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Sensitivity analysis applied to ISO recommended camera color calibration methods to determine how much of an advantage, if any, does spectral characterization of the camera offer over the chart-based approach.

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Abstract

Accurate characterization (profiling) of a capture system is essential to have the system accurately reproduce the colors in a scene. ISO 17321 [1][2] describe two methods to achieve this calibration. One based on standard reflective targets (chart-based method) and the other on making accurate measurements of the cameras responsivity functions and the spectral power distribution of the deployed illuminant (spectral characterization). The most prominent of the two is the chart-based method for the reason that it involves a simple capture of an inexpensive, standard color pattern (e.g., Macbeth/Xrite Color Checker). However, the results obtained from this method are illuminant specific and are very sensitive to the technique used in the capture process. Lighting non-uniformity on the chart, incorrect framing, and flare can all erroneously affect the results. ISO also recommends a more robust technique, involving the measurement of the camera's responsivity and the spectral power distribution of the capture illuminant. Measurements of these features can require the use of expensive and sophisticated instruments such as monochromators and spectro-radiometers.

Both methods involve tradeoffs in cost, ease of use, and most importantly in the accuracy of the final capture system characterization. The results obtained are very sensitive to the technique of capture and precision of measurements of the various parameters involved. The end-user is often left confused asking such questions as, What accuracy is needed in individual measurements?, What are the tradeoffs (particularly in color accuracy) in using the chart-based method vs. the spectral characterization based method?, also, How sensitive is the system to the various parameters?

In this study, both of the ISO recommended techniques are utilized for camera calibration on a broad range of professional cameras and illuminants. Such characterization was conducted by approximately ten different users so as to capture the variability of the deployed capture technique. The collected data was used to calculate and quantify the system characterization accuracy using the color inconstancy index for a set of evaluation colors as the metric. Sensitivity analysis techniques were used to attempt to answer the question "How much of an advantage, if any, does the spectral characterization of the camera offer over the chart-based approach?" In answering the question, parameters (and their sensitivities) were identified to most influence the results.

Introduction

Color characterization of a digital still camera (DSC) is an important component of the imaging system pipeline and in determining objective image quality. This paper focuses on the two most common color characterization methods as presented in ISO 17321-1:2012 and the accuracy of each method performed. The first method is spectral characterization and involves measurements of the cameras responsivity functions and the spectral power distribution (SPD) of the light source. The second method is the chart based method, and is illuminant specific. A 24 patch X-Rite Color Checker and a 140 patch Semi-Gloss (SG) test target were used under common illuminants (high intensity discharge (HID), strobe, tungsten, LED etc.). The color reproduction accuracy of either method was determined through the comparison of the CIE Total Color Differences acquired from applying the color profile created as an end product of the utilized method. Furthermore, sensitivity analysis is applied to the measurements and associated parameters to recommend best practices for camera calibration.

Methodology

The ISO standards for Graphic Technology and Photography [1][2] provide specific guidelines and methodologies for performing each of the two characterization methods. These guidelines were followed as closely as possible unless the procedures were unachievable due to a lack of resources.

Equipment

Manufacturer	Model
Buhl SC	150 HID
Broncolor	Senso A2
Canon	EOS 5D Mark II
	EF50mm f/2.5 Compact Macro
Image Engineering	camSPECS
Leica	S typ006
Newport	Monochromator
Olympus	OMD
Photo Research	SpectraScan PR-650
X-Rite	i1 Pro2

Test Chart-based method:

For the chart-based method, we used two different charts the Macbeth Color Checker and the Color Checker SG to determine a camera profile for a set of illuminants. Images of the uniformly illuminated charts were captured under different illuminants such as tungsten, HID (high-intensity discharge) and fluorescent. All images were captured in raw mode with automatic settings disabled.

Figure 1. *ColorChecker Classic and ColorChecker Digital SG were used on the chart-based method*

Images of the uniformly illuminated charts were captured under different illuminants such as tungsten, HID, and fluorescent. All images were captured in raw mode with all automatic settings disabled.

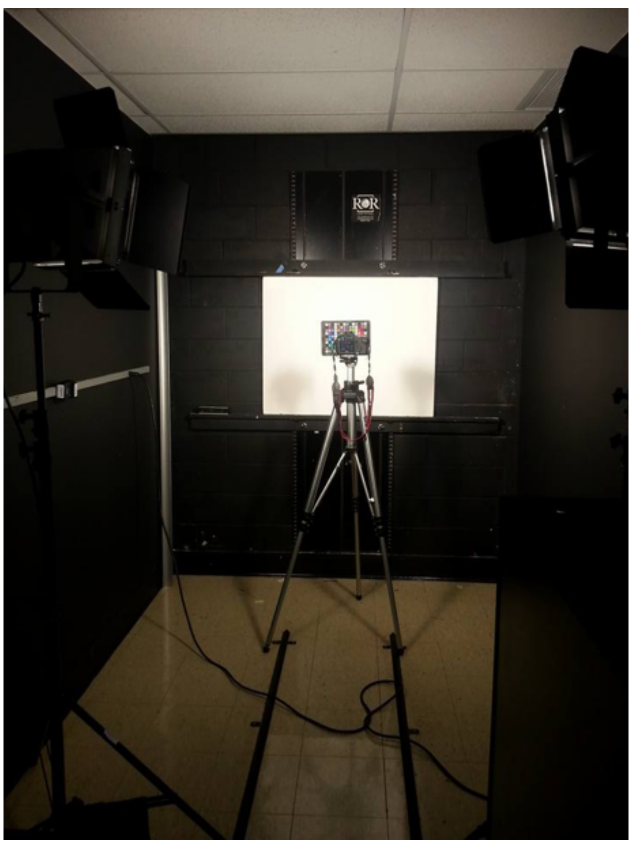


Figure 2. *Target capturing setup.*

The SPD of the illuminants was measured using two different spectrophotometers the X-Rite i1Pro2 and the Photo Research PR-655.

All this information was used to generate a color correction matrix (CCM) which was incorporated in an ICC profile using Xrites software ProfileMaker.

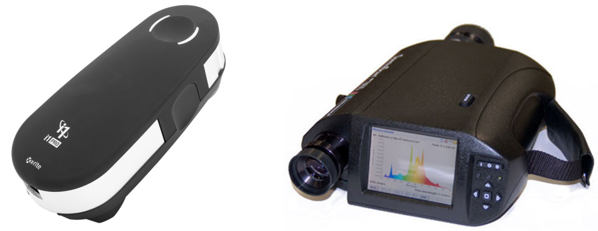
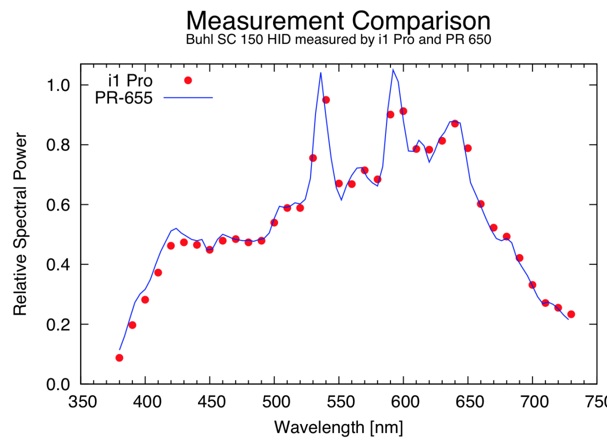


Figure 3. *X-Rite i1Pro2 and the Photo Research PR-655.*



Spectral responsivity based method:

For the spectral technique, the camera responsivity functions of the cameras were measured using a monochromator as well as an interference filter based device (Image Engineerings camSPECS).

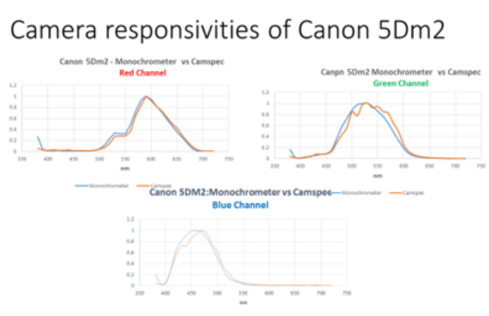
Figure 4. *Newport Monochromator.*

The average ΔE* CIE94 was validated between measurements of the colors before and after the application of the CCM.

Figure 5. *Image Engineering camSPECS.*

Sensitivity analysis:

Sensitivity analysis was also conducted on the various measurements to determine which parameters most affected the final results. It was assumed that the measured camera responsivities were correct. For wavelengths within the visible spectrum, an error of 10% of the peak of the capture SPD was added. These changes in capture SPD resulted in changes in RGB, and ultimately in displayed L*, a*, and b*. The ΔE* CIE94 values in a 24 patch color checker induced by the change in illuminant were computed. The higher the E, the greater the sensitivity.

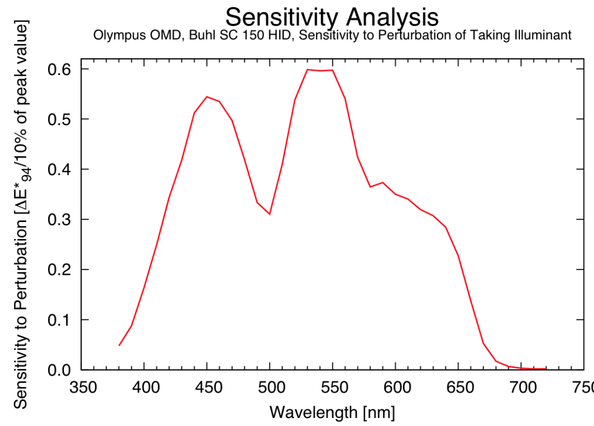


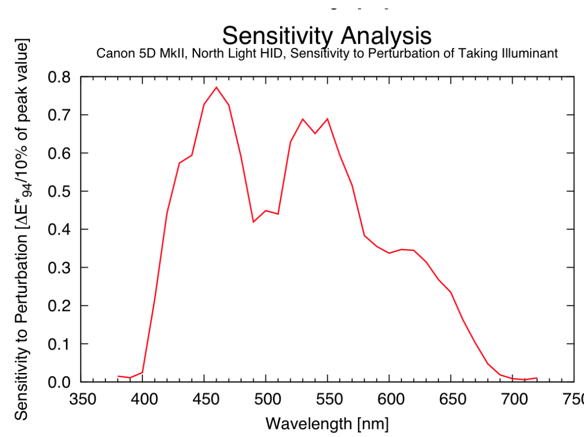
This information was combined with the measured spectral power distribution of the illuminants (similar to the Test Chart Method) to calculate and apply a CCM to a set of standard color patches.

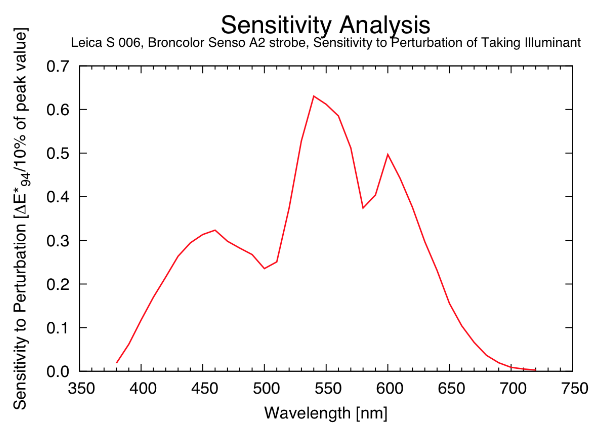
Sensitivity Analysis of the capture illuminant:

It was assumed the measured camera responsivities were correct. For wavelengths within the visible spectrum, an error of 10% of the peak of the capture SPD was added. These changes in capture SPD result in changes in RGB, and ultimately in displayed L*, a*, and b*. The ΔE* CIE94 values in a 24 patch color checker induced by the change in illuminant were computed. The higher the ΔE*, the greater the sensitivity.

When replacing measurements of this illuminant with the other, the patches in the Color Checker as seen by Canon 5D Mk2 changed by an average ΔE* CIE94 of 0.10; 90th percentile was 0.20. Results are typical of those for which i1 Pro 2 had sufficient signal.

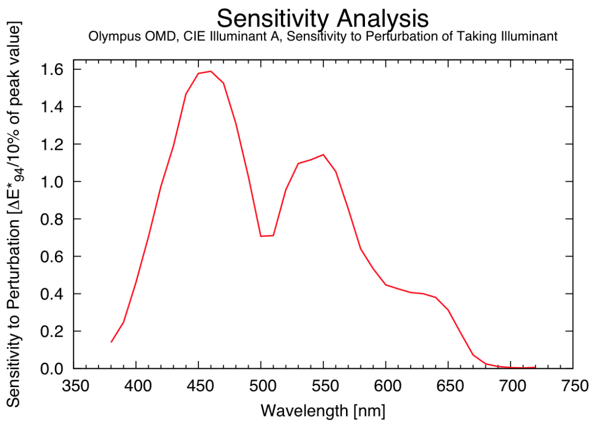


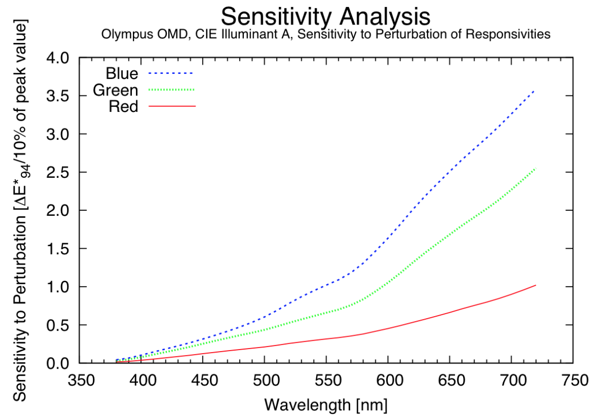




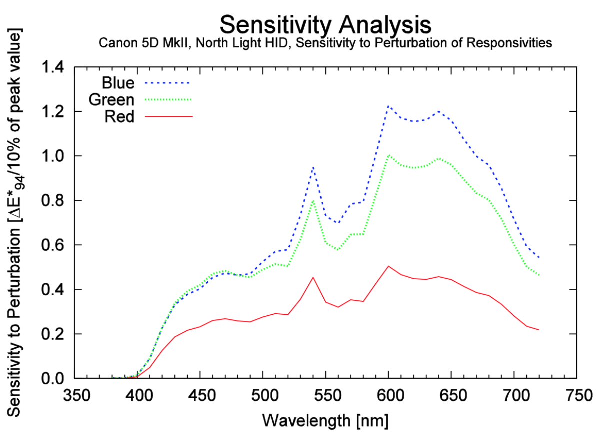
Sensitivity Analysis of the camera responsivities:

It was assumed that the measured SPD of the capture illuminant was accurate for this analysis. For wavelengths within the visible spectrum, an error of 10% of the peak response of the camera responsivities was added. These changes result in changes in RGB, and, ultimately, in CIELAB as displayed. The ΔE* CIE94





differences in the 24 patch color checker caused by these biases were computed. The higher the ΔE*, the greater the sensitivity.



Assessing Change:

Differences in camera responsivities and taking illuminants result in changes in captured RGB. Using *measured* responsivities and illuminants, these changes can be assessed numerically and visually. The spectra of the 24 patches in the X-rite color checker was used as representative objects of the subject being photographed. Linear (camera) RGB was captured and converted to XYZ and CIELAB. A camera responsivity or the illuminant was changed, resulting in changed RGB, XYZ, and CIELAB coordinates. These changes were assessed numerically (ΔE* CIE94) and visually. For visual analysis, a simulated color checker was used to visually evaluate the effect of the changes as responsivities and illuminants were changed.

Conclusion

Test Chart Method:

These techniques are inexpensive, utilize simple workflows and can be unpredictable; results can vary dramatically from high error to perfection. Such errors can largely be attributed to operator error. Consistency in the capture process and uniform illumination of the target are the primary requirements. The uniformity can be mathematically compensated for by capturing an image of a diffuse white board in the location of the test target. Flare can be estimated, and compensated for. The one primary limitation of this technique is that it remains illuminant-dependent; i.e. a CCM must be generated for every capture illuminant under which an image will be taken. While the variety of illuminants are few, estimating the SPD of these illuminants using correlated color temperature (CCT) is error prone. Measuring the illuminants with spectrophotometers, even the newer relatively lower cost ones, produces satisfactory results.

Spectral method:

Lower cost and less complex instruments for measuring illuminant SPDs are adequate using this method as well. The only exception is low light conditions. Estimating the SPD of a light source using the CCT is error prone (highly sensitive; average ΔE* 4.3 - 9.2).With respect to camera responsivities, measurement of the blue and green channel responsivities are much more sensitive to errors than the red channel. Measurements with a lower cost and less complex instrument such as the camSPECS vis-a-vis a higher cost and more complex instrument like the monochromator is adequate for most applications. The primary advantage of this method remains its ability to calculate the CCM for a wide variety of illuminants. However, in this study it was determined that the target based method is far simpler to use. With the limited variety of light sources available, it can easily and accurately estimate the CCM using these techniques as long as the SPD is accurately measured (and not estimated using CCT) using a spectrophotometer.

Plans for Future Work

We are currently quantifying the repeatability of chart-based and spectral-based characterization methodologies to provide baseline measures of their relative accuracies.

CCT measurements are often used in imaging to estimate practical illuminants. It would be useful to quantify how well one can estimate practical illuminants using CCT measurements. Preliminary work seems to indicate that such estimations are prone to error.

Acknowledgments

Special thanks to Image Engineering, for the donation of image quality testing equipment which was deployed in this study. Specifically, the camSPECS used in this study is a simpler (than monochromators) device for measuring camera spectral sensitivities.

References

[1] ISO 17321-1:2006 Graphic technology and photography Color characterization of digital still cameras-Part 1: Stimuli, metrology and test procedures
[2] ISO-17321-2:2006 Graphic technology and photography Color characterization of digital still cameras Part 2: Considerations for determining scene analysis transforms

Author Biography

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J A Stephen Viggiano is Assistant Professor of Photographic Science at Rochester Institute of Technology. Previously, Viggiano taught Statistics and Printing Technology at RIT, and was employed as Principal Imaging Scientist at RIT Research Corporation. He also worked as a consultant in digital color imaging. He holds a PhD in Imaging Science and Masters' degrees in Statistics and Printing Technology, all from RIT.