Project 5 Report

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Contents

Initialization

```
clear all; close all; clc;

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

Step 3

```
cam_RGBs = [83, 196,  86,  68, 125, 109, 199,  31, 196,  50, 166, 222, 6, 58,...
            166, 237, 186,  11, 219, 188, 152, 102,  44,   5;...
            47,146,112, 87,125,189,104, 55, 68, 13,196,163, 4,126, 20, 204,...
            64,113,218,188,151,102, 46, 8; 28,119,156, 36,177,165, 27, 151,...
            79, 65, 41, 45,113, 43, 29, 47,139,154,213,185,149, 99, 47, 16];

cam_rgbs = cam_RGBs / 255;

cam_gray_rgbs = cam_rgbs(:, 19:24);
```

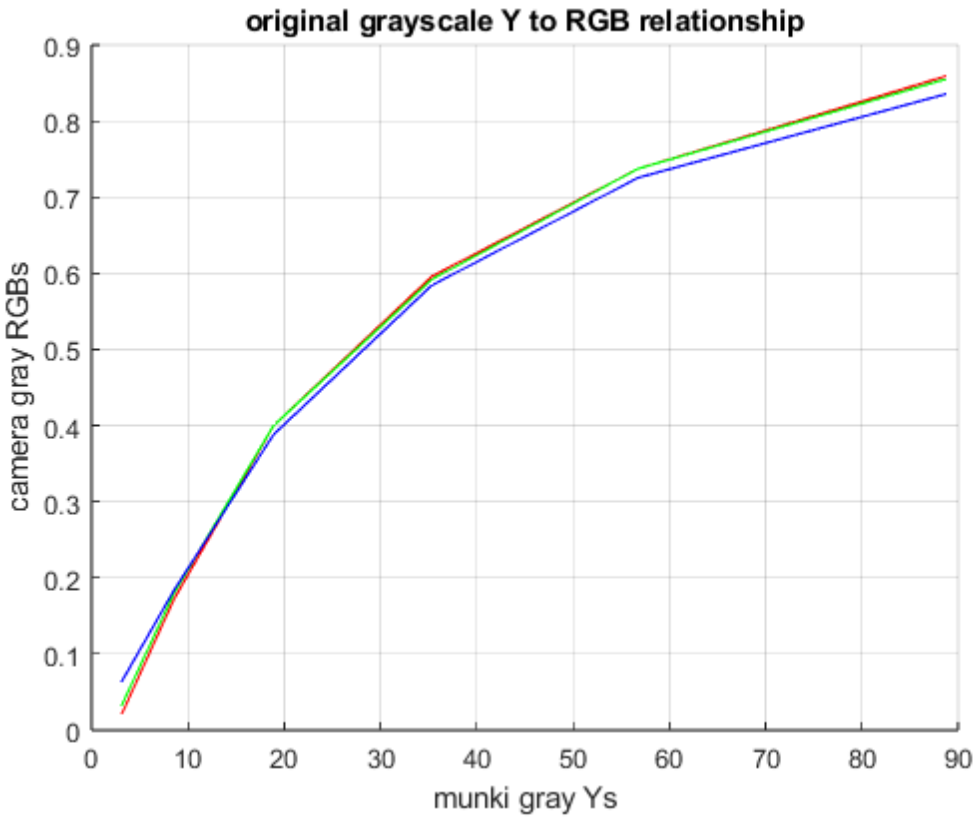
Step 4

```
% Load the data
data = load('munki_CC_XYZs_Labs.txt');
```

```
% Separate into XYZ and Lab arrays
munki_XYZs = data(:, 2:4)';   % Columns 2-4 for XYZ values, transpose to make it 3x24
munki_Labs = data(:, 5:7)';   % Columns 5-7 for Lab values, transpose to make it 3x24

% Extract Y values for gray patches #19-24
gray_Y_values = munki_XYZs(2, 19:24);

% Normalize the Y values by dividing by 100
normalized_gray_Ys = gray_Y_values / 100;

% Flip the vector so it runs from low (black) to high (white)
munki_gray_Ys = fliplr(normalized_gray_Ys);
```

Step 5

```
% Plot the Tone Transfer Functions (TTFs)
figure;
hold on;

% Plot each channel (Red, Green, and Blue)
plot(gray_Y_values, cam_gray_rgbs(1, :), '-r'); % Red channel
plot(gray_Y_values, cam_gray_rgbs(2, :), '-g'); % Green channel
plot(gray_Y_values, cam_gray_rgbs(3, :), '-b'); % Blue channel

% Labeling the plot
xlabel('munki gray Ys');
ylabel('camera gray RGBs');
title('original grayscale Y to RGB relationship');
grid on;
hold off;
```



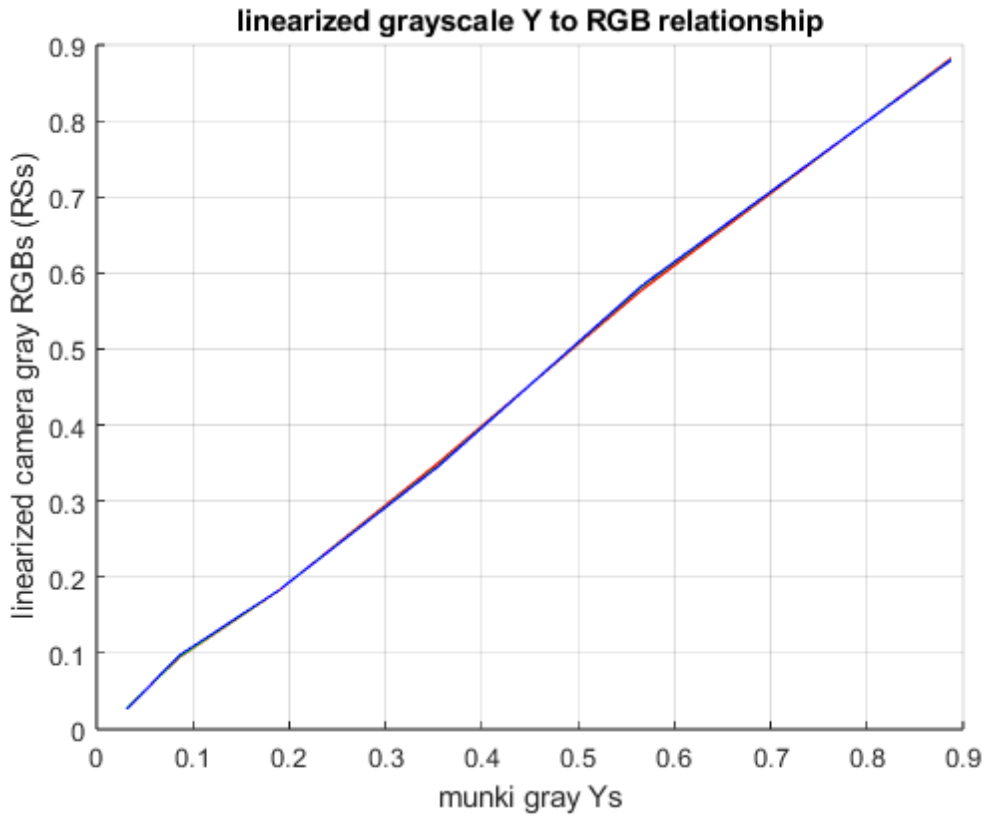
Step 6

```
% Define indices for color channels
r = 1; g = 2; b = 3;
% a) fit low-order polynomial functions between normalized
% camera-captured gray RGBs and the munki-measured gray Ys
cam_polys(r,:)=polyfit(cam_gray_rgbs(r,:),normalized_gray_Ys,3);
cam_polys(g,:)=polyfit(cam_gray_rgbs(g,:),normalized_gray_Ys,3);
cam_polys(b,:)=polyfit(cam_gray_rgbs(b,:),normalized_gray_Ys,3);
% b) use the functions to linearize the camera data
cam_RSs(r,:) = polyval(cam_polys(r,:),cam_rgbs(r,:));
cam_RSs(g,:) = polyval(cam_polys(g,:),cam_rgbs(g,:));
cam_RSs(b,:) = polyval(cam_polys(b,:),cam_rgbs(b,:));
% c) clip out of range values
cam_RSs(cam_RSs<0) = 0;
cam_RSs(cam_RSs>1) = 1;
```

Step 7

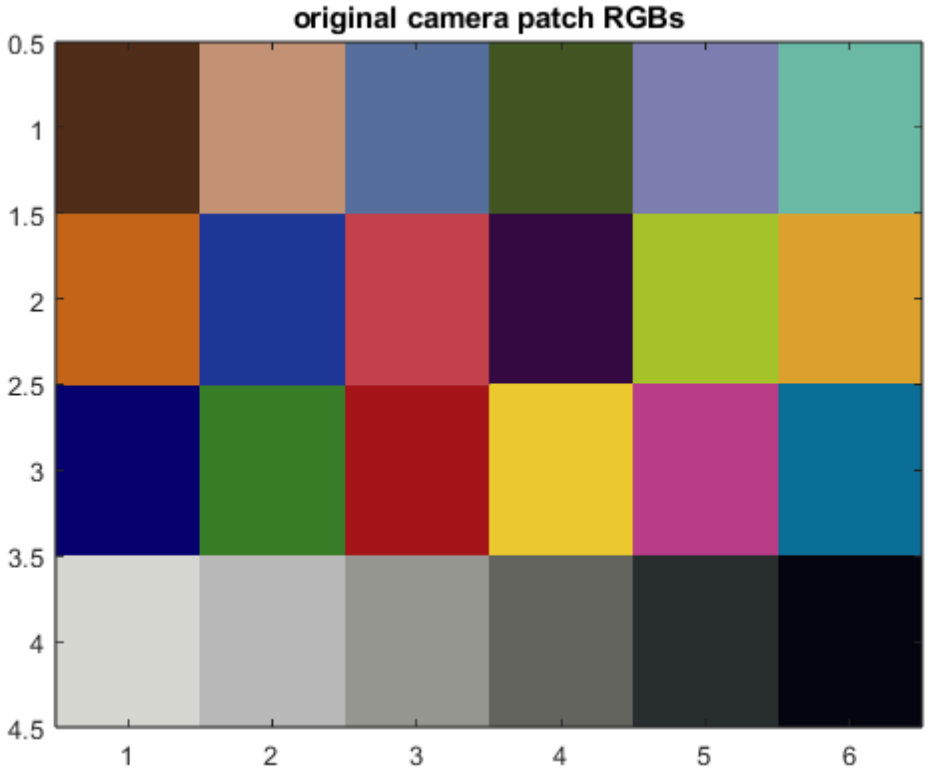
```
% Extract radiometric scalars for gray patches (#19-24)
gray_RSs = cam_RSs(:, 19:24);

% Plot the TTFs using the radiometric scalars for verification
figure;
hold on;

% Plot each channel's radiometric scalars for gray patches
plot(normalized_gray_Ys, gray_RSs(1, :), '-r'); % Red channel
plot(normalized_gray_Ys, gray_RSs(2, :), '-g'); % Green channel
plot(normalized_gray_Ys, gray_RSs(3, :), '-b'); % Blue channel
```

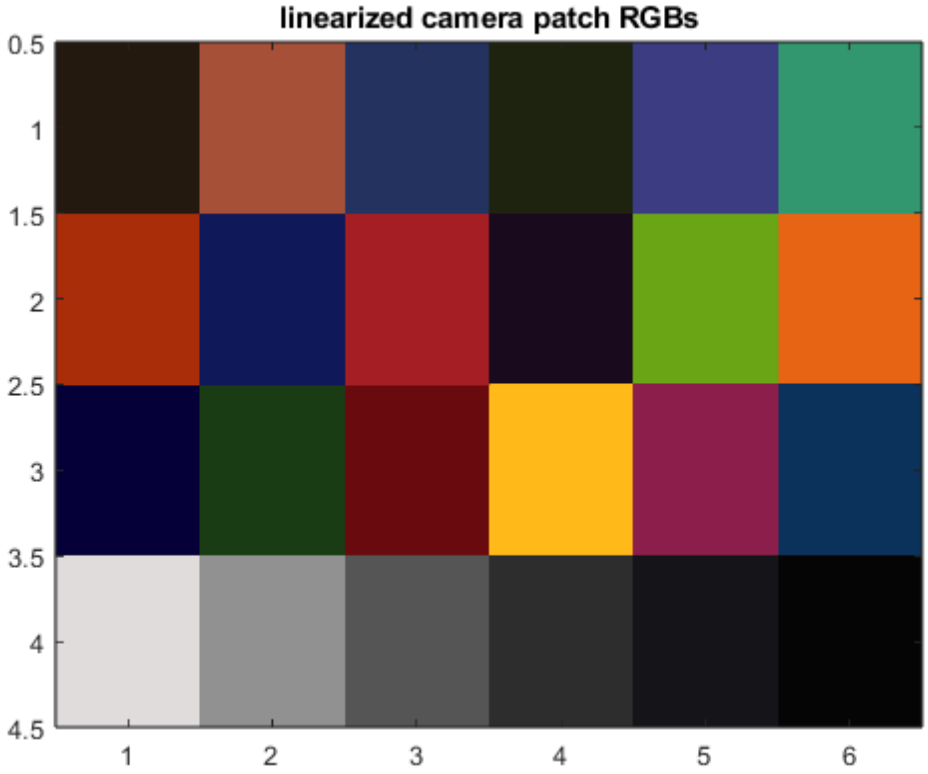
```
% Label the plot for clarity
xlabel('munki gray Ys');
ylabel('linearized camera gray RGBs (RSs)');
title('linearized grayscale Y to RGB relationship');
grid on;
hold off;
```



Step 8

```
% visualize the original camera RGBs
pix = reshape(cam_rgbs', [6 4 3]);
pix = uint8(pix*255);
pix = imrotate(pix, -90);
pix = flipdim(pix,2);
figure;
image(pix);
title('original camera patch RGBs');

% visualize the linearized camera RGBs
pix = reshape(cam_RSs', [6 4 3]);
pix = uint8(pix*255);
pix = imrotate(pix, -90);
pix = flipdim(pix,2);
figure;
image(pix);
title('linearized camera patch RGBs');
```





Step 9

```
% use the munki-measured ColorChecker XYZs and camera-captured RGB RSs to
% derive a 3x3 matrix that can be used to estimate XYZs from camera RGBs
cam_matrix3x3 = munki_XYZs * pinv(cam_RSs)
```

```
cam_matrix3x3 =

   42.1733   25.5418   22.5755
   20.8446   56.9833   16.4482
   -1.4126    3.9189   77.4845
```

Step 10

```
% estimate the ColorChecker XYZs from the linearized camera rgbs using
% the 3x3 camera matrix
cam_XYZs = cam_matrix3x3 * cam_RSs
```

```
cam_XYZs =

  Columns 1 through 7

    9.9881   40.6913   20.2649   10.9455   28.1071   33.2503   34.4405
    9.5310   35.6141   21.1540   12.6487   27.3932   44.9620   25.6034
    4.6532   18.1834   30.0899    6.3029   40.8227   35.6976    4.0742

  Columns 8 through 14

   13.9377   33.8050    8.1306   36.5103   51.2355    6.5105   13.0420
   13.5392   23.0515    6.3807   47.4240   43.9657    5.0990   17.8175
   27.7568   11.0148    9.7830    8.6113    7.5458   16.6086    7.7552

  Columns 15 through 21

   20.6221   62.9629   33.5519   15.3683   79.5116   52.4961   31.3031
   12.8482   63.9356   23.4835   18.7891   82.9864   54.9025   32.6103
    4.2740    8.9579   22.8486   29.4141   70.3343   46.7538   27.5271

  Columns 22 through 24

   16.4578    8.5953    2.4104
   17.1957    8.9872    2.5133
   14.6003    7.7570    2.0393
```

Step 11

```
% convert XYZ to Lab
XYZ_D50 = ref2XYZ(cie.PRD, cie.cmf2deg, cie.illD50);
lab_D50_Cam = XYZ2Lab(cam_XYZs, XYZ_D50);

% Calculate deltaEab
DEab_D50 = deltaEab(lab_D50_Cam, munki_Labs);

% print table
print_camera_model_error(munki_Labs, lab_D50_Cam, DEab_D50)
```

```
Camera model color error
camera->camera_RGBs->camera_model->estimated_XYZs

        colormunki measured vs. camera estimated ColorChecker Lab values
                    measured                  estimated
patch #      L        a        b        L        a        b       dEab
      1   37.1865  14.9985  15.2592  36.9872   6.4315  14.6656   8.5899
      2   65.8188  16.8695  18.0267  66.2240  20.6309  20.9691   4.7927
      3   49.9949  -3.1841 -23.5159  53.1176  -0.6419 -23.7110   4.0314
      4   42.6411 -15.3251  20.0423  42.2291  -8.8877  15.5403   7.8662
      5   54.6852   9.6978 -26.7126  59.3365   6.8026 -28.2816   5.6990
      6   71.2441 -33.1391  -0.5010  72.8668 -32.4177   1.9639   3.0380
      7   62.2558  34.1094  57.7774  57.6587  37.2695  53.6289   6.9520
      8   39.5890   9.9980 -43.6388  43.5647   5.6655 -36.3890   9.3346
      9   51.8424  48.1403  16.0636  55.1254  45.9931  20.4212   5.8632
     10   29.4495  22.4255 -21.7661  30.3533  19.4600 -18.3278   4.6296
     11   71.6264 -24.3441  57.6850  74.4602 -28.1819  61.8088   6.3059
     12   72.2288  20.6039  69.0149  72.2056  24.7893  61.9773   8.1882
     13   28.6402  18.5907 -51.4092  27.0150  18.1945 -43.0396   8.5352
     14   54.6309 -39.5493  32.8341  49.2740 -24.6900  21.6141  19.3748
     15   42.5988  54.6049  25.7315  42.5336  46.7154  26.3712   7.9157
     16   82.4265   3.8689  78.8570  83.9322   3.0457  76.8934   2.6078
     17   51.5476  49.5154 -14.3758  55.5669  43.2078  -6.9601  10.5324
     18   49.3892 -26.5473 -28.6645  50.4395 -15.2803 -27.2507  11.4039
     19   95.4458  -0.4414   0.0244  93.0085  -0.9866  -1.6748   3.0207
     20   80.0339   0.1309  -0.9345  78.9851  -1.1380  -1.7214   1.8247
     21   66.0107  -0.0004  -1.1463  63.8441  -0.5092  -1.0398   2.2281
     22   50.5546  -0.6207  -0.9616  48.5057  -0.6845  -1.0584   2.0522
     23   35.1532  -0.0632  -0.9708  35.9597  -0.6051  -1.3487   1.0425
     24   20.3224  -0.2858  -0.5603  17.9787  -0.2613   0.3301   2.5073

                                                    min      1.0425
                                                    max     19.3748
                                                    mean     6.1807
```

Step 12

```
% split the radiometric scalars (cam_RSs) into r,g,b vectors
RSrgbs = cam_RSs;
RSrs = RSrgbs(1,:);
RSgs = RSrgbs(2,:);
RSbs = RSrgbs(3,:);

% create vectors of these RSs with multiplicative terms to
% represent interactions and square terms to represent non-linearities in
% the RGB-to-XYZ relationship
RSrgbs_extd = [RSrgbs; RSrs.*RSgs; RSrs.*RSbs; RSgs.*RSbs; RSrs.*RSgs.*RSbs; ...
RSrs.^2; RSgs.^2; RSbs.^2; ones(1,size(RSrgbs,2))];

% find the extended (3x11) matrix that relates the RS and XYZ datasets
cam_matrix3x11 = munki_XYZs * pinv(RSrgbs_extd)
```

```
cam_matrix3x11 =
```

```
  Columns 1 through 7

   64.7600   19.3070   20.6893   39.5074  -48.1134   53.4091   42.5711
   28.6057   71.3533   15.1166   25.8634  -38.4367   45.8319   59.4179
    3.4950  -10.7304  115.1717    1.4706  -16.0630   22.1297   67.3254

  Columns 8 through 11

  -32.3731  -34.3686  -23.8248   -0.3033
  -14.6694  -53.9021  -32.5543   -0.3189
   -7.0171    8.9373  -95.1470   -1.1015
```

Step 13

```
% estimate XYZs from the RSs using the extended matrix and RS representation
cam_XYZs_estimated = cam_matrix3x11 * RSrgbs_extd
```

```
cam_XYZs_estimated =

  Columns 1 through 7

   11.6832   41.2536   18.8800   11.9038   24.7386   31.4972   36.1428
   11.0826   37.0964   20.0062   14.4769   23.2169   43.0466   27.1929
    4.7149   19.9469   29.1456    6.2052   34.3058   36.0678    2.7490

  Columns 8 through 14

   11.6244   32.5605    8.7029   34.1370   49.9654    5.1494   12.7912
   11.1912   21.6540    6.3410   43.5957   45.1202    3.3893   19.5657
   27.5455   11.7475   11.7421    7.7742    5.6170   19.0951    7.2059

  Columns 15 through 21

   23.3274   60.5831   29.1095   13.0382   85.4983   53.5147   32.3123
   13.4087   60.6942   18.6406   17.8275   88.9393   55.3804   33.8454
    4.9519    8.4111   22.9666   28.4469   73.4523   46.0468   28.6614

  Columns 22 through 24

   17.5236    9.2647    2.4774
   18.7723   10.0695    2.7110
   16.1532    8.6313    1.5852
```

Step 14

```
% Calculate XYZ values for cam_XYZs
XYZ_D50 = ref2XYZ(cie.PRD, cie.cmf2deg, cie.illD50);
lab_D50_Cam_estimated = XYZ2Lab(cam_XYZs_estimated, XYZ_D50);

% Calculate deltaEab
DEab = deltaEab(lab_D50_Cam_estimated, munki_Labs);
```

```
% Print table
print_extended_camera_model_error(munki_Labs, lab_D50_Cam_estimated, DEab)
```

```
Extended camera model color error
camera->camera_RGBs->extended_camera_model->estimated_XYZs

        colormunki measured vs. camera estimated ColorChecker Lab values
                    measured                  estimated
patch #      L        a        b        L        a        b       dEab
      1   37.1865  14.9985  15.2592  39.7192   7.2522  19.0389   8.9836
      2   65.8188  16.8695  18.0267  67.3493  17.5005  19.1239   1.9861
      3   49.9949  -3.1841 -23.5159  51.8442  -2.0851 -24.3962   2.3243
      4   42.6411 -15.3251  20.0423  44.9092 -13.5707  20.6017   2.9214
      5   54.6852   9.6978 -26.7126  55.2951  10.4110 -26.3405   1.0095
      6   71.2441 -33.1391  -0.5010  71.5866 -33.1732  -0.7645   0.4334
      7   62.2558  34.1094  57.7774  59.1524  36.5820  65.2221   8.4361
      8   39.5890   9.9980 -43.6388  39.9006   6.0541 -42.3526   4.1601
      9   51.8424  48.1403  16.0636  53.6580  47.9374  15.6732   1.8681
     10   29.4495  22.4255 -21.7661  30.2570  24.9032 -24.6571   3.8921
     11   71.6264 -24.3441  57.6850  71.9574 -25.4083  60.6494   3.1669
     12   72.2288  20.6039  69.0149  72.9710  18.1156  71.7403   3.7643
     13   28.6402  18.5907 -51.4092  21.5402  26.4820 -58.0582  12.5257
     14   54.6309 -39.5493  32.8341  51.3426 -35.2623  27.3801   7.6772
     15   42.5988  54.6049  25.7315  43.3727  55.6408  24.0684   2.1066
     16   82.4265   3.8689  78.8570  82.2141   4.9158  75.9130   3.1318
     17   51.5476  49.5154 -14.3758  50.2641  49.8029 -16.3270   2.3532
     18   49.3892 -26.5473 -28.6645  49.2863 -24.7680 -27.6675   2.0422
     19   95.4458  -0.4414   0.0244  95.5550  -0.4788  -0.0458   0.1352
     20   80.0339   0.1309  -0.9345  79.2599   0.3011  -0.4091   0.9508
     21   66.0107  -0.0004  -1.1463  64.8396  -1.1463  -1.2030   1.6394
     22   50.5546  -0.6207  -0.9616  50.4198  -3.0722  -1.6055   2.5383
     23   35.1532  -0.0632  -0.9708  37.9670  -3.6036  -1.1832   4.5274
     24   20.3224  -0.2858  -0.5603  18.8471  -2.6603   6.5196   7.6118

                                                      min      0.1352
                                                      max     12.5257
                                                      mean     3.7577
```

Step 15

```
% save the (extended) camera model for use in later projects
save('cam_model.mat', 'cam_polys', 'cam_matrix3x11');
```

Step 16

Include a listing of the camRGB2XYZ function

```
function cam_XYZs = camRGB2XYZ(cam_model, cam_RGBs)

    % Load cam_polys and cam_matrix3x11 from the cam_model file
    load(cam_model, 'cam_polys', 'cam_matrix3x11');

    % Normalize cam_RGBs to the range 0-1
    cam_rgbs = cam_RGBs / 255;
```

```
    % Define indices for color channels
    r = 1; g = 2; b = 3;

    % linearize the camera data
    cam_RSs(r,:) = polyval(cam_polys(r,:), cam_rgbs(r,:));
    cam_RSs(g,:) = polyval(cam_polys(g,:), cam_rgbs(g,:));
    cam_RSs(b,:) = polyval(cam_polys(b,:), cam_rgbs(b,:));

    % clip out of range values
    cam_RSs(cam_RSs<0) = 0;
    cam_RSs(cam_RSs>1) = 1;

    % split the radiometric scalars (cam_RSs) into r,g,b vectors
    RSrgbs = cam_RSs;
    RSrs = RSrgbs(1,:);
    RSgs = RSrgbs(2,:);
    RSbs = RSrgbs(3,:);

    % create vectors of these RSs with multiplicative terms to
    % represent interactions and square terms to represent non-linearities in
    % the RGB-to-XYZ relationship
    RSrgbs_extd = [RSrgbs; RSrs.*RSgs; RSrs.*RSbs; RSgs.*RSbs; RSrs.*RSgs.*RSbs; ...
    RSrs.^2; RSgs.^2; RSbs.^2; ones(1,size(RSrgbs,2))];

    % Return estimated XYZ values
    cam_XYZs = cam_matrix3x11 * RSrgbs_extd;

end
```

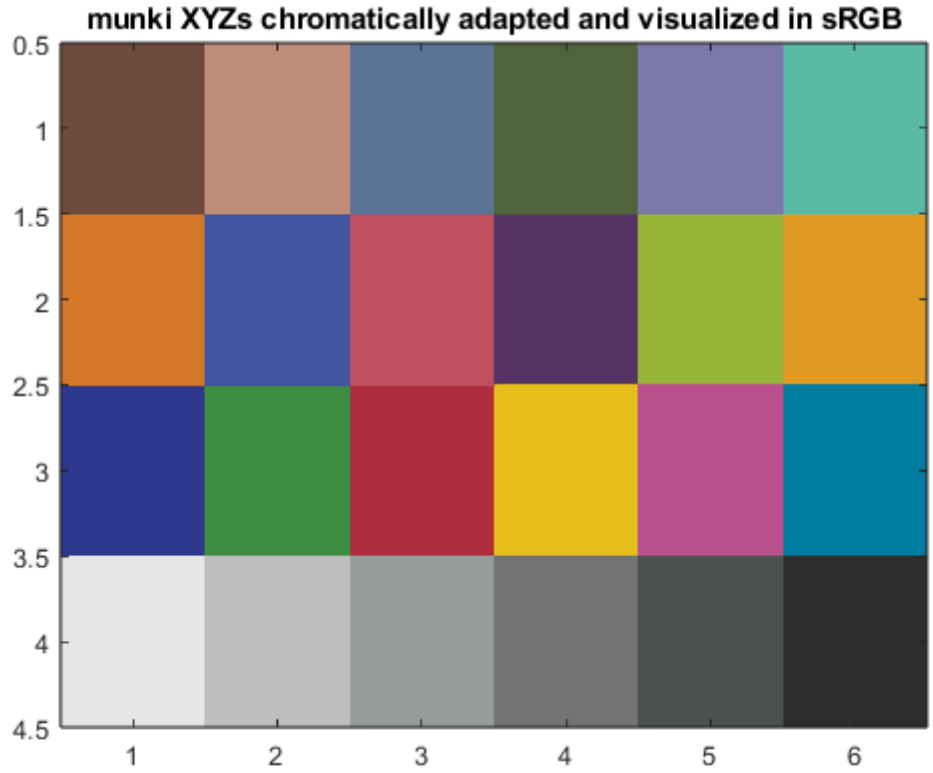
```
% test that the camRGB2XYZ function works correctly
cam_XYZs = camRGB2XYZ('cam_model.mat', cam_RGBs)
```

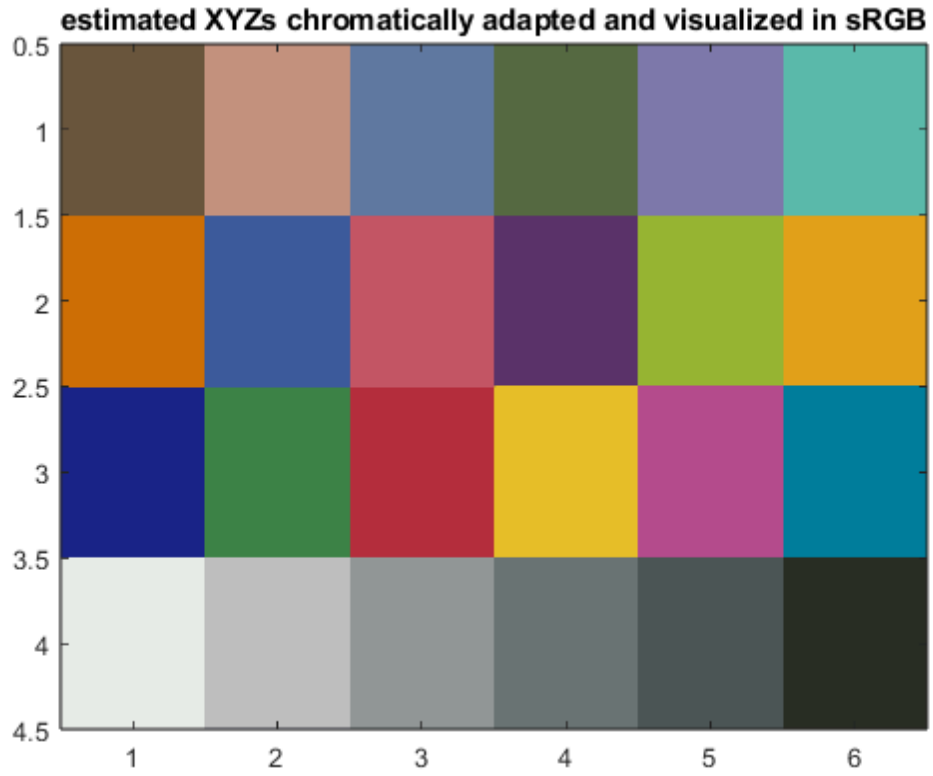
```
cam_XYZs =

  Columns 1 through 7

   11.6832   41.2536   18.8800   11.9038   24.7386   31.4972   36.1428
   11.0826   37.0964   20.0062   14.4769   23.2169   43.0466   27.1929
    4.7149   19.9469   29.1456    6.2052   34.3058   36.0678    2.7490

  Columns 8 through 14

   11.6244   32.5605    8.7029   34.1370   49.9654    5.1494   12.7912
   11.1912   21.6540    6.3410   43.5957   45.1202    3.3893   19.5657
   27.5455   11.7475   11.7421    7.7742    5.6170   19.0951    7.2059

  Columns 15 through 21

   23.3274   60.5831   29.1095   13.0382   85.4983   53.5147   32.3123
   13.4087   60.6942   18.6406   17.8275   88.9393   55.3804   33.8454
    4.9519    8.4111   22.9666   28.4469   73.4523   46.0468   28.6614

  Columns 22 through 24
```

```
    17.5236    9.2647    2.4774
    18.7723   10.0695    2.7110
    16.1532    8.6313    1.5852
```

Step 17

```
XYZ_D65 = ref2XYZ(cie.PRD, cie.cmf2deg, cie.illD65);

% visualize the munki-measured XYZs as an sRGB image
munki_XYZs_D65 = catBradford(munki_XYZs, XYZ_D50, XYZ_D65);
munki_XYZs_sRGBs = XYZ2sRGB(munki_XYZs_D65);
pix = reshape(munki_XYZs_sRGBs', [6 4 3]);
pix = uint8(pix*255);
pix = imrotate(pix, -90);
pix = flipdim(pix,2);
figure;
image(pix);
title('munki XYZs chromatically adapted and visualized in sRGB');

% visualize the camera-estimated XYZs as an sRGB image
cam_XYZs_D65 = catBradford(cam_XYZs, XYZ_D50, XYZ_D65);
cam_XYZs_sRGBs = XYZ2sRGB(cam_XYZs_D65);
pix = reshape(cam_XYZs_sRGBs', [6 4 3]);
pix = uint8(pix*255);
pix = imrotate(pix, -90);
pix = flipdim(pix,2);
figure;
image(pix);
title('estimated XYZs chromatically adapted and visualized in sRGB');
```





Feedback

i. Who did which parts

Shakira - parts 2 - 10

Hridiza - parts 1, 11 - 18

ii. Problems

- No issues with this project

iii. Valuable parts

- Learning how to compare estimated and measured XYZ values in practice

- Practically seeing how the estimation models work

iv. Improvements

- Perhaps there were slightly too many hints for the code for this project

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