CIE Recommendations on Color Capture for Digital Preservation: Phase 1 Progress Report

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Abstract

At the 2011 IS&T Archiving Conference, we described the preliminary results of a study to assess the performance points of the protocols and methods that participating institutions used to capture representative cultural heritage materials. The goal of the study is to assess the color accuracy of different color capture and encoding approaches with a view to establishing a knowledge base and set of techniques which an institution can reference to either select or confirm the approach to color capture that is most compatible with its goals and capabilities. This paper and the associated presentation will give a progress report on that study, which has been expanded in the past year to include more institutions and additional data analysis. This study is being conducted under the auspices of CIE TC8-09, the CIE Division 8 Technical Committee on Archival Color Imaging, in partnership with the US Federal Agencies Digitization Guidelines Initiative (FADGI).

Introduction

It hardly seems necessary to point out the value of accurate color capture in the context of cultural heritage materials. When materials such as historic documents, prints and photographs for example, are scanned to provide digital surrogates for scholarly study, online access or preservation, it is important to capture the properties of the material, including its color or spectral content, so that they are faithful to the original and support the intended use cases, which can include reproduction on a wide range of media.

The growing interest and practice of digitization and the requirements for color digitization were among the factors that led to the creation of CIE TC8-09 around 2005. CIE TC8-09 is the CIE Division 8 Technical Committee 9 on Archival Color Imaging. It was formed "to recommend a set of techniques for the accurate capture, encoding and long-term preservation of colour descriptions of digital images that are either born digital or the result of digitizing 2D static physical objects, including documents, maps, photographic materials and paintings." The committee has about 30 members from six countries. Besides color experts and researchers from industry and academia, the membership also includes practitioners from libraries, museums and archives who are responsible for the capture, preservation, reproduction and distribution of images in digital and print format.

Around the same time as CIE TC8-09 was getting underway, the Federal Agencies Digitization Guidelines Initiative (FADGI) was also forming [1]. FADGI is a collaborative activity by US Federal government agencies and institutions with digitization programs; it has Still Image and Audio-Visual working groups. In 2008, the Still Image Working Group issued its charter [2], according to which the stated goal of the group is "to identify and establish common standards, methods, practices, and guidelines …for the digitization of static or still visual materials (such as textual content, maps, photographic prints and negatives) in a sustainable manner." While the FADGI charter is broader than that of CIE TC8-09, the two have a mutual interest in the color component of digitization. As a result, many members of the FADGI Still Image Working Group are also members of TC8-09, and the two are working together to achieve their mutual goals around color capture.

In 2009, CIE TC8-09 distributed a questionnaire to members soliciting their answers to several questions about their color imaging requirements, workflows and problems. One question asked them to identify topics in the areas of capture, processing, archiving and preserving digital images that would be useful to them. Of the 19 topics from which they were asked to choose (adding a topic was an option), the one that received the most responses was a "method to evaluate and validate the accuracy of images"; color is one component of this [3].

In 2010, TC8-09 decided on a study in which participating institutions would "shoot" the same target or targets using their existing protocols for image capture with the goal of establishing a consistent and fundamental baseline for capture. At the time, the expectation was that this baseline would be adapted to special collections, different types of materials and individual pieces. This was based on the perceived need to adjust the capture procedures according to the material and the capture results because of "errors" in the values obtained.

At the 2011 IS&T Archiving Conference, we described the preliminary results of a study [6]. These preliminary observations were based on the results from three institutions, using five different imaging devices. This paper and the associated presentation will give a progress report on that study, which has been expanded in the past year to include more institutions and additional data analysis [12].

Approaches to Color Capture

A single approach to color capture is not expected to meet the needs of all institutions in all cases; most practitioners don't want a single answer because no one answer will work for all original types or capture scenarios. This has led to the notion that what would be useful is an analysis of the different options so that practitioners can choose the one that fits best their resources and quality requirements since there is a cost-quality tradeoff.

Even if a single approach were demonstrated to be able to give the best color accuracy and the smallest difference between original and captured color values, there is still a cost associated with increased color accuracy. Practitioners are more interested in a cost-benefit analysis that will allow them to make an informed choice about capture methodology based on their particular mix of skills, budget, equipment, materials and schedule. This study is intended to describe the accuracy-cost tradeoff so that an institution will be in a position to confirm or select a performance point on the curve that meets their requirements and constraints with awareness of the cost-accuracy tradeoffs that point represents.

The implicit objective of capture in the context of CIE TC8-09 is creating a master image, which can then be rendered or reproduced according to the requirements of the use case or reproduction medium. The reference to capture in the TC8-09's charter and the omission of reproduction is deliberate: decoupling capture from reproduction when in the color encoding is based on the premise that an archived image can serve as a common, institution-neutral starting point for diverging media- and organizational-specific rendering decisions downstream.

Different capture guidelines can take different approaches to the split between capture and reproduction. For example, the Metamorfoze Preservation Imaging Guidelines [4], originally developed with newspapers and other mass digitization projects in mind, are intended to create master image files, with rendering and re-purposing to follow in a subsequent step. In the FADGI technical guidelines [5], which are based on the 2004 NARA guidelines [7], the primary (but not exclusive) use case is viewing images on a generic computer monitor. These two different use cases are reflected in the different sets of aims for color and tone reproduction, embedded color profiles, and related color encoding for the final image files. This difference emerged in the study and is an abiding issue is the extent to which an output goal is factored into the original capture.

This decoupling of capture from reproduction and the focus of this study on capture are significant points. Previous work has looked at the complete interchange cycle. For example, Frey et al. have explored workflows and requirements for the creation of reproductions of artwork [8]. They examined the perceptual image quality of the entire reproduction process with an emphasis on the end use of the art image interchange cycle. They reported a surprising result indicating that the ΔE_{00} values (CIEDE2000 color difference metric) of the output prints of the Macbeth ColorChecker chart were not nearly as good at predicting the perceived reproduction quality as the values measured at capture (page 65 in [8]).

In a precursor to this study, Berns et al. evaluated and reported on the colorimetric accuracy of digital masters created by four museums from the digital capture of two paintings [9]. The color values in the images were either ICC color-managed or visually edited. While visual editing of the captured image on a color monitor may have been intended to improve color accuracy or subjective quality, the study found that it did not improve color accuracy.

Berns et al. also evaluated the colorimetric accuracy of the capture process with respect to 11 targets, including the Macbeth ColorChecker and the ColorChecker DC, which since has been superseded by the X-Rite Digital ColorChecker SG chart, which was used in this study. They found a considerable range of color accuracy across targets and across the four museums. They concluded that the differences across institutions were due mainly to the spectral sensitivities of the camera systems, none of which were very similar to the human visual system. Another factor was camera system's color-management profile. In the absence of an easy way to change a camera's spectral sensitivities, they concluded that the way to improve color accuracy was to improve the profile, in particular by using targets representing the pigments and materials in the original being captured. The use of custom targets continues is a recurring theme in the capture of cultural heritage materials.

Among the key findings of this last study were that digital preservation was still in its infancy and that "future cross-media publishing workflows would benefit greatly from a use-neutral digital master." This and the objective of capture in the context of CIE TC8-09 are well aligned.

CIE Imaging Study

For the study that was proposed in 2010, a package was assembled with seven different originals: three commercially-available test targets (Figure 1) and four sample prints (Figure 2) that are representative of the materials within scope of the TC8-09 terms of reference. For each sample print, a paper mask or sleeve was created with circular holes that identified regions of interest or ROIs on the print. Figure 3 shows one of the sample prints with and without its mask. The masks had between five and twelve ROIs. The ROIs were selected to show uniform regions with colors that were representative of those in the print and of the material.

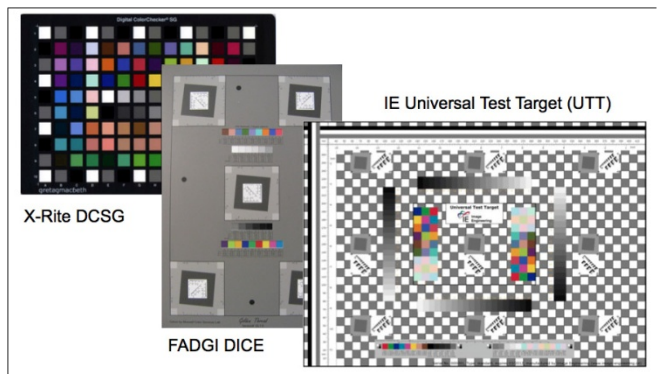

***Figure 1**. Test targets used in the study (L to R): X-Rite Digital ColorChecker® SG; Library of Congress DICE (Digital Image Conformance Evaluation) Object Target (same as the Device-Level Target from Image Science Associates); and Image Engineering Universal Test Target (UTT)*

***Figure 2**. Sample originals used in the study: (a) Hand-colored photo-gravure; (b) hand-colored etching; (c) hand-colored albumen photograph; and (d) chromogenic print*

Figure 3. Sample print A with ROI mask.

The test targets with their color patches and the sample prints with their ROIs provide a wide range of color samples that can be used to assess the color accuracy of capture. CIELAB values (2-degree Standard Observer, D50 illuminant) of the target patches and print ROIs were measured independently at the Munsell Color Science Laboratory at the Rochester Institute of Technology and at the Library of Congress using X-Rite 530 spectrodensitometers with a 3.4 mm aperture. These values were acquired for comparison with the CIELAB values from the image captures.

The assembled package was passed from one participating institution to the next. Each lab was asked to capture eleven pieces—the three test targets and the four prints, both with and without their masks—using their existing color image capture methodology. Using the FADGI or Metamorfoze guidelines was not a requirement, although some of the participating institutions in the study did follow them. Each institution provided TIFF files with the captured color image represented using an RGB color space encoding.

At the time this was written, the follow institutions had participated in the study and provided color images for analysis:

- Library of Congress
- National Archives and Records Administration
- Metropolitan Museum of Art
- Harvard College Library
- Art Institute of Chicago
- Stanford University Library
- National Gallery of Art

The package is at this moment in Europe where four institutions and a service bureau have agreed to participate in the study.

The participating institutions' choices for capture included using digital cameras and planetary and flatbed scanners, with manufacturer's or custom profiles and in some cases post-capture image processing. The captured values were then compared to the color values of the color patches on the targets and selected ROIs on the prints, which had been measured previously with a spectro-densitometer to establish ground truth, even though capture and spectrodensitometer illumination-material-sensor geometries are different.

Besides providing images, institutions were also asked to fill out the online questionnaire given in the following table. This questionnaire asked them to describe their capture methodology, their rationale for their approach to image capture and the intended use of the images that their capture methodology was designed for.

Table 1. Online questionnaire for institutions participating in the study

About the capture device and setup
• Capture Device: Make and Model • Calibration Procedure and Setup • Capture Settings • Light Source
About the image processing and file format
• Post-capture Image Processing • Image File Parameters
About the purpose and intent of the capture setup
• Intended purpose of final images • General Description of original types intended for this capture procedure used in the test
General Questions and Discussion (optional)
• Please provide a general description and some background describing the intended objectives for and purposes of the imaging performed by your operation • How well do you feel your current standard operating procedures fulfill those objectives or purposes • What do you think would allow you to better meet those objectives - particularly with regard to the accuracy of color encoding? • Please feel free to offer any additional comments and feedback you feel will help inform the analysis of and the subsequent discussion of the test results.

Analysis

Of the institution-scanner combinations for which captured image data is available, all but one used embedded ICC profiles in the TIFF files that were exported. The one exception used RGB with no calibration data in the file; in this case, the RGB values were used without interpretation.

Of the institution-scanner combinations that exported TIFF files with ICC profiles:

- Three used eci RGB v2 (two 48-bit and one 24-bit)
- Five used the Adobe RGB (1998) profile (one 48-bit and four 24-bit)
- Two used ProPhoto RGB (both 48-bit)
- Two used sRGB (24-bit)

One significant observation is that in general the images were saved with a higher bit depth (16-bits per channel vs. 8-bits per channel) for the color spaces with the larger gamut. While eciRGB v2, Adobe RGB (1998), and ProPhoto (ROMM) RGB are output-referred color encodings, they are used here essentially as input- or original-referred color encodings without regard to the viewing environment defined in their specifications.

The study will ask participating institutions about their choice of color space. One obvious factor is the range of colors that they expect to see in the materials they scan and thus need to represent in the files they export. Bennett and Wheeler found that most of the colors they sampled in selected materials from the Library of Congress were contained in the sRGB gamut [10,12]. However, they and others have noted that sRGB is not always sufficient; see for example Geffert [11]. So while the sRGB color space may be sufficient in many cases, it cannot be used indiscriminately for accurate color capture and representation.

Another measure of the fidelity of capture is the tone response curve (TRC) [5], which here we are calling the Tone Capture Curve to distinguish it from Tone Reproduction Curve or TRC. Figure 4 shows the Tone Capture Curve for three institution-scanner combinations. For each is plotted the captured L* values versus the measured L* values for 12 gray patches on the X-Rite Digital ColorChecker® SG chart. The gray patches are located on Rows 5 and 6 from Columns E to J on the chart.

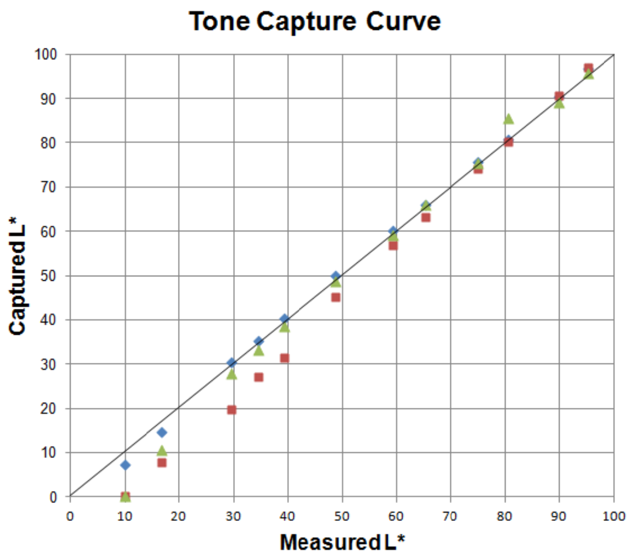

***Figure 4**. Tone Capture Curves for Insitution1-Scanner B (green triangles), Institution 2-Scanner B (brown squares) and Institution 3 (blue diamonds)*

The straight line on the plot in Figure 4 is the aim for accurate capture. The three captures follow the curve for the lighter patches at L* values of 50 and above. Institution 3 follows it at L* values below 50 while the other two institutions represent the patches as darker than they are. When reproduced on a monitor display, the grayscales in the files from Institutions 1 and 2 have higher contrast and look richer than the one from Institution 3, but are in fact less accurate and faithful to the original based on measurement. The general observation is that an accurately captured image looks somewhat washed out and needs to be reproduced with more contrast to obtain pleasing visual reproduction, this emphasizes the point that accurate capture is not the same as preferred reproduction.

The images from the first round of scanning, initial three institutions participating in the study, were analyzed and color accuracy for the regions of interest calculated using ΔE 2000. Both mean and maximum ΔE values were used to rank accuracy.

First, the following tables show the ranking data for one target, the XRite Digital ColorChecker SG, and the four sample originals.

Digital ColorChecker SG

		ΔE 2000		Rank Ave	Rank Max
Institution	Scanner	mean	max		
1	A	5.3	17.1	3	3
	B	7.2	22.2	4	5
2	A	8.3	21.0	5	4
	B	4.2	9.8	2	2
3	A	1.1	4.7	1	1
	Average	5.2	15.0		

Print A

Average, highest max		ΔE 2000		Rank Ave	Rank Max
Institution	Scanner	mean	max		
1	A	6.3	12.6	4	3
	B	5.0	12.7	3	4
2	A	8.3	17.8	5	5
	B	3.8	9.3	2	2
3	A	2.6	8.6	1	1
	Average	5.2	12.2		

Print B

Slightly better than average		ΔE 2000		Rank Ave	Rank Max
Institution	Scanner	mean	max		
1	A	5.6	8.2	4	4
	B	4.1	7.0	3	3
2	A	6.7	8.3	5	5
	B	3.3	6.4	2	2
3	A	3.2	3.7	1	1
	Average	4.6	6.7		

Print C

Overall most accurate		ΔE 2000		Rank Ave	Rank Max
Institution	Scanner	mean	max		
1	A	3.9	5.7	3	3
	B	3.7	5.6	2	2
2	A	4.7	8.7	4	5
	B	3.9	7.0	3	4
3	A	2.3	4.5	1	1
	Average	3.7	6.3		

Print D

Overall least accurate		ΔE 2000		Rank Ave	Rank Max
Institution	Scanner	mean	max		
1	A	6.0	10.0	4	3
	B	5.8	13.3	3	4
2	A	10.8	14.4	5	5
	B	4.1	7.0	2	2
3	A	2.0	3.4	1	1
	Average	5.7	9.6		

A second way of looking at the ranking data is to compare the institution-scanner approaches for the target and four sample originals. The following tables illustrate three selected approaches: the most accurate, the middle of the range accuracy, and the least accurate.

Institution 3

Overall Rank 1 Most accurate	ΔE 2000 mean	ΔE 2000 max
Digital ColorChecker SG	1.1	4.7
Print A	2.6	8.6
Print B	3.2	3.7
Print C	2.3	4.5
Print D	2.0	3.4
Average	2.2	5.0

Institution 1 – Scanner B

Overall Rank 3 Average, high max on DCSG	ΔE 2000 mean	ΔE 2000 max
Digital ColorChecker SG	7.2	22.2
Print A	5.0	12.7
Print B	4.1	7.0
Print C	3.7	5.6
Print D	5.8	13.3
Average	5.2	12.2

Institution 2 – Scanner A

Overall Rank 5 Least accurate	ΔE 2000 mean	ΔE 2000 max
Digital ColorChecker SG	8.3	21.0
Print A	8.3	17.8
Print B	6.7	8.3
Print C	4.7	8.7
Print D	10.8	14.4
Average	7.8	14.0

Conclusions

The initial round of the study represented a relatively broad range of approaches in regards to equipment, color encoding, and corresponding range of color accuracy across a variety of institutions. Based on the preliminary results, we observed more accurate and less variable color imaging with the use of digital cameras in the way they were used and with well calibrated and color managed approaches to color capture. The default calibration for document/book scanners was less accurate. In general, the overall average color accuracy for sample prints was better than that for a wide gamut target. The study is ongoing; this paper gives a progress report and the associated presentation at the conference will provide an update, expanded to include results from more institutions and additional data analysis.

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