Project 4 Report

Team 5: Shakira Garnett, Hridiza Roy

Contents

Initialization

```
clear all; close all; clc;

% load the CIE observer and illuminant data
cie = loadCIEdata;
```

Step 2

Include a listing of the ref2XYZ function

```
function XYZ = ref2XYZ(ref,cmfs,ill);
% simple version of ref2XYZ that doesn't use matrix mults

%compute normalizing constant for the illuminant
k = 100./sum(cmfs(:,2).*ill);

%compute the XYZs
X = k.*sum(cmfs(:,1).*ill.*ref);
Y = k.*sum(cmfs(:,2).*ill.*ref);
Z = k.*sum(cmfs(:,3).*ill.*ref);

% return them in a 3xn array
XYZ = [X;Y;Z];

end
```

Step 3

Test ref2XYZ function

```
CC_spectra = load('ColorChecker_380-780-5nm.txt');
```

```
CC_XYZs = ref2XYZ(CC_spectra(:, 2:25), cie.cmf2deg, cie.illD65)
```

```
CC_XYZs =

  Columns 1 through 7

   11.5145   39.1346   18.3488   11.1492   25.8437   31.7110   37.1457
   10.3819   36.5981   19.6332   13.8551   24.3868   43.8600   29.5592
    7.1502   27.0564   35.6470    7.4267   45.6142   44.8778    6.5006

  Columns 8 through 14

   13.8627   29.1328    8.5889   33.9174   46.1864    8.9183   15.0353
   12.3179   19.8475    6.4569   44.1533   42.4957    6.4177   24.1079
   39.3093   14.9941   15.4745   11.4297    8.6771   32.2736    9.6379

  Columns 15 through 21

   19.3447   55.8457   29.6768   14.4138   87.8402   57.9621   35.2286
   11.3576   58.9726   19.3515   19.9750   92.3781   61.0426   37.0414
    5.5526    9.6411   32.2626   39.0008   95.6125   65.4909   40.2256

  Columns 22 through 24

   19.3492    8.7646    3.2111
   20.4708    9.2915    3.3763
   22.1545   10.3188    3.9312
```

Step 4

Create XYZ2Lab function

```
function Lab = XYZ2Lab(XYZ, XYZn)

    % Split the matrix into corresponding row vectors
    X = XYZ(1,:,:);
    Y = XYZ(2,:,:);
    Z = XYZ(3,:,:);
    X_n = XYZn(1,:,:);
    Y_n = XYZn(2,:,:);
    Z_n = XYZn(3,:,:);

    % calculate chromaticitity coords
    Y_ratio = Y ./ Y_n;
    L = 116 * ((Y_ratio > 0.008856) .* Y_ratio.^(1/3) + (Y_ratio <= 0.008856) ...
        .* (7.787 * Y_ratio + (16/116))) - 16;

    % a calculation
    X_ratio = X ./ X_n;
    a = 500 * (((X_ratio > 0.008856) .* X_ratio.^(1/3) + (X_ratio <= 0.008856) ...
        .* (7.787 * X_ratio)) - ((Y_ratio > 0.008856) .* Y_ratio.^(1/3) + ...
        (Y_ratio <= 0.008856) .* (7.787 * Y_ratio)));

    % b calculation
    Z_ratio = Z ./ Z_n;
```

```
    b = 200 * (((Y_ratio > 0.008856) .* Y_ratio.^(1/3) + (Y_ratio <= 0.008856) ...
        .* (7.787 * Y_ratio)) - ((Z_ratio > 0.008856) .* Z_ratio.^(1/3) + ...
        (Z_ratio <= 0.008856) .* (7.787 * Z_ratio)));

    % reconstruct & return LAB matrix
    Lab = [L;a;b];

end
```

Step 6

Test XYZ2Lab function

```
% compute the XYZ values for XYZ in XYZ2Lab
CC_spectra = load('ColorChecker_380-780-5nm.txt');
CC_XYZs = ref2XYZ(0.02 * CC_spectra(:,2:25),cie.cmf2deg,cie.illD65);

% compute the XYZ values of D65 for XYZn in XYZ2Lab
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("\nColorChecker XYZ and Lab values (D65 illuminant and 2 deg. observer)\n\n");
fprintf("Patch #\t   X\t  Y\t  Z\t  L*\t  a*\t  b*\t Patch Name\n");

% loop to print the patch values
for i=1:size(CC_Labs,2)
    fprintf("%7d\t %6.3f\t%6.3f\t%6.3f\t%6.3f\t%6.3f\t%6.3f\t %s\n", i, ...
        CC_XYZs(1, i), CC_XYZs(2, i), CC_XYZs(3, i), CC_Labs(1, i), ...
        CC_Labs(2, i), CC_Labs(3, i), names{i});
end
```

```
ColorChecker XYZ and Lab values (D65 illuminant and 2 deg. observer)

Patch #     X       Y       Z       L*      a*      b*      Patch Name
      1   0.230   0.208   0.143   1.876   1.350   1.188   Dark Skin
      2   0.783   0.732   0.541   6.612   3.565   3.659   Light Skin
      3   0.367   0.393   0.713   3.547  -0.255  -4.082   Blue Sky
      4   0.223   0.277   0.149   2.503  -1.654   2.191   Foliage
      5   0.517   0.488   0.912   4.406   2.184  -5.453   Blue Flower
      6   0.634   0.877   0.898   7.924  -8.173   0.823   Bluish Green
      7   0.743   0.591   0.130   5.340   7.416   7.347   Orange
      8   0.277   0.246   0.786   2.225   1.766  -7.409   Purplish Blue
      9   0.583   0.397   0.300   3.586   8.414   1.893   Moderate Red
     10   0.172   0.129   0.309   1.166   2.009  -2.416   Purple
     11   0.678   0.883   0.229   7.977  -6.593  10.483   Yellow Green
     12   0.924   0.850   0.174   7.677  73.612  10.754   Orange Yellow
     13   0.178   0.128   0.645   1.159   2.309  -7.234   Blue
     14   0.301   0.482   0.193   4.355  -6.454   4.752   Green
```

```
    15   0.387  0.227   0.111   2.052   7.005   1.949   Red
    16   1.117  1.179   0.193  10.405  -0.138  42.768   Yellow
    17   0.594  0.387   0.645   3.496   9.246  -3.202   Magenta
    18   0.288  0.399   0.780   3.609  -3.745  -4.935   Cyan
    19   1.757  1.848   1.912  14.666   0.021   0.885   White
    20   1.159  1.221   1.310  10.710  -0.036   0.226   Neutral 8
    21   0.705  0.741   0.805   6.692   0.019   0.030   Neutral  6.5
    22   0.387  0.409   0.443   3.698  -0.088   0.038   Neutral 5
    23   0.175  0.186   0.206   1.679  -0.054  -0.058   Neutral 3.5
    24   0.064  0.068   0.079   0.610   0.002  -0.073   Black
```

Step 7

Create deltaEab function

```
function DEab = deltaEab(Lab1, Lab2)
    DEab = sqrt(sum((Lab2 - Lab1) .^ 2));
end
```

Step 8

Test deltaEab function

```
MC_spectra = load('MetaChecker_380-780-5nm.txt');

% compute the XYZ values of D65 and illuminant A
XYZ_D65 = ref2XYZ(cie.PRD, cie.cmf2deg, cie.illD65);
XYZ_illA = ref2XYZ(cie.PRD, cie.cmf2deg, cie.illA);

% compute XYZ values for ColorChecker and MetaChecker under D65
XYZ_D65_CC = ref2XYZ(CC_spectra, cie.cmf2deg, cie.illD65);
XYZ_D65_MC = ref2XYZ(MC_spectra, cie.cmf2deg, cie.illD65);

% compute XYZ values for ColorChecker and MetaChecker under illuminant A
XYZ_A_CC= ref2XYZ(CC_spectra, cie.cmf2deg, cie.illA);
XYZ_A_MC = ref2XYZ(MC_spectra, cie.cmf2deg, cie.illA);

% convert XYZ to Lab
lab_D65_CC = XYZ2Lab(XYZ_D65_CC, XYZ_D65);
lab_D65_MC = XYZ2Lab(XYZ_D65_MC, XYZ_D65);

lab_A_CC = XYZ2Lab(XYZ_A_CC, XYZ_illA);
lab_A_MC = XYZ2Lab(XYZ_A_MC, XYZ_illA);

% Calculate deltaEab for D65
DEab_D65 = deltaEab(lab_D65_CC, lab_D65_MC);

% Calculate deltaEab for illuminant A
DEab_A = deltaEab(lab_A_CC, lab_A_MC);

% Display results
numPatches = size(DEab_D65, 2);

fprintf("\nColorChecker and MetaChecker color differences\n\n")
fprintf("  patch #    DEab(D65)    DEab(illA)\n");
```

```
for i = 1+1:numPatches
    fprintf("%9d   %10.3e%10.3f\n", i-1, DEab_D65(i), DEab_A(i));
end
```

```
ColorChecker and MetaChecker color differences

  patch #    DEab(D65)    DEab(illA)
        1    2.597e-07    22.636
        2    1.136e-07    22.178
        3    1.056e-07    32.275
        4    1.905e-07    28.232
        5    3.980e-07    25.937
        6    1.326e-07    29.487
        7    8.581e-08    17.309
        8    1.454e-07    27.241
        9    1.665e-07    12.210
       10    2.907e-07    19.509
       11    1.561e-07    22.623
       12    1.305e-07    16.970
       13    1.083e-07    20.083
       14    1.193e-07    26.099
       15    6.708e-08     7.053
       16    1.330e-07    11.532
       17    6.468e-09    10.690
       18    8.581e-08    31.619
       19    2.661e-07     2.545
       20    6.948e-08    15.940
       21    1.846e-07    28.926
       22    8.337e-08    26.751
       23    3.668e-07    20.574
       24    1.022e-07    18.567
```

Step 9

Calculate CIELab values and color differences for real, imaged and matching color patches

```
cm_lams = 380:10:730;

cm_h_offset_im = 18;
cm_h_offset_r = 19;

% load and normalize the measured spectral data for the patch #1
data = importdata('1.1_real.sp', ' ', cm_h_offset_r);
real_11 = data.data/100;
data = importdata('1.1_imaged.sp', ' ', cm_h_offset_im);
imaged_11 = data.data/100;
data = importdata('1.1_matching.sp', ' ', cm_h_offset_im);
matching_11 = data.data/100;

% repeat for patch #2
data = importdata('1.2_real.sp', ' ', cm_h_offset_r);
real_12 = data.data/100;
data = importdata('1.2_imaged.sp', ' ', cm_h_offset_im);
imaged_12 = data.data/100;
data = importdata('1.2_matching.sp', ' ', cm_h_offset_im);
```

```
matching_12 = data.data/100;

% interpolate/extrapolate the CM spectral data to 380-780, 5nm
% Patch #1
real_11i = interp1(cm_lams, real_11, cie.lambda, 'linear', 'extrap');
imaged_11i = interp1(cm_lams, imaged_11, cie.lambda, 'linear', 'extrap');
matching_11i = interp1(cm_lams, matching_11, cie.lambda, 'linear', 'extrap');

% Patch #2
real_12i = interp1(cm_lams, real_12, cie.lambda, 'linear', 'extrap');
imaged_12i = interp1(cm_lams, imaged_12, cie.lambda, 'linear', 'extrap');
matching_12i = interp1(cm_lams, matching_12, cie.lambda, 'linear', 'extrap');

% Calculated XYZs
XYZcalc.real_11 = ref2XYZ(real_11i, cie.cmf2deg, cie.illD50);
XYZcalc.imaged_11 = ref2XYZ(imaged_11i, cie.cmf2deg, cie.illD50);
XYZcalc.matching_11 = ref2XYZ(matching_11i, cie.cmf2deg, cie.illD50);

XYZcalc.real_12 = ref2XYZ(real_12i, cie.cmf2deg, cie.illD50);
XYZcalc.imaged_12 = ref2XYZ(imaged_12i, cie.cmf2deg, cie.illD50);
XYZcalc.matching_12 = ref2XYZ(matching_12i, cie.cmf2deg, cie.illD50);

XYZn_D50 = ref2XYZ(cie.PRD, cie.cmf2deg, cie.illD50);

% Calculate LAB values

% Patch 1
lab_real_11 = XYZ2Lab(XYZcalc.real_11, XYZn_D50);
lab_imaged_11 = XYZ2Lab(XYZcalc.imaged_11, XYZn_D50);
lab_matching_11 = XYZ2Lab(XYZcalc.matching_11, XYZn_D50);

% Patch 2
lab_real_12 = XYZ2Lab(XYZcalc.real_12, XYZn_D50);
lab_imaged_12 = XYZ2Lab(XYZcalc.imaged_12, XYZn_D50);
lab_matching_12 = XYZ2Lab(XYZcalc.matching_12, XYZn_D50);

% Calculate deltaEab
% For patch 1
DEab_real_imaged_11 = deltaEab(lab_real_11, lab_imaged_11);
DEab_real_matching_11 = deltaEab(lab_real_11, lab_matching_11);

% For patch 2
DEab_real_imaged_12 = deltaEab(lab_real_12, lab_imaged_12);
DEab_real_matching_12 = deltaEab(lab_real_12, lab_matching_12);

% Display table
fprintf('\nCalculated XYZ, Lab, and deltaE values (w.r.t. real patches)\n\n');
fprintf('                                 patch 1.1\n');
fprintf('              X          Y          Z          L          a          b        dEab\n');
fprintf('    real %9.4f  %9.4f  %9.4f  %9.4f  %9.4f  %9.4f\n', ...
    XYZcalc.real_11(1), XYZcalc.real_11(2), XYZcalc.real_11(3), ...
    lab_real_11(1), lab_real_11(2), lab_real_11(3));
fprintf('  imaged %9.4f  %9.4f  %9.4f  %9.4f  %9.4f  %9.4f  %9.4f\n', ...
    XYZcalc.imaged_11(1), XYZcalc.imaged_11(2), XYZcalc.imaged_11(3), ...
    lab_imaged_11(1), lab_imaged_11(2), lab_imaged_11(3), DEab_real_imaged_11);
fprintf('matching %9.4f  %9.4f  %9.4f  %9.4f  %9.4f  %9.4f  %9.4f\n', ...
    XYZcalc.matching_11(1), XYZcalc.matching_11(2), XYZcalc.matching_11(3), ...
    lab_matching_11(1), lab_matching_11(2), lab_matching_11(3), DEab_real_matching_11);
```

```
fprintf('\n');
fprintf('                                 patch 1.2\n');
fprintf('              X          Y          Z          L          a          b        dEab\n');
fprintf('    real %9.4f  %9.4f  %9.4f  %9.4f  %9.4f  %9.4f\n', ...
    XYZcalc.real_12(1), XYZcalc.real_12(2), XYZcalc.real_12(3), ...
    lab_real_12(1), lab_real_12(2), lab_real_12(3));
fprintf('  imaged %9.4f  %9.4f  %9.4f  %9.4f  %9.4f  %9.4f  %9.4f\n', ...
    XYZcalc.imaged_12(1), XYZcalc.imaged_12(2), XYZcalc.imaged_12(3), ...
    lab_imaged_12(1), lab_imaged_12(2), lab_imaged_12(3), DEab_real_imaged_12);
fprintf('matching %9.4f  %9.4f  %9.4f  %9.4f  %9.4f  %9.4f  %9.4f\n', ...
    XYZcalc.matching_12(1), XYZcalc.matching_12(2), XYZcalc.matching_12(3), ...
    lab_matching_12(1), lab_matching_12(2), lab_matching_12(3), DEab_real_matching_12);
```

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

                                 patch 1.1
              X          Y          Z          L          a          b        dEab
    real   73.4272    75.6094    58.5257    89.6777     1.0918     3.8507
  imaged   85.7827    88.8525    66.3528    95.5187     0.2096     6.3010     6.3954
matching   92.4571    95.0145    79.3425    98.0393     1.5071    -0.7734     9.5641

                                 patch 1.2
              X          Y          Z          L          a          b        dEab
    real   24.7922    27.7377    18.9920    59.6510    -8.1353     7.8716
  imaged   24.1542    26.1875    18.7918    58.2146    -4.6949     5.8272     4.2519
matching   40.3173    46.0177    26.3524    73.5570   -12.1295    17.7084    17.4956
```

Step 10

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

```
% Create the plot for a* and b* values
figure;
hold on;

% Plot for Patch 1.1
plot(lab_real_11(2), lab_real_11(3), 'bo', 'MarkerFaceColor', 'b', 'DisplayName', '1.1 real');
plot(lab_imaged_11(2), lab_imaged_11(3), 'bs', 'MarkerFaceColor', 'b', 'DisplayName', '1.1 imaged');
plot(lab_matching_11(2), lab_matching_11(3), 'bd', 'MarkerFaceColor', 'b', 'DisplayName', '1.1 matching');

% Plot for Patch 1.2
plot(lab_real_12(2), lab_real_12(3), 'ro', 'MarkerFaceColor', 'r', 'DisplayName', '1.2 real');
plot(lab_imaged_12(2), lab_imaged_12(3), 'rs', 'MarkerFaceColor', 'r', 'DisplayName', '1.2 imaged');
plot(lab_matching_12(2), lab_matching_12(3), 'rd', 'MarkerFaceColor', 'r', 'DisplayName', '1.2 matching');

% Add circles with radius 2.5 around the real patches
viscircles([lab_real_11(2), lab_real_11(3)], 2.5, 'EdgeColor', 'black', 'LineWidth', 0.5);
viscircles([lab_real_12(2), lab_real_12(3)], 2.5, 'EdgeColor', 'black', 'LineWidth', 0.5);

% Set axis limits and make the plot square
xlim([-60 60]);
ylim([-60 60]);
axis('square');
```

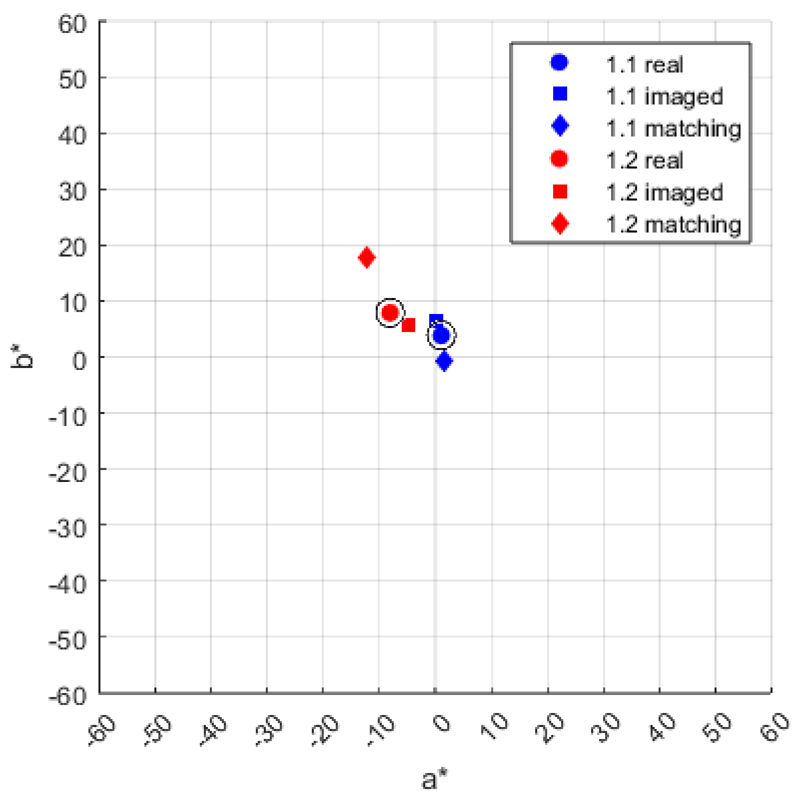
```
grid on;

xticks(min(xlim):10:max(xlim));
yticks(min(ylim):10:max(ylim));

% Label axes
xlabel('a*');
ylabel('b*');

% Add legend
legend('show');

hold off;
```



Feedback

i. Who did which parts

Shakira - parts 2, 3, 4, 5, 6

Hridiza - parts 7, 8, 9, 10, 11

ii. Problems

- Formatting the tables

iii. Valuable parts

- Understanding what deltaEab represents

- Getting practice with functions and matrix operations in MATLAB

iv. Improvements

- More hints on formatting

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