Predicting Color Image Match

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Abstract

When assessing color printing conformity, ANSI/CGATS TR016 specifies multiple tolerances, in terms of the 95th percentile ΔE_{00}, and the color characterization target. This research investigates if the 95th percentile ΔE_{00} metric applies to color image match. The experiment involves the selecting the CRPC6 dataset as the reference, altering the CRPC6 reference with known colorimetric differences, generating ICC profiles and preparing pictorial color images in the specified printing conditions, conducting psychometric experiments. The results show that (1) color image match is proportional to the magnitude of the device-based 95th percentile ΔE_{00}, and (2) color image match is scene dependent when the device-based 95th percentile ΔE_{00} is between 4-5 or approaches color conformity of a printing device. Color differences between two pictorial color images of the same scene can also be quantified by image-based CRF and the 95th percentile ΔE_{00}. Image-based CRF only takes colors in the scene into consideration. In this research, image-based prediction of color image match did not show significant difference than the device-based prediction. This was largely due to the fact that the entire CRPC6 gamut is uniformly shifted in the direction of –L* and –b* by specified amounts. By means of simulation, we showed how image-based 95th percentile ΔE_{00} differs under the same device-based 95th percentile ΔE_{00}. The image-based 95th percentile ΔE_{00} possesses better potential in predicting color image match than the device-based approach.

Introduction

Color perception begins with the detection of visual stimuli by an observer. Colorimetry begins with capturing spectral reflectance of an object at a specified geometry and resulting in tristimulus values, e.g., CIELAB. We can predict the degree of color match between two spot colors, e.g., a color swatch and a printed package, quite well. But, we cannot readily apply the same method to predict color image match because pictorial images have many pixels, thus, many ΔE_{00}. Given

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that colorimetry is not color perception, this research is aimed at exploring the use of colorimetry to predict color perception.

Many ΔE values represent a distribution. If we are interested in finding out the number of items which are smaller, or greater than, a specified value, this kind of information is not easily obtainable from a histogram; it is best displayed by a plot of cumulative relative frequency. As shown in Figure 1, a distribution can be plotted as a histogram (left) and a CRF or cumulative relative frequency (right). A CRF can be generated from a device-based list, e.g., IT8.7/4, (TAGA, 2001) or from an image-based list, using Microsoft Excel, as outlined below:

1) Enter data column-wise as a list. Sort the list (from low to high). This is the value for the x-axis.
2) Create an index column from 1~n where n is the total number of data. Convert the index column as a cumulative relative frequency (CRF) or 0 – 1.0. This is the value for the y-axis.
3) Plot the graph of the sorted value (x-axis) and the CRF (y-axis).

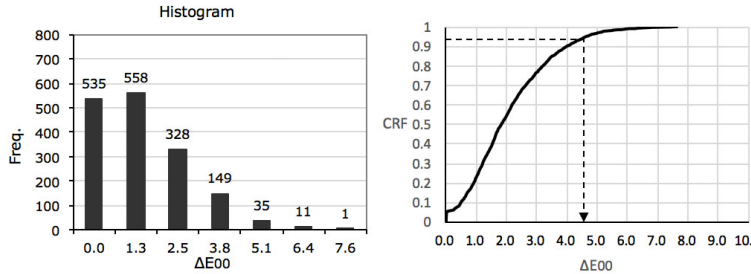

Figure 1. *Histogram, CRF, and the 95th Percentile ΔE00*

When CRF is used to plot the ΔE00 distribution between two color characterization targets (1,617 color patches), the 95th percentile ΔE_{00}, shown as dotted lines from 0.95 of the y-axis to 4.6 ΔE_{00} of the x-axis in Figure 1 (right), is a metric that depicts the device-to-device color difference. ANSI/CGATS TR016 (CGATS, 2014) specifies multiple tolerances for dataset conformity levels in terms of the 95th percentile ΔE_{00}. As shown in Table 1, the 95th percentile ΔE00, 4.5, specifies the tolerance for printing to dataset (Level III). It will be interesting to test if the 95th percentile ΔE_{00}, based on IT8.7/4, is a useful metric for color image match.

[illegible] 95th percentile		2.0	3.0	4.5	6.0
Solid	100C				
	100M				
	100Y				

Table 1. *ANSI/CGATS TR016 tolerances for printing to dataset*

There are three research questions in this project: (1) What is the relationship between the device-based 95th percentile ΔE00 and visual match of color images, and (2) Are different scenes affected differently by the device-based 95th percentile ΔE00 metric, and (3) Will image-based 95th percentile ΔE00 possess better potential in predicting color image match than device-based approach?

Methodology

The following seven steps, from test image selection, dataset alteration, CRF generation, to psychometric experiments, are carried out in this research:

1) Select CMYK pictorial images, 3.5" x 3.5" (300 ppi), with varying colors of interest (Figure 2).

Figure 2. *Pictorial scenes: Baby Face, Sky, Tree, and Corn*

2) Select CRPC6 as the reference printing condition.

3) Use ChromaChecker, color management utility, to alter the CRPC6 dataset. Note that there are many ways to alter a dataset. It was decided that the entire CRPC6 gamut is shifted in the direction of minus L* and minus b* by specified amounts (Table 2). Altered datasets are used to build ICC profiles.

Scene	CRPC6 Alteration	95th Percentile ΔE_{00}
1~4 Plus TC1617	Varying amount of ΔC* and ΔL*	0
		2~3
		4~6
		8~10

Table 2. *Altering the datasets by specified amounts*

4) Create a test form (Figure 3), including four high-res (300 ppi), four low-res (5 ppi) pictorial images, and the TC1617 color characterization chart. The test form was color managed using the device link profile, and output as hardcopy using an Epson inkjet proofer.

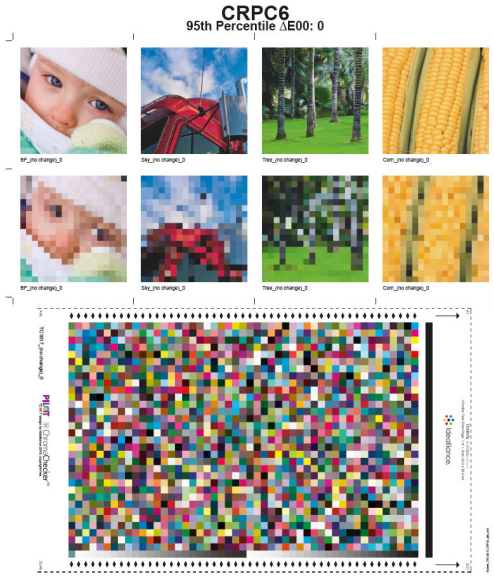

Figure 3. *Test form*

5) Generate device-based CRF and the 95th percentile ΔE_{00} between CRPC6 and CRPC6 altered dataset. The following step-by-step simulation procedure is used:

a) Open the IT8.7/4 TDF (target definition file) in ColorThink's worksheet. Assign the reference ICC profile and the absolute colorimetric rendering. Save as the IT874_ref_Lab list.
b) Repeat the above steps by replacing the reference ICC profile with sample ICC profiles and save as IT874_sample_Lab list.
c) Drag and drop the IT874_ref_Lab list and the IT874_sample_Lab list in the same worksheet. Click the ΔE_{00} and save the ΔE_{00} as a list and as a vector graph.
d) Use the ΔE_{00} lists to create histogram, CRF, and 95th percentile ΔE_{00} for all device-pairs.

Note: While the IT8.7/4 (1,617 color patches) target was used in the simulation, the TC1617 target, a variation of the IT8.7/4 target, was used in this experiment. The difference between these two targets is the inclusion of 3C neutrals in the TC1617 target instead of redundant patches. They do not yield significant difference in the 95th percentile ΔE_{00} when rounded to the first place after the decimal.

6) Generate image-based CRF and the 95th percentile ΔE_{00} between CRPC6 and CRPC6 altered dataset. The following step-by-step simulation procedure is used:

a) Open the pictorial image in ColorThink. Custom sample a section or the entire image, e.g., 18 x 18. Assign the reference ICC profile and absolute colorimetric rendering. Save it as Scene_ref_Lab list.
b) Repeat the above step to generate Scene_sample_Lab lists using the sample ICC profiles.
c) Drag and drop the Scene_ref Lab list and the Scene_sample Lab list in the same worksheet. Save the ΔE_{00} as a list and the ΔE_{00} vector plot as a graph.
d) Copy and paste the ΔE_{00} lists in an Excel template to create histogram, CRF, and 95th percentile ΔE_{00} for all device-pairs.

7) Conduct paired comparison experiments.

a) Qualify 15 observers with normal color vision via the Ishihara Colorblind test.
b) Present two hardcopies (a CRPC6 reference and a randomized sample) in the ISO 3664 (500 lux) viewing booth (Figure 4).

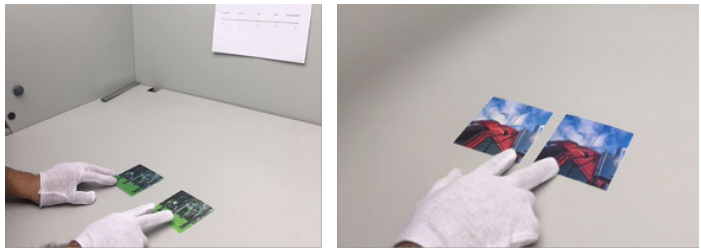

Figure 4. *Paired comparison experiment*

c) Ask the observer to judge the degree of the color image match between the pair according to the following categories scores: Excellent match (1), Good match (2), Fair match (3), Poor match (4), and Unacceptable match (5).

In the experimental design, we included two independent variables: (1) A degree of colorimetric difference produced by the datasets with the associated ICC profiles applied to the images. This colorimetric difference was expressed as the device-based 95th percentile ΔE_{00}, between CRPC6 and CRPC6 altered dataset, and (2) Four pictorial color images. The dependent variable was the degree of color image match with the reference CRPC6 image – 5 rating categories.

Results

Verification of device-based CRF and 95th percentile ΔE_{00}

Figure 5 is the verification of the device-based CRF and 95th percentile ΔE_{00}. The device-based CRF between CRPC6 and CRPC6 altered datasets show very steep slopes with distinct 95th percentile ΔE_{00} differences, i.e., 2.4, 4.6, and 9.8, respectively.

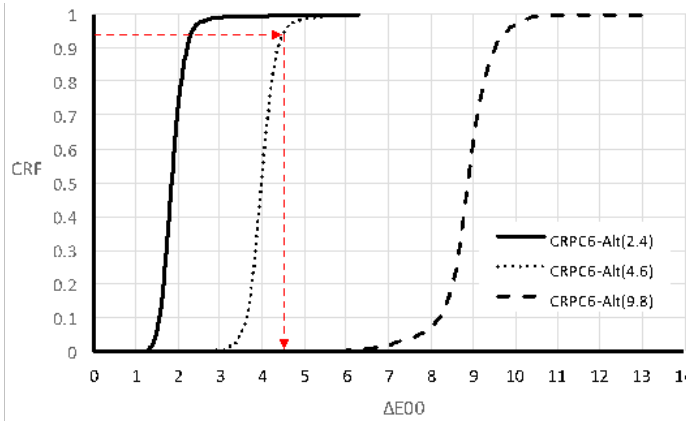

Figure 5. *Device-based CRF between CRPC6 and CRPC6 altered datasets due to uniform color shifts*

Figure 6 (top) shows three levels of gamut corner shifts. Figure 6 (bottom) shows uniform shifts of in-gamut colors as vectors. They provide further evidences that the steep device-based CRF is the result of uniform CIELAB shifts over the entire color gamut.

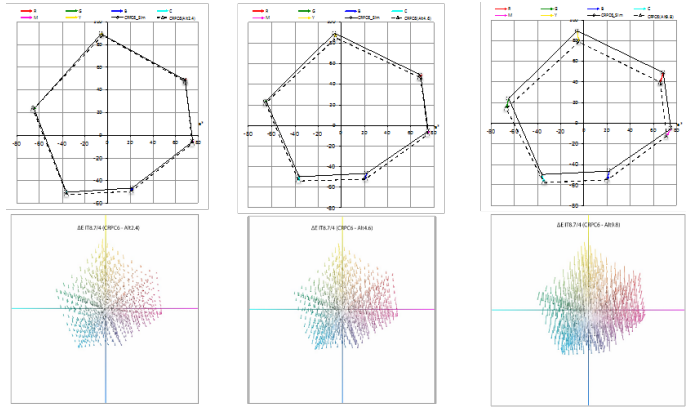

Figure 6. *Uniform CIELAB shifts over the entire color gamut*

Verification of image-based CRF and 95th percentile ΔE_{00}

Figure 7 is the verification of the image-based CRF and 95th percentile ΔE_{00}. The image-based CRF between CRPC6 and CRPC6 altered datasets also show very steep slopes with distinct 95th percentile ΔE_{00} differences around 2.4, 4.6, and 9.8, respectively. Because the color differences are due to uniform shifts in the dataset, the color difference distribution of the image gamut behaves the same as the device gamut.

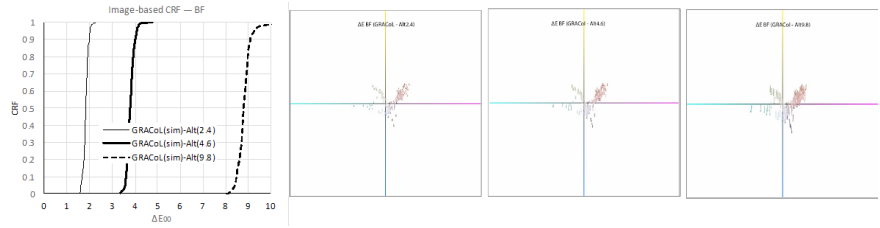

Figure 7. *Image (Baby Face)-based CRF between CRPC6 and CRPC6 altered datasets*

Figure 8 shows the other three image-based CRF, i.e., Sky, Tree, and Corn. Because the two ΔE_{00} distributions are similar, all four image-based CRFs have the same shape as the device-based CRF. So are the 95th percentile ΔE_{00} values between them.

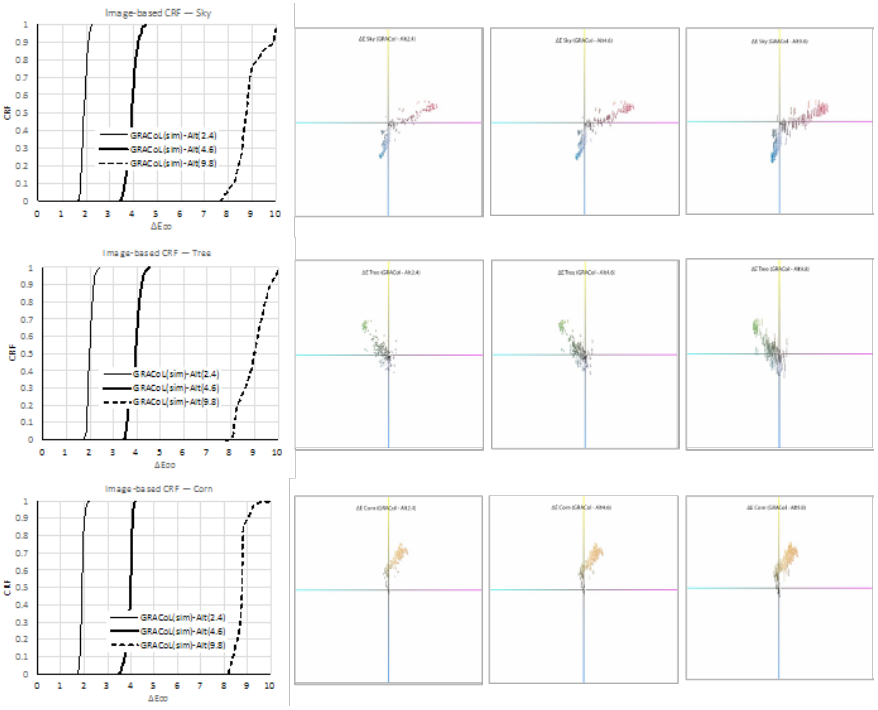

Figure 8. *The other three image-based CRF, i.e., Sky, Tree, and Corn*

Experimental data analysis

The psychometric data were analyzed using ANOVA - analysis of variance. We used a mixed model ANOVA to test fixed main effects of colorimetrical difference with the reference CRPC6 compliant image (Device-based 95th percentile ΔE_{00}) - 4 levels, Scene - 4 levels; interaction effect between Device-based 95th percentile ΔE_{00} and Scene. Observers were treated as a random effect.

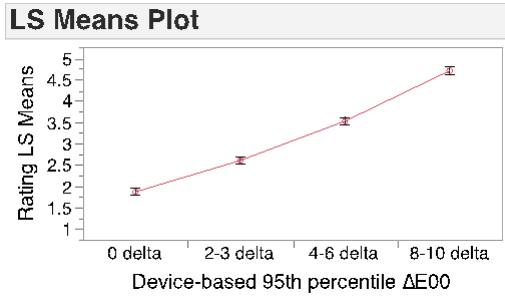

Figure 9. *Device-based 95th percentile ΔE_{00} and color image match*

To answer the 2nd research question, "Are different scenes affected differently by the devicebased 95th percentile ΔE_{00} metric," Figure 10 shows that when the device-based 95th percentile ΔE_{00} is small (0~2.4), there is good agreement of color image match regardless of the scene. This is also true when the device-based 95th percentile ΔE_{00} is large (9.8), there is good agreement of color image mismatch regardless of the scene.

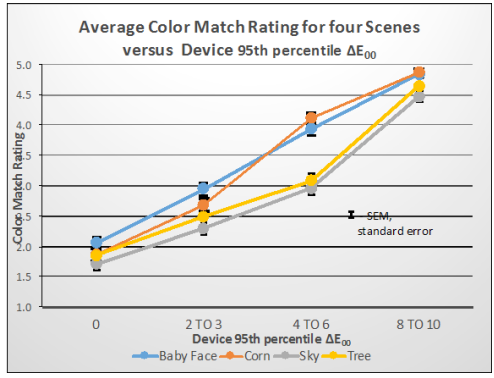

Figure 10. *Device-based 95th percentile ΔE_{00} and scene-dependent color image match*

Figure 10 also shows that there is scene dependency when the device-based 95th percentile ΔE_{00} is between 4-6. This means that the device-based 95th percentile ΔE_{00} is no longer a good predictor of color image match when its magnitude approaches color conformity of a printing device.

Simulate Image-based CRF using Other Profiles

To answer the 3rd research question, "Will image-based 95th percentile ΔE00 possess better potential in predicting color image match than device-based approach," the analyses show that there are many causes of color difference between two datasets. While "uniformly shifted" datasets satisfy the experimental design requirements, such variations do not represent typical printing variations in the real world. Therefore, it is necessary to apply other profiles that differ in gamut size, gray balance, and tone reproduction to the reference dataset to study the effect of 95thpercentile ΔE_{00} on color image match. The so-called "Other Profiles" are

resources that we are investigating factors that impact consistent color appearance (TAGA, 2017).

Figure 11 illustrates the device-based CRF between CRPC4 (reference) and four CRPC4 altered datasets. These color differences did not come from uniform gamut shifts, but changes in gray balance, tone reproduction, reduced gamut volume, and expanded gamut volume.

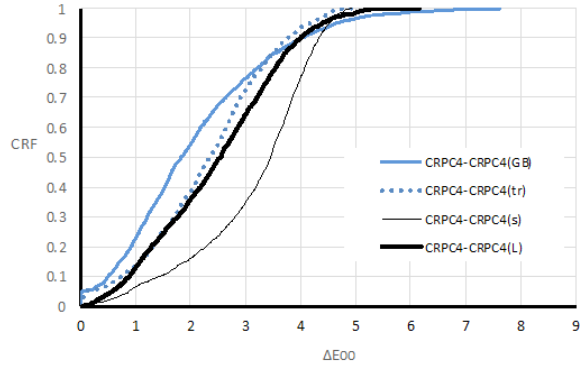

Figure 11. *Device-based CRF between CRPC4 and CRPC4 altered datasets*

While the device-based 95th percentile ΔE00 is averaged at 4.4 with a range of 4.2~4.6, the imagebased CRFs of the Baby Face scene do not converge at 95th percentile. As shown in Figure 12, the image-based 95th percentile ΔE_{00} of the Baby Face scene is averaged at 3.6 with a range of 2.5~4.5. Using the image-based 95th percentile ΔE_{00}, the prediction of color image match (from best to worst) would be Large (2.5), small (3.6), tr (3.8), and GB (4.5).

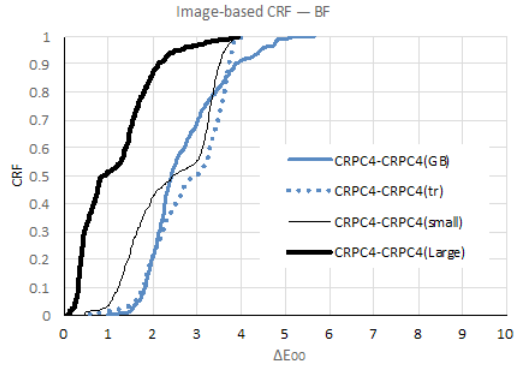

Figure 12. *Baby Face-based CRF between CRPC4 and CRPC4 altered datasets*

Corn-based CRFs between CRPC4 (reference) and four altered profiles do not converge at 95th percentile either (Figure 13). Corn-based 95th percentile ΔE_{00} is averaged at 4.0 with a range of 3.2~4.4. Notice that the gray balance altered ICC profile is predicted to have high impact on Baby Face scene, but little impact on the Corn scene.

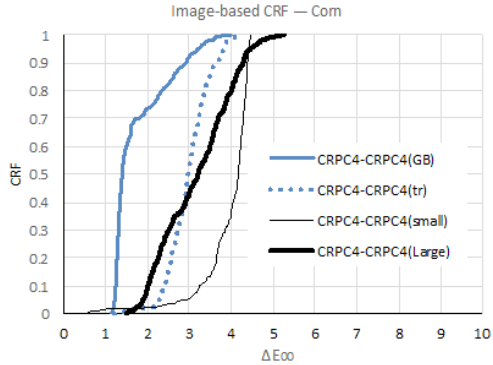

Figure 13. *Corn-based CRF between CRPC4 and CRPC4 altered datasets*

Tree-based CRFs and Sky-based CRFs between CRPC4 (reference) and four altered profiles are shown in Figure 14. Notice that none of these CRFs converges at 95th percentile. This suggests that device-based CRF is limited in predicting color image match unless the 95th percentile ΔE_{00} is less than 2.

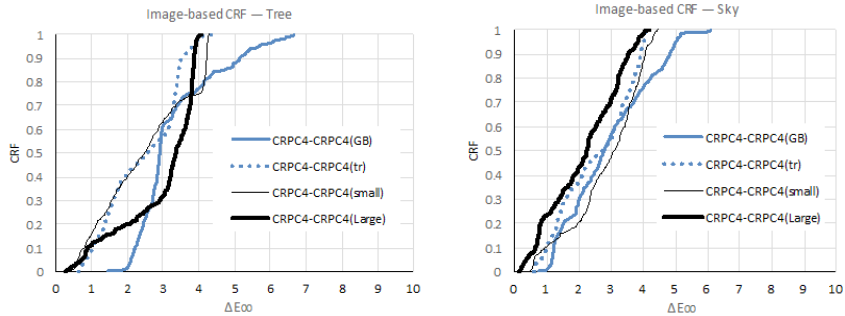

Figure 14. *Tree- and Sky-based CRF between CRPC4 and CRPC4 altered datasets*

Conclusions

Color differences between two datasets can be quantified by CRF and the 95th percentile ΔE_{00}. In this research, we conclude that color image match is proportional to the magnitude of the devicebased 95th percentile ΔE_{00}. In addition, we conclude that color image match is scene dependent when the device-based 95th percentile ΔE_{00} is between 4-5 or approaches color conformity of a printing device.

In this research, we also set out to investigate if the image-based 95th percentile ΔE_{00} possesses better potential in predicting color image match than device-based approach. The result shows that image-based CRF did not predict color image match better than device-based CRF. This was because the entire reference gamut was shifted by specified amounts. By means of simulation, this research showed how image-based 95th percentile ΔE_{00} differ under the same device-based 95th percentile ΔE_{00}. The image-based 95th percentile ΔE_{00} possesses better potential in predicting color image match. Finally, more psychometric experiments are needed to find out how reliable is the image-based prediction of color image match.

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