Predictive Color Rendering of Camera Raw Images Using ICC Profiles

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Keywords

Digital Camera, CIE Lab, Colorimetry, ICC profiles, Camera Raw, Rendering

Abstract

Digital photography has become a widely accepted method for capturing images for printed matter. There remains however considerable subjectivity regarding the demosaicing and color processing of raw images. This subjectivity affects ICC profiling, in that profiling an image can have variable results based on the software used to demosaic the raw data, and the color rendering settings that are manipulated prior to conversion.

Camera profiling allows the shooting of a color target in a controlled environment that is limited in environmental variances and offers controlled exposure. The resulting target image is then profiled to achieve color information that is representative of the target under this controlled environment. In an uncontrolled environment, both the images shot and the observer visually assessing the scene are subject to environmental variables, such as variations in lighting, shadows, movement, and observer response. If these images are profiled using an accurate camera profile, the resulting image should be a color managed image from the perspective of the observer. The color of the image will be affected by the subjectivity of the scene, but the profile allows us to manage the variability in a controlled and predictable way.

The research for this project explored colorimetric analysis of how camera raw color rendering settings of different camera raw editors affect the ability camera profiles to achieve accurate color prediction. To explore this, a GretagMacbeth Digital ColorChecker SG chart was shot in raw format using both a Canon and a Nikon digital SLR camera in a controlled lighting environment. The raw files were then converted into RGB using various approaches.

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The findings showed that color managed workflows with tailored profiles have the ability to overcome some inconsistency between images, producing images that more accurately predict color representation, even when the degree of accuracy of the initial image varies.

In general, camera raw images color rendered in a linear state with minimal highlight and neutral adjustment produced profiles that were consistently empirically close to the target values (low ΔE and variance).

Generic color settings in Vendor and Mainstream software solutions did not adequately remedy exposure imbalances, as they are bounded by algorithms which do not base corrections on reference data relating to actual color information. Conversely, custom made profiles apply data-fitting algorithms or transformational matrices based on the variations between the captured data and actual color information, allowing them to blindly compensate for variations in individual images. When the linear raw data was compensated for lightness and gray balance, the results of the proofing were more consistent and repeatable, suggesting that these simple adjustments allowed the profiling software to better compensate for variations between images by providing a base constant to reference.

If the goal of photography is to create a representation of the scene that appeals to our visual assessment (pleasing color), then the goal of profiling a camera should not be to make the camera match the scene. Instead, camera profiling should attempt to provide more stability and predictability in the way the scene is altered in order to achieve that desirable pleasing color image.

Introduction

The quality and economy of today's digital single reflex lens cameras (DSLRs) have resulted in a wide-range acceptance of digital photography as an alternative to traditional film-based photography. In a traditional workflow, digital image quality was dependant upon the quality of the original scene capture, the expertise of film developing, and the skill of the scanner operator. In many cases, a good scanner operator could use the hardware and software of his craft to produce a final digital image that looked better than the original. For example, shadow detail could be enhanced, or flat color could be "punched up."

Digital photography has the advantage of being first generation digital. This eliminates the variability of film processing, and the need for scanning. Many professional photographers will shoot images on their camera in raw format. The advantage of the raw format is that is retains all the information captured in the scene. This data, usually captured as 12 bit data, is then compressed down for 8 bit when saved as RGB or CMYK for print. When photography is done by a digital camera, there is an avenue to explore the viability of color management right at the camera stage.

Profiled color management, by nature, is a digital phenomenon. By creating an ICC profile for a device, we are manipulating that device to create colors in a prescribed way by altering the digital information that is used to interpret and display color. Traditional photography is an analog process, and as such does not lend itself to the theories and constructs of profiling. With traditional photography, the earliest an ICC profiled workflow could be employed was at the scanning stage, since this was the first point where color could be electronically manipulated.

Digital photography opens up the ability to introduce an ICC managed workflow right at the camera stage. A digital camera is really a dual-purpose device that replaces both a traditional camera as well as a scanner. Just like a scanner can be profiled, so to can a digital camera. If it is logical to employ an ICC managed workflow at the point where an image is digitized, then it seems reasonable that color management should include digital cameras. There is however, one major difference between digital photography and scanning that makes camera profiling a challenge.

When it comes to device profiling, scanners have the benefit of controlled environment. The target (or scene) being captured by a scanner is contained within a consistently controlled environment that is relatively impervious to external factors such as temperature, weather, and lighting conditions. This results in repeatability and consistency when profiles are created and employed. In contrast, digital cameras that are used outside of controlled studio environments are subjected to numerous environmental factors that have a dramatic impact on the way a digital image is captured and interpreted. It would be impossible to create a camera profile for every possible scenario in which a digital image would be captured. Several images taken in different environments will have very different outcomes, even if the camera and profiles used remain constant.

The research presented in this paper was done in an attempt to determine if camera profiles for digital cameras improve the overall quality and predictability of digital camera color. To improve the overall quality, profiles would have to result in better color reproduction and greater consistency and predictability of color when compared to the subjective vendor-specific color rendering done by the camera or preset software.

The Camera Raw Format

Simply stated, the camera raw file format is very similar to a traditional film negative. The camera raw file contains all the data captured for a particular scene without any adjustments. It is the truest representation of the information that was captured by the camera. In order to use the camera raw data, it must first be translated into an RGB or CMYK file format, depending on the intended use. This transformation is done in a two-step process. First, the raw CCD information is demosaiced to convert the monochrome CCD data into RGB information. Second, the converted RGB data is typically put through a color rendering process to adjust colors to represent a scene that is pleasing to the eye. In some cases these two steps are done transparently right in the camera. This is the case when digital SLR cameras are set to save images as Jpegs or Tiffs, and not camera raw. When camera raw is used, the demoaicing and color rendering must be done by a software application. All digital SLR manufacturers have their own software to convert camera raw images. In addition, there are many third party solutions that also perform this function. The vendor software has the advantage of knowing and understanding the proprietary nature of the cameras CCD and filter array, but may have limited adjustment capabilities. In contrast, third part solutions such as Adobe Camera Raw plug-in and Phase One's CaptureOne Pro have many enhancement features and tools, but rely on reverse engineering to determine the correct interpretation of the proprietary CCD information.

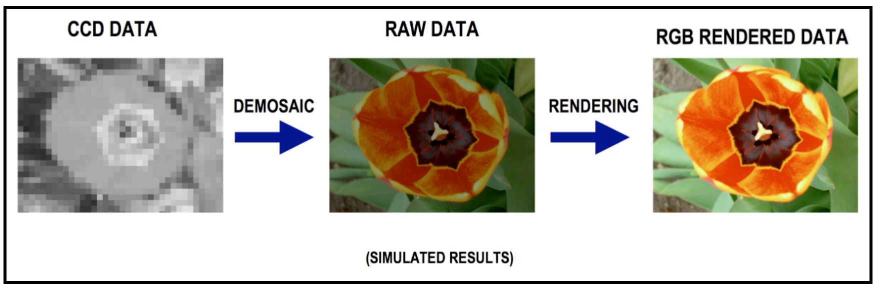

Figure 1: Demosaicing and rendering of camera raw data.

The Research Aim

This research project was done to determine if ICC profiles for digital cameras could be used to create more predictable color outcomes, even with the variability of environmental factors.

In order to achieve consistent color image quality, the camera raw conversion process should permit obtainable and consistent color characteristics by calibrating the process in order to allow for a true colorimetric representation of the scene. The method used by camera vendors to generate "pleasing" images often involves manipulating the initially flat and dark raw data through image adjustment to create a representation of the scene that is subjectively pleasing to the eye. This end result may or may not be an accurate reflection of the true scene. By using a camera raw editing program, photographers have greater control over the result of the final image through color rendering setting adjustments.

The parameters applied to the images during the color rendering stage may be manipulated in seemingly infinite combinations, and even "switched off " to produce linear images, closely representing the color data of the raw file but not representative of the scene. The settings used during the color rendering process of raw conversion are crucial, and will impact the success of the profile in achieving a good colorimetric match to the target.

The research for this project explored accuracy of ICC profiling when applied to camera raw images that were demosaiced and color rendered in various ways by different camera raw editing software. To achieve this, a GretagMacbeth Digital ColorChecker SG chart was shot in raw format using both a Canon and a Nikon digital SLR camera in a controlled lighting environment. The raw files were then converted into RGB using different color rendering settings as seen in Figure 2. The rendered images were then color managed using both industry standard generic input profiles and custom made profiles for comparison. The resulting CIE L*a*b* color data for the images were analyzed by comparing the □E of the profiled images to the colorimetric readings of the physical target. The image with the lowest □E values should represent the closest empirical match to the color of the actual target.

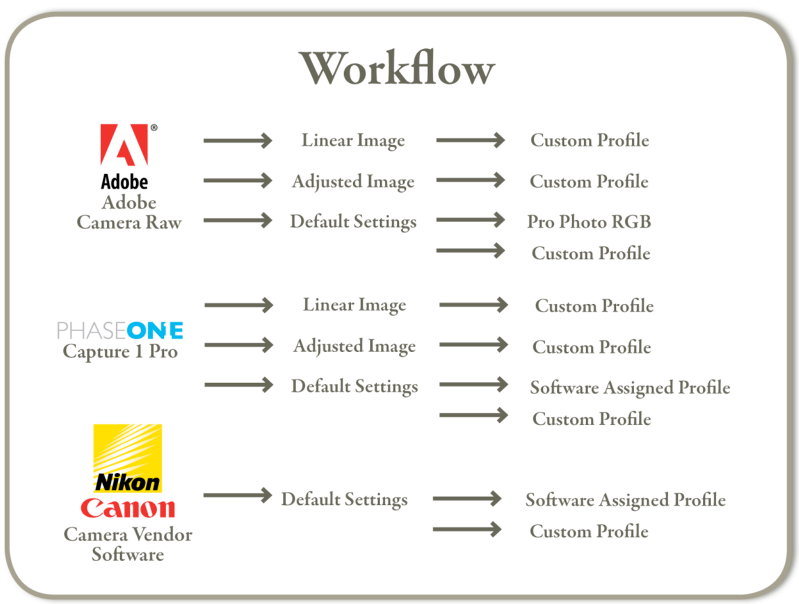

Figure 2: Workflow used for Research Method

To reduce the potential of human error, MathWorks MATLAB® was used to record and compare the CIE L*a*b* values of each patch and generate the corresponding □E values. The MATLAB results were exported to an Excel file that could then be analyzed and compared.

Results and Discussion

It should be noted that with the limited number of sample images and cameras used in this research, the results may or may not be reproducible using another camera under differing environments. The limited number of samples still allow for objective observations that may outline patterns and indicators for further research initiatives.

Tables 1a and 1b summarize the average ΔE obtained by comparing the full set of patches of the test target to the measured set under D65 illuminate. The tables are sorted in ascending order based on the ΔE mean for each sample. The results show a separation between the samples generated through a color managed workflow, employing custom profiling for the sample, versus those employing generic profiles. The results also demonstrate the possibility of an underlying pattern of increased consistency and/or accuracy in color prediction with the employment of adjustments (in bold) as these samples ranked among the top three and demonstrated a narrow range of less than 0.6 ΔE across both sets.

Table 1a - Average ΔE for all patches under different workflows with Canon

Sample ID	Raw Software	Rendering	Profile	Mean ΔE
CAPC1P	**Capture One Pro**	**Adjusted**	**Custom**	**3.421**
CDPC1P	Capture One Pro	Default	Custom	3.783
CAPACR	**Adobe Camera Raw**	**Adjusted**	**Custom**	**3.802**
CDPACR	Adobe Camera Raw	Default	Custom	3.901
CLPACR	Adobe Camera Raw	Linear	Custom	4.034
CLPC1P	Capture One Pro	Linear	Custom	4.084
CDPVEN	Vendor Software	Default	Custom	4.521
CDGC1P	Capture One Pro	Default	Generic	6.756
CDGVEN	Vendor Software	Default	Generic	7.651
CDGACR	Adobe Camera Raw	Default	Generic	7.844

Table 1b - Average ΔE for all patches under different workflows with Nikon

Sample ID	Raw Software	Rendering	Profile	Mean ΔE
NLPC1P	Capture One Pro	Linear	Custom	2.565
NAPC1P	**Capture One Pro**	**Adjusted**	**Custom**	**2.614**
NAPACR	**Adobe Camera Raw**	**Adjusted**	**Custom**	**3.178**
NDPACR	Adobe Camera Raw	Default	Custom	3.941
NDPVEN	Vendor Software	Default	Custom	4.289
NLPACR	Adobe Camera Raw	Linear	Custom	4.309
NDPC1P	Capture One Pro	Default	Custom	4.348
NDGACR	Adobe Camera Raw	Default	Generic	11.135
NDGVEN	Vendor Software	Default	Generic	11.421
NDGC1P	Capture One Pro	Default	Generic	12.139

To further explore these observations a breakdown of the average ΔE values categorized by both the color management policies and workflows is detailed in the following sections.

Color Management Factors

Table 2a - ΔE Breakdown for all patches with different profile types

Camera and Profile	Average	Range	Minimum	Maximum
Canon (Generic)	7.417	**1.088**	6.756	7.844
Canon (Custom)	**3.935**	1.100	**3.421**	**4.521**
Nikon (Generic)	11.565	**1.004**	11.135	12.139
Nikon (Custom)	**3.606**	1.783	**2.565**	**4.348**

Table 2a summarizes the lack of color predictability achievable through generic camera profiles. Although the generic dataset for both cameras demonstrated a small range of 1.088 and 1.004 for the Canon and Nikon, respectively, the average ΔE values for each are high and somewhat unpredictable from a process perspective. The average ΔE values for generic profiling indicate that the accuracy of color representation is quite low due to the high ΔE values. The fact that there is a fairly large spread between the average ΔE value for each camera suggests that the predictability of color is significantly influenced by variables in the process, such as the camera, the scene, the settings, etc.

In contrast, the average ΔE achieved with custom profiles indicate a more stable process with both higher accuracy and greater consistency. An average ΔE of 3.935 for Canon and 3.606 for Nikon implies that the accuracy of color prediction is relatively high, and since there is less of a spread between the two averages, it appears that this accuracy is less impacted by variables in the process.

It should be noted that the range of the custom profiles set represents images with a similar color management policy but with varied processing workflows; conversely, the generic profiles set represents images with a standard color management policy and pre-specified processing workflows. The range for the custom profile set is affected by differing workflow methods, while the range for the generic profiles set will only be affected by differences in the default software processing methods.

Based on these findings, custom profiles appear to yield images that produce more predictable outcomes, and custom profiles seem to be less influenced by environmental factors than generic profiles.

Workflow Implications

The Color rendering stage of camera raw conversion has a dramatic impact on the way the final RGB or CMYK image will look. In many ways, adjusting the color rendering settings is like adjusting capture settings on a scanner. If done well, these settings will capture the maximum range of tones of the original. To study the effects of color rendering settings on color predictability, three different processing workflows were employed in this research: default, linear, and adjusted. Each workflow represents a set of color corrections settings applied to the images while processing the raw files to produce the samples. The default workflow was based on the software vendors' pre-defined defaults, including exposure adjustments, tonal curves, sharpening and other settings. The linear workflow was defined with no corrections, by setting all adjustments and features to zero. Both the default and linear workflow were set to include the 'As Shot' white point, which is measured and appended to each raw file by the camera during capture. The adjusted workflow was built on the linear settings but adjusted the exposure setting to achieve a predefined tonal range target. This target was set through eyedropper readings of patch E5 of the target to achieve a specific L value equivalent to R236 G236 B236 for the white point, and by adjusting patch H5 to read as a neutral gray.

These workflows resulted in three distinct sets of samples from each raw image, each with unique characteristics. The linear workflow resulted in images that are flat in appearance, allowing the tonal characteristics of the raw file to remain persistent in the final image. The default workflow resulted in images with amplified tonal characteristics and enhanced appearance, shifting the tonal characteristics of the original raw file without optimizing it to a particular standard. The adjusted workflow resulted in images with standardized tonal characteristics, where the tonal characteristics were optimized to some degree to a predefined standard.

The effect of these different color rendering workflows changes the degree to which the image preserves the original color information of the raw image. This in turn impacts the ability of creating a profile that can accurately match the color characteristics of the original target. In other words, if the color rendering settings produce an image with a compressed color gamut that is too far out of range, the ability to create a profile that can map the image to the original color characteristics becomes compromised.

From tables 3a, 3b, and 3c, we can observe that the adjusted color rendering workflow resulted in the most accurate color prediction average, emphasized in bold. This relationship is outlined by comparing the average ΔE values for Canon, Nikon, and the overall of both cameras, to their counterparts.

Table 3a - ΔE breakdown for all patches under different workflows with Canon				
Method and Profile	Average	Range	Minimum	Maximum
Adjusted (Custom)	**3.612**	0.380	**3.421**	**3.802**
Linear (Custom)	4.059	**0.051**	4.034	4.084
Default (Custom)	4.068	0.739	3.783	4.521

Table 3b - ΔE breakdown for all patches under different workflows with Nikon				
Method and Profile	Average	Range	Minimum	Maximum
Adjusted (Custom)	**2.896**	0.565	2.614	**3.178**
Linear (Custom)	3.437	1.745	**2.565**	4.309
Default (Custom)	4.193	**0.407**	3.941	4.348

Table 3c - ΔE breakdown for all patches under different workflows (both cameras)				
Method and Profile	**Average**	**Range**	**Minimum**	**Maximum**
Adjusted (Custom)	**3.254**	1.188	2.614	**3.802**
Linear (Custom)	3.748	1.745	**2.565**	4.309
Default (Custom)	4.130	**0.739**	3.783	4.521

When the various workflows were cross-compared, the default workflow achieved the smallest ΔE range for both the Nikon and Canon cameras, further substantiating previous findings. However, the default workflow also resulted in the lowest color accuracy predictions for both cameras, with an average ΔE of 4.068 and 4.193 for the Canon and Nikon images, respectively. This raises a question as to the ability of these pre-defined correction workflows to preserve the detail of the images for further color management. While the default settings are meant to create a final RGB image that has the most pleasing color, the deviation from the rue scene representation is great enough to question whether or not the overall tonal range is negatively impacted.

Default rendering works with raw files that are only affected by the ISO and exposure and not any of the other on-camera settings, including white point (Rodney, p. 165). Furthermore, raw converters like Adobe Camera raw and CaptureOne Pro rely on locked down settings, with no automatic features, as evident in their default settings, to allow for profiling (Rodney, p. 168). If the exposure and ISO settings are not configured to adjust for optimal tonal preservation, clipping of detail may occur affecting the highlight or shadow areas. Most camera raw editors will apply contrast and brightness adjustments, spreading the tones outwards and towards the highlight end of the histogram. As such, with default settings, an image with a relatively high exposure will be susceptible to further clipping during conversion, especially in the highlights.

A final observation with regards to workflow is that both linear and adjusted workflows resulted in better color accuracy than the default; however, the adjusted workflow yields a lower and more consistent range with raw formats of both cameras used. The linear workflow achieved a range of 0.051 and 1.745 for the Canon and Nikon, respectively, while the Adjusted workflow achieved a range of 0.380 and 0.565, for the same respective images. This indicates that the adjusted workflow is better for optimizing raw data for color management across samples from different cameras with differing tonal characteristics.

Implications of the Raw Image Characteristics on Color Accuracy

When comparing the color accuracy achieved with the Canon image (Table 3a) to those achieved with the Nikon image (Table 3b), it can be seen that the Nikon image resulted in higher color accuracy (average ΔE) for both adjusted and linear but not for the default samples. When referring to the original raw images, a noticeable difference in the tonal characteristics of these images might provide some explanation for these results.

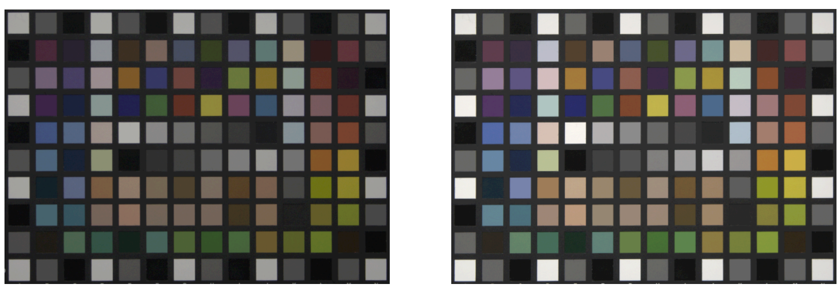

Figure 3 - Comparison of linear raw images for Canon (left) and Nikon (right).

The Canon image (Figure 3) was shot under good exposure, which resulted in the raw image being flat and dark in its linear state. On the other hand, the Nikon image is over exposed, resulting in a linear image of noticeably lighter tone. Over exposure usually results in loss of detail in the highlights, while under exposure will affect the shadows.

The histogram (Figure 4) of the Canon and Nikon images shows that, while the Nikon image might have been over exposed, the amount of information at the higher end of the histogram is minimal to have any substantial effect on the highlight detail. On the other hand, the fact that the data is more widely spread over the tonal range, when compared to the Canon image, suggests that the Nikon image might have preserved more definition between the colors of the scene due to the higher tonal range. This might have enhanced the results of the linear images as well as the adjusted images for Nikon. However, when processed using the default workflow, expanding contrast and increasing brightness, clipping might have occurred in the highlights, slightly decreasing the achieved color accuracy.

Based on these findings, it is possible that for the linear and adjusted workflows, the amount of detail preserved for the Nikon image might have contributed to 1) a more accurate profiling process 2) a more accurate gamut mapping when applying the profiles to the images.

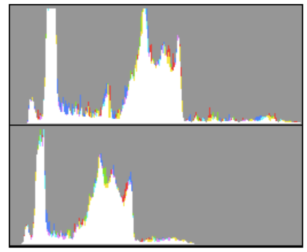

Figure 4 - Histogram of Nikon Linear image (top) and Canon linear image (bottom).

Accuracy of Color Rendering of Individual Patches within Samples

While the average ΔE information for each sample allowed for the selection of the best and worst samples, a further validation on the color accuracy of the individual patches was also done to ensure that the average color accuracy results reflect the accuracy achievable across the gamut and that the results are not skewed due to mixed areas of extremely high accuracy and other with extremely low accuracy.

Table 4a – Breakdown of ΔE results for patches with Canon

Sample	CAPACR	CDGACR	CDPACR	CLPACR	CAPC1P	CDGC1P	CDPC1P	CLPC1P	CDGVEN	CDPVEN
Mean	3.802	7.844	3.901	4.034	3.421	6.756	3.782	4.084	7.651	4.521
Minimum	0.389	1.472	0.443	0.675	0.706	1.159	0.640	0.595	1.363	0.829
Maximum	11.309	20.667	10.858	11.778	18.553	21.692	19.927	19.342	20.890	11.736
≤ 2 ΔE	31	2	32	30	43	5	28	35	3	18
2-5 ΔE	77	22	77	67	71	46	77	70	44	75
>5 ΔE	32	116	31	43	26	89	35	35	93	47

Table 4b – Breakdown of ΔE results for patches with Nikon

Sample	NAPACR	NDGACR	NDPACR	NLPACR	NAPC1P	NDGC1P	NDPC1P	NLPC1P	NDGVEN	NDPVEN
Mean	3.178	11.135	3.941	4.309	2.614	12.139	4.348	2.565	11.421	4.289
Minimum	0.396	1.943	0.656	0.156	0.381	1.631	0.513	0.314	1.452	0.734
Maximum	8.954	25.455	13.224	18.200	8.951	37.339	12.032	9.079	28.177	18.870
≤ 2 ΔE	40	1	24	56	54	1	28	62	4	33
2-5 ΔE	83	32	80	47	75	31	63	68	29	67
>5 ΔE	17	107	36	37	11	108	49	10	107	40

From Table 4a and 4b, we can see the most accurate colorimetric reproduction for each camera. For Canon, the image that was converted using the adjusted workflow through CaptureOne Pro with a custom profile produced the best results. This image (Table 4a, highlighted in grey) exhibits a low minimum and a high maximum, suggesting that color will be relatively unpredictable given that some patches have high ΔE values. For Nikon, the best colorimetric match was achieved with the Linear workflow using CaptureOne Pro with a custom profile. When comparing the best match Canon to the best match Nikon, the Canon image contains a fewer number of patches that fall in the category of ΔE less than or equal to 2 when compared to the best sample for the Nikon image The opposite applies to the patches that fall above a ΔE of 5, with the Canon sample having more patches in the extremely noticeable color difference range. As such it can be inferred that the conditions of the best Nikon sample would result in higher color accuracy for the overall average as well as across the entire gamut.

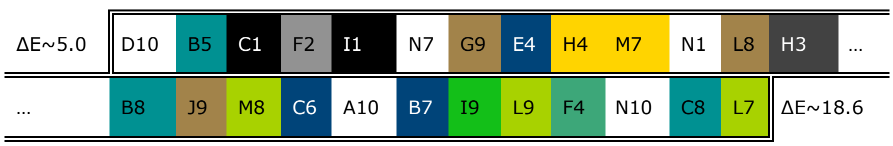

Figure 5a – Worst patches with ΔE >5 for the best Canon sample.

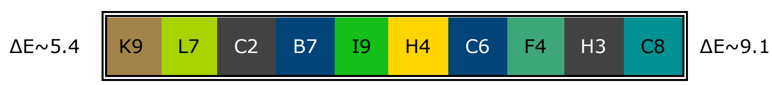

Figure 5b – Worst patches with ΔE >5 for the best Nikon sample.

Further breakdown of the results based on the color of the worst patches for the best samples also reveals that the patches with the lowest accuracy for the Nikon sample were also among those that have a ΔE of over 5 for the Canon sample — patches: I9, J9, L7, L8, L9, M7, M8, N1, N10, N7. These patches demonstrated less than ideal colorimetric reproduction when captured using different cameras, under different exposure settings, using different raw converting software, applying different rendering parameters, and corrected using different color profiles. Such results may be due to the patches being physically damaged or the reference data may be inaccurate resulting in a shift. It may also be caused by the spectral characteristics of the patches causing inaccurate capture due to matamerism or other effects when light is passed through the camera’s filters.

Effect of Extraneous Validation Patches on Results

A final validation to the accuracy of the data used in this research was done to ensure that the patches used for the overall average assessment of the samples was not skewed by more dominant colors — with the same color being repeated. Since the Digital ColorChecker SG chart is designed to have a boundary of white, grey, and black patches for light intensity validation purposes, the inclusion of these patches within the data was found to be a possible contaminant to the accuracy of the results. To ensure that the results were not affected, the patches were removed from the data to produce the results in Table 5a and 5b. A slight variation was noted in the results with an average of 0.406 ΔE units across the samples. It was concluded that the shift falls within an acceptable range and the shift in data is insignificant when compared to the number of patches involved.

Table 5a - Average ∆E for select patches under different workflows with Canon

Sample ID	Raw Software	Rendering	Profile	Mean ∆E
CAPC1P	Capture One Pro	Adjusted	Custom	3.377
CDPACR	Adobe Camera Raw	Default	Custom	3.483
CDPC1P	Capture One Pro	Default	Custom	3.587
CLPACR	Adobe Camera Raw	Linear	Custom	3.633
CLPC1P	Capture One Pro	Linear	Custom	3.678
CAPACR	Adobe Camera Raw	Adjusted	Custom	3.708
CDPVEN	Vendor Software	Default	Custom	4.322
CDGC1P	Capture One Pro	Default	Generic	7.336
CDGACR	Vendor Software	Default	Generic	7.948
CDGVEN	Adobe Camera Raw	Default	Generic	8.593

Table 5b - Average ∆E for select patches under different workflows with Nikon

Sample ID	Raw Software	Rendering	Profile	Mean ∆E
NAPC1P	Capture One Pro	Adjusted	Custom	2.666
NLPC1P	Capture One Pro	Linear	Custom	2.697
NAPACR	Adobe Camera Raw	Adjusted	Custom	3.207
NLPACR	Adobe Camera Raw	Linear	Custom	3.756
NDPACR	Adobe Camera Raw	Default	Custom	4.506
NDPVEN	Vendor Software	Default	Custom	4.943
NDPC1P	Capture One Pro	Default	Custom	4.983
NDGACR	Capture One Pro	Default	Generic	13.301
NDGVEN	Vendor Software	Default	Generic	13.654
NDGC1P	Adobe Camera Raw	Default	Generic	14.472

Conclusion

Summary of Findings

Overall, the “adjusted” images in this research delivered the best profiling results, as determined by the empirical accuracy of color to the original target (ΔE) and consistency (variance). The images that were profiled using the software’s default color rendering settings produced the least accurate and least consistent results of all images that were profiled. Images that were created using default color rendering settings and generic profiles were predictably the farthest way from the target, both in accuracy and consistency.

When looking at consistency only, the images that were profiled after going through default color rendering settings had a slightly smaller variance than the adjusted images. One possible reason for this might be that the default settings that were used included some image sharpening and noise reduction. These two factors, when employed, would produce smoother and more uniform color across the patches.

Despite the fact that linear images are dark and lack contrast, the potential to achieve accurate profiles with these images is apparent by the positive results of the Nikon target that was profiled from linear. A linear RGB image that is created from camera raw should have very little color or range compression, and should contain most of the original scene data. Linear images have the ability to produce accurate results when profiled because they contain much of the original color information from the original 12-bit camera raw file, assuming that the original camera raw data is not too dark (under exposed).

Adjusting exposure and whitepoint to set the highlight and gray balance of the image can actually extend the tonal range of camera raw images that are too dark. This can greatly reduce tonal range clipping and preserve uncompressed tonal contrast, resulting in more consistency and accuracy when profiling. The positive results obtained from the adjusted images in this study are likely due to the fact that (1) the adjusted images were created from linear images and therefore had minimal color compression and good tonal range, and (2), by creating a highlight point within an acceptable range and manipulating patch H5 to create a neutral gray, the profiling software had good foundation blocks upon which it could achieve accurate color mapping for the full gamut of colors, maximizing the data fitting capabilities of the software.

Creating a profile from a camera raw file that is linear with only highlight and gray balance adjustments offers nearly full, uncompressed color range of the original camera raw image, with little to no tonal contrast compression, making it easier for the profiling software to create accurate color maps for the profile.

For Further Study

When the research for this project was complete, several of the images were printed using G7 calibrated proofing systems. Interestingly, when the images that were deemed to be the closest colorimetric match to the original target were subjectively viewed under controlled lighting conditions, many felt they were not the best visual match to the original target. This result puts into question whether or not ΔE is the best color equation for measuring color accuracy when trying to correlate a visual match. Recently, Dr. Martin Habekost explored a similar theory when he compared the scores of proofing methods at the IPA Round-Up to various color measuring equations.

For future study, the author would like to collaborate with Dr. Habekost, and see if there is a better color equation than ΔE for predicting visual color match.

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