IRL #10: Progress Review
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Team G: EXCALIBR

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Individual Progress

Color Calibration

Color calibration is to measure and adjust the color response of a device (input or output) to a known state. We use an X-Rite ColorChecker Classic Card as our ground truth (The manufacture gives us the true color values) and aim at mapping the colors recorded by the cameras these ground truths.

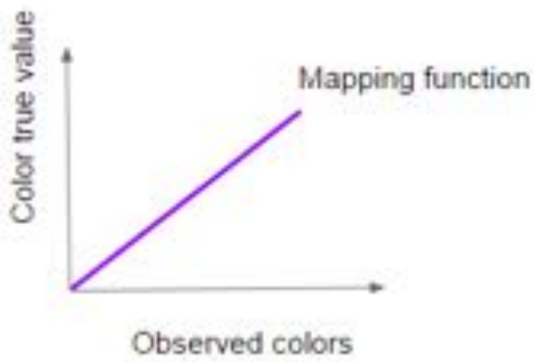


Figure 1. Mapping function (unreal): This graph is only for illustrating the concepts

Current Status

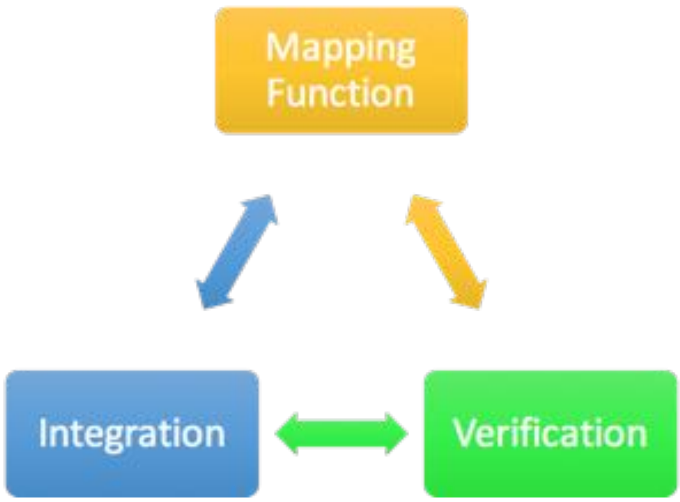


Figure 2. Status

The mapping function has been developed but needs some verifications. I am working on verifying my algorithm these weeks. The whole process is both forward and backward. On one hand, I am using my calibrated results to do the verifications. On the other hand, it is probably that my mapping algorithm has bugs and the verification results would point the problem out and then I will correct my algorithm. Meanwhile, I am waiting for the setup of the dome so that I can move my algorithm onto the main system and test my algorithm on the cameras that we are going to use in the final presentation.

ColorChecker Information

Figure 3. The 1-24 in this image correspond to the 1-24 in the x-axis below

No.	Number		sRGB R	sRGB G	sRGB B	CIE L*a*b* L*	CIE L*a*b* a*	CIE L*a*b* b*	Munsell Notation Hue	Munsell Notation Value / Chroma
1.	dark skin		115	82	68	37.986	13.555	14.059	3 YR	3.7 / 3.2
2.	light skin		194	150	130	65.711	18.13	17.81	2.2 YR	6.47 / 4.1
3.	blue sky		98	122	157	49.927	-4.88	-21.925	4.3 PB	4.95 / 5.5
4.	foliage		87	108	67	43.139	-13.095	21.905	6.7 GY	4.2 / 4.1
5.	blue flower		133	128	177	55.112	8.844	-25.399	9.7 PB	5.47 / 6.7
6.	bluish green		103	189	170	70.719	-33.397	-0.199	2.5 BG	7 / 6
7.	orange		214	126	44	62.661	36.067	57.096	5 YR	6 / 11
8.	purplish blue		80	91	166	40.02	10.41	-45.964	7.5 PB	4 / 10.7
9.	moderate red		193	90	99	51.124	48.239	16.248	2.5 R	5 / 10
10.	purple		94	60	108	30.325	22.976	-21.587	5 P	3 / 7
11.	yellow green		157	188	64	72.532	-23.709	57.255	5 GY	7.1 / 9.1
12.	orange yellow		224	163	46	71.941	19.363	67.857	10 YR	7 / 10.5
13.	blue		56	61	150	28.778	14.179	-50.297	7.5 PB	2.9 / 12.7
14.	green		70	148	73	55.261	-38.342	31.37	0.25 G	5.4 / 8.65
15.	red		175	54	60	42.101	53.378	28.19	5 R	4 / 12
16.	yellow		231	199	31	81.733	4.039	79.819	5 Y	8 / 11.1
17.	magenta		187	86	149	51.935	49.986	-14.574	2.5 RP	5 / 12
18.	cyan		8	133	161	51.038	-28.631	-28.638	5 B	5 / 8
19.	white (.05*)		243	243	242	96.539	-0.425	1.186	N	9.5 /
20.	neutral 8 (.23*)		200	200	200	81.257	-0.638	-0.335	N	8 /
21.	neutral 6.5 (.44*)		160	160	160	66.766	-0.734	-0.504	N	6.5 /
22.	neutral 5 (.70*)		122	122	121	50.867	-0.153	-0.27	N	5 /
23.	neutral 3.5 (.1.05*)		85	85	85	35.656	-0.421	-1.231	N	3.5 /
24.	black (1.50*)		52	52	52	20.461	-0.079	-0.973	N	2 /

Cie L*a*b* values use Illuminant D50 2 degree observer sRGB values for Illuminate D65.

Figure 3. Color ground truth

Mapping function

The mapping function currently used:

Polynomial Model:

$$CalibratedR = \alpha_0 + \alpha_1 R + \alpha_2 G + \alpha_3 B + \alpha_4 R^2 + \alpha_5 G^2 + \alpha_6 B^2$$

$$CalibratedG = \beta_0 + \beta_1 R + \beta_2 G + \beta_3 B + \beta_4 R^2 + \beta_5 G^2 + \beta_6 B^2$$

$$CalibratedB = \gamma_0 + \gamma_1 R + \gamma_2 G + \gamma_3 B + \gamma_4 R^2 + \gamma_5 G^2 + \gamma_6 B^2$$

Fitting Method:

$$\begin{pmatrix} B^2 & G^2 & R^2 & B & G & C & 1 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \end{pmatrix}_{Camera} \begin{bmatrix} \alpha_6 \\ \vdots \\ 1 \end{bmatrix} = \begin{bmatrix} R \\ \vdots \\ R \end{bmatrix}_{Truth}$$

$$\begin{bmatrix} \alpha_6 \\ \vdots \\ 1 \end{bmatrix} = \begin{pmatrix} B^2 & G^2 & R^2 & B & G & C & 1 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \end{pmatrix}_{Camera} / \begin{bmatrix} R \\ \vdots \\ R \end{bmatrix}_{Truth}$$

Experiments

Three verification methods are used here:

Method 1. Error comparison of before and after calibration

Errors mean the difference between the recorded color values with the ground truth values.

<IMG_1462.JPG> (The image was taken in yellow light)

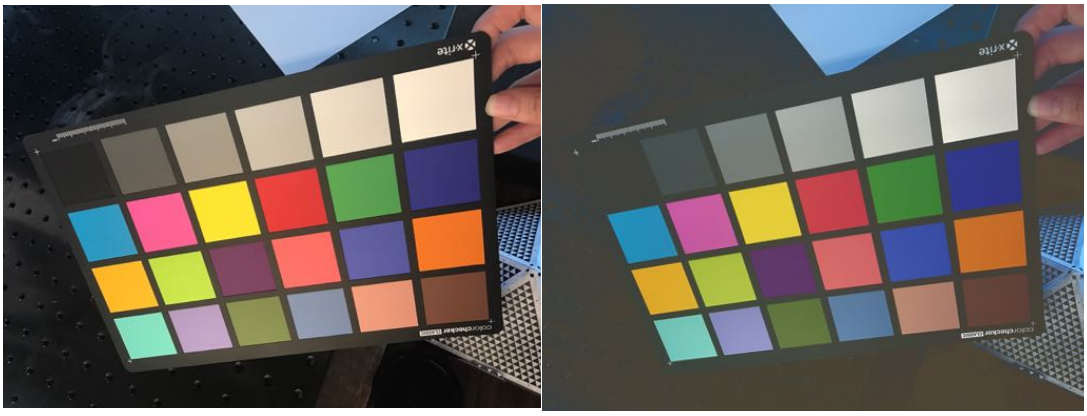
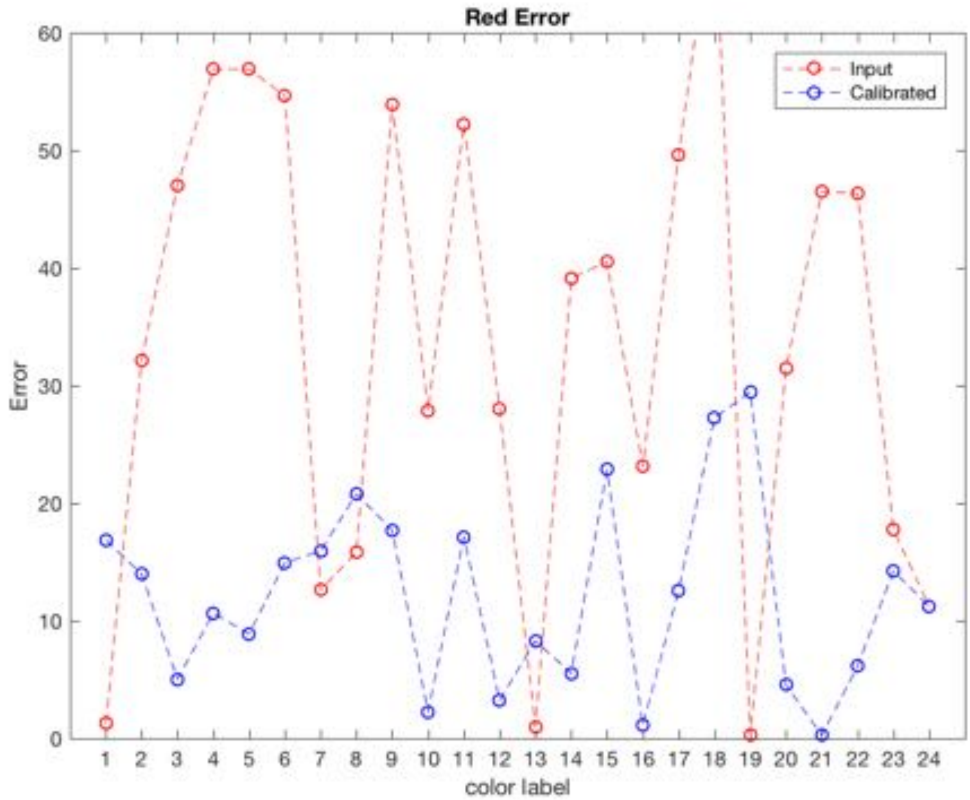
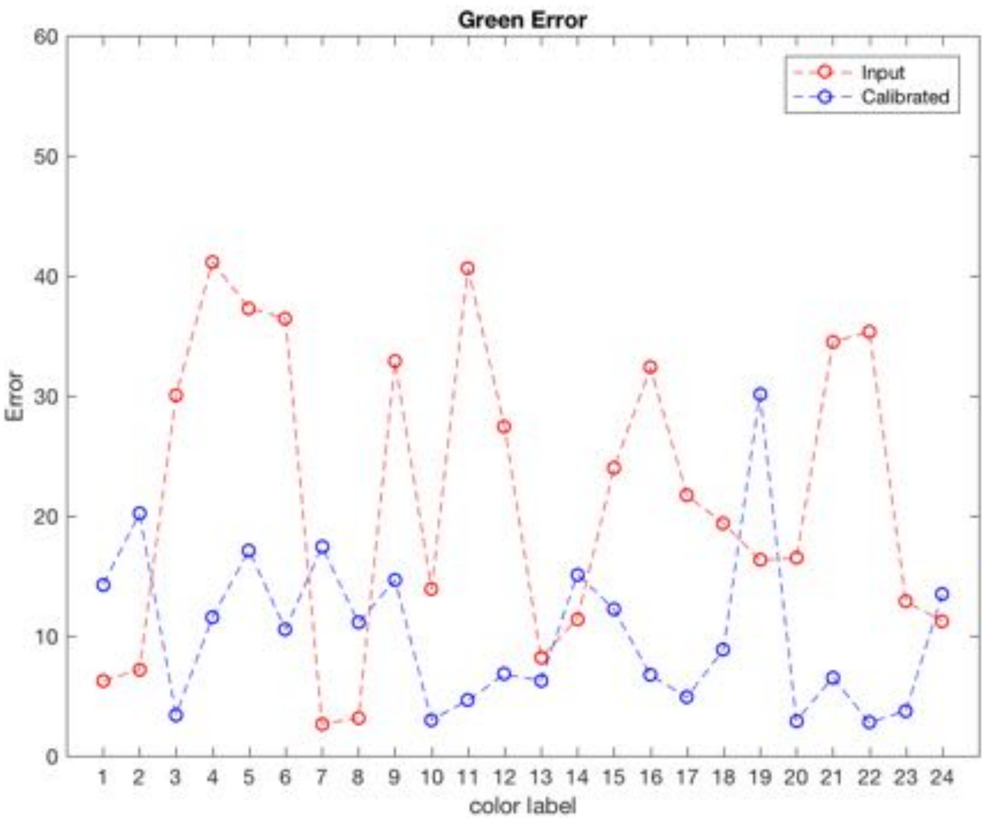


Figure 4. The left image is the input image and the right image is the calibrated image.


Red Error
Input
Calibrated
Error
color label


Green Error
Input
Calibrated
Error
color label

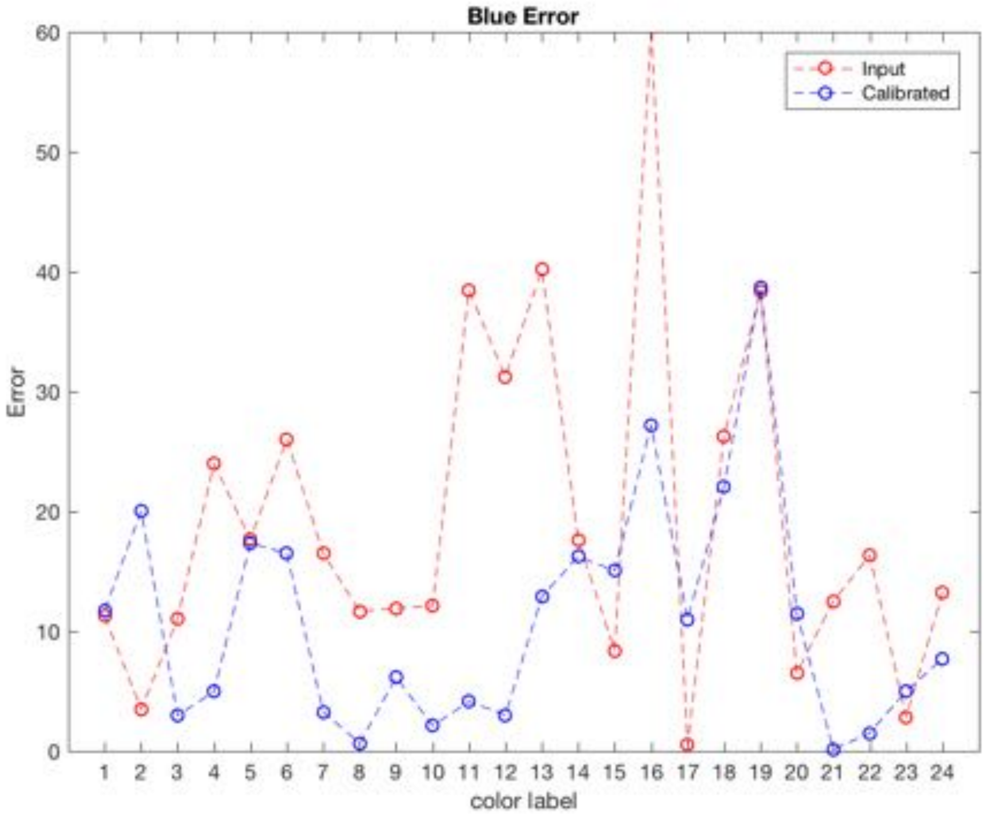


Figure 5. Errors in IMG_1462.JPG and its calibrated result

<IMG_1461.JPG> (The image was taken in normal office lighting condition)

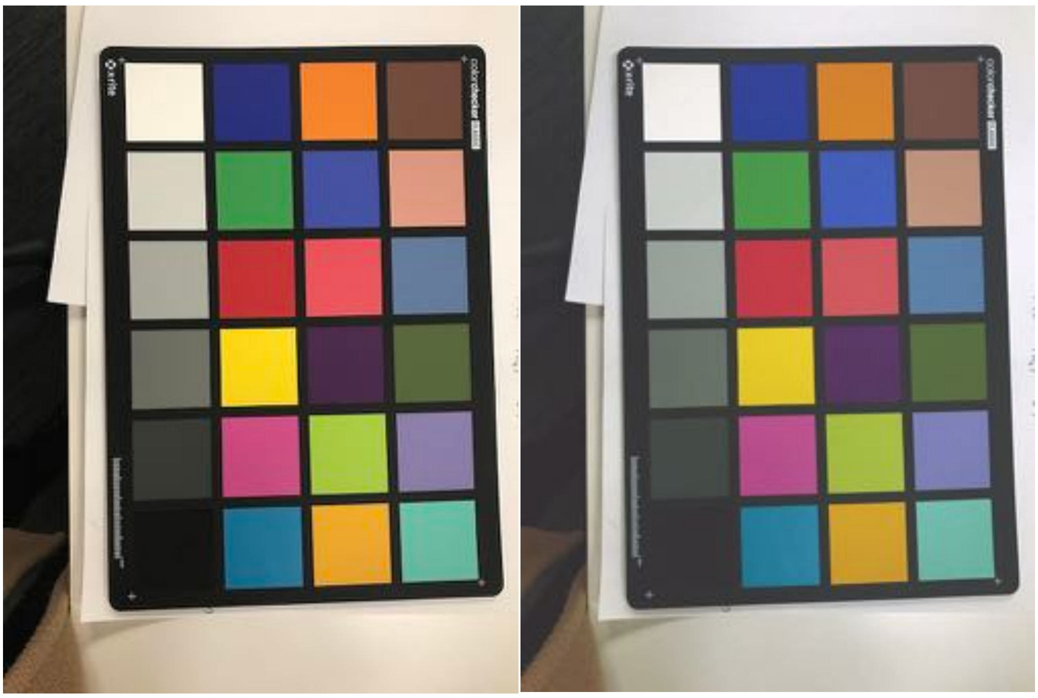
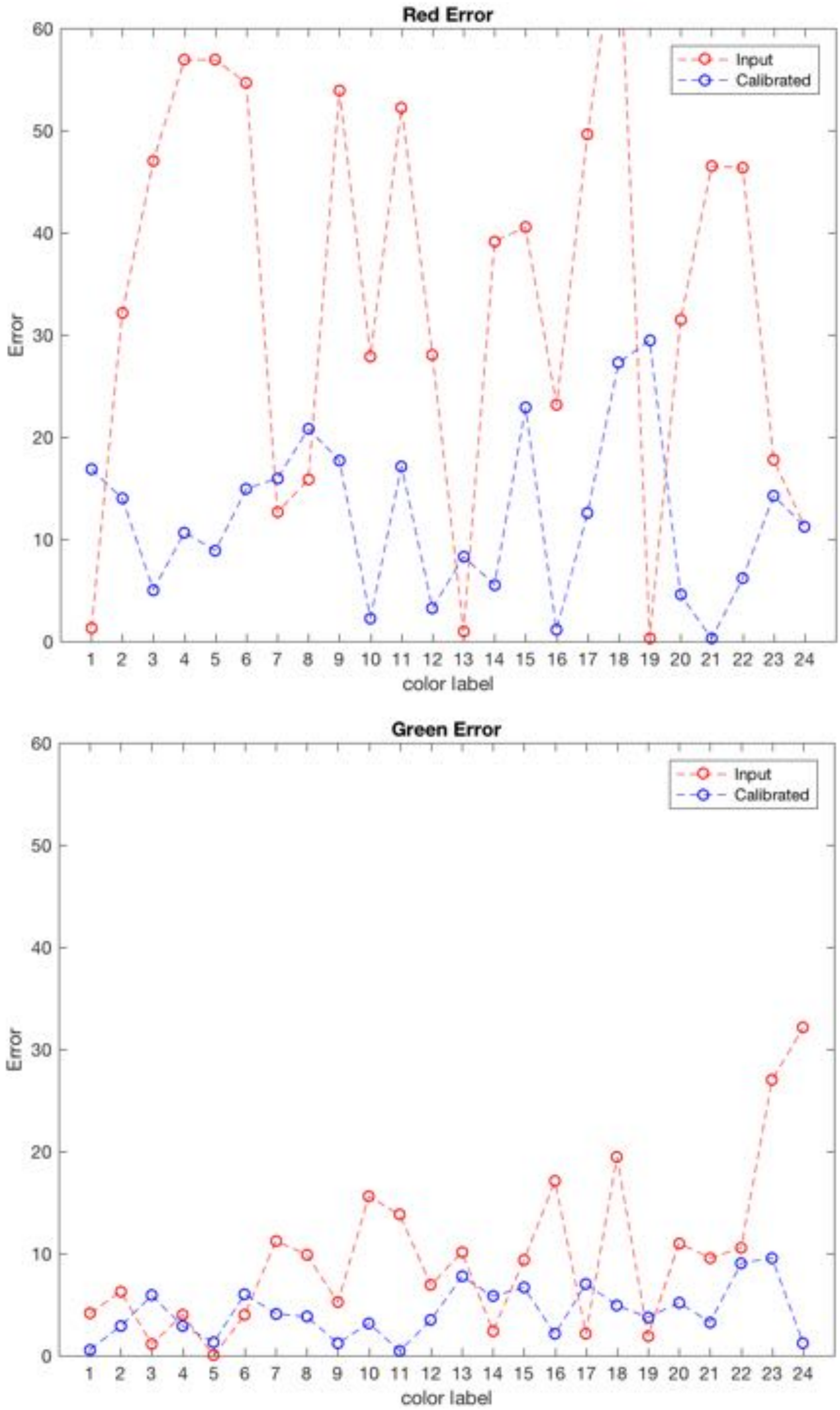


Figure 6. The left image is the input; the right image is the output


Red Error
Input
Calibrated
Error
color label
Green Error
Input
Calibrated
Error
color label

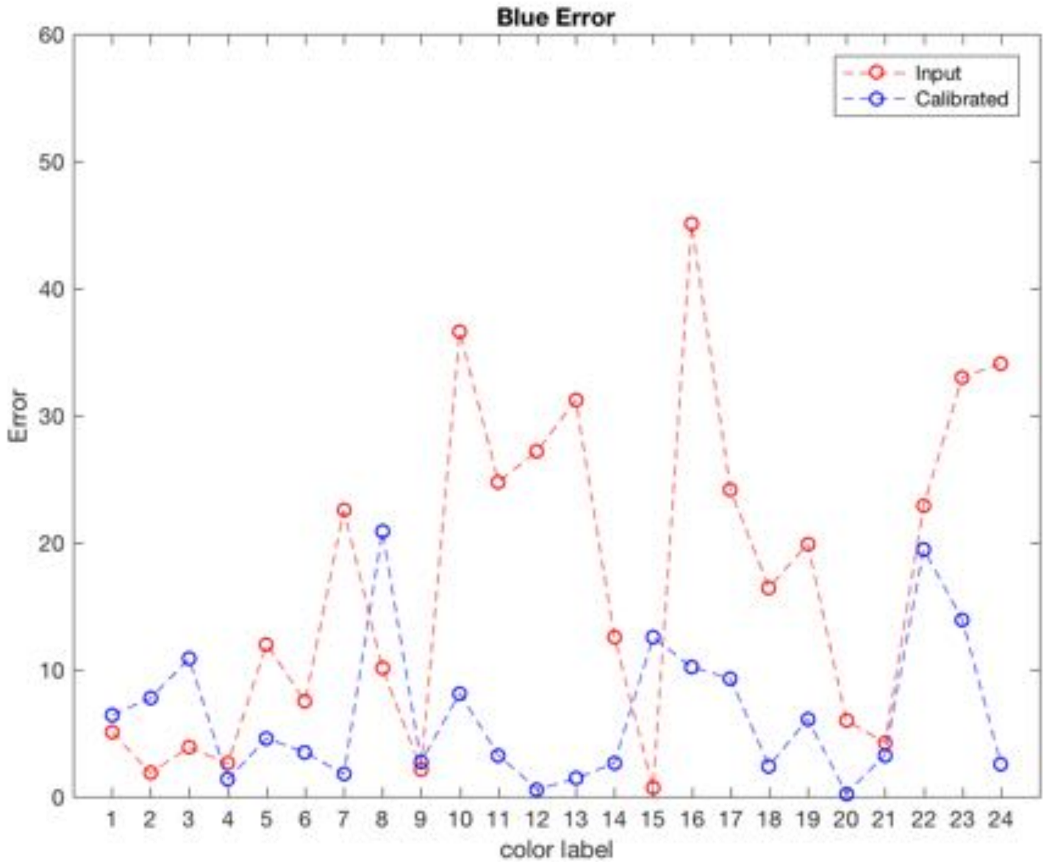


Figure 7. Errors in IMG_1461.JPG and its calibrated result

We can see that in each channel of the two input images, the errors reduce generally. However, there are some color patches that become worse after calibration.

Method 2. Error differences between two calibrated images

According to the Xrite standard, when using sRGB ground truth for calibration, the calibrated image should perform like the colorchecker in illuminant D65, which means no matter in what lighting condition the images were taken, they should look similar after the calibration. It can be seen in images below that after the calibration, the color differences become much smaller. The difference means the absolute value of the difference between the according color patches in IMG_1461 and IMG_1462. In addition, we can see that in Figure 4 and Figure 6 the original images look quite different because of the different lighting condition but after calibration they look much more alike.

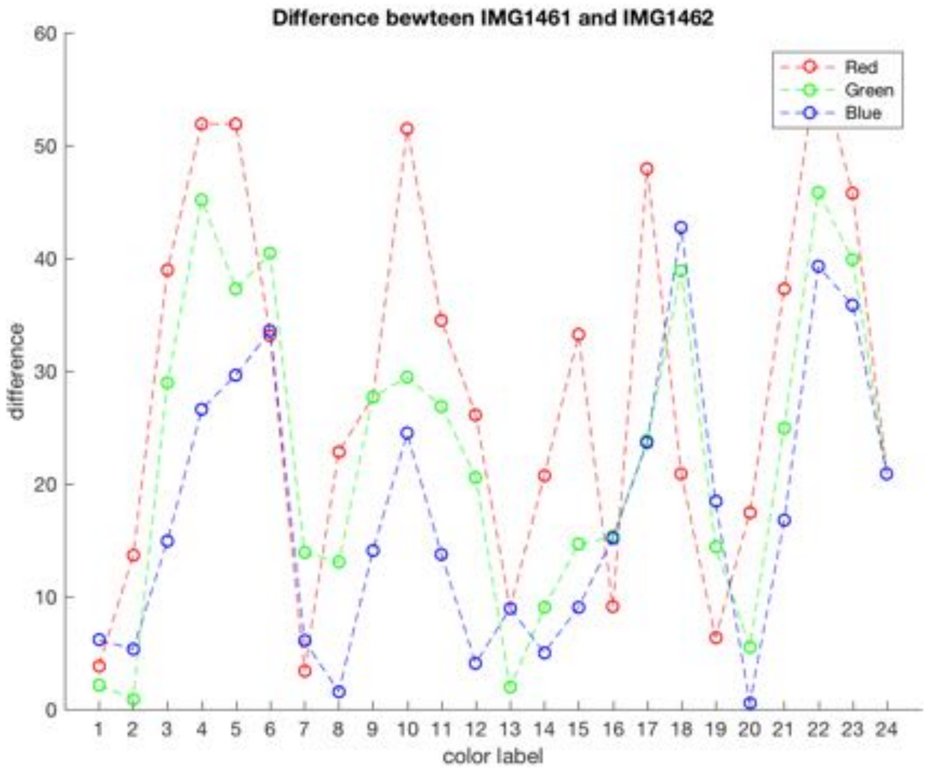


Figure 8. Differences between IMG1461 and IMG1462 before calibration

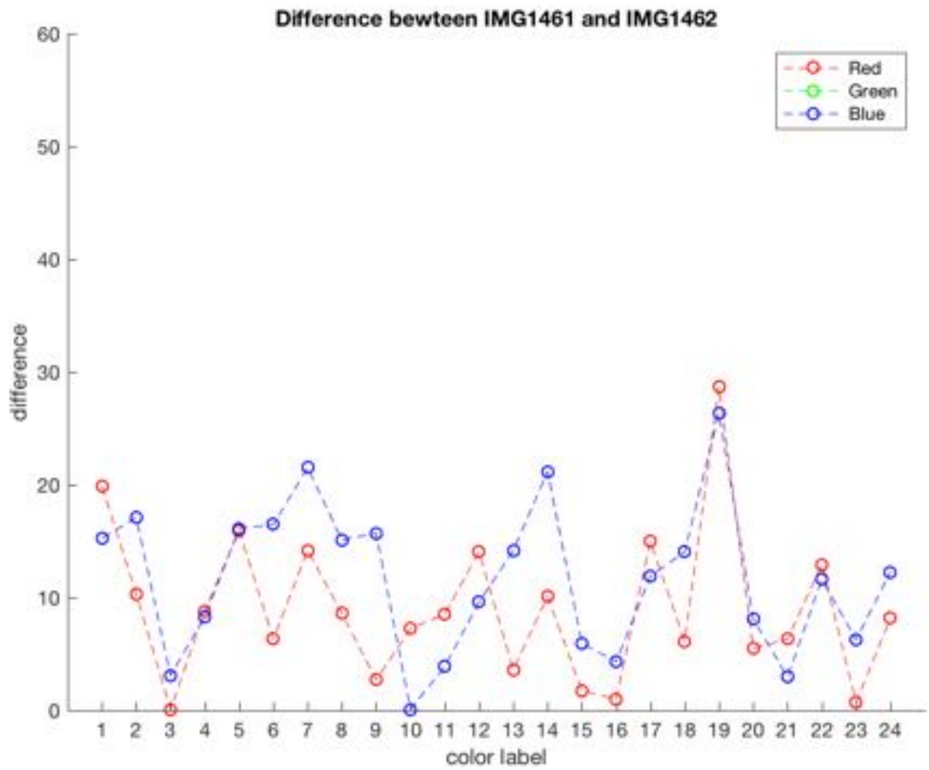
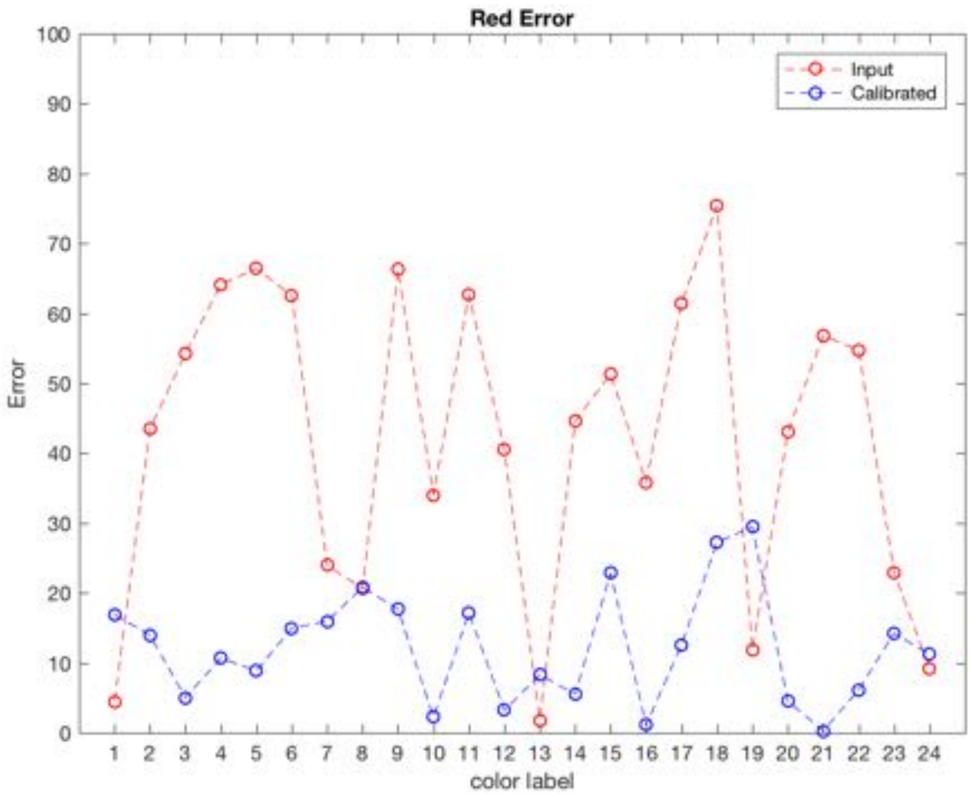
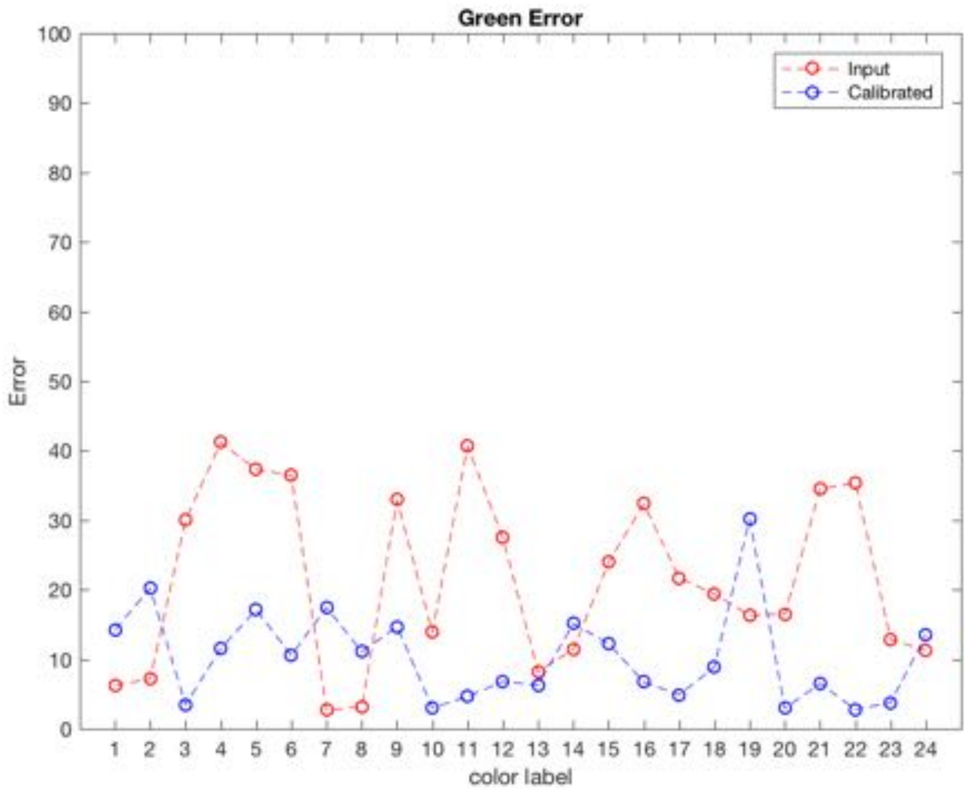


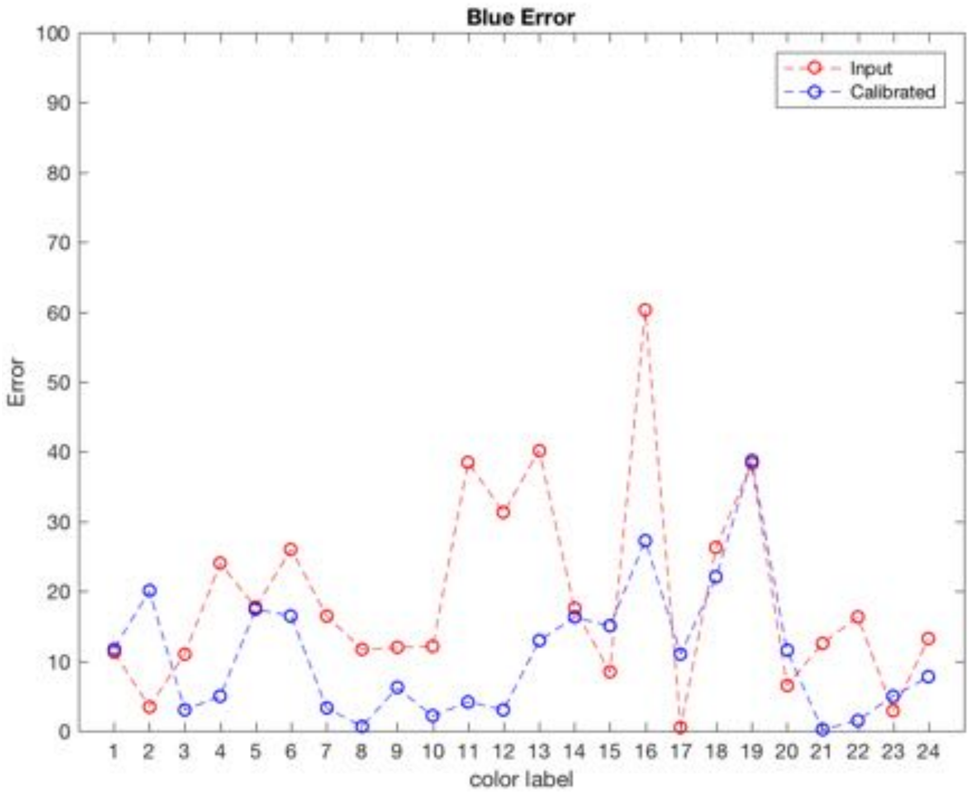
Figure 9. Differences between IMG1461 and IMG1462 after calibration

Method 3. Manipulate the colors and see how it performs after calibration

IMG_1462.JPG Red Channel*1.05 (5%)

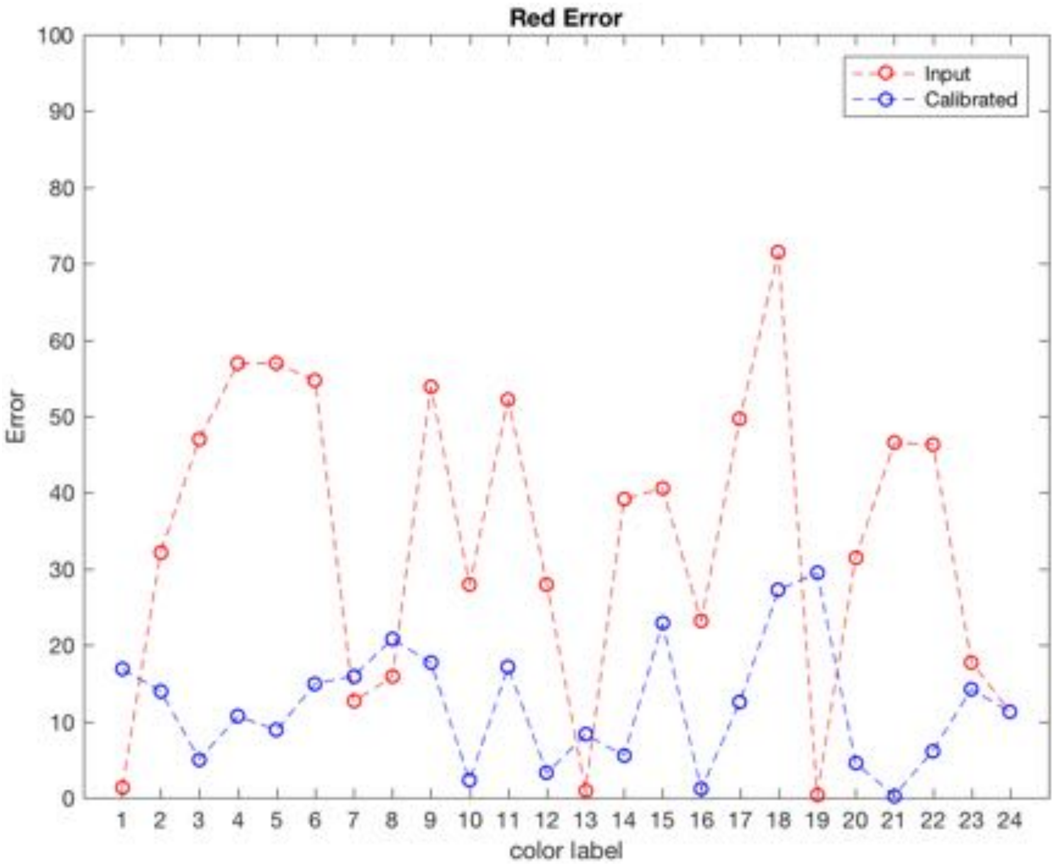


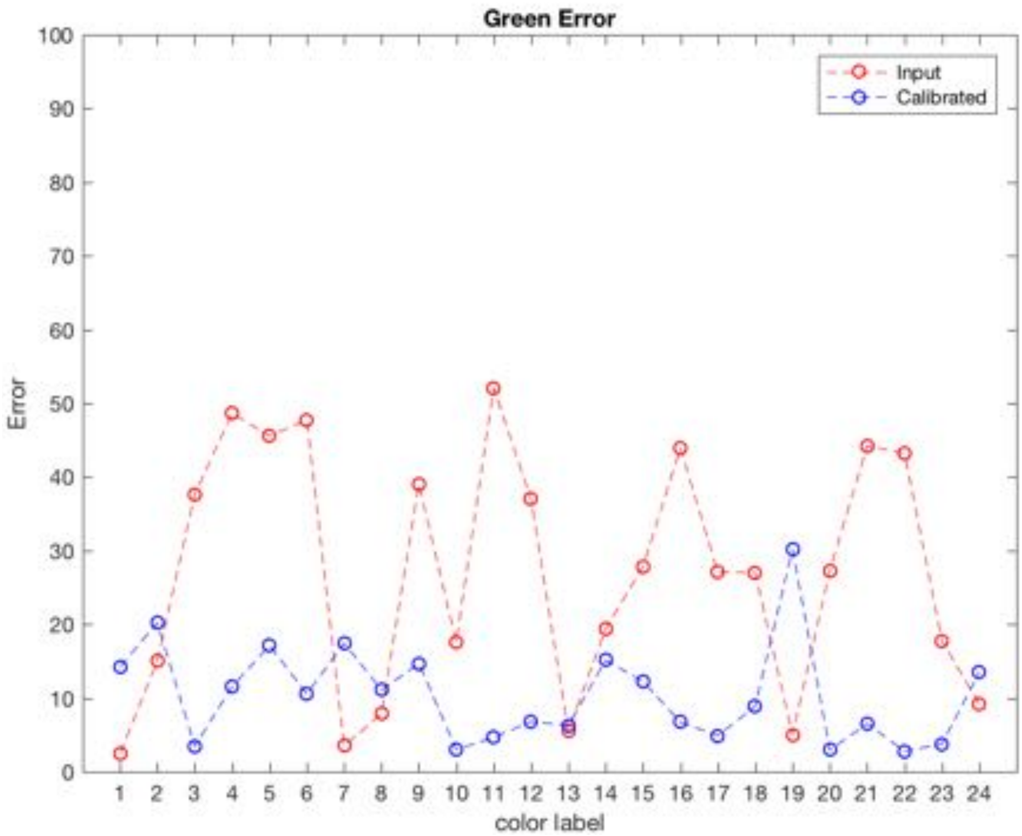

Green Error
Input
Calibrated
Error
color label
100
90
80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24


Blue Error
Input
Calibrated
Error
color label
100
90
80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

Calibrated Image

IMG_1462.JPG Green Channel*1.05 (5%)


Red Error
Input
Calibrated
Error
color label
0
10
20
30
40
50
60
70
80
90
100
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24


Green Error
Input
Calibrated
Error
color label
0
10
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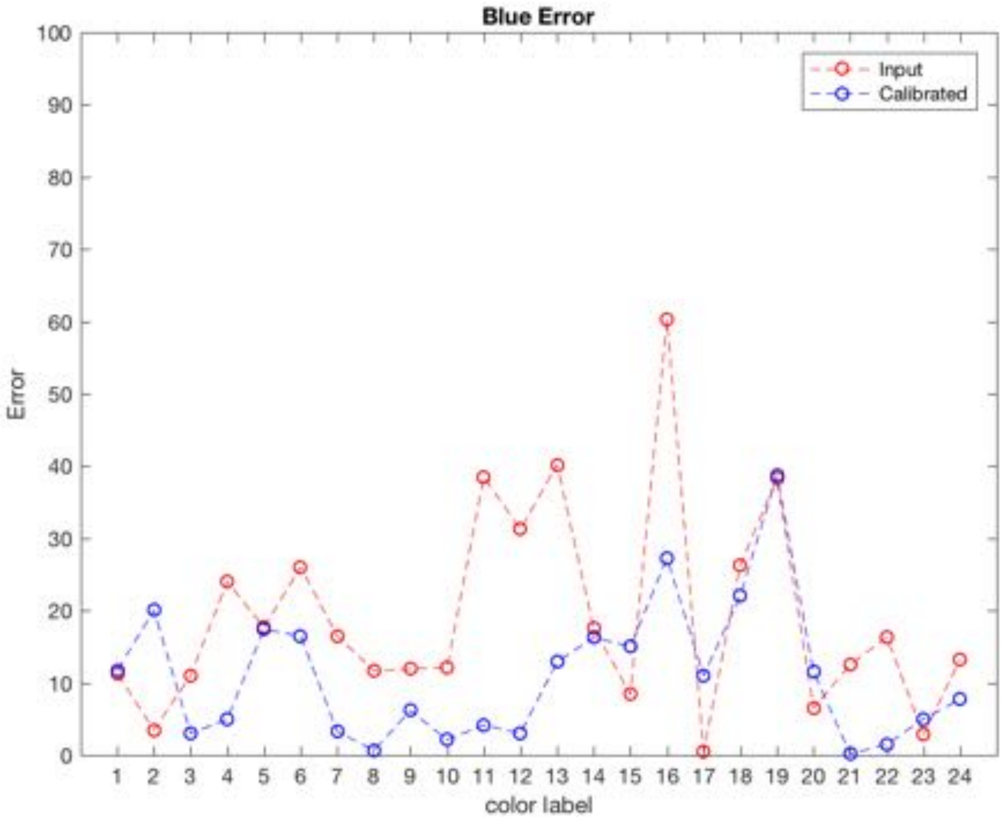
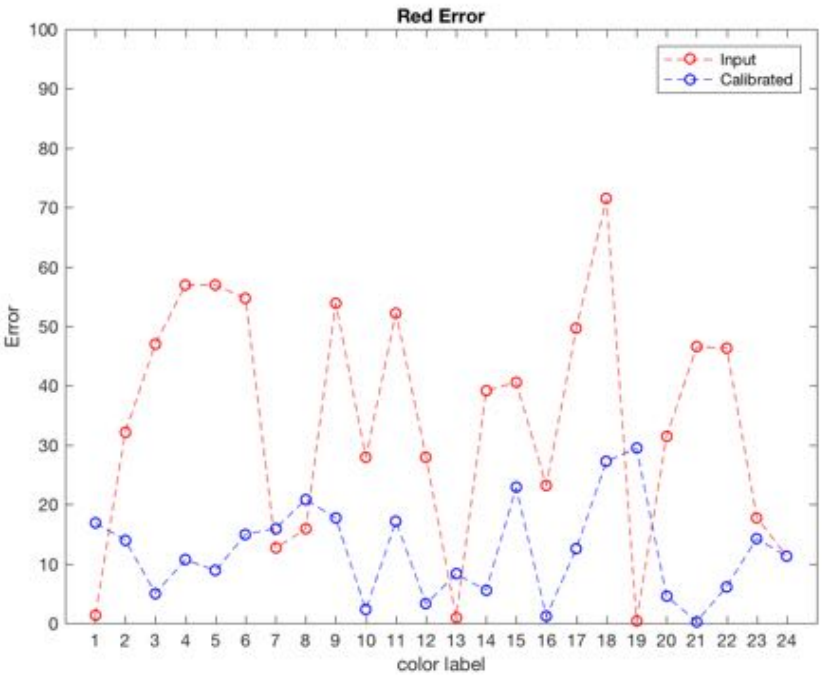
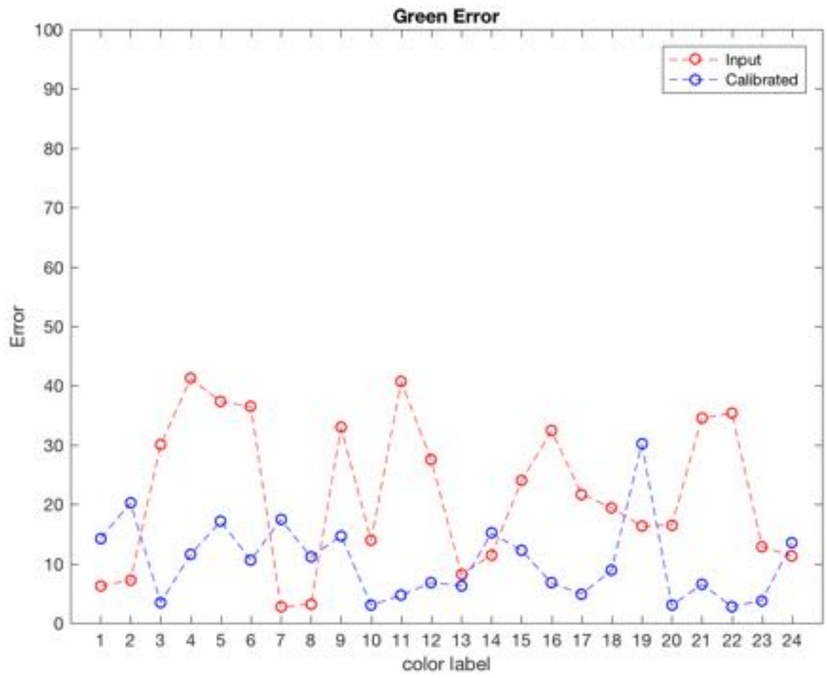
70
80
90
100
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

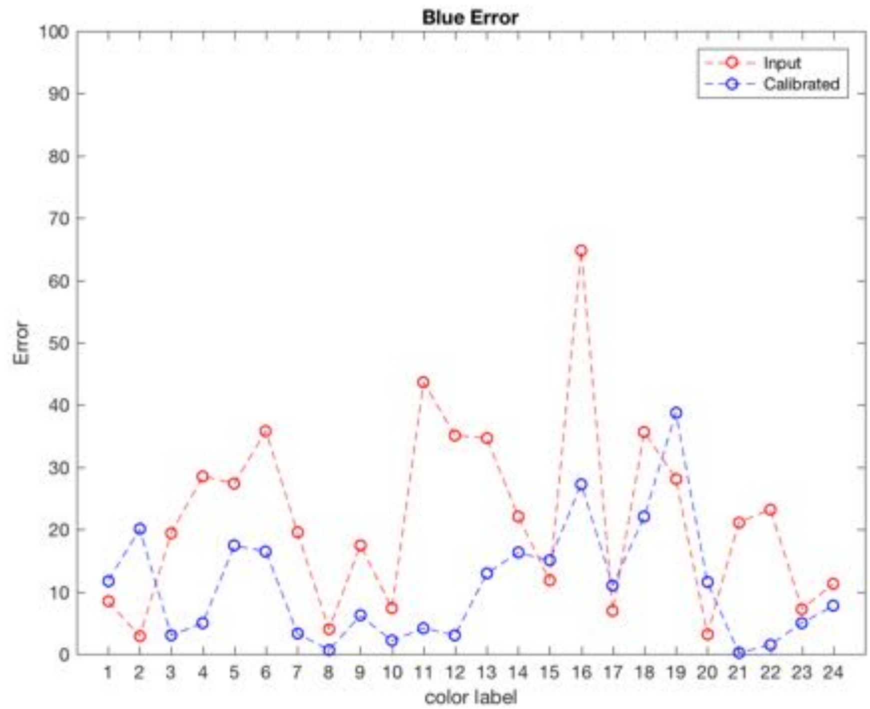


Calibrated Image

IMG_1462.JPG Blue Channel*1.05 (5%)




Green Error
Input
Calibrated
Error
color label


Blue Error
Input
Calibrated
Error
color label

Calibrated Image

The whole comparison process is lengthy. In brief, we can see that the calibration can bring the manipulated images back to very similar results.

Challenge

1. PR11 goal: Testing the mapping model in different lighting conditions and comparing the results. → After comparison, it is shown that the calibrated results indeed are generally better than before calibration. However, some color patches have worse performance. This is still worth analyzing. I am guessing it might be the problem of my fitting method.

   Fitting Method:

$$\begin{pmatrix} B^2 & G^2 & R^2 & B & G & C & 1 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \end{pmatrix}_{Camera} \begin{bmatrix} \alpha_6 \\ \vdots \\ 1 \end{bmatrix} = \begin{bmatrix} R \\ \vdots \\ R \end{bmatrix}_{Truth}$$

$$\begin{bmatrix} \alpha_6 \\ \vdots \\ 1 \end{bmatrix} = \begin{pmatrix} B^2 & G^2 & R^2 & B & G & C & 1 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \end{pmatrix}_{Camera} / \begin{bmatrix} R \\ \vdots \\ R \end{bmatrix}_{Truth}$$

   The matrix is not a square matrix and does not have an inverse matrix. Hence, I am using pseudo-inverse matrix to solve the problem. This can lead to some errors. I will try to use other polynomial fitting method to redo the algorithm and compare the results.

2. Due to the delay of the dome construction, it is not easy to test the color calibration on the final system. We need to fasten our process.

Teamwork

Yiqing Cai	Generate one of the best path for robot arm. Test optimized path on the simplified dome setup.
Huan-Yang Chang	Simulation system setup, Robot arm manipulation. Test optimized path on the simplified dome setup.
Siddharth Raina	Sensor noise calibration plan development
Sambuddha Sarkar	Works on Blender. Generate virtual calibration target and render the virtual images of the target.

References

[1] https://en.wikipedia.org/wiki/Color_calibration

[2] https://en.wikipedia.org/wiki/Flood_fill