ACCURACY OF COLOR MEASUREMENT BY USING DIGITAL CAMERAS AND THE STANDARD COLOR CHART

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ABSTRACT

We examined five different digital cameras and evaluated their accuracies of color measurement. Commercially available digital cameras are not intended for use in color measurement. Thus, users have to calibrate the camera system by themselves for the purpose. We adopted the image correction method, in which, samples are photographed with some standard color charts side by side in one photo and the photographed images are color-corrected using the colorimetric data of the color charts. This method has an advantage that the measurement accuracy does not depend on the camera used; Users can freely replace the cameras. Using the X-rite ColorChecker 24-color chart as standard colors, we examined how the accuracy of color measurement depends on the camera used. As a result, we showed that the expected accuracy is less than 5 in the CIE L*a*b* color difference unit within the color gamut of the standard colors, irrespective of the camera.

INTRODUCTION

Recently, commercially available digital cameras are widely used to measure a color [1,2]. They are high resolution, easy to use and not expensive. However, they are not intended for use in color measurement. Therefore, for the accurate color measurement, users, not manufacturers, have to calibrate the camera system. Calibration methods fall roughly into two categories, "the camera calibration method" and "the image correction method." The camera calibration method is to measure the camera's spectral response functions beforehand, and using these response functions, photographed images with the camera's inherent color space are converted to colorimetric images [1]. The image correction method is to photograph a sample and some standard color charts side by side in one photo, and the photographed image is color-corrected using the colorimetric data of the standard color charts as references [2].

The camera calibration method has the same advantage that the usual measuring instruments have. Once the response functions are obtained for a camera in hand, there is no need to repeat the calibration process (i.e., measuring response functions). However, it has some disadvantages. The measurement accuracy depends on the camera system and the repeat accuracy is difficult to evaluate. They are usually certified by manufacturers for measuring instruments, but it is not the case for digital cameras.

On the other hand, the image correction method requires users to take a photo with the well-calibrated color charts each time. However, owing to this extra work, a photographed image itself has colorimetric data in it. Users can freely replace the cameras; Theoretically, the measurement accuracy does not depend on the camera used. This is a great advantage of the method.

In this study, we focus our attention on the image correction method and examine how the accuracy of color measurement depends on the cameras used. We applied the same image correction method to the photos taken by five different cameras and compared their accuracies of color measurement.

METHOD

The digital cameras compared in the experiment are listed in Table 1. All cameras were used in RAW mode and the RAW format files were converted to the uncompressed 24-bit TIFF format with 8-bit per channel sRGB color space using the computer programs provided by the camera makers. The sRGB color space was defined by the International Electrotechnical Commission (IEC) [3]; Its color gamut is narrow and it covers only a central part of the whole color space as discussed later. However, we adopted the sRGB because it is one of the most common color spaces in the imaging products and almost all digital cameras on the market have the sRGB color space mode.

As a standard color chart, the X-rite ColorChecker 24-color "Passport" version was used. This product is a *de facto* standard in the imaging society and the sRGB values of 24 constituent colors are provided by the X-rite; the colorimetric data are shown in Table 2.

Table 1: Specifications of Digital Cameras Used in the Experiment

No.	Name	Maker and model	Lens	Image sensor	Image size (pixels)
1	EOS	Cannon EOS kiss Digital N	EF-S 18-55 mm F3.5-5.6	8 megapixel CMOS 22.2×14.8 mm	3456 × 2304
2	LUMIX	Panasonic LUMIX DMC-G1	G Vario 14-45 mm F3.5-5.6	12 megapixel live MOS 17.3×13 mm	4000 × 3000
3	D50	Nikon D50	DX 18-55 mm F3.5-5.6 GII	6 megapixel CCD 23.7×15.6 mm	3008 × 2000
4	D5100-1	Nikon D5100	(same as above)	16 megapixel CMOS 23.6×15.6 mm	4928 × 3264
5	D5100-2	Nikon D5100	(same as above)	(same as above)	4928 × 3264

Table 2: Colorimetric Data of X-rite ColorChecker 24 Colors

ColorChecker		Munsell (standard)		sRGB (standard)			L*a*b* (D65, standard)		
No.	color name	H	V / C	Rstd	Gstd	Bstd	L*	a*	b*
1	dark skin	3 YR	3.7 / 3.2	115	82	68	38.0	11.8	13.7
2	light skin	2.2 YR	6.47 / 4.1	194	150	130	65.7	13.7	16.9
3	blue sky	4.3 PB	4.95 / 5.5	98	122	157	50.6	0.4	-21.6
4	foliage	6.7 GY	4.2 / 4.1	87	108	67	43.0	-15.9	20.4
5	blue flower	9.7 PB	5.47 / 6.7	133	128	177	55.7	12.8	-25.2
6	bluish green	2.5 BG	7 / 6	103	189	170	71.0	-30.6	1.5
7	orange	5 YR	6 / 11	214	126	44	61.1	28.1	56.1
8	purplish blue	7.5 PB	4 / 10.7	80	91	166	41.1	17.4	-41.9
9	moderate red	2.5 R	5 / 10	193	90	99	51.3	42.1	14.9
10	purple	5 P	3 / 7	94	60	108	31.1	24.4	-22.1
11	yellow green	5 GY	7.1 / 9.1	157	188	64	71.9	-28.1	57.0
12	orange yellow	10 YR	7 / 10.5	224	163	46	71.0	12.6	64.9
13	blue	7.5 PB	2.9 / 12.7	56	61	150	30.4	26.4	-49.7
14	green	0.25 G	5.4 / 8.65	70	148	73	55.0	-40.1	32.3
15	red	5 R	4 / 12	175	54	60	41.3	49.3	24.7
16	yellow	5 Y	8 / 11.1	231	199	31	80.7	-3.7	77.5
17	magenta	2.5 RP	5 / 12	187	86	149	51.1	48.2	-15.3
18	cyan	5 B	5 / 8	8	133	161	51.2	-19.7	-23.4
19	white	N	9.5	243	243	242	95.8	-0.2	0.5
20	neutral 8	N	8	200	200	200	80.6	0.0	0.0
21	neutral 6.5	N	6.5	160	160	160	65.9	0.0	0.0
22	neutral 5	N	5	122	122	121	51.2	-0.2	0.5
23	neutral 3.5	N	3.5	85	85	85	36.1	0.0	0.0
24	black	N	2	52	52	52	21.7	0.0	0.0

The procedures of the image correction method applied for each camera are as follows:

Step 1) Take photos of an A4 (size: 210 x 297 mm) white matt sheet under the uniform illumination of D65 fluorescent lamps in a spherical dome with a diameter of 600 mm, and calculate the shading correction coefficient for each pixel of photos.
Step 2) Take photos of a sample with the ColorChecker 24-color chart (size: 60 x 90 mm) under the same illumination condition of Step 1. As a sample, another ColorChecker chart was used.
Step 3) Perform the shading corrections for photos of Step 2 using the coefficients derived at Step 1.
Step 4) Calculate the color correction values, which convert the camera's inherent RGB values of 24 colors of the standard chart in the photos of Step 3 to the standard sRGB values in the Table 2.
Step 5) Apply the color correction values derive at Step 4 to all pixels of photos of Step 3.

At Step 5, the color corrected image files in the sRGB space are obtained. Conversion equations between sRGB and the tristimulus values are defined in Ref.[3]. Then, the color data can be converted to any color space attributes. We converted the sample data to the CIE 1976 L*a*b* color space for discussion.

RESULTS AND DISCUSSIONS

The results of measurement accuracies of the five cameras are shown in Table 3. In the Table, the color differences between the measured values of the sample chart and the standard values (Table 2) are shown in the L*a*b* unit. All data are the average values of three trials.

Table 3: Measurement Accuracies of the Image Correction Method in the ΔE^*_{ab} Unit

Camera name	EOS			LUMIX	D50	D5100-1	D5100-2
Correction method	No corr.	Shading Corr.	Color Corr.	Color Corr.	Color Corr.	Color Corr.	Color Corr.
1 dark skin	10.7	9.9	1.2	0.8	2.2	3.6	1.9
2 light skin	6.1	5.5	0.4	0.3	1.4	1.3	0.9
3 blue sky	5.4	5.7	0.5	0.5	1.4	1.3	1.2
4 foliage	10.3	9.8	2.5	1.3	0.9	1.6	3.1
5 blue flower	2.4	2.8	1.4	0.9	1.2	0.8	0.8
6 bluish green	6.2	6.8	1.5	0.7	2.3	0.4	0.9
7 orange	11.8	13.1	2.1	1.5	2.5	1.6	2.4
8 purplish blue	13.1	15.4	2.3	0.8	1.8	1.4	1.6
9 moderate red	9.5	10.9	1.6	1.3	0.7	2.0	0.6
10 purple	10.0	9.8	2.2	4.2	0.8	1.2	1.1
11 yellow green	3.2	0.3	1.5	2.1	0.5	0.7	0.3
12 orange yellow	5.7	6.1	2.7	2.0	2.0	2.8	2.2
13 blue	11.1	13.6	1.7	1.5	0.8	3.3	1.1
14 green	9.2	11.1	2.2	1.8	1.3	1.5	1.1
15 red	9.7	11.3	1.5	3.2	1.3	1.4	1.4
16 yellow	6.6	3.5	1.9	1.5	0.6	0.3	0.5
17 magenta	4.6	6.4	1.5	1.4	0.9	0.9	0.4
18 cyan	6.6	8.8	2.3	0.6	0.4	1.3	0.8
19 white	6.7	3.3	0.2	0.1	0.3	0.3	0.3
20 neutral 8	2.3	2.3	0.9	0.4	0.3	0.3	0.4
21 neutral 6.5	2.6	3.7	1.1	0.8	0.3	0.4	0.7
22 neutral 5	5.7	4.1	0.5	0.8	1.2	0.5	0.9
23 neutral 3.5	10.2	9.3	0.9	1.1	1.0	1.7	0.9
24 black	12.6	12.1	0.8	1.0	2.0	3.3	2.4
Maximum $\Delta E^*_{ab,max}$	13.1	15.4	2.7	4.2	2.5	3.6	3.1
Minimum $\Delta E^*_{ab,min}$	2.3	0.3	0.2	0.1	0.3	0.3	0.3
Average $\Delta E^*_{ab,ave}$	7.6	7.7	1.5	1.3	1.2	1.4	1.2

For the camera 1 (EOS), the results of each step are shown from the 2nd to the 4th column. When no corrections were applied (Step 2), the color differences (2nd column) were rather high and more than 10 for eight colors. Applying shading corrections (Step 3) showed no improvement (3rd) because these corrections only resolve the shading problem. Color corrections (Step 5) produced much improvement in the measurement accuracy (4th) and the maximum color difference was 2.7. For other cameras, the maximum color differences were 4.2, 2.5, 3.6, and 3.1. These results suggest that the measurement accuracy of less than 5 in the L*a*b* color difference unit is expected for the image correction method irrespective of camera used.

Finally, measurement range of digital cameras is summarized. In this experiment, we adopted sRGB color space as shown in Figure 1. The measurement range is limited within the sRGB color gamut. Moreover, we used the ColorChecker chart for the color correction standard. Thus, high measurement accuracy is expected within the ColorChecker color gamut (i.e., interpolation condition), but the accuracy would get worse outside the ColorChecker color gamut (i.e., extrapolation condition).

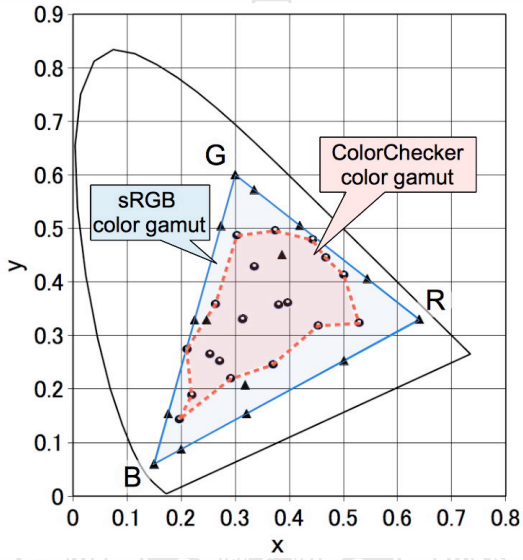

Figure 1. sRGB and ColorChecker Color Gamuts in the CIE 1931 xy Chromaticity Diagram

CONCLUTIONS

We measured colors by using five different digital cameras and showed that the measurement accuracy of the image correction method does not depend on the camera used. The expected accuracy is less than 5 in the L*a*b* color difference unit within the color gamut of the reference colors.

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