
plot(imaged28_2(2), imaged28_2(3), 'sr', 'LineWidth', 1, 'MarkerFaceColor', 'r')
plot(matching28_2(2), matching28_2(3), 'dr', 'LineWidth', 1, 'MarkerFaceColor', 'r')
xlabel('a*', 'FontSize', 15)
ylabel('b*', 'FontSize', 15)
title('Color Differences in Patches', 'FontSize', 15)
lgd = legend('28.1 real', '28.1 imaged', '28.1 matching', ...
'28.2 real', '28.2 imaged', '28.2 matching', 'FontSize', 10);
lgd.Location = 'northeast';
lgd.LineWidth = 1;
axis([-15,5,0 30]);
axis equal;
```



Feedback

Malcolm did steps 1-6. Max did steps 7-11, adjusted formatting on print statements and improved style for the published document. Max personally did not have any problems with the project besides some minor issues indexing on the data to start. Max enjoyed furthering his knowledge on the material in class in a lab setting. Max cannot think of any ways to heavily improve the lab. Malcom did not struggle with the lab report apart from fprintf statements. Malcolm enjoyed building the XYZ2LAB function.

Published with MATLAB® R2019b