Credits

Team #: 1 | Authors: Cooper White & Gian-Mateo Tifone | Date: 11/02/2023

Contents

Step 1 - Initialize

```
clear
disp("Hello Jim :D", newline)
```

```
Hello Jim :D
```

Step 2 - Import CC

```
cie = loadCIEdata;
Camera.RGBNorm = importdata('CameraRGB.txt',' '); % Read in RGBs of CC image [3x24] [R;G;B]
% RGB's were calculated as averaged over a span of 255, meaning they're imported
% normalized to 255
```

Step 3 - Filter out Camera's gray and flip

Filter out grays

```
Camera.gray = Camera.RGBNorm(:, 19:24); % 19-24th patches
% Flip grays
Camera.gray = flip(Camera.gray, 2); % Black -> White
```

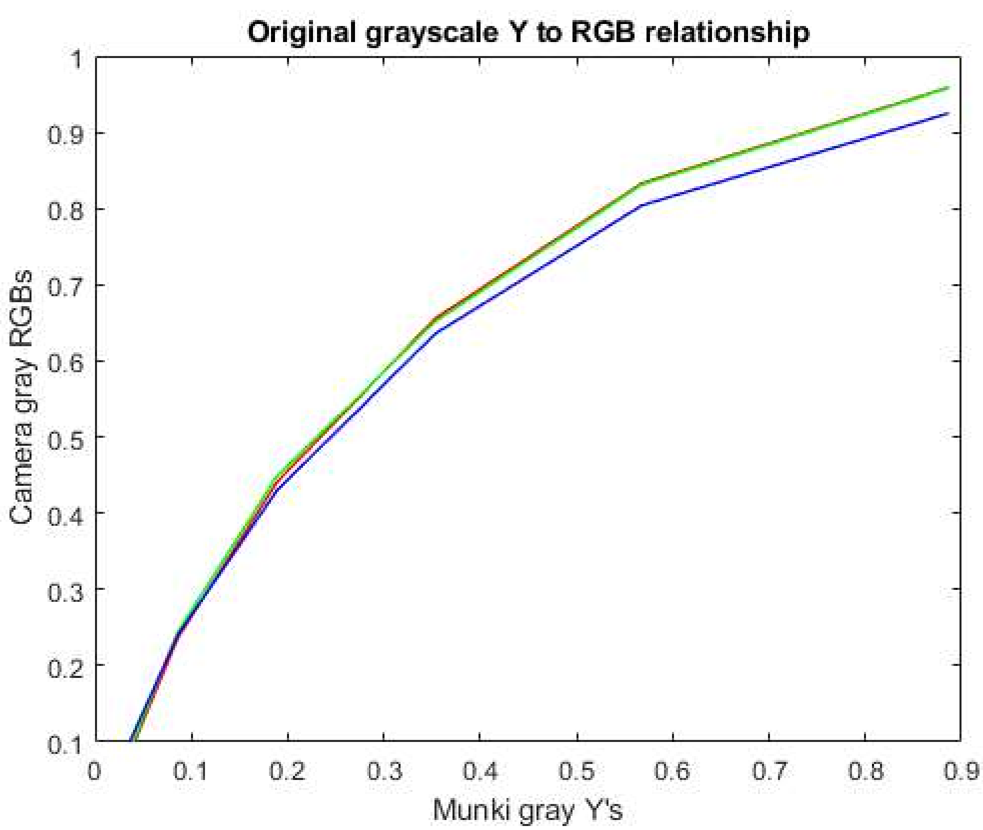
Step 4 - Import Munki LAB and XYZ

```
% Part a
Munki.data = importdata('munki_CC_XYZs_Labs.txt','\t'); % Read in Munki XYZ and LAB  [24x7]
Munki.XYZ = Munki.data(:, 2:4)';                        % Munki XYZ [3x24]
Munki.Lab = Munki.data(:, 5:7)';                        % Munki LAB [3x24]

% Part b
Munki.grayY = Munki.XYZ(2,19:24);           % Only Gray Y's of Munki XYZ [1x6]
Munki.grayNormY = Munki.grayY / 100;        % Normalize Y's
Munki.grayNormY = flip(Munki.grayNormY, 2); % Flip Y's
```

Step 5 - Plot Grayscale Y vs RGB

```
figure
plot (Munki.grayNormY, Camera.gray, 'LineWidth', 1);
title("Original grayscale Y to RGB relationship")
xlabel("Munki gray Y's")
ylabel("Camera gray RGBs")
colororder(["r", "g", "b"]) % Plot Red, Green, then Blue lines
xlim([0 .9])
ylim([.1 1.0])
```



Step 6 - Linearize RGB resposne

```
% Part a
r=1;g=2;b=3;
```

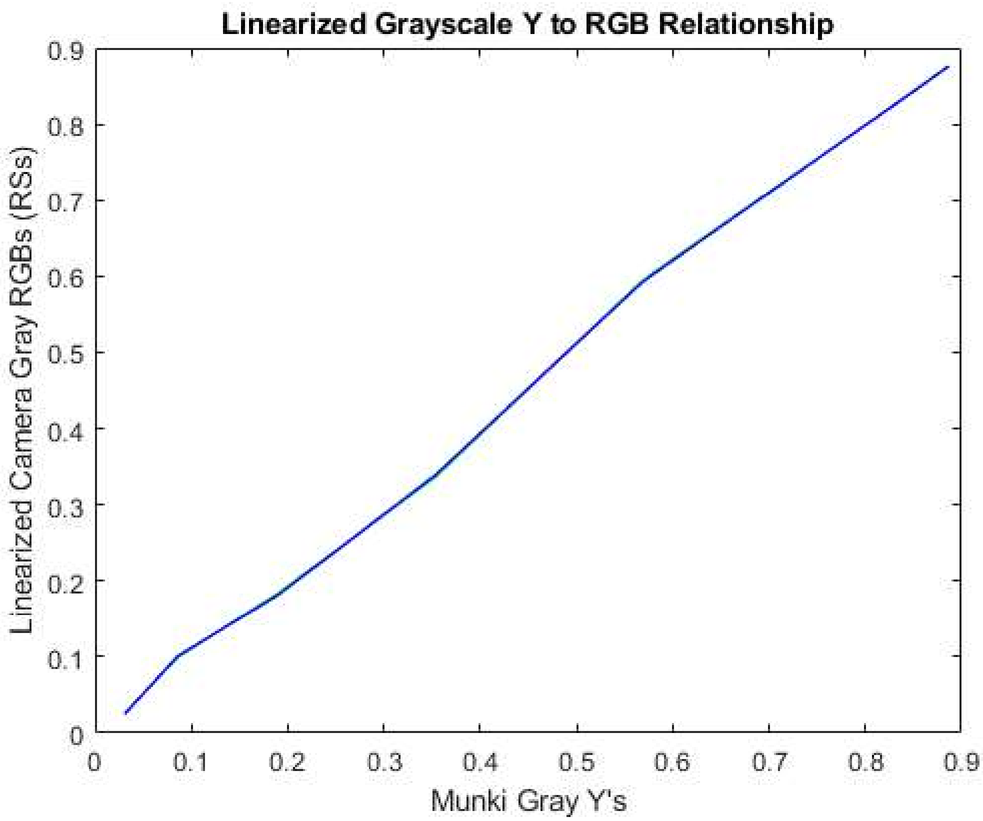
```
% Fits low-order (x^3) polynomial functions between normalized grey patch's RGBs and
% munki-measured gray Ys
%   Ployfit returns the coefficients for a polynomial p(x) of degree n that is a best fit
CameraPolys(r,:) = polyfit(Camera.gray(r,:), Munki.grayNormY, 3); % Polys -Red   line
CameraPolys(g,:) = polyfit(Camera.gray(g,:), Munki.grayNormY, 3); % Polys -Green line
CameraPolys(b,:) = polyfit(Camera.gray(b,:), Munki.grayNormY, 3); % Polys -Blue  line

% Part b
% Linearize camera's response to the ColorChecker patches
%   Polyval evaluates a polynomial (Some p(x)) at certain x values, and
%   retuns the result
%    Each index of P[#, #, #] is the coeffecient of the polynomial
%    Each index of x[#, #, #] is the polynomial to be evaluated
Camera.RS(r,:) = polyval(CameraPolys(r,:), Camera.RGBNorm(r, :)); % All Patches -Red
Camera.RS(g,:) = polyval(CameraPolys(g,:), Camera.RGBNorm(g, :)); % All Patches -Green
Camera.RS(b,:) = polyval(CameraPolys(b,:), Camera.RGBNorm(b, :)); % All Patches -Blue

% Part c
% Fix out of range values
Camera.RS(Camera.RS<0) = 0;
Camera.RS(Camera.RS>1) = 1;
```

Step 7 - Plot RS Scalars vs RGBs

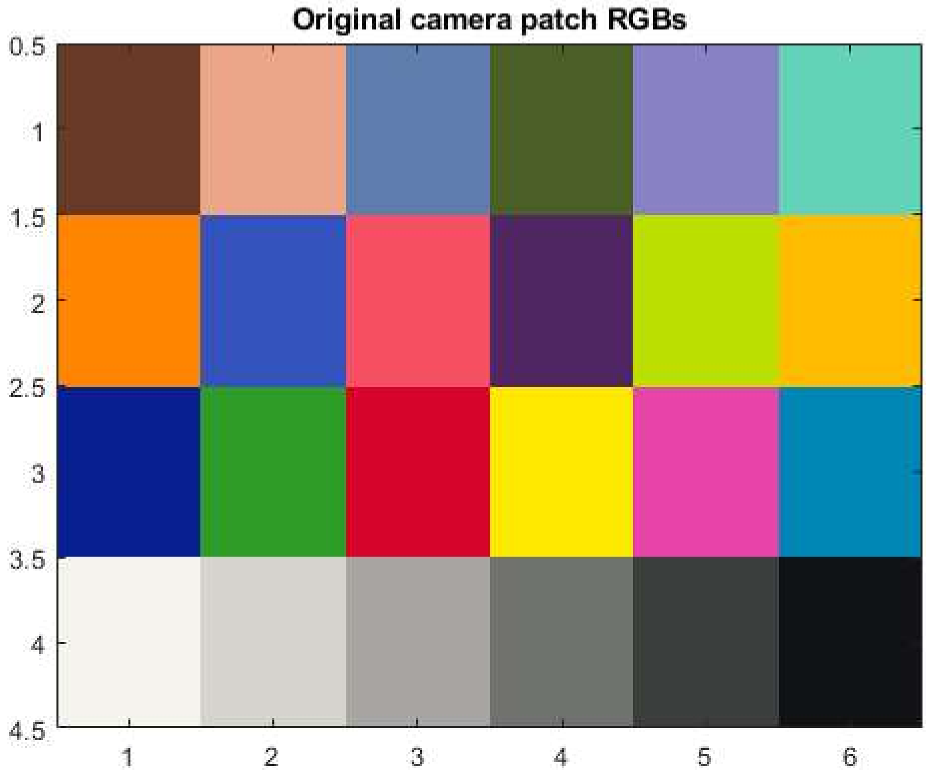
```
figure
%                       Only gray RS, flipped B->W
plot (Munki.grayNormY, flip(Camera.RS(:, 19:24), 2), 'LineWidth', 1);
title("Linearized Grayscale Y to RGB Relationship")
xlabel("Munki Gray Y's")
ylabel("Linearized Camera Gray RGBs (RSs)")
colororder(["r", "g", "b"]) % Plot Red, Green, then Blue lines
```

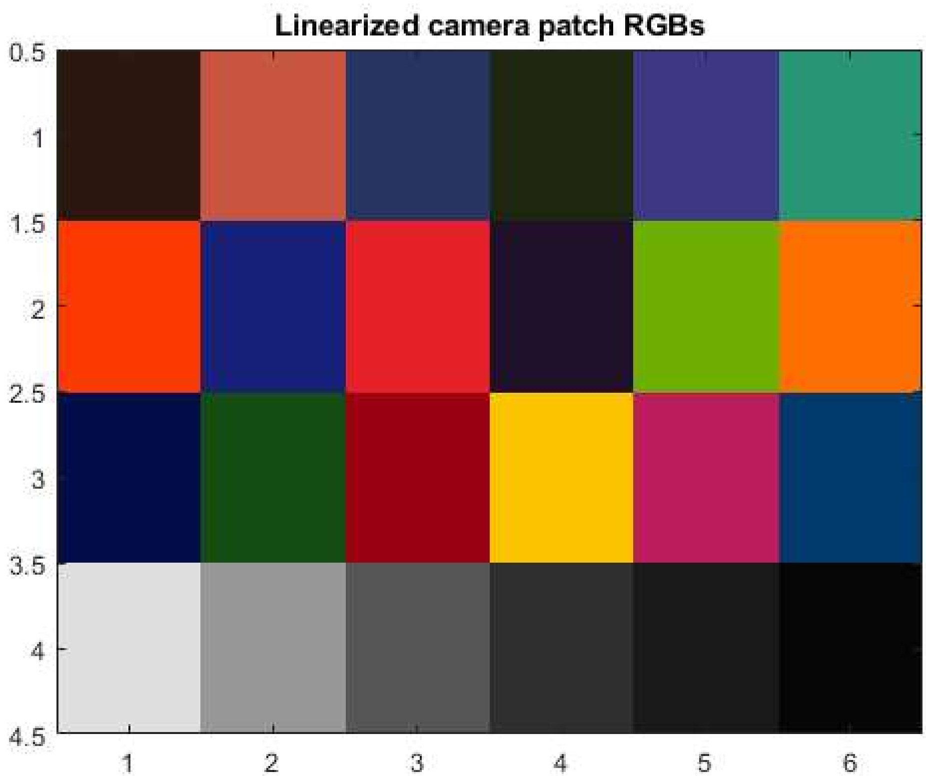


Step 8 - Plot the Color Checker Pre/Post Linearized

```
% Original camera RGBs
pix = reshape(Camera.RGBNorm', [6 4 3]);
pix = uint8(pix*255);
pix = imrotate(pix, -90);
pix = flip(pix, 2);
figure;
image(pix);
title("Original camera patch RGBs")

% Linearized camera RGBs
pix = reshape(Camera.RS', [6 4 3]);
pix = uint8(pix*255);
pix = imrotate(pix, -90);
pix = flip(pix, 2);
figure;
image(pix);
title("Linearized camera patch RGBs")
```





Step 9 - Estimate XYZ from RSs

```
camMatrix3x3 = Munki.XYZ * pinv(Camera.RS)
```

```
camMatrix3x3 =

   31.1586   38.6034   18.4415
   15.5795   62.1670   14.6513
   -0.1762   13.4580   65.1305
```

Step 10 - Estimate XYZ of CC

```
Camera.XYZ = camMatrix3x3 * Camera.RS; % [3x24]
Camera.XYZ
```

```
ans =

  Columns 1 through 7

    9.7652   41.9769   19.5618   10.5669   25.3163   36.0729   39.4432
    9.1580   36.6793   20.5731   11.9587   24.8340   45.7939   29.3747
    5.2142   20.6794   27.6264    5.8163   36.5187   37.7218    2.8567

  Columns 8 through 14

   16.2303   35.6775    9.3289   39.5766   47.6335    7.1117   15.3155
   16.1045   24.0222    8.1863   48.9542   42.4632    7.1916   20.9335
   32.0157   11.8936   11.2219    9.0816    5.6797   18.8616    8.2728

  Columns 15 through 21

   20.1410   60.5363   33.8217   16.6682   77.2457   52.2787   29.7704
   10.4416   63.2419   23.5136   20.4411   80.9166   54.7821   31.1455
    4.3420   10.1780   24.8091   30.7838   68.7019   46.4038   26.5318

  Columns 22 through 24

   16.0310    8.8316    2.2071
   16.8379    9.2196    2.3250
   14.2088    7.8855    1.9450
```

Step 11 - Create a camera model + analyze error

```
% Part a
Camera.XYZn_D50 = ref2XYZ(cie.PRD,cie.cmf2deg,cie.illD50); % calculating XYZn of D50
Camera.Lab = XYZ2Lab(Camera.XYZ, Camera.XYZn_D50);         % calulates Lab values of CC
% Worth noting, MATLAB might be insisting here on using its own XYZ2lab instead of ours

% Part b
dEab = deltaEab(Munki.Lab,Camera.Lab); % dEab measured from CC Labs and imaged CC Labs

% Part c
% Print table of L*a*b*'s - Munki and Camera-calculated
print_camera_model_error(Munki.Lab, Camera.Lab, dEab);
```

```
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  36.2868   7.6909  10.4925   8.7712
      2   65.8188  16.8695  18.0267  67.0357  21.0412  17.0766   4.4482
      3   49.9949  -3.1841 -23.5159  52.4791  -1.3684 -20.8012   4.1033
      4   42.6411 -15.3251  20.0423  41.1504  -7.0622  15.9230   9.3523
      5   54.6852   9.6978 -26.7126  56.9133   5.8902 -26.6931   4.4117
      6   71.2441 -33.1391  -0.5010  73.4116 -25.1124   0.0966   8.3357
      7   62.2558  34.1094  57.7774  61.1109  38.7957  67.7693  11.0955
      8   39.5890   9.9980 -43.6388  47.1113   4.0424 -37.0522  11.6377
      9   51.8424  48.1403  16.0636  56.1100  48.1421  19.4698   5.4603
     10   29.4495  22.4255 -21.7661  34.3679  12.4372 -16.0042  12.5363
     11   71.6264 -24.3441  57.6850  75.4228 -22.4756  61.7847   5.8917
     12   72.2288  20.6039  69.0149  71.1891  19.4485  68.3654   1.6846
     13   28.6402  18.5907 -51.4092  32.2392   1.7604 -39.1090  21.1543
     14   54.6309 -39.5493  32.8341  52.8766 -26.0954  25.8459  15.2618
     15   42.5988  54.6049  25.7315  38.6236  61.2254  19.2362  10.0907
     16   82.4265   3.8689  78.8570  83.5695  -1.0367  72.1197   8.4121
     17   51.5476  49.5154 -14.3758  55.5974  44.0165 -10.5340   7.8357
     18   49.3892 -26.5473 -28.6645  52.3323 -16.0016 -26.1550  11.2326
     19   95.4458  -0.4414   0.0244  92.0946  -1.5440  -1.7720   3.9590
     20   80.0339   0.1309  -0.9345  78.9156  -1.4030  -1.4271   1.9612
     21   66.0107  -0.0004  -1.1463  62.6303  -0.9800  -1.4405   3.5318
     22   50.5546  -0.6207  -0.9616  48.0552  -1.1610  -0.8224   2.5609
     23   35.1532  -0.0632  -0.9708  36.4036  -0.4904  -1.0825   1.3261
     24   20.3224  -0.2858  -0.5603  17.1081  -0.7404  -0.2588   3.2603

                                                         min      1.3261
                                                         max     21.1543
                                                         mean     7.4298
```

Step 12 - Improved Camera Model with Non-Linear Relationships

```
% Part a
RSrgb = Camera.RS;
RS_r = RSrgb(1,:);
RS_g = RSrgb(2,:);
RS_b = RSrgb(3,:);

RSrgb_extd = [RSrgb; RS_r.*RS_g; RS_r.*RS_b; RS_g.*RS_b; RS_r.*RS_g.*RS_b;
              RS_r.^2; RS_g.^2; RS_b.^2; ones(1,size(RSrgb,2))];

% Part b
camMatrix3x11 = Munki.XYZ * pinv(RSrgb_extd);

% Print result
camMatrix3x11
```

```
camMatrix3x11 =
```

```
  Columns 1 through 7

   49.3824   27.7567    6.5651   38.1431  -20.4391   40.1257    6.7869
   28.6126   63.1370    0.6269   24.8025  -17.5586   42.3513   13.6278
    5.9386   14.8939   76.5446    1.7667  -20.9341    1.5837   51.2541

  Columns 8 through 11

  -24.6323  -27.0364    2.0483    0.9369
  -16.9800  -33.3667   -2.2305    0.6732
   -5.1400   -7.3996  -29.0141   -1.0480
```

Step 13 - estimate XYZs from RGB and RS

```
Camera.XYZ = camMatrix3x11 * RSrgb_extd;
Camera.XYZ
```

```
ans =

  Columns 1 through 7

   11.6706   42.3460   18.2964   11.3412   24.1219   31.6266   39.0376
   10.8892   37.5625   19.1437   13.2347   22.7051   43.2114   30.4109
    5.5611   21.8051   27.0595    6.0039   33.8342   36.1785    3.1780

  Columns 8 through 14

   13.6761   31.7750    9.8642   34.9933   49.0645    4.8661   12.6625
   12.5028   21.3671    8.1572   44.5182   44.1883    4.3394   20.2307
   30.0797   11.4852   11.6825    7.7726    5.6336   18.8142    8.1032

  Columns 15 through 21

   21.4282   60.0788   28.6622   12.9334   85.1032   54.8437   30.3882
   11.0822   60.0666   18.2858   17.3409   88.4433   57.2326   31.9892
    4.8898    8.2178   21.9990   29.4361   73.3175   46.5204   27.1050

  Columns 22 through 24

   16.4499    9.4168    3.0327
   17.4932    9.8716    2.9980
   14.9616    8.1994    1.3313
```

Step 14 - Evaluate accuracy of Camera Model

Calulates L*a*b* values of Camera XYZ (under D50)

```
Camera.Lab = XYZ2Lab(Camera.XYZ, Camera.XYZn_D50);
% delta Eab of measured Munki L*a*b* and Camera L*a*b*
dEab = deltaEab(Munki.Lab,Camera.Lab);
```

```
% Print table
print_extended_camera_model_error(Munki.Lab, Camera.Lab, 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   39.3931    8.5684   14.1193    6.8931
      2   65.8188   16.8695   18.0267   67.6969   19.2988   15.9688    3.6964
      3   49.9949   -3.1841  -23.5159   50.8549   -0.8442  -22.6451    2.6406
      4   42.6411  -15.3251   20.0423   43.1148   -9.8220   18.4310    5.7536
      5   54.6852    9.6978  -26.7126   54.7673   10.0235  -26.5631    0.3677
      6   71.2441  -33.1391   -0.5010   71.6982  -33.1836   -0.7271    0.5093
      7   62.2558   34.1094   57.7774   62.0072   33.6560   66.9572    9.1943
      8   39.5890    9.9980  -43.6388   42.0044   10.7387  -42.8557    2.6449
      9   51.8424   48.1403   16.0636   53.3489   46.4469   15.9235    2.2708
     10   29.4495   22.4255  -21.7661   34.3081   17.0046  -17.4956    8.4398
     11   71.6264  -24.3441   57.6850   72.5735  -25.1308   61.7179    4.2166
     12   72.2288   20.6039   69.0149   72.3541   18.3460   70.5967    2.7597
     13   28.6402   18.5907  -51.4092   24.7630    9.0721  -51.8965   10.2895
     14   54.6309  -39.5493   32.8341   52.0971  -39.3723   25.1414    8.1012
     15   42.5988   54.6049   25.7315   39.7186   62.6957   18.0966   11.4913
     16   82.4265    3.8689   78.8570   81.8744    5.1887   76.0485    3.1519
     17   51.5476   49.5154  -14.3758   49.8409   49.9001  -15.1965    1.9324
     18   49.3892  -26.5473  -28.6645   48.6868  -22.8729  -30.3081    4.0862
     19   95.4458   -0.4414    0.0244   95.3473   -0.3245   -0.2862    0.3462
     20   80.0339    0.1309   -0.9345   80.3102   -0.8526    0.8392    2.0469
     21   66.0107   -0.0004   -1.1463   63.3340   -1.6913   -1.2067    3.1667
     22   50.5546   -0.6207   -0.9616   48.8756   -2.3234   -1.3392    2.4209
     23   35.1532   -0.0632   -0.9708   37.6110   -0.8224   -0.1985    2.6858
     24   20.3224   -0.2858   -0.5603   20.0359    2.5046   11.5965   12.4763

                                                            min       0.3462
                                                            max      12.4763
                                                            mean      4.6492
```

Step 15 - Save Extended Camera Model

```
save('cam_model.mat', 'CameraPolys', 'camMatrix3x11');
```

Step 16 - Camera XYZ from improved model

```
function camXYZ = camRGB2XYZ(camModel, camRGB)
% Takes Camera Model and Camera RGBs and converts them to XYZ values
%
%   camModel = .mat variable file
%    CameraPolys
%    camMatrix3x11
%
%   camRGB   = vector of RGBs [3xn]
%
%   camXYZ   = vector of XYZs [3xn]
```

```
% Import .mat variables
load(camModel)

% Calculate Radiometric Scalars
r=1;g=2;b=3;
Camera_RS(r,:) = polyval(CameraPolys(r,:), camRGB(r, :)); % All Patches -Red
Camera_RS(g,:) = polyval(CameraPolys(g,:), camRGB(g, :)); % All Patches -Green
Camera_RS(b,:) = polyval(CameraPolys(b,:), camRGB(b, :)); % All Patches -Blue

% Fix out-of-bounds values
Camera_RS(Camera_RS<0) = 0;
Camera_RS(Camera_RS>1) = 1;

% Calculate Extended RS RGBs
RSrgb = Camera_RS;
RS_r = RSrgb(1,:);
RS_g = RSrgb(2,:);
RS_b = RSrgb(3,:);

RSrgb_extd = [RSrgb; RS_r.*RS_g; RS_r.*RS_b; RS_g.*RS_b; RS_r.*RS_g.*RS_b;
              RS_r.^2; RS_g.^2; RS_b.^2; ones(1,size(RSrgb,2))];

% Estimate/Calculate XYZs
camXYZ = camMatrix3x11 * RSrgb_extd;
end
```

```
% Take raw camera RGBs and convert to XYZs using a camera model
Camera.XYZ = camRGB2XYZ('cam_model.mat', Camera.RGBNorm);
Camera.XYZ
```

```
ans =

  Columns 1 through 7

   11.6706   42.3460   18.2964   11.3412   24.1219   31.6266   39.0376
   10.8892   37.5625   19.1437   13.2347   22.7051   43.2114   30.4109
    5.5611   21.8051   27.0595    6.0039   33.8342   36.1785    3.1780

  Columns 8 through 14

   13.6761   31.7750    9.8642   34.9933   49.0645    4.8661   12.6625
   12.5028   21.3671    8.1572   44.5182   44.1883    4.3394   20.2307
   30.0797   11.4852   11.6825    7.7726    5.6336   18.8142    8.1032

  Columns 15 through 21

   21.4282   60.0788   28.6622   12.9334   85.1032   54.8437   30.3882
   11.0822   60.0666   18.2858   17.3409   88.4433   57.2326   31.9892
    4.8898    8.2178   21.9990   29.4361   73.3175   46.5204   27.1050

  Columns 22 through 24

   16.4499    9.4168    3.0327
   17.4932    9.8716    2.9980
```

```
   14.9616    8.1994    1.3313
```

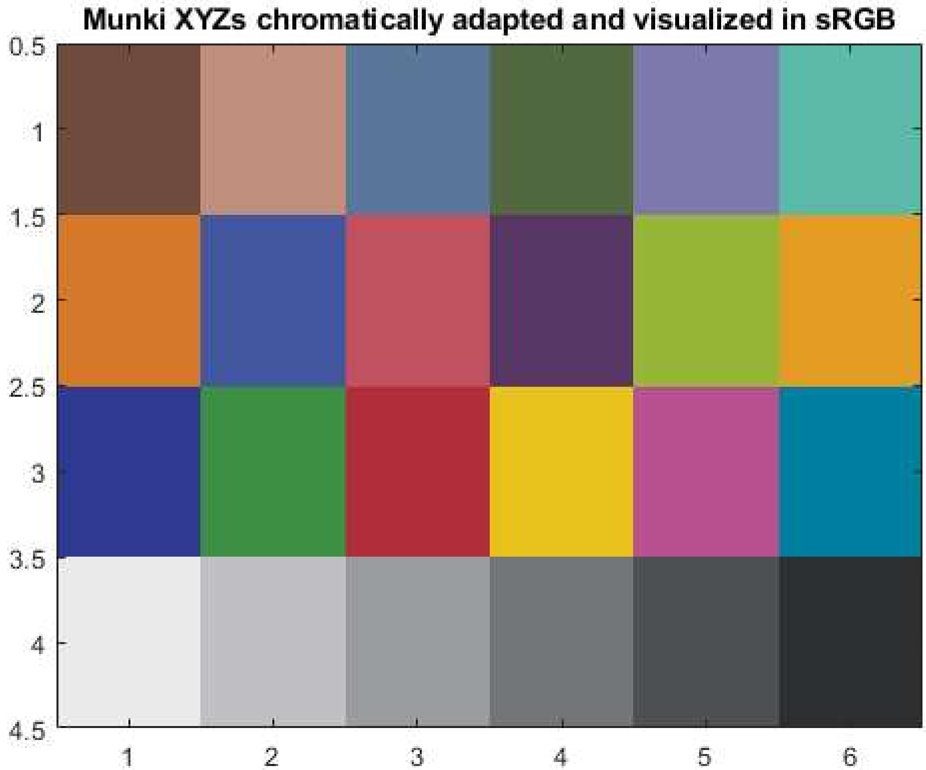
Step 17 - Visualize the munki-measured XYZs as an sRGB image

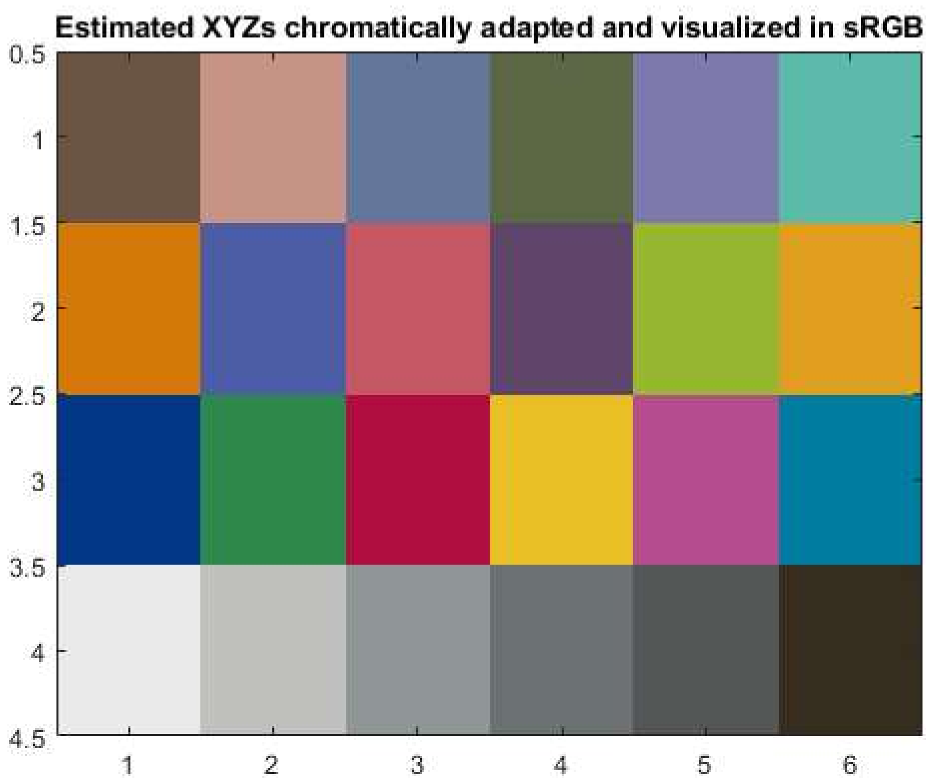
```
Camera.XYZn_D65 = ref2XYZ(cie.PRD,cie.cmf2deg,cie.illD65);

% Jim Code ~
% Visualize the Munki XYZs in sRGB color space

%                           Munki XYZ      D50             D65
Munki.XYZ_D65 = catBradford(Munki.XYZ,Camera.XYZn_D50,Camera.XYZn_D65);
% sRGB of Munki's XYZ
Munki.sRGB = XYZ2sRGB(Munki.XYZ_D65);
pix = reshape(Munki.sRGB', [6 4 3]);
pix = uint8(pix*255);
pix = imrotate(pix, -90);
pix = flip(pix, 2);
figure;
image(pix);
title("Munki XYZs chromatically adapted and visualized in sRGB")

% Visualize the camera-estimated XYZs in sRGB color space
%                            Camera XYZ       D50             D65
Camera.XYZ_D65 = catBradford(Camera.XYZ,Camera.XYZn_D50,Camera.XYZn_D65);
% sRGB of Camera's XYZ
Camera.sRGB = XYZ2sRGB(Camera.XYZ_D65);
pix = reshape(Camera.sRGB', [6 4 3]);
pix = uint8(pix*255);
pix = imrotate(pix, -90);
pix = flip(pix, 2);
figure;
image(pix);
title("Estimated XYZs chromatically adapted and visualized in sRGB")
```





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