Color Performance Review Tool for Endoscopy Devices - User's Manual

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1. Introduction

The Color Performance Review (CPR) Tool for Endoscopy Devices is a software program written in Matlab for analyzing color performance testing data in endoscopy device. The tool accepts the testing data and then generates quantitative analyses for the user to compare color performance between devices. The input testing data include the measurement data of a standard test target from the device output as well as the ground truth of the test target.

The tool provides the following analyses:

- Visual simulation of the test target and sample scenes
- Absolute color errors in comparison with the ground truth
- Preservation of the patch order in lightness, hue, and chroma
- Preservation of color contrast between patches

1.1 Software Requirements

- Matlab Runtime 9.12 (Version 9.12 tested)
- Matlab (Version 9.12 tested)
- Image Processing Toolbox (Version 11.5 tested)
- Computer Vision Toolbox (Version 9.12 tested)
- Statistics and Machine Learning Toolbox (Version 12.3 tested)

2. Data Processing

2.0 Data Preparation

The input data should include the measured CIEXYZ values of the 24-patch ColorChecker for the test target and the subject device. The input files are text files in the comma-separated value (CSV) format. Each input file contains 25 rows of the CIE X, Y, and Z values separated by commas. Lines #1~#24 describe the 24 color patches, and Line #25 describes the reference white. Follow the patch order defined by the ColorChecker.

The following is a sample input file:

```
type('XYZ_Subject.csv')
```

```
19.1,16.2,8.9
76.6,72.2,58.4
40.6,41.7,80.7
20.1,26.4,9.8
61.3,58.6,99.5
80.7,95,106.7
66.8,58.4,12.1
24.5,20.3,77.6
47.3,29.1,24.3
5.5,3.3,12.1
66.5,85.1,19.3
74.1,74.9,11.2
10.8,6.8,46
29.3,46.6,15.1
29.2,16.4,5.3
95,107.4,14.7
56.4,38,69.2
44.2,51.1,100.4
167.3,174.2,193.4
124.8,130.3,145.4
88.1,92.2,103.4
45.2,47.3,52.6
13.6,14.2,17.4
0.6,0.6,0.8
167.3,174.2,193.4
```

Figure 2.0: CIEXYZ input file. A sample input file of the CIEXYZ data measured from the device.

2.1 Import Data

Provide filenames for loading data files that contain the measured CIEXYZ values of the 24-patch ColorChecker for the test target (e.g., 'XYZ_Reference.csv') and the subject device (e.g., 'XYZ_Subject.csv'):

```
XYZ_Reference_filename = "XYZ_Reference.csv";
XYZ_Reference = csvread(XYZ_Reference_filename);

XYZ_Subject_filename = "XYZ_Subject.csv";
XYZ_Subject = csvread(XYZ_Subject_filename);
```

2.2 CIEXYZ Data

The input data are combined into `CIEXYZ_Data` as a 25x6 table for inspection:

```
% create a table to show the data

Ref_X = XYZ_Reference(:,1);
Ref_Y = XYZ_Reference(:,2);
Ref_Z = XYZ_Reference(:,3);
```

```
Sub_X = XYZ_Subject(:,1);
Sub_Y = XYZ_Subject(:,2);
Sub_Z = XYZ_Subject(:,3);

CIEXYZ_Data = table(Ref_X,Ref_Y,Ref_Z,Sub_X,Sub_Y,Sub_Z)
```

CIEXYZ_Data = 25×6 table

	Ref_X	Ref_Y	Ref_Z	Sub_X	Sub_Y	Sub_Z
1	51.1000	46.2000	32.2000	19.1000	16.2000	8.9000
2	149.7000	139.3000	108.5000	76.6000	72.2000	58.4000
3	69.4000	73.2000	144.7000	40.6000	41.7000	80.7000
4	47	59.4000	31	20.1000	26.4000	9.8000
5	103.7000	97.5000	190	61.3000	58.6000	99.5000
6	125.6000	171	189.6000	80.7000	95	106.7000
7	160.1000	131.2000	31.4000	66.8000	58.4000	12.1000
8	52.6000	43.9000	164.4000	24.5000	20.3000	77.6000
9	110.9000	72.8000	58	47.3000	29.1000	24.3000
10	25.5000	17.4000	44.5000	5.5000	3.3000	12.1000
11	129.1000	171.9000	41.2000	66.5000	85.1000	19.3000
12	169.1000	159	24.7000	74.1000	74.9000	11.2000
13	29.1000	21.7000	105.1000	10.8000	6.8000	46
14	56.8000	94.1000	39.6000	29.3000	46.6000	15.1000

⋮

Figure 2.2: Verification of the input data. The CIEXYZ data of the ground truth (first three columns) and the device output (last three columns).

2.3 CIELAB Data

The CIEXYZ data are converted into CIELAB data:

```
% create the DeviceData objects
LAB_Reference = CPR.DeviceData;
LAB_Reference.setXYZ(XYZ_Reference);

LAB_Subject = CPR.DeviceData;
LAB_Subject.setXYZ(XYZ_Subject);

% create an object of the ColorPerformaneReview class
cpr = CPR.ColorPerformanceReview(LAB_Reference,LAB_Subject);
```

Show the CIELAB data for the user to examine:

```
% create a table to show the data
```

```
Ref_L_star = LAB_Reference.Lab(:,1);
Ref_a_star = LAB_Reference.Lab(:,2);
Ref_b_star = LAB_Reference.Lab(:,3);

Sub_L_star = LAB_Subject.Lab(:,1);
Sub_a_star = LAB_Subject.Lab(:,2);
Sub_b_star = LAB_Subject.Lab(:,3);

CIELAB_Data = table(Ref_L_star,Ref_a_star,Ref_b_star,Sub_L_star,Sub_a_star,Sub_b_star)
```

CIELAB_Data = 24×6 table

	Ref_L_star	Ref_a_star	Ref_b_star	Sub_L_star	Sub_a_star	Sub_b_star
1	43.0069	13.4819	13.7046	36.5549	16.0282	18.9414
2	69.2457	15.7802	14.9991	70.4877	12.5809	14.9385
3	52.7901	0.0828	-26.6662	56.0257	1.4192	-25.2700
4	48.1630	-16.1059	23.7018	45.8458	-19.8571	32.6213
5	59.6874	12.8386	-28.5801	64.6754	10.0484	-21.1622
6	75.2755	-31.9891	-1.5924	78.7727	-16.3737	-0.6324
7	67.5603	31.7213	56.7733	64.5835	20.8401	59.5397
8	42.0110	20.3700	-51.5650	40.6597	19.3255	-49.8244
9	52.6646	50.7821	11.2775	47.8861	52.7936	9.9764
10	26.6127	28.7565	-24.5855	14.9229	26.8858	-26.0821
11	75.4354	-29.3516	62.0779	75.3591	-26.1584	64.7479
12	73.0884	15.1033	73.0162	71.5526	3.7517	73.5749
13	29.8679	24.2854	-51.5005	23.3500	30.9640	-56.0720
14	58.7972	-44.9705	34.6449	58.7430	-42.4243	43.3861

⋮

Figure 2.3: Verification of the color conversion. The converted CIELAB data of the ground truth (first three columns) and the device output (last three columns).

3. Data Analysis

3.1 Visual simulation of the test target and sample scenes

3.1.1 Visualize CIEXYZ data

The following charts show the simulated visual results when using D65 as the reference white. Use these charts to check excessive color shift caused by the light source and/or the device.

```
if strcmp(cpr.devDataOriginal.source,'XYZ')
    cpr.evaluate_visual_XYZ;
end
```

Figure 3.1.1: Visual verification of the CIEXYZ data. The charts show the simulated visual results when using D65 as the reference white. Use these charts to check excessive color shift caused by the light source and/or the device.

3.1.2 Visualize CIELAB data

The following charts show the simulated visual results when using the provided reference white. Use these charts to assess how the device would reproduce the ColorChecker.

```
cpr.check_Lab_visual
```

Figure 3.1.2: Visual verification of the CIELAB data. The charts show the simulated visual results when using the provided reference white. Use these charts to assess how the device would reproduce the test target.

3.1.3 Visualize endoscopic scene

The following charts show the simulated visual results of an endoscopic scence. Use the default polyp sample or provide a different image according to the intended use.

Superficial esophageal cancer (type 0–IIa) is identified as slight reddish lesion

```
simulate_filename = "sample_polyp.png";
cpr.check_endoscopic_scene(simulate_filename);
```

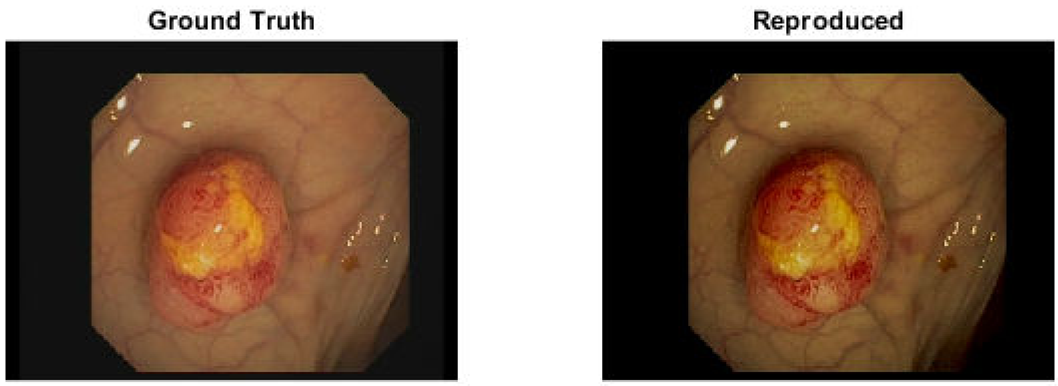

Figure 3.1.3: Visualize endoscopic scenes. The charts show the simulated visual results of an endoscopic scene. Use the default polyp sample or provide a different image according to the intended use.

3.2 Absolute color errors in comparison with the ground truth

The left chart shows the per-patch color difference between the subject device and the ground truth. The right chart shows the boxplot. Statistics (mean, std, min, median, and max) are provided in the titles.

```
cpr.check_dE_from_truth
```

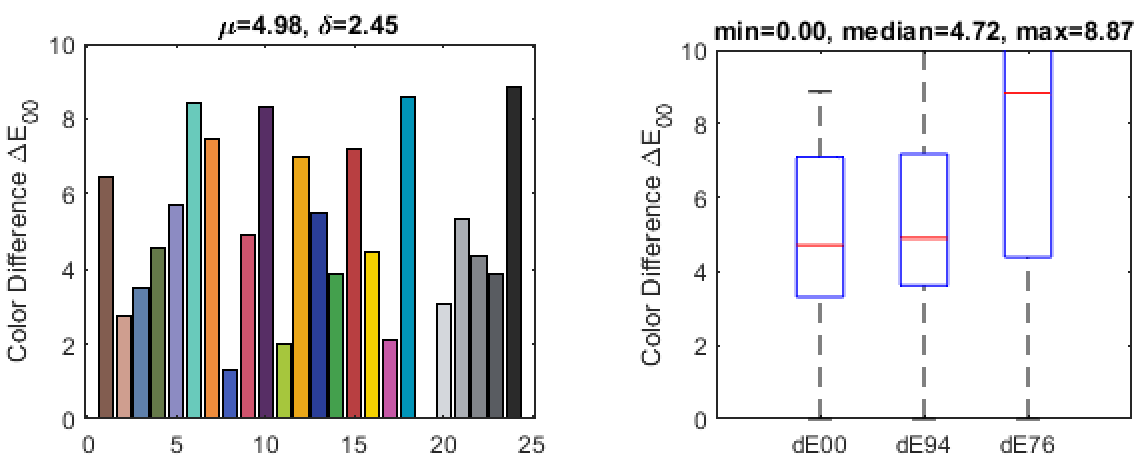

Figure 3.2: Absolute color errors in comparison with the ground truth. The left chart shows the per-patch color difference between the subject device and the ground truth. The right chart shows the box plot. The statistics (mean, standard deviation, minimum, median, and maximum) are provided in the titles.

3.3 Preservation of the patch order in lightness, hue, and chroma

3.3.1 Order in lightness, chroma, and hue - 1D view

The following charts show the patch order in lightness, chroma, and hue (1D view). The top row is the reference, the bottom row is the device output, and each line connects the same patch. Use these charts to identify any out-of-order patches and assess concordance and monotonicity.

```
cpr.check_order
```

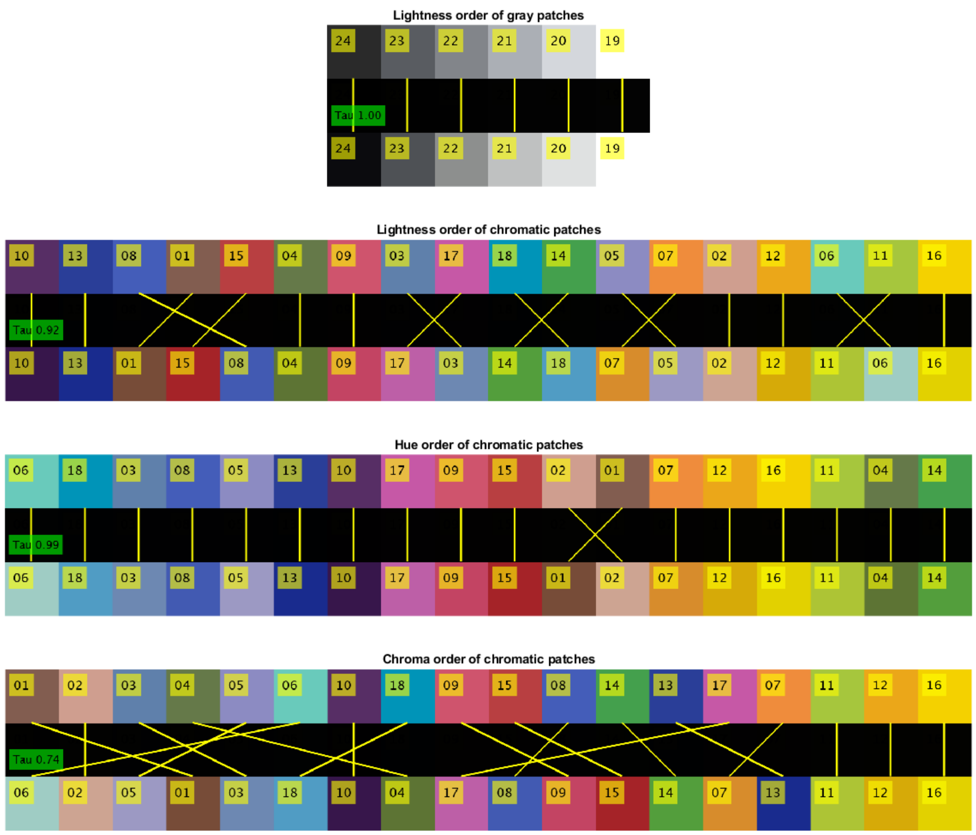

Figure 3.3.1: Preservation of the patch order in lightness/hue/chroma -- monotonicity. The charts show the patch order in lightness, chroma, and hue. In each chart, the top row is the reference, the bottom row is the device output, and each line connects the same patch. The top chart shows the patch order in lightness for gray patches (#19-#24). The remaining three charts show the chromatic patches in the lightness, hue, and chroma order. Use these charts to identify any out-of-order patches. The Kendall Tau-a rank correlation coefficients are included in each plot.

3.3.2 Order in lightness, chroma, and hue - 2D view

The following charts show the patch order in lightness, chroma, and hue (2D view). Use these charts to identify any out-of-order patches and assess linearity, concordance, and monotonicity.

```
cpr.check_linearity
```

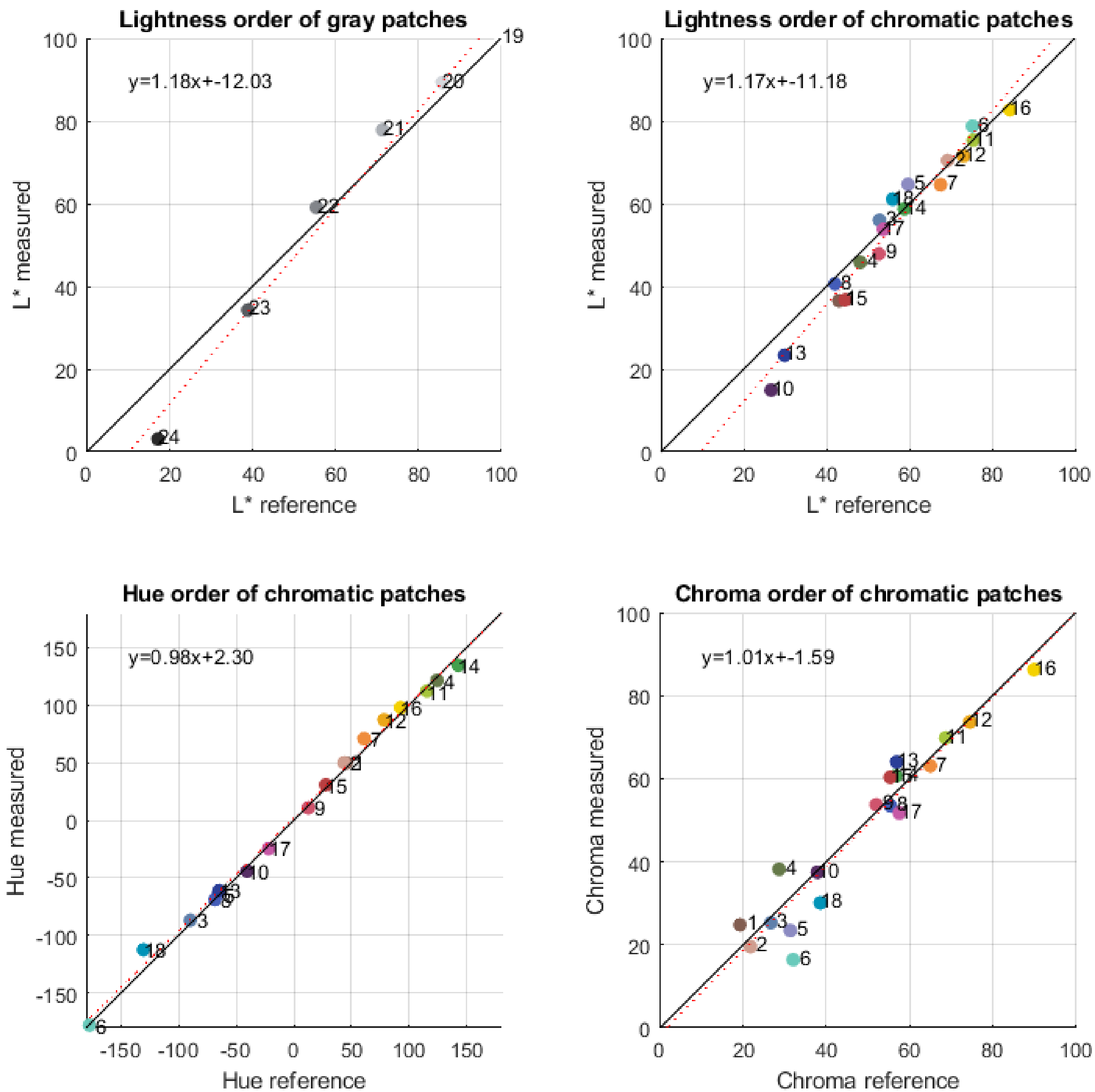

Figure 3.3.2: Preservation of the patch order in lightness/hue/chroma -- linearity. The top two charts show the patch order in lightness for gray patches (#19-#24) and chromatic patches (#1-#18). The lower left chart shows the chromatic patches in the hue order, and the lower right in the chroma order. Linear regression coefficients are included in each plot.

3.3.3 Three-dimensional color transfer

The following charts show the color transfer from the ground truth (spheres) to the device output (crosses) of all patches in the CIELAB color space. Rotate the 3D plots in Matlab to observe the spatial relationship.

```
cpr.check_color_transfer
```

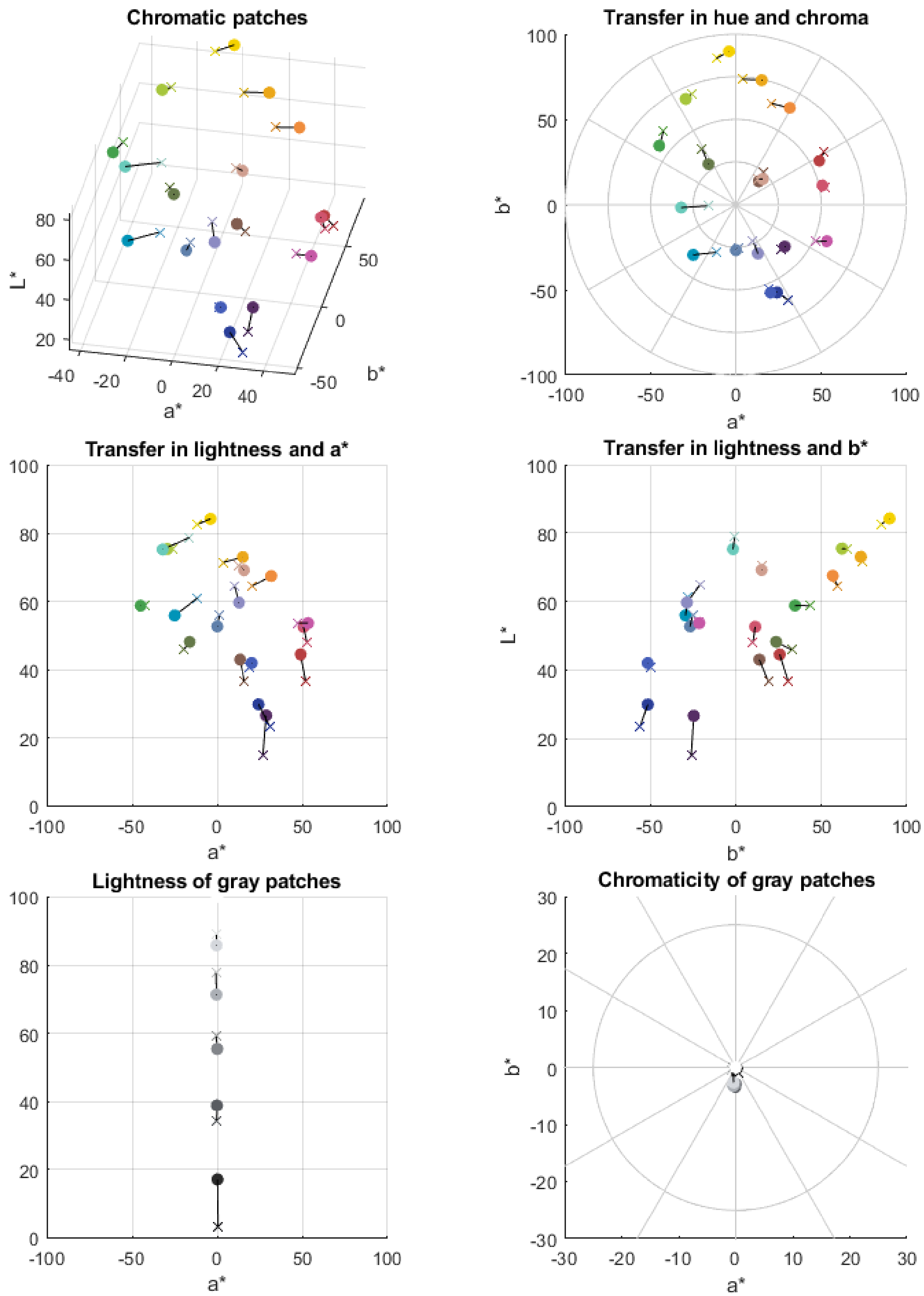

Figure 3.3.3: Visualization of color transfer. The top four charts show the color transfer of the chromatic patches observed from different angles. The bottom two charts show the color transfer of the gray patches to observe their lightness and chromaticity.

3.4 Preservation of Color Contrast between Patches

The following charts show all datapoints plotted according to their ground truth and device output. The color contrast enhancement (CCE) is defined as follows:

$$CCE = \frac{\Delta E(sub(i), sub(j))}{\Delta E(ref(i), ref(j))},$$

where i and j are patch numbers $1 \le i \le 24, 1 \le j \le 24, i \ne j$. $ref(i)$ and $sub(i)$ are reference and subject device output for patch #i, respectively. ΔE is a function calculating the CIE color difference between two colors based on either the ΔE_{00}, ΔE_{94}, or ΔE_{76} formulas.

$CCE = 1$ (represented by the dotted red line) means that the device reproduces the color contrast perfectly. $CCE > 1$ means that the device enhances the color contrast.

```
cpr.check_cce
```

Figure 3.4: Preservation of color contrast between patches. The CCE values calculated based on the ΔE_{00}, ΔE_{94}, or ΔE_{76} formulas. Each colored cross represents a patch-pair where the horizontal and vertical bars are colored separately according to the patch-pair. The percentage indicates patch-pairs that have $CCE \ge 1$.

```
% close all figures
close all
```