# Analysis of Color Management Default Camera Profiles for Museum Imaging Applications

***Roy S. Berns, Munsell Color Science Laboratory, Rochester Institute of Technology, Rochester, NY USA***
***Stanley Smith, J. Paul Getty Museum, Los Angeles, CA USA***

## Abstract

*Experiments were performed to analyze the color accuracy of five camera systems used for museum image-archiving applications: Phase One IQ 180, Leaf Aptus 75, Hasselblad H4D-50, Cruse scanner, and a Sinar 75H modified to incorporate the RIT Dual-RGB approach. A Betterlight Super 8K was also tested to provide a benchmark. Default color management profiles were used in all cases. Experimental conditions were identical to the greatest extent possible. Targets included the X-rite ColorChecker Classic, a 100-patch acrylic-dispersion paint target made from 27 different pigments, and a 35-patch oil-paint target. Average performance varied between 1.5$\Delta E_{00}$ (Dual-RGB Sinar) and 6.0$\Delta E_{00}$ (Betterlight). Only the Sinar and Cruse systems produced acceptable results, systems optimized for archival imaging. The Hasselblad system produced self-luminous appearing images while the Phase One had severe tone reproduction error for high-chroma colors. Both of these new systems would require considerable visual editing to produce archival color images.*

## Introduction

Within a museum imaging department, a work of art is most often imaged for two applications: documentation and reprographics. For documentation, the image should be a record of the physical properties of the object. For reprographics, the image should be a record of the viewing experience. The former goal is objective color reproduction and the latter, subjective color reproduction. We believe that the most efficient workflow would be to record the physical properties as the archival image and to re-render the image depending on usage, for example, web display, catalog printing, posters, etc. From a color management perspective, camera systems should be colorimetric, that is, imaging colorimeters, such that when targets are evaluated, the color differences are small between the image data and data based on contact spectrophotometry. According to the FADGI guidelines [1], a four star performance has an average CIEDE2000 below 3 and maximum below 6 (aim values being 0). These are equivalent to about 5 and 10 $\Delta E^*_{ab}$ (based on the current research).

Two benchmarking studies were carried out at Rochester Institute of Technology during 2003-2005 [2] and 2008-2010 [3] that assessed the color quality of museum imaging systems. Average color accuracy in 2005 for four museums was 12.4 $\Delta E^*_{ab}$. Five years later, average performance improved slightly to 8.9 $\Delta E^*_{ab}$. The range of values for the 22 museums was 4.25 – 17.15 where only a few of the museums would earn a four star rating. The majority of institutions were not able to produce archival images with reasonable accuracy. The higher-accuracy images had required a considerable amount of visual editing time. Furthermore, there was highly disparate quality for identical hardware and lighting, for example, 4.3 and 9.9 for the Sinar Evolution 75H, 5.4 and 11.8 for the Betterlight Super 8K, and 7.2 and 15.3 for the Sinar 54H. We hypothesized that the root cause for both the inter- and intra-camera performance were the default ICC camera profiles, used by all participants, and the necessity for considerable visual editing. This research tested this hypothesis where default camera profiles were evaluated.

## Imaging Systems

For four cameras, experiments were conducted in the imaging department at the Getty Museum using a Digital Transitions copy stand affixed with Broncolor strobe lights. Local sales representatives supplied the following cameras: Phase One IQ 180, Leaf Aptus 75 and Hasselblad H4D-50. In all cases, the photometric response was set to linear and the camera software performed color management. For the Hasselblad, its "reprographics" profile was used. Photoshop was used to convert all the images to 16-bit CIELAB encoding.

Sinar sent a modified eVolution 75H P3 system that incorporated the RIT Dual-RGB approach [4, 5]. The modification included using a clear cover glass in front of the detector rather than the stock blue-green filter. The system also included a filter slider that sequentially placed two custom colored filters in the beam path. Matlab software was written to perform flatfielding, registration, color processing, and encoding in 16-bit CIELAB. Two color transformations were derived: One was optimized to minimize average $\Delta E^*_{ab}$ for the ColorChecker; the second was optimized to minimize average $\Delta E_{00}$ and maximize image quality, also for the ColorChecker.

To provide a benchmark, Getty's Betterlight Super 8K with Northlight 900 lighting was also included. This system was the Getty's workhorse when imaging paintings until recently.

A sixth system was later added to the study, a modified Cruse tri-linear array scanning system. The modifications included the addition of a blue-green filter to tune the red spectral sensitivity and new color processing using a custom color target containing hundreds of color patches. Neither author performed the imaging.

## Targets

Three targets were used: an X-rite ColorChecker Classic, a 100-patch acrylic-dispersion paint target made from 27 different pigments, and a 35-patch oil-paint target consisting of dark, high chroma colors, shown in Figure 1. The spectral reflectance factor of each sample was measured four times with replacement using an X-rite i1 45/0 spectrophotometer, the averages plotted in Figure 2. The oil target was quite challenging with sharp absorption transitions and low reflectances in their absorption regions. Colorimetry was calculated for the 1931 standard observer and illuminant D50, selected being the most common illuminant in museum workflows.

## Performance Metrics

Two color-difference formulas were used: CIEDE2000 ($\Delta E_{00}$), currently recommended by the CIE, and $\Delta E^*_{ab}$, commonly used by the museum community, though no longer recommended. Because color differences only provide magnitude information, vector plots were used to provide directional and systematic information.

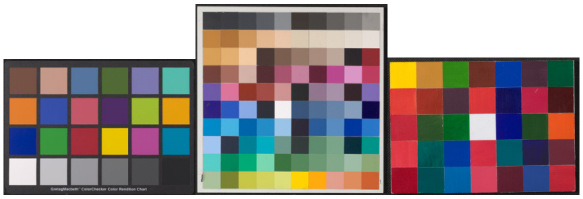

***Figure 1****. Test targets: X-rite ColorChecker Classic (left), 100-patch acrylic-dispersion paint target (middle), and 35-patch oil-paint target (right).*

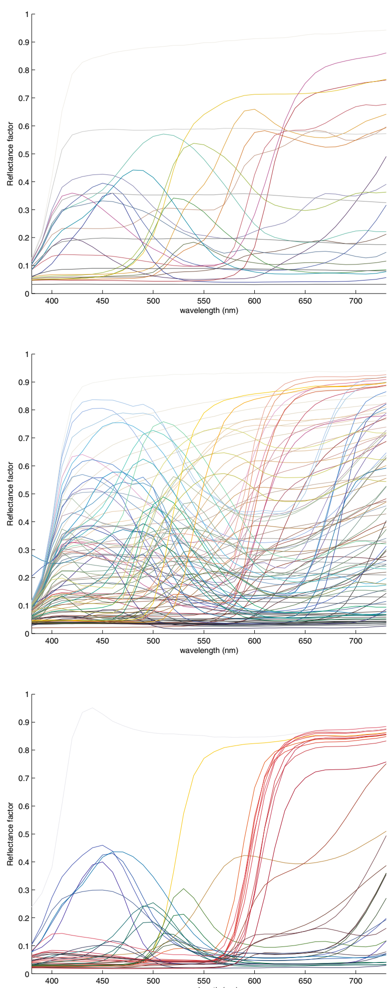


***Figure 2****. Spectral reflectance factor measurements of test targets: X-rite ColorChecker Classic (left), 100-patch acrylic-dispersion paint target (middle), and 35-patch oil-paint target (right).*

## Results and Discussion

The performance for all the targets when combined is listed in Table I. The range was surprising, even excluding the somewhat obsolete BetterLight: 1.5 – 5.3 $\Delta E_{00}$ (2.4 – 8.3 $\Delta E^*_{ab}$). The three worst performers were all new models: Leaf Aptus 75, Hasselblad H4D-50 and Phase One IQ180. The best performers were designed for archival imaging: the Dual-RGB Sinar 75H and the updated Cruse scanner. T-tests were conducted to determine if the differences in rank were statistically significant. The two Dual-RGB transforms were not different, and the Cruse and Leaf systems were not different, otherwise each had a unique ranking, shown in parentheses in Table I. Observers tend to notice large errors; thus we included the $90^{th}$ percentile as a metric. This metric would be a good indicator of the need for visual editing. Without question the Phase One and BetterLight would require considerable visual editing, based on this metric alone.

The average performance categorized by target is listed in Tables II and III. In general, performance was independent of target except for the PhaseOne system where the oil target produced the largest errors, a result of the target colors being dark and high chroma.

Vector plots for all the systems are shown in Figures 3 – 9. The Dual-RGB system optimized for average $\Delta E^*_{ab}$ was an extremely accurate imaging colorimeter; nearly all the arrow tips were contained inside the filled dot. This system would not require visual editing to achieve objective color reproduction. In fact, this optimization was performed to demonstrate the excellent color accuracy that can be achieved by using the Dual-RGB approach. However, this accuracy has a price: The image quality suffers where chromatic noise is amplified and there are chromatic fringes for color transitions at high spatial frequencies, for example, between color patches. During 2011, the first listed author has been performing new research to reduce spatial artifacts. When the color optimization included both color accuracy and image quality, these artifacts were minimized without a reduction in average color accuracy. Although the vectors for the three high chroma yellows appear alarming, the $\Delta E_{00}$ values were 3.1, 2.1, and 3.3. As seen in Table I, both the $90^{th}$ percentile and maximum $\Delta E_{00}$ error were reduced using the new optimization approach. The image quality was also improved dramatically.

The Cruse scanner would also perform well for objective color reproduction. In fact, its profile was optimized for this goal. There were several colors with similar colorimetry but different color reproduction; this is a result of the profile being a look-up table.

The Leaf Aptos showed a systematic trend where dark colors became darker.

The Hasselblad system produced images that appeared self-luminous, despite using its "reprographics" mode. As seen in Figure 6, the vectors for the chromatic colors (except yellows) are all increasing and the dark colors are getting darker. This corresponds to boosting contrast and saturation in Photoshop. Oddly, the light colors were reduced in chroma. Only the yellow colors were recorded accurately.

The PhaseOne had large errors in tone reproduction where high chroma colors darkened along with reductions in chroma. There was a nonlinear contrast increase with slight darkening for light colors and large darkening for dark colors.

The BetterLight camera reduced chroma for yellows, green-yellows, and blues; increased chroma for reds; and darkened dark colors. Although difficult to discern from Figure 8, blue colors with long wavelength tails such as ultramarine and cobalt were reproduced purplish.

**Table I. Average, 90th percentile, and maximum color differences for all the targets combined for each listed imaging system. Numbers in parentheses are statistically determined rank orders.**

| Camera | Statistics | $\Delta E_{00}$ | $\Delta E^*_{ab}$ |
|---|---|---|---|
| Dual-RGB Sinar 75H Color (1) | Mean | 1.5 | 2.4 |
| | 90th | 3.3 | 5.2 |
| | Maximum | 6.8 | 8.3 |
| Dual-RGB Sinar 75H Color and Image Quality (1) | Mean | 1.7 | 3.2 |
| | 90th | 3.1 | 5.4 |
| | Maximum | 6.2 | 18.1 |
| Cruse (3) | Mean | 2.9 | 4.4 |
| | 90th | 5.5 | 8.3 |
| | Maximum | 8.7 | 14.8 |
| Leaf Aptus 75 (3) | Mean | 3.2 | 5.7 |
| | 90th | 5.1 | 9.6 |
| | Maximum | 9.0 | 19.1 |
| Hasselblad H4D-50 (5) | Mean | 4.6 | 9.1 |
| | 90th | 6.7 | 13.4 |
| | Maximum | 9.8 | 20.3 |
| Phase One IQ 180 (6) | Mean | 5.3 | 8.3 |
| | 90th | 8.5 | 13.5 |
| | Maximum | 11.6 | 30.6 |
| BetterLight Super 8K (7) | Mean | 6.0 | 10.3 |
| | 90th | 9.9 | 19.5 |
| | Maximum | 18.3 | 32.0 |

**Table II. Average $\Delta E^*_{ab}$ for each listed target and imaging system.**

| | Color Checker | 100 Acrylic | 35 Oil |
|---|---|---|---|
| Dual-RGB C | 1.1 | 2.2 | 3.6 |
| Dual-RGB C+IQ | 2.4 | 2.9 | 4.8 |
| Cruse | 4.9 | 4.1 | 5.1 |
| Leaf Aptos 75 | 6.6 | 4.5 | 8.5 |
| Hasselblad H4D-50 | 9.0 | 8.9 | 10.0 |
| Phase One IQ 180 | 7.0 | 7.7 | 11.0 |
| BetterLight Super 8K | 9.8 | 9.6 | 12.6 |

**Table III. Average $\Delta E^*_{00}$ for each listed target and imaging system.**

| | Color Checker | 100 Acrylic | 35 Oil |
|---|---|---|---|
| Dual-RGB C | 0.7 | 1.6 | 1.9 |
| Dual-RGB C+IQ | 1.3 | 1.6 | 2.4 |
| Cruse | 2.9 | 2.7 | 3.3 |
| Leaf Aptos 75 | 3.5 | 2.7 | 4.4 |
| Hasselblad H4D-50 | 4.6 | 4.8 | 4.2 |
| Phase One IQ 180 | 4.0 | 5.1 | 6.7 |
| BetterLight Super 8K | 5.8 | 5.8 | 6.6 |

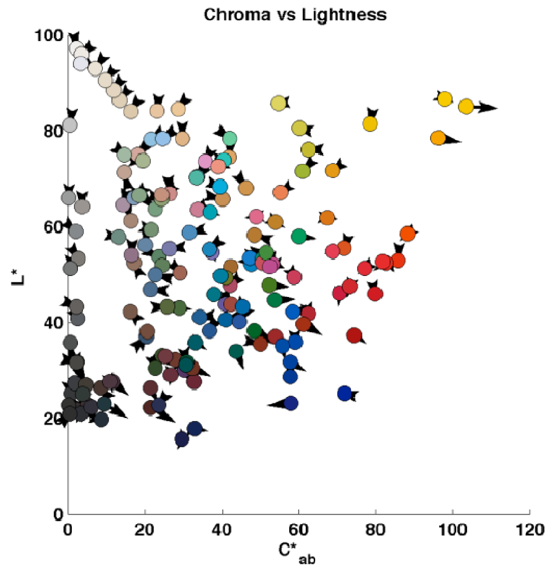


*Figure 3. Colorimetric performance for the Sinar Dual-RGB optimized for color accuracy where the filled circle defines the test patch color based on direct spectrophotometry and the arrowhead defines the imaging system's estimate.*

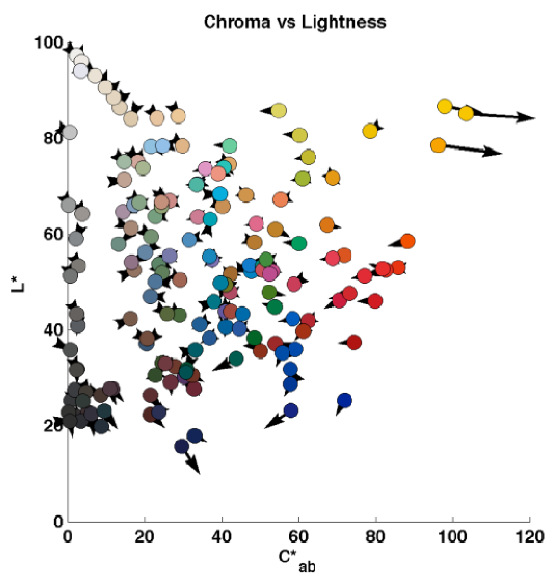


*Figure 4. Colorimetric performance for the Sinar Dual-RGB optimized for color and image quality.*

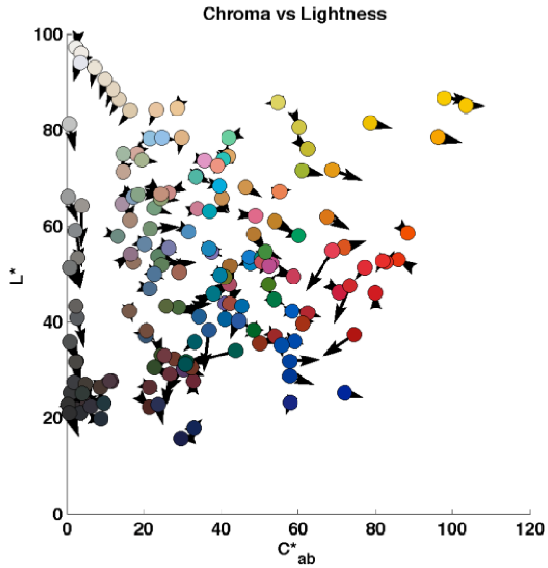


***Figure 5***. *Colorimetric performance for the Cruse scanner.*

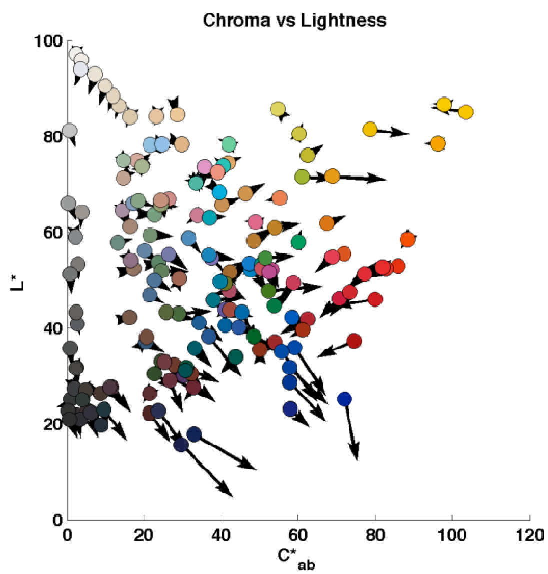


***Figure 6***. *Colorimetric performance for the Leaf Aptos 75*

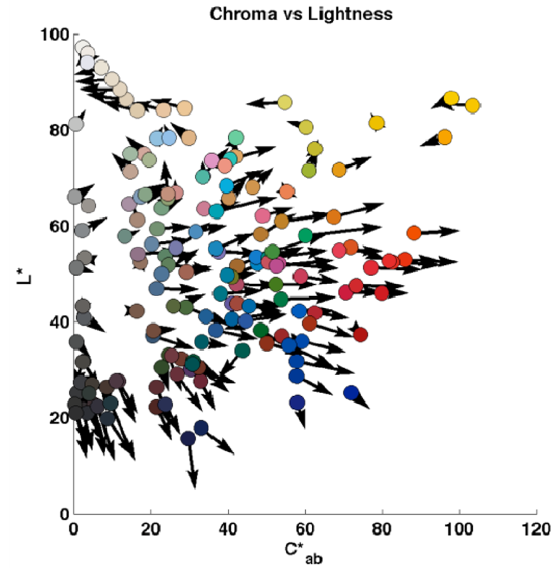


***Figure 7***. *Colorimetric performance for the Hasselblad.*

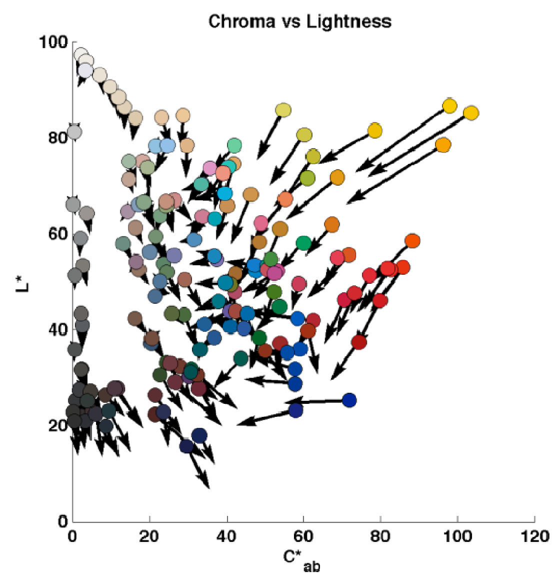


***Figure 8***. *Colorimetric performance for the Phase One IQ 180.*

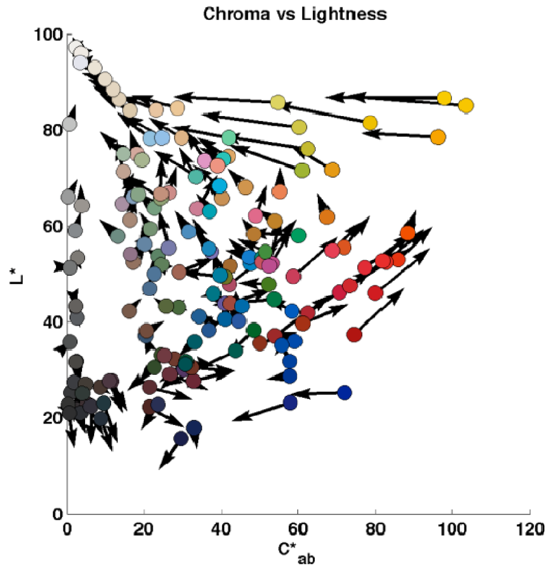


***Figure 9**. Colorimetric performance for the Betterlight 8000 K.*

## Conclusions

Our hypothesis was confirmed: the commercial cameras with profiles optimized for subjective color reproduction produced large colorimetric errors. The results for the Hasselblad and Phase One were especially disappointing. As a consequence, considerable visual editing would be required. Based on the second RIT benchmark study where editing did not improve performance in most of the cases, such editing would be unlikely to result in acceptable color accuracy. The Cruse and Sinar systems had acceptable color accuracy because their profiles were optimized for objective, colorimetric color reproduction. It seems that museums choosing to use commercial camera systems need to build their own profiles. Finally, of all the systems tested, only the Sinar system using the RIT Dual-RGB approach and software would achieve a four-star rating using the FADGI criteria.

## References


[1] Federal Agencies Digitization Initiative (FADGI) - Still Image Working Group, "Technical Guidelines for Digitizing Cultural Heritage Materials: Creation of Raster Image Master Files," http://www.digitizationguidelines.gov/guidelines/FADGI_Still_Image-Tech_Guidelines_2010-08-24.pdf (2010).

[2] RS Berns, FS Frey, MR Rosen, EP Smoyer and LA Taplin, Direct Digital Capture of Cultural Heritage - Benchmarking American Museum Practices and Defining Future Needs Final Report, RIT, http://www.cis.rit.edu/museumSurvey/documents/Benchmark_Final_Report_Web.pdf (2005).

[3] Franziska Frey and Susan Farnand, "Benchmarking Art Image Interchange Cycles: Final Report 2011," RIT, http://artimaging.rit.edu/wordpress/wp-content/uploads/2011/07/MellonFinalReport_FreyFarnand.pdf (2011).

[4] 7,554,586 Francisco H. Imai and Roy S. Berns, System and method for scene image acquisition and spectral estimation using a wide-band multi-channel image capture, June 30, 2009, Assignee: Rochester Institute of Technology (Rochester, NY).

[5] R. S. Berns, L. A. Taplin, M. Nezamabadi, M. Mohammadi, "Spectral imaging using a commercial color-filter array digital camera," *Proc. 14th Triennial Meeting The Hague, ICOM Committee for Conservation,* 743-750 (2005).


## Author Biography


*Roy S. Berns is the Richard S. Hunter Professor in Color Science, Appearance, and Technology and Director of the Munsell Color Science Laboratory within the Center for Imaging Science at Rochester Institute of Technology, USA. He received B.S. and M.S. degrees in Textiles from the University of California at Davis and a Ph.D. degree in Chemistry from Rensselaer Polytechnic Institute (RPI). Berns has received scientific achievement awards from the Inter-Society Color Council, the Society of Imaging Science and Technology, and the Colour Group of Great Britain. He is the author of the third edition of "Billmeyer and Saltzman's Principles of Color Technology.*

*Stanley Smith received his BA in fine Art from Western Washington University (1975). In 1982 he founded Argentum, a Seattle-based custom photographic lab and early adopter of digital imaging. In 1995, he designed and implemented the digital imaging studios for Experience Music Project, Paul Allen's rock & roll museum, located in Seattle. In 2004, he was hired to manage the photographic and imaging studios at the J. Paul Getty Museum in Los Angeles. Currently Mr. Smith is the Head of Collection Information and Access at the Getty.*