

Color Error in Digital Imaging for Fine Art Reproduction

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Abstract

Various aspects of digital fine art reproduction imaging were examined to determine possible sources for image color errors. Differences between two color charts used for making profiles were examined and tested with a special test chart. Possible color errors due to the camera's spectral response were investigated. The use of tone curve adjusted chart images for profiling were compared against using raw images. The type of ICC tables in the profiles were checked as an error source. Profile induced neutral color errors were tested. The results show that some profile creation algorithms and the type of tables available in the profiles may be sources for some of the image color errors.

Introduction

In the field of digital imaging, fine art reproduction is the most difficult task. The fine art image is compared to the original artwork with the client's expectation that the image be as accurate a reproduction of the original as possible. Other photographic tasks, such as scenic or portrait photography, have much more relaxed criteria; usually the image only has to be visually pleasing¹.

As the field of fine art reproduction has expanded in size beyond simply recording originals of historic and cultural importance within institutions to the commercial world where artists are now using imaging for their livelihood, color management has found an increasing role in the process.

In a previous paper the issue of observer metamerism failure was investigated². While this was found to be helpful for solving one problem with digital imaging of artworks, color reproduction issues still remain.

This paper examines possible additional sources for color errors in fine art digital images. Several sources might be the cause of image color errors; choice of the color chart used to make the color management profile, use of images with a tone curve or without one (raw images), the choice of the ICC profile format, the spectral sensitivity of the camera, or the profile itself.

Color Chart Differences

To check the profile accuracy against an independent reference, a custom test chart was prepared. The chart consists of 60 patches made from artist acrylic paints and consists of 40 saturated hues, 11 miscellaneous colors and a 9 step gray scale. Paints from 4 manufacturers were used, with 34 pigments represented.

Profiles were created using a ColorChecker® (24 patch original, matte finish) and a ColorChecker SG® (140

patches, semi-gloss finish) with programs from 3 vendors. The lighting was adjusted to give a variance of 1 RGB unit across the chart image area. Each chart was imaged using a Better Light Super 8k-HS digital scanning camera at 100% resolution (no interpolation). If available, options in the profiling software were selected for "reproduction", assuming they would produce the most accurate reproductions.

The profiles were applied to the test images in Adobe Photoshop CS2, then converted to CIE L*a*b* 1976 using the Adobe Color Engine with the Absolute Colorimetric intent without black point compensation.

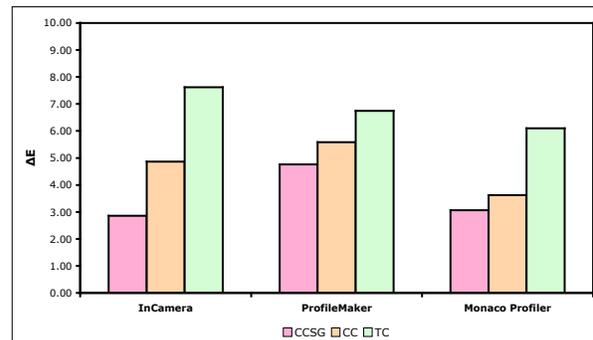


Figure 1, Mean CIE 1976 ΔE for profiles generated by three profiling programs using a ColorChecker SG (CCSG) chart then applied to images of a ColorChecker SG, a ColorChecker (CC) and a custom test chart (TC).

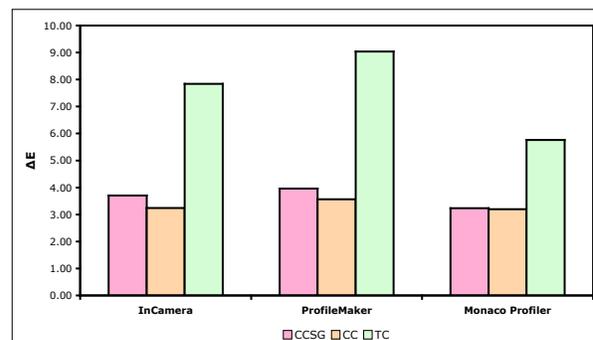


Figure 2, Mean CIE 1976 ΔE for profiles generated by three profiling programs using a ColorChecker (CC) chart then applied to images of a ColorChecker SG (CCSG), a ColorChecker and a custom test chart (TC).

As shown in Figures 1 and 2, profiles made with either ColorChecker and applied to images of both ColorCheckers did not produce a large change in the mean ΔE . Applying these same profiles to the test chart images does produce a large increase in the mean color differences.

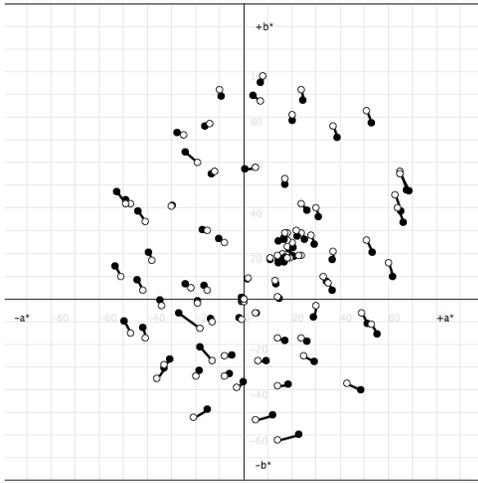


Figure 3a. InCamera profile applied to the CCSG image. Reference values in black, profile values in white.

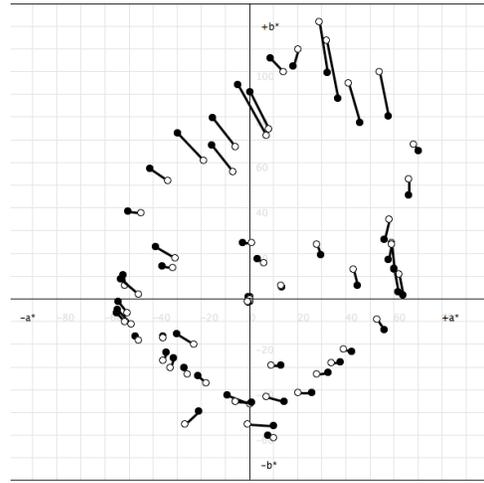


Figure 3b. InCamera profile applied to the Test Chart image. Reference values in black, profile values in white.

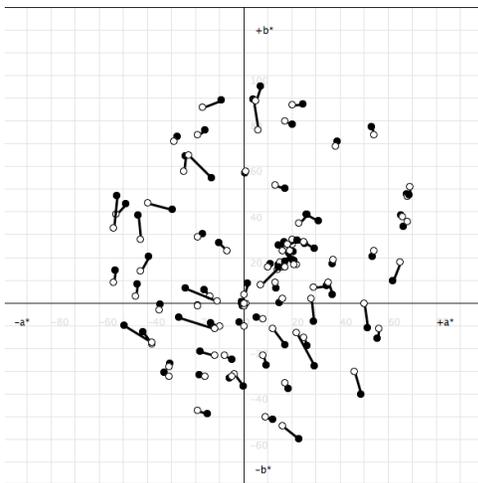


Figure 3c. ProfileMaker profile applied to the CCSG image. Reference values in black, profile values in white.

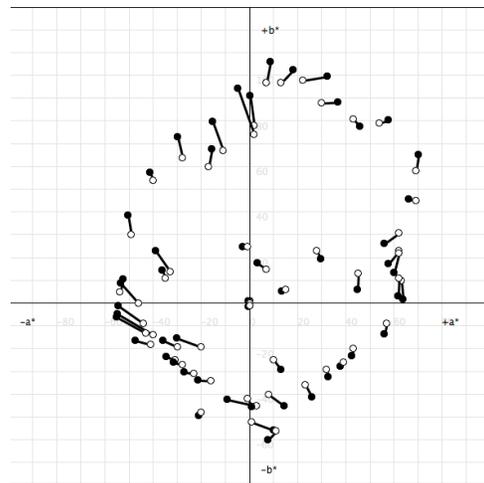


Figure 3d. ProfileMaker profile applied to the Test Chart image. Reference values in black, profile values in white.

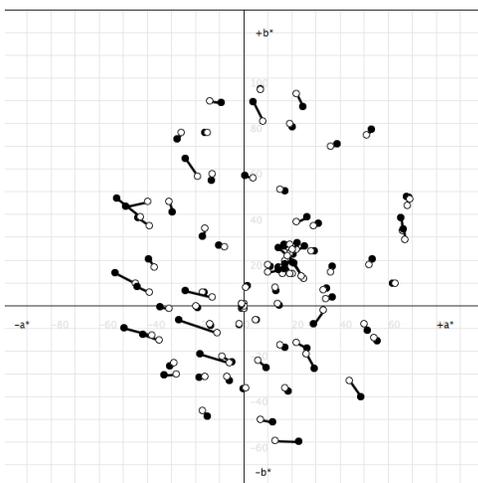


Figure 3e. Profiler profile applied to the CCSG image. Reference values in black, profile values in white.

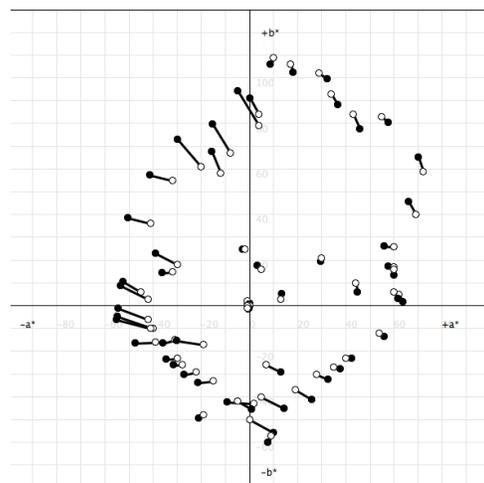


Figure 3f. Profiler profile applied to the Test Chart image. Reference values in black, profile values in white.

One reason for the increase could be the differences in materials used in the charts. The ColorCheckers are produced by the same company that produces the Munsell Book of Color and it is a fair assumption that the ColorCheckers are made from the same materials. Although the number of colorants used in their manufacture is not known, a small set of colorants might make the ColorChecker patches so spectrally similar that programs using spectral calculations might be tuned to give good results only with this set of colorants. However, program number 3 in Figure 1 uses colorimetric values for the calculations and performed as well as, and in some cases, better than, the spectral calculation programs.

Another reason for the mean difference increases could be that the mathematics used to create the profile are tuned to give good values only for the training set of colors. This hypothesis seems to be indicated by the color difference graphs 3a-3f.

Comparison of the graphs for the ColorChecker SG and the Test Chart show unexpected differences. In all three cases, there are much larger changes using the Test Chart than expected by examining the CCSG differences. With all three profiles the patches in the $-a^*+b^*$ region show large decreases in chroma with the Test Chart which are not apparent for the same colors in the CCSG image. This type of color shift is often associated with clipping to a smaller device gamut. However, the conversion in these tests was from camera RGB to Lab values, which would not involve clipping.

The InCamera profile also increased the chroma for the colors in the $+a^*+b^*$ region with high initial b^* values, a color change not associated with clipping. The visual result of this $+a^*+b^*$ increase was the production of overly saturated yellow and orange colors.

Examination of the $+a^*-b^*$ region in the area near to the $-b^*$ axis shows a consistent blue shift in the CCSG and Test Chart images for all the profiles. Blue-violet, violet and some purple colors were hue shifted to much bluer values. One possible explanation for this shift is an attempt by the profile program engineers to solve an often encountered problem where some blue colors will appear purple. The result of this shift in the profile is that some blue, violet and purple colors cannot be reproduced.

Figures 3b and 3d also show that profiles for Programs 1 and 2 shift magenta-red colors to redder hues for both the CCSG and Test Charts as shown in the $+a^*+b^*$ region near to the $+a^*$ axis.

Sensor Response

The spectral response of the camera might be another source for color errors. The Test Chart has 40 patches which were defined to be spaced at approximately equal perceptual hue steps. For each patch the dominant wavelength was calculated then compared to the spectral response of the camera. The results are shown in Figure 4. Only the dominant wavelengths for patches with spectral correlates were graphed (i.e. no purples).

It is expected that correlations between the sensor spectral response and color error will appear as peaks in the error curves at the points of maximum, or perhaps minimum, crossover between the sensor channel response curves.

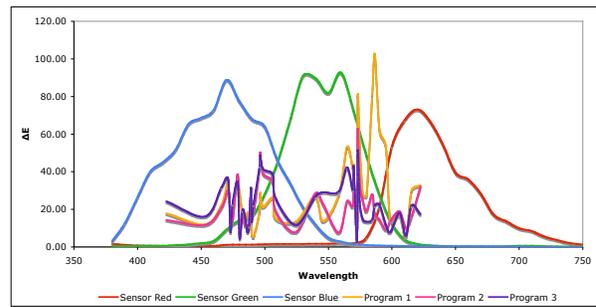


Figure 4. Mean CIE $L^*a^*b^*$ ΔE for the Test Chart patches defined by each patch's dominant wavelength compared to the spectral response of the camera. For clarity, the ΔE values are scaled to 3x the actual values.

There does not seem to be a correlation between the color errors produced by the profiles and the sensor's spectral response. This leads to the conclusion that the color errors produced by the profiles are a result of the mathematics used in creating the profiles rather than a product of the camera's spectral response.

Raw Images

Examining current professional imaging practices shows that raw image capture and processing is a popular technique. In this test, profiles made from raw images are compared to profiles made from images with a tone curve applied. Having no tone curve applied to the image produces an image with the most minimal camera processing. Any color errors due to the application of a tone curve should be reflected in the image statistics.

Figure 5 presents the mean differences for profiles created from ColorChecker SG images with and without (raw image) a tone curve applied in the camera software. The tone curve was one designed to reproduce the ColorChecker tonal scale with compensation for a 2.2 monitor gamma.

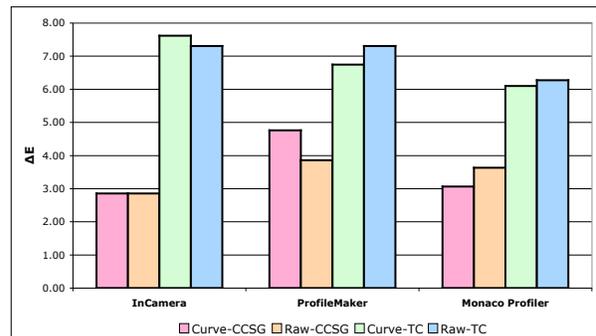


Figure 5. Mean CIE $L^*a^*b^*$ ΔE for profiles prepared from ColorChecker SG images with a tone curve and without a tone curve (raw) applied in the camera capture software.

The profiles were applied to images of the ColorChecker SG and the Test Chart. The similar results for the two charts shows that raw image capture does not significantly affect the color errors.

Neutrals

To test profiles for introducing color errors into the image neutrals, an RGB image was constructed consisting of 256 grays (R, G, and B values all equal) with channel values from 0 to 255. This simulates an ideal camera image with perfect neutral balance across the entire tonal range.

A profile was assigned to each image then the image was converted to Lab using an absolute colorimetric rendering intent. The C* value was calculated for each gray patch.

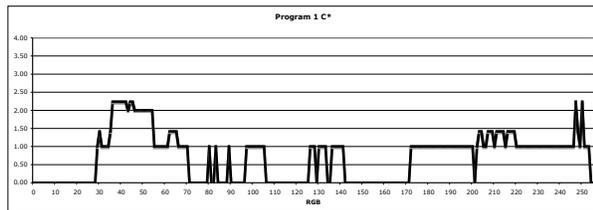


Figure 6. C* for InCamera profile.

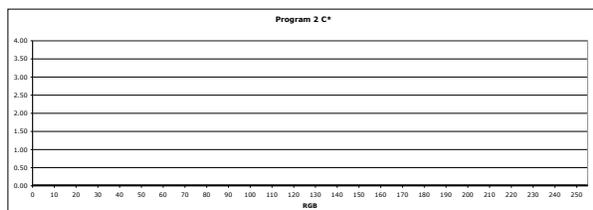


Figure 7. C* for ProfileMaker profile.

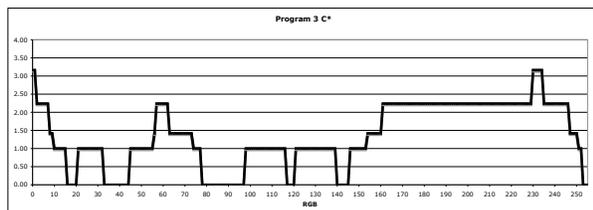


Figure 8. C* for Profiler profile.

As demonstrated in Figures 6-8, some programs will take a perfectly neutral balanced image and introduce color errors. ProfileMaker produces very “clean” neutrals with no introduced color error. The grayscale image produced by Programs 1 and 3 showed visible color bands when the profile is applied.

The author believes the source of the error to be an incorrect assumption by the profile generation program’s designer about the manner by which cameras operate. When digital images were almost exclusively obtained from scanning film negatives and positives, three independent tonal reproduction curves were necessary in the profile to compensate for dye interactions in the film. Digital cameras use a single tone curve with a scalar applied to each channel. This allows for a single gray reference be used to set the neutral balance for the entire tonal scale in the camera. If three independent curves were used in the camera, it would be necessary to use a gray scale to set the neutral balance, in a similar manner to the way film scanners were calibrated.

The tone curves for the profile are determined using the ColorChecker neutral patches. Using three separate tone curves makes the algorithms overcorrect for small deviations in the chart patch characteristics (e.g. colorant formulation, surface characteristics), chart image noise, and in the reference file measurements

(e.g. spectrometer bias or errors).

Profile Tables

Each ICC profile was analyzed using ColorThink Pro, a profile visualization tool, to discover the types of information embedded in the profile. The ICC profile format allows for four renditions of an image selected by the rendering intent tables within the profile. Usually these tables are built from an image of the test chart, a colorimetric or spectral reference file for the chart, and the profiling program’s algorithms. The colorimetric table is used in two ways; relative and absolute. The table consists of relative colorimetric values that are referred to the media white point. An absolute colorimetric table is generated by transforming the relative colorimetric table with the white point tag.

	Perceptual	Colorimetric	Saturation
InCamera	*		
ProfileMaker	*	(see note)	(see note)
Profiler	*	*	*

Table 1. Rendering intent tables produced by each profiling program. * indicates the table is present. Note: ProfileMaker shares the perceptual table for all three rendering intents.

The absence of a colorimetric table in profiles from two of the programs would lead to the expectation that colorimetric color matching would be impossible with these profiles.

Conclusions

Several possible causes of digital image color errors were examined. One major error source appears to be the test chart used to verify the algorithms employed generating the color management profile. The algorithms are tuned to give good results for the colors in the chart used to make the profile, but they do not give as accurate results for non-chart colors.

The lack of colorimetric profile tables makes the ability of a profile to produce colorimetrically accurate images problematic. Two of the three profilers tested used the perceptual tables for colorimetric rendering. The subjective adjustments encapsulated in the perceptual rendering intent tables cannot be expected to work properly for the colorimetric intents.

Some profilers create profiles that introduce color errors into neutrals. The author proposes that this is due to the algorithms using a film based model that uses three independent tone curves instead of a more realistic single tone curve model. The result is that the algorithms are sensitive to test chart image noise, variations in the test chart patch characteristics and spectrophotometer measurement errors.

References

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Author Biography

Robin D. Myers has a BSc degree in Chemistry from CSU, Fresno. He is a member of IS&T and the ISCC. He worked for Lawrence Livermore National Laboratory, Versatec, and Apple Computer. He has 5 patents on color matching technologies. Currently he works for Better Light, a digital scanning camera manufacturer and operates an imaging business providing consulting, products and services for digital photography, color science and color management.