Credits

Team #: 1 | Authors: Cooper White & Gian-Mateo Tifone | Date: 11/28/2023

Contents

Step 1/2 - initilization

```
clear;

cie = loadCIEdata;
XYZ_D50 = ref2XYZ(cie.PRD, cie.cmf2deg, cie.illD50);
XYZ_D65 = ref2XYZ(cie.PRD, cie.cmf2deg, cie.illD65);
```

Step 3

```
load_ramps_data;
```

Step 4 - Forward Matrix

```
Red_max.X = max(ramp_R_XYZs(1, :)); %X_r,max
Red_max.Y = max(ramp_R_XYZs(2, :)); %Y_r,max
Red_max.Z = max(ramp_R_XYZs(3, :)); %Z_r,max

Green_max.X = max(ramp_G_XYZs(1, :)); %X_g,max
Green_max.Y = max(ramp_G_XYZs(2, :)); %Y_g,max
Green_max.Z = max(ramp_G_XYZs(3, :)); %Z_g,max

Blue_max.X = max(ramp_B_XYZs(1, :)); %X_g,max
Blue_max.Y = max(ramp_B_XYZs(2, :)); %Y_g,max
Blue_max.Z = max(ramp_B_XYZs(3, :)); %Z_g,max

% Create matrix of max
m_fwd = [Red_max.X, Green_max.X, Blue_max.X ;
         Red_max.Y, Green_max.Y, Blue_max.Y ;
         Red_max.Z, Green_max.Z, Blue_max.Z];

% Subtract the XYZ of display (XYZk)
m_fwd = m_fwd-XYZk;

% Add XYZk (black) collumn
m_fwd = cat(2, m_fwd, XYZk);

% Divide the XYZw value (Y)
m_fwd = m_fwd / XYZw(2, 1);
```

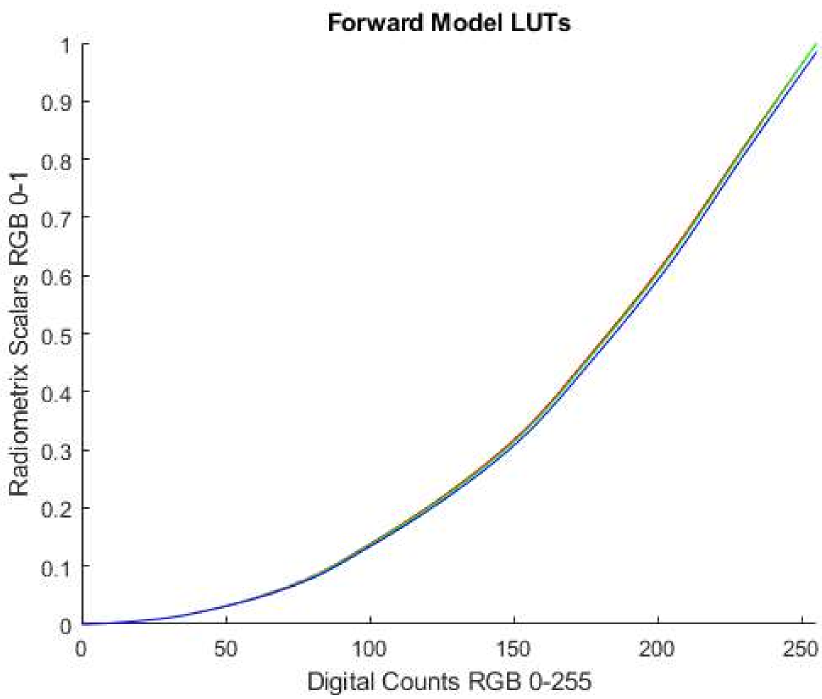
```
% Display Matrix
m_fwd
```

```
m_fwd =

    0.3736    0.3652    0.2095    0.0008
    0.2248    0.6260    0.1452    0.0008
    0.0518    0.1140    1.0149    0.0014
```

Step 5 - Derive the LUTs

```
% Step a/b
RedRamp =   ramp_R_XYZs - XYZk; % XYZ of Red minus black
GreenRamp = ramp_G_XYZs - XYZk; % XYZ of Green minus black
BlueRamp =  ramp_B_XYZs - XYZk; % XYZ of BLue minus black

% Step c
RedRamp   = RedRamp   / XYZw(2, 1); % Divide XYZ by (Y) of white
GreenRamp = GreenRamp / XYZw(2, 1); % Divide XYZ by (Y) of white
BlueRamp  = BlueRamp  / XYZw(2, 1); % Divide XYZ by (Y) of white

% Clip out of bounds numbers
RedRamp(RedRamp<0)     = 0; % Less than 0 becomes 0
RedRamp(RedRamp>1)     = 1; % Greater than 1 becomes 1
GreenRamp(GreenRamp<0) = 0;
GreenRamp(GreenRamp>1) = 1;
BlueRamp(BlueRamp<0)   = 0;
BlueRamp(BlueRamp>1)   = 1;

% Step d
% Estiamte Radiometric Scalars
m_fwd_inv = pinv(m_fwd(1:3,1:3)); % Calculate inverse matrix of 3x3 forward matrix

% The RS means they're converted into RGB, meaning R;G;B [3x11] for 11
% patches
RedRampRS   = m_fwd_inv * RedRamp;   % Multiply XYZ by inverse forward matrix
GreenRampRS = m_fwd_inv * GreenRamp; %
BlueRampRS  = m_fwd_inv * BlueRamp;  %

% Step e
% Extract the Red/Green/Blue channels from the RSs of each ramp
% I.e. Extract Red RS from RedRamp
%      Extract Green RS from GreenRamp
%      Extract Blue RS from BlueRamp
RedRampRS_R = RedRampRS(1,:);     % Red channel of red
%RedRampRS_G = RedRampRS(2,:);
%RedRampRS_B = RedRampRS(3,:);

%GreenRampRS_R = GreenRampRS(1,:);
GreenRampRS_G = GreenRampRS(2,:); % Green channel of green
%GreenRampRS_B = GreenRampRS(3,:);

%BlueRampRS_R = BlueRampRS(1,:);
%BlueRampRS_G = BlueRampRS(2,:);
BlueRampRS_B = BlueRampRS(3,:);   % Blue channel of blue

% Step f
% Interpolate channels from 0-255 using 'pchip'
ramp_DCs = round(linspace(0,255,11));

% Create LUT for Red/Green/Blue
RedLUT_fwd   = interp1(ramp_DCs, RedRampRS_R, 0:1:255, 'pchip');   % Red LUT forward
GreenLUT_fwd = interp1(ramp_DCs, GreenRampRS_G, 0:1:255, 'pchip'); % Green LUT forward
BlueLUT_fwd  = interp1(ramp_DCs, BlueRampRS_B, 0:1:255, 'pchip');  % Blue LUT forward
```

```
% Plot LUT
figure
hold on
plot(0:255, RedLUT_fwd,  'Color', [1, 0, 0])
plot(0:255, GreenLUT_fwd,'Color', [0, 1, 0])
plot(0:255, BlueLUT_fwd, 'Color', [0, 0, 1])

xlabel("Digital Counts RGB 0-255")
ylabel("Radiometrix Scalars RGB 0-1")
title("Forward Model LUTs")
ylim([0 1])
xlim([0 255])
```



Step 6 - Reverse Model

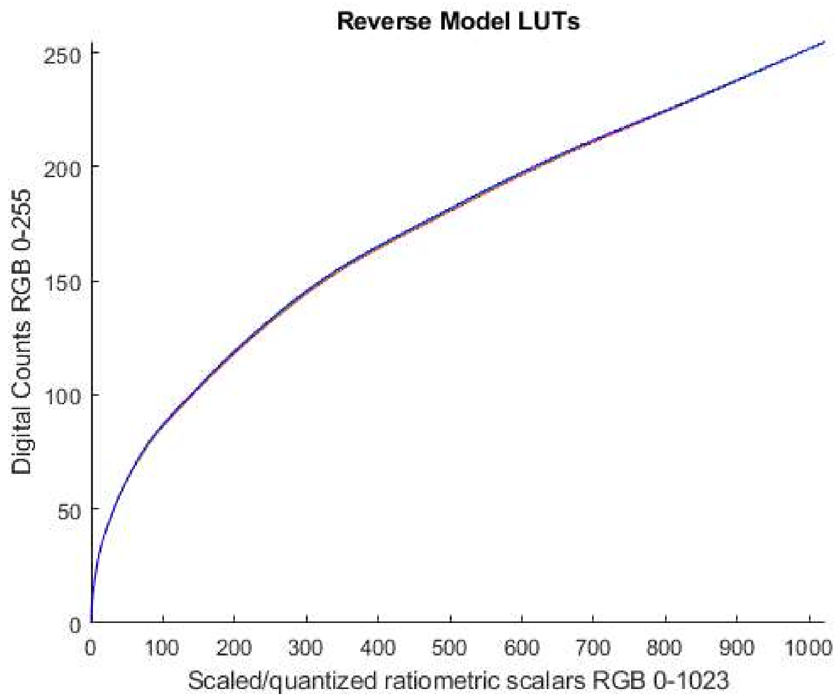
```
m_rev = m_fwd_inv
```

```
m_rev =

    4.1476   -2.3243   -0.5238
   -1.4787    2.4687   -0.0479
   -0.0455   -0.1586    1.0174
```

Step 7 - Reverse LUT

```
RedLUT_rev   = uint8(round(interp1(RedLUT_fwd, 0:255, linspace(0, max(RedLUT_fwd), 1024), 'pchip', 0)));     % Red LUT reverse
GreenLUT_rev = uint8(round(interp1(GreenLUT_fwd, 0:255, linspace(0, max(GreenLUT_fwd), 1024), 'pchip', 0))); % Green LUT reverse
BlueLUT_rev  = uint8(round(interp1(BlueLUT_fwd, 0:255, linspace(0, max(BlueLUT_fwd), 1024), 'pchip', 0)));   % Blue LUT reverse

% Plot
figure
hold on
plot(0:1023, RedLUT_rev,  'Color', [1, 0, 0])
plot(0:1023, GreenLUT_rev,'Color', [0, 1, 0])
plot(0:1023, BlueLUT_rev, 'Color', [0, 0, 1])
```

```
ylabel("Digital Counts RGB 0-255")
xlabel("Scaled/quantized ratiometric scalars RGB 0-1023")
title("Reverse Model LUTs")
ylim([0 255])
xlim([0 1023])
```



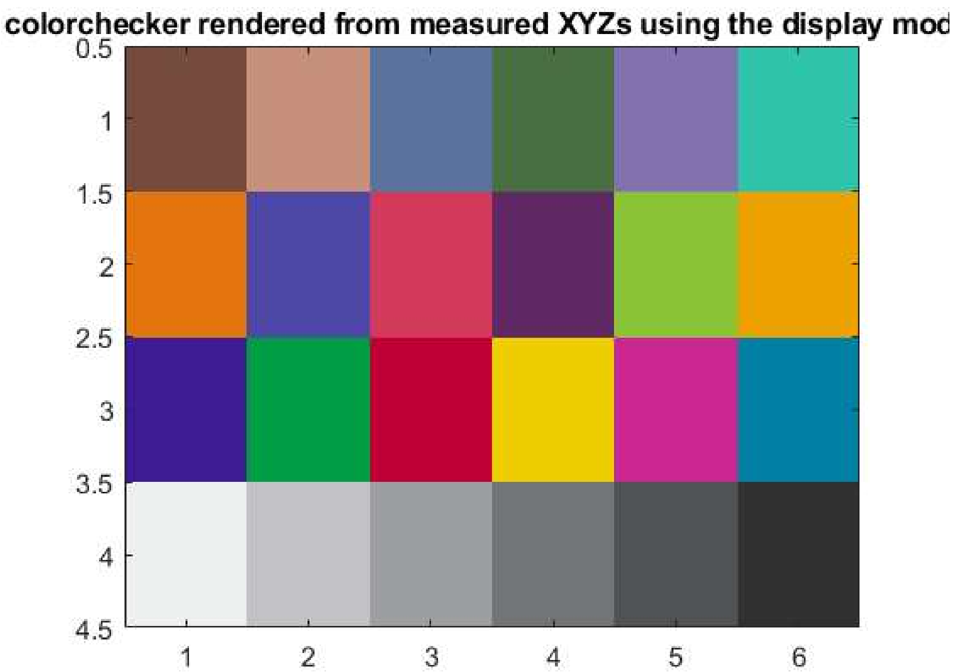
Step 8 - Final Display Model

```
XYZw_display = XYZw; % White of dispaly
XYZk_display = XYZk; % Black of display
M_Display = m_rev;   % Reverse matrix of dispaly
RLUT_display = RedLUT_rev;   % Red LUT reverse model
GLUT_display = GreenLUT_rev; % Green LUT reverse model
BLUT_display = BlueLUT_rev;  % Blue LUT reverse model

% Saves the B&W, and Reverse matrix of the display. Saves the R,G,B LUTs of
% the reverse model
save ('display_model.mat', 'XYZw_display', 'XYZk_display', 'M_Display', ...
      'RLUT_display', 'GLUT_display', 'BLUT_display');
```

Step 9 - Render RGB image from XYZ

```
% Step a
XYZ_D50;

% Step b - Load in Munki XYZ + Lab
load("loadMunkiData.mat")

% Step c - Adapt XYZ under D50 -> XYZ under Display's whitepoint
catXYZ = catBradford(Munki.XYZ, XYZ_D50, XYZw_display);

% Step d - Subtract the black level
catXYZ = catXYZ - XYZk_display;

% Step e - Multiply XYZ by the Display to produce RS
%                [3x3]     [3x24]
munki_CC_RS = M_Display * catXYZ;

% Step f
munki_CC_RS = munki_CC_RS/100;
```

```
% Step g
munki_CC_RS(munki_CC_RS<0) = 0;
munki_CC_RS(1<munki_CC_RS) = 1;

% Step h
munki_CC_RS = round(munki_CC_RS*1023 + 1);

% Step i
munki_CC_DC(1,:) = RedLUT_rev(munki_CC_RS(1,:));
munki_CC_DC(2,:) = GreenLUT_rev(munki_CC_RS(2,:));
munki_CC_DC(3,:) = BlueLUT_rev(munki_CC_RS(3,:));

% Step j - Visualize Chart Patches
pix = uint8(reshape(munki_CC_DC', [6 4 3]));
pix = fliplr(imrotate(pix, -90));
figure
image(pix);
set(gca, 'FontSize', 12);
title("colorchecker rendered from measured XYZs using the display model")
```



Step 10 - Evaluate Color Accuracy of Display Model

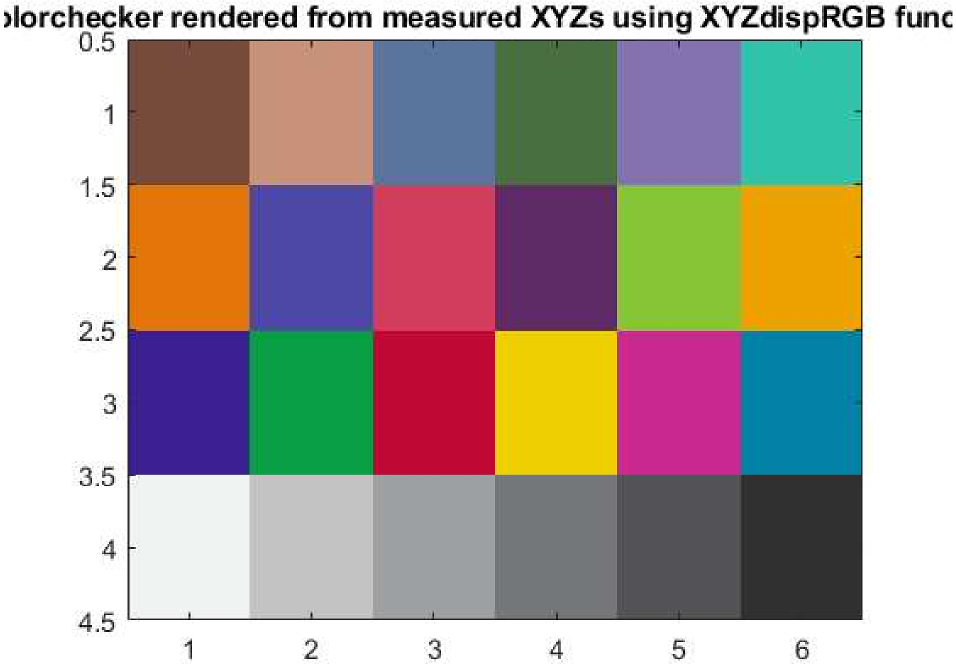
```
% Step a - Double cast and rescale to [0-100] range
munki_CC_DC = uint8( double(munki_CC_DC) * (100/255) );%Normalize to 1, then x100.

% Step b - Matrix table4ti1
table4ti1 = ones(30, 4);
table4ti1(:, 1) = 1:30;
table4ti1(1:24, 2:4) = munki_CC_DC';
table4ti1(25:27, 2:4) = 0;
table4ti1(28:30, 2:4) = 100;

% Step c - Write .ti1 file
write_ti1_file(table4ti1, 'disp_model_test.ti1');

% Step d - Use da Munki
% disp_model_test.ti3 made

% Step e - Load in XYZ values
disp_XYZs = importdata('disp_model_test.ti3',' ',20);
```

```
% Step f - Extra XYZs and average
CC_XYZ = disp_XYZs.data(1:24, 5:7);          % Extract XYZ Color
display_black = disp_XYZs.data(25:27, 5:7); % Extract XYZ display black
display_white = disp_XYZs.data(28:30, 5:7); % EXtract XYZ display white
XYZw = mean(display_white); % XYZ white is average of three measurements
XYZk = mean(display_black); % XYZ black is average of three measurements
CC_XYZ = CC_XYZ';
XYZw = XYZw';

% Step g - Calculate Lab from CC patches
Display_Lab = XYZ2Lab(CC_XYZ, XYZw);

% Step h - Calculate dEab
dEab = deltaEab(Display_Lab, Munki.Lab);

% Step i
print_display_model_error(Munki.Lab, Display_Lab, dEab);
```

```
Display model color error
XYZ_real->display_model->RGB_disp->display

               Real vs. displayed ColorChecker Lab values
                     real                        displayed
patch #       L         a         b         L         a         b       dEab
      1   37.1865   14.9985   15.2592   36.8865   14.2261   15.5284   0.8713
      2   65.8188   16.8695   18.0267   65.6802   14.8212   18.1930   2.0596
      3   49.9949   -3.1841  -23.5159   51.0788   -0.7536  -21.3123   3.4552
      4   42.6411  -15.3251   20.0423   42.7415  -17.8604   21.8983   3.1437
      5   54.6852    9.6978  -26.7126   55.2683   12.8836  -26.1391   3.2891
      6   71.2441  -33.1391   -0.5010   71.3126  -32.6945    1.0255   1.5914
      7   62.2558   34.1094   57.7774   61.6009   30.0253   57.6497   4.1383
      8   39.5890    9.9980  -43.6388   40.5232   17.0778  -42.7419   7.1972
      9   51.8424   48.1403   16.0636   51.4238   46.1820   14.6605   2.4451
     10   29.4495   22.4255  -21.7661   30.0405   23.9639  -21.6209   1.6543
     11   71.6264  -24.3441   57.6850   71.4577  -30.1075   58.1888   5.7878
     12   72.2288   20.6039   69.0149   71.7194   15.9079   67.0791   5.1048
     13   28.6402   18.5907  -51.4092   29.8424   25.7203  -48.6971   7.7221
     14   54.6309  -39.5493   32.8341   55.0122  -41.1915   34.6212   2.4567
     15   42.5988   54.6049   25.7315   42.8231   50.4198   25.3424   4.2092
     16   82.4265    3.8689   78.8570   82.3103   -2.5619   76.1660   6.9721
     17   51.5476   49.5154  -14.3758   51.2270   50.0912  -14.4897   0.6688
     18   49.3892  -26.5473  -28.6645   51.9430  -13.5950  -24.4903  13.8459
     19   95.4458   -0.4414    0.0244   96.0094   -0.9179    0.3093   0.7911
     20   80.0339    0.1309   -0.9345   80.3975   -0.0666    0.2644   1.2683
     21   66.0107   -0.0004   -1.1463   66.4131    0.1474   -0.4507   0.8171
     22   50.5546   -0.6207   -0.9616   51.0370   -0.4016   -0.8122   0.5504
     23   35.1532   -0.0632   -0.9708   35.8202    0.2682   -0.7166   0.7870
     24   20.3224   -0.2858   -0.5603   19.9919    0.0087    0.2874   0.9564

                                                            min       0.5504
                                                            max      13.8459
                                                            mean      3.4076
```

Step 11 - Create Display RGB Function

```
Display_RGB = XYZ2dispRGB("display_model.mat", CC_XYZ, XYZw) ;

% Reusing Ye' Holy Jim Code
pix = reshape(Display_RGB', [6 4 3]);
pix = fliplr(imrotate(pix, -90));
figure;
image(pix);
set(gca, 'FontSize', 12);
title("colorchecker rendered from measured XYZs using XYZdispRGB function");
```



Display XYZ2RGB function

```
function munki_CC_DC = XYZ2dispRGB(display_model, XYZ, XYZn)
% display_model = display_model.mat file
% XYZ [3xn]      = XYZ valeus of CC patches
% XYZn [3x1]     = Whitepoint / Reference white

load("display_model");

% Step c - Adapt XYZ under D50 -> XYZ under Display's whitepoint
catXYZ = catBradford(XYZ, XYZn, XYZw_display);

% Step d - Subtract the black level
catXYZ = catXYZ - XYZk_display;

% Step e - Multiply XYZ by the Display to produce RS
%               [3x3]      [3x24]
munki_CC_RS = M_Display * catXYZ;

% Step f
munki_CC_RS = munki_CC_RS/100;

% Step g
munki_CC_RS(munki_CC_RS<0) = 0;
munki_CC_RS(1<munki_CC_RS) = 1;

% Step h
munki_CC_RS = round(munki_CC_RS*1023 + 1);

% Step i
munki_CC_DC(1,:) = RLUT_display(munki_CC_RS(1,:));
munki_CC_DC(2,:) = GLUT_display(munki_CC_RS(2,:));
munki_CC_DC(3,:) = BLUT_display(munki_CC_RS(3,:));

% Convert to uint8
uint8(munki_CC_DC);
end
```

Flex write_ti1_file.m

```
function filename = write_ti1_file (table4ti1, filename)

% Open/Create document
fid = fopen(filename, 'w+');

% Create Document
fprintf(fid, '%s\n\n', "CTI1");

fprintf(fid, '%s\n\n', 'COLOR_REP "RGB"');

fprintf(fid, '%s\n', "NUMBER_OF_FIELDS 4");
fprintf(fid, '%s\n', "BEGIN_DATA_FORMAT");
fprintf(fid, '%s\n', "SAMPLE_ID RGB_R RGB_G RGB_B");
fprintf(fid, '%s\n\n', "END_DATA_FORMAT");

fprintf(fid, '%s\n', "NUMBER_OF_SETS 30");
fprintf(fid, '%s\n', "BEGIN_DATA");

for i = 1:size(table4ti1(:, 1))
    fprintf(fid, '%i %i %i %i\n' ,table4ti1(i, 1),table4ti1(i, 2),table4ti1(i, 3),table4ti1(i, 4));
end

fprintf(fid, '%s', "END_DATA");

fclose(fid);
end % End function
```

Step 12 - Feedback

i) Gian-Mateo failed to realize that uint8 did not in-fact mean "round", but all was resolved in the end. ii) Cooper and Gian-Mateo did the functions, code, and revision/cleanup. iii) Using the ones function to build a matrix iv) Explanation of what Step 9.j is doing.

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