Profiling CMOS vs. CCD Digital Cameras

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Keywords: ICC profiling, color management

Abstract

Although introduced commercially in 1995, digital camera sensors that use complimentary metal oxide semiconductor (CMOS) chips have become increasingly popular in mid-range and professional digital single-lens reflex (DSLR) cameras, gradually replacing older charge-coupled device (CCD) sensors. Manufacturers claim that CMOS sensors have higher light sensitivity that results in greater shadow detail with less noise. This study sought to determine if CMOS-equipped DSLR cameras have a larger color gamut and produce more accurate ICC profiles than CCD cameras. The authors also tested the effects of other variables, including lighting (LED, fluorescent, and incandescent), lighting evenness, use of a polarizing filter, turning off settings in Adobe Camera Raw, and outputting captures into different Camera Raw standard working space profiles.

The authors assessed the accuracy of ICC camera profiles by comparing original to captured color values. Profile accuracy (Table 1) is expressed as the average delta-E color difference between original and captured color values of a Macbeth ColorChecker SG 140-patch color target.

Introduction

Since the development of desktop publishing in the 1980s, with its "plug-and-play" scanners, monitors, and printers, users have sought accurate color throughout the system—accurate color that is not necessarily guaranteed because different devices reproduce color with different technologies.

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In the early 1990s, several scanner and raster image processor (RIP) manufacturers introduced color management systems to help get more accurate color. These systems worked by comparing standardized color targets on input and output with known standards. However, each manufacturers system was proprietary and worked only with its own equipment.

In the mid-1990s Apple Computer introduced its ColorSync system-level color management and sought to unite various proprietary systems by introducing a standardized profile format, which it turned over to the non-profit International Color Consortium (ICC, www.color.org). In the 2000s, color management became increasingly popular as costs of spectrophotometers and software declined.

Michigan, USA-based X-Rite Inc. has a virtual monopoly on color management systems, except for some competition from smaller Swiss company Techkon and Japanese company Ishihara. In 2005 X-Rite merged with its largest competitor, Swiss-based GretagMacbeth. Both companies made color measurement instruments and color management software.

Methodology of Color Management

An idealized color reproduction system has four steps:
1. Images are captured using a scanner or digital camera.
2. Digital images are reproduced on a computer monitor.
3. Images to be printed are first proofed on a low-cost proofing device to check color and page layout.
4. Images are printed on a press or digital production printer.

Applying color management, the user would like:
1. Digital images that match the original scene or product.
2. A computer monitor that accurately reproduces the color of digital files.
3. A proofing device that accurately simulates a production printer or press.
4. A production printer or press.

Table 1 summarizes how color management works with each of these devices.

Table 1. Color Management Basics		
Device	*Tools required*	*How color management works*
Digital camera	Reflective color target of known values, such as Macbeth ColorChecker	Software compares captured color target values with known values and builds ICC profile to convert color.
Monitor	Emissive spectrophotometer or colorimeter	Software interfaces with instrument to measure emitted color values, which are used to calibrate contrast (gamma) and color balance (color temperature) and to make ICC profile.
Printer/Proofer	Reflective spectrophotometer	Software interfaces with spectrophotometer to measure printed color values and to make ICC printer profile.

Color Management for Digital Cameras

ICC profiling of digital cameras seeks to get a digital file, the colors of which match those of the original as closely as possible (Adams et al., 2008; ICC, 2005). Color management software creates a camera profile by comparing captured RGB values of a target, such as the Macbeth ColorChecker 24 or ColorChecker SG, with the target's "true" colors, as expressed by spectral or colorimetric measurements of each patch. The program then calculates a color look-up table that converts captured color to values that more closely match those of the original.

As a practical solution, ICC profiling helps users create photos that more closely match original subjects (Figure 1). This capability could be important in graphic arts photography, where photographers capture images of products for sales or informative purposes—such as in newspapers, magazines, catalogs, online stores, and web sites.

Purpose of Study

Although introduced commercially in 1995, digital camera sensors that use complementary metal oxide semiconductor (CMOS) chips have become increasingly popular in mid-range and professional digital single-lens reflex (DSLR) cameras, gradually replacing older charge-coupled device (CCD) sensors. Manufacturers claim that CMOS sensors have higher light sensitivity that results in greater shadow detail with less noise, however dynamic range specifications are difficult to find. Manufacturer Teledyne Dalsa, in its undated white paper, "CMOS vs. CCD," states the CCD sensors have "high" dynamic range while CMOS is listed as “moderate.” The authors sought to determine if CMOS-equipped DSLR cameras have a larger color gamut and produce more accurate ICC profiles than CCD cameras. While comparing the two types of cameras, they also tested the effects of other settings and properties, including the use of a polarizing filter; LED, fluorescent, and incandescent light; the output profile from the Adobe Camera Raw plug-in, high density-range (HDR) photography, and the choice of profiling program.

Materials and Methods

The authors conducted the study with two Pentax DSLR cameras, including a K200D 10-megapixel CCD-equipped model purchased in 2008 and a 12-megapixel CMOS-equipped K-r purchased in 2010. Treatments are outlined in Table 2.

The following procedure was used to compare the accuracy of color profiles:

1. Custom measurements were taken of a Macbeth ColorChecker SG 140-patch color target and a miniature ColorChecker 24 target using an Eye-One spectrophotometer and ProfileMakerMeasureTool software. The custom measurements were used as the reference file for profiling in i1 Match software and used as the benchmark for the “true” colors of the target.

2. Exposures of the ColorChecker SG and 24 targets were taken with the Pentax K200D CCD and K-r CMOS cameras in Camera Raw digital negative (DNG) format, except that the in-camera HDR photos were captured in JPEG format as required by the camera’s firmware.

3. The ColorChecker SG target captures were used to make ICC camera profiles in i1 Match, while the ColorChecker 24 captures were used to make a profile in ColorChecker Passport software.

4. Captures were opened in Adobe Photoshop CS4 or CS5, and the appropriate ICC camera profile was applied with the Edit > Assign profile command. Captures were then converted to Adobe RGB standard working space using the Edit > Convert to Profile command, and were then converted to LAB color space.

5. The LAB values of profiled and unprofiled captures were measured using Chromix’sColorThink software utility (Figure 2). However, getting color measurements in the same sequence as the ColorChecker SG target required rotating the captured targets 90° clockwise and flipping them horizontally in Photoshop.

6. To compare the accuracy of colors in the unprofiled and profiled targets, the custom-measured reference file and the measurements of the captured file were opened in a Chromix ColorThink worksheet. The worksheet was set to measure ΔE between the reference file and the captured file. The resulting 140 readings were saved to a text file and opened in Microsoft Excel.

7. Microsoft Excel was used to calculate the mean, minimum, and maximum of the 140 ΔE values.

Table 2. Treatments		
Treatment	*Details*	*Effect*
Polarizing filter	A Crystal Vision 52-mm polarizing filter was attached to the camera lens.	Reduces reflective glare, increasing color saturation
LED, fluorescent, and incandescent light	LED: 2 Lights of America model 2001LEDE26-65K, 1-watt lamps Fluorescent: 2 Bowens photo fluorescent lights, Incandescent: 2 Anoma 25-watt projection lamps	LED and fluorescent light have a more even spectral power distribution than incandescent
Camera Raw Profile	Image output to Adobe RGB and the larger ProPhoto RGB were compared.	Although color profiling works better with color management turned off, users of the Adobe Camera Raw plug-in must select an output profile for images converted in that software
HDR photography	High density-range photography combines two or more exposures to capture a wider range of highlights and shadows, but sometimes produces a “posterized” or distorted look.	Pentax K-r HDR “normal” setting
Color management software	The higher-end i1 Match program was compared with the entry-level ColorChecker Passport.	i1 Match uses the 140-patch ColorChecker SG target, while ColorChecker Passport uses the original 24-patch ColorChecker target.

Results and Discussion

Results of ΔE measurements between the ColorChecker SG reference file and measured capture are shown in Table 3.

Table 3. ΔE with Various Camera Profiling Techniques			
	Without Profile	*With Profile*	*Profile CuΔE*[1]
CMOS Camera (Pentax K-r)[3]	4.10	2.59	874,195
CCD Camera (Pentax K200D)	4.59	3.16	870,566
Fluorescent Lighting[3]	4.10	2.59	874,195
LED Lighting	6.69	3.87	928,680
Tungsten Lighting	6.28	3.24	842,404
Polarizing Filter[4]	4.76	2.68	928,614
Camera Raw Zeroed Settings[4]	5.56	5.63	967,869
ProPhoto RGB Camera Raw Space[5]	7.90	3.74	1,338,050
HDR Photography	5.30	2.67	776,899
X-Rite ProfileMaker Software	4.10	4.13	904,855
X-Rite ColorChecker Passport Software	5.92	5.45	—[2]
1 Cubic ΔE, or profile volume, calculated in Chromix ColorThink 2 Cannot read cubic ΔE because profile is in .dcp format that works with Adobe Camera Raw; cannot be read in ColorThink. 3 Made with fluorescent lighting. 4 Made with Pentax K-r CMOS camera 5 Other profiles are made with default Camera Raw settings. 6 Other profiles are made with Adobe RGB color space set in Camera Raw.			

CMOS vs. CCD. Interpreting the results in Table 3, one can see that with the CMOS digital camera produced captures that differed from the original target values by an average of 4.95 ΔE. However, applying an ICC profile reduced the average ΔE to 2.67. Results for the CCD camera were very similar and probably not statistically different: 4.59 without a profile and 3.16 with a profile (Figure 3).

LED, fluorescent, and tungsten lighting. The authors found the results for lighting type (Figure 4) to be inconclusive. Although the fluorescent light profiles had lower ΔEs than those made with LED and incandescent lights, the LED and incandescent lights were also less even which could have produced a greater variation in original patch colors.

Polarizing filter. Since a polarizing filter reduces unwanted glare from the subject, the authors presumed that photographing the ColorChecker target through a polarizing filter would produce a more accurate profile. However, the filter actually produced an unprofiled color difference of about 2 ΔE greater than captures without the filter.

Camera raw settings. A key principle in ICC profiling is to turn off color management when capturing or printing a profiling target, otherwise the user is "profiling the profile" and not the device. However, the Adobe Camera Raw plug-in requires that users choose from a predefined output profile from a popup menu for Camera Raw images; there is no setting of "None." In a personal communication from an Adobe technical representative, the authors were advised that setting all Camera Raw plug-in settings to zero effectively turned off color management. Therefore we compared profile accuracy with the default settings to that with all settings at zero. In addition, accuracy was compared with the target image saved to

HDR photography. First conceived in 1850, high density-range photography was introduced into Photoshop CS3 and has recently been incorporated into some of the newer DSLR cameras including the Pentax K-r and Sony Alpha. HDR combines two or more exposures to capture highlight and shadow detail but can produce a posterized look. HDR has potential for photographing products that include both high-key and low-key elements. The authors were surprised that unprofiled images captured with the Pentax K-r's HDR setting produced a ΔE of only 5.30, compared to 4.95 for conventional captures. Profiling reduced the ΔE to 2.67 (Figure 5).

Profiling program. X-Rite's entry-level ColorChecker Passport software, which uses a 24-patch ColorChecker target, performed very well compared to the higher-end i1 Match that uses a 140-patch ColorChecker SG target (Figure 6). Whereas i1 Match brought an unprofiled ΔE of 5.89 down to 2.99, Passport reduced it to 5.45. However, proofs of captures profiled with both programs were more impressive: Hues were noticeably more accurate with Passport profiles vs. no profile, but not as accurate as with i1 Match. However, Match lightened images and desaturated colors, while Passport maintained image lightness. The lightening of Match could be corrected with the program's profile editing feature, however.

Conclusion

To observe the effects of profiling on subjective color, proofs of profiled and unprofiled images were printed on an Epson 4880 inkjet printer and compared under standard viewing conditions. After comparing delta-E data and color proofs, the authors concluded that:

1. ICC camera profiling reduced the difference between captured and original target values by 2-4 ΔE.

2. Few of the capture techniques made much noticeable difference in the profiled images, including the CMOS sensor, polarizing filter, and lighting, except that evenness of lighting did affect camera profiles.

3. The technique that reduced profiled color difference the most was using Adobe Camera Raw's default settings instead of turning off color management by setting all capture settings to zero.

4. X-Rite's entry-level ColorChecker Passport software, which uses a 24-patch ColorChecker target, performed very well compared to the higher-end i1 Match that uses a 140-patch ColorChecker SG target.

5. HDR (high-density-range) photographs taken on the Pentax K-r DLSR could be profiled and produced remarkably low ΔE values.

Overall, the authors concluded that, to get the closest color match for critical work, users should use a CMOS digital camera with even, fluorescent lighting, no polarization filter, Adobe Camera Raw defaults, Adobe RGB standard working space in Camera Raw, and i1 Match profiles.

Ideas for Further Research

While working on this project the authors recognized several additional area where research on digital camera profiling could be helpful:

1. How do other camera brands, such as Nikon, Canon, Sony, and others, compare to Pentax for color accuracy, with and without profiles?

2. How does lighting evenness affect profile accuracy?

3. How does editing the profile affect color accuracy? For example, the authors noted that i1 Match profiles produce lighter images than do ColorChecker Passport profiles. If Match profiles were edited to make the resulting images darker, how would this affect color accuracy?

Table			
Illuminant	*Color temp.*	*Intensity*	*CRI*
Fluorescent	5055 K	2219 lux	81
LED	4819	1881	62
Incandescent	(Note 1)	283	(Note 1)

References

Adams II, R.M., A. Sharma and J. Suffoletto. 2008. Color Management Handbook. Printing Industries Press, Sewickley, PA.

Teledyne Dalsa, CCD vs. CMOS (white paper from the web at http://www.dalsa.com/corp/markets/CCD_vs_CMOS.aspx).

White Paper #17, Using ICC Profiles with Digital Camera Images, International Color Consortium, April 2005.

Figures

Figure 1. Effects of ICC camera profiling on a product photo of colorful toy cars are evident when comparing an unprofiled capture (left) with profiled capture. The profile was applied in Photoshop with Edit > Assign Profile.

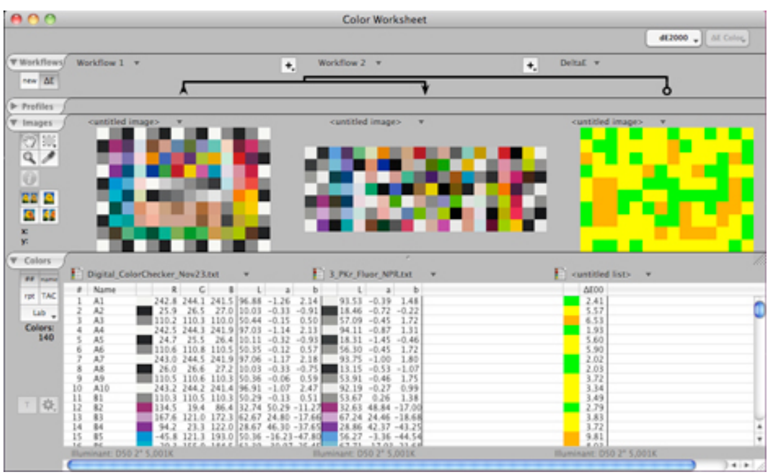
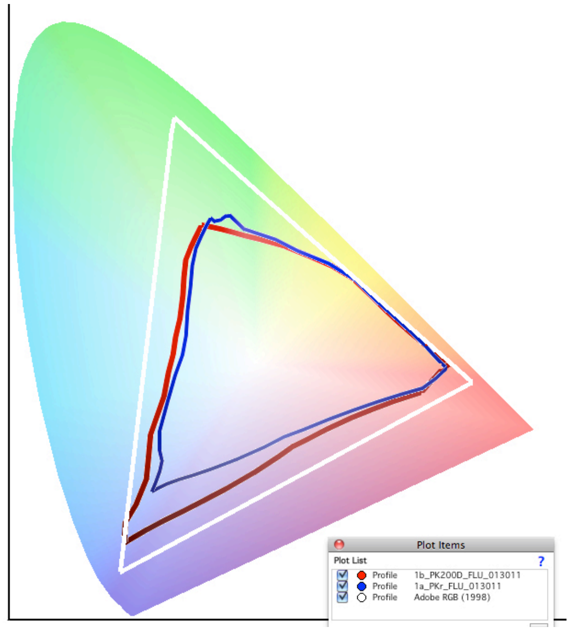


Figure 2. Measuring ΔE in Chromix ColorThink Pro.

Figure 3. Color gamuts of profiles for the Pentax K-r (CMOS) and K200D (CCD) cameras compared to Adobe RGB.



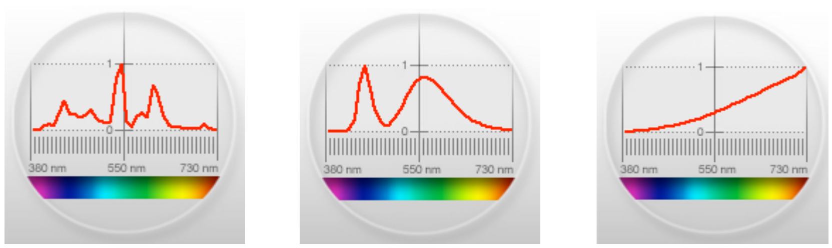


Figure 4. Spectral power distribution curves for fluorescent, LED, and incandescent light sources used in the study.

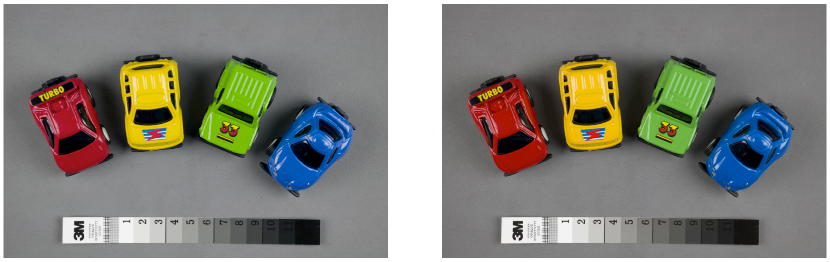


Figure 5. Entry-level ColorChecker Passport profile (right) compared with higher-end i1 Match profile (left).