A Prototype Calibration Target for Spectral Imaging

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ABSTRACT

A prototype calibration target was designed and tested for spectral imaging that consisted of 14 samples, nine of which were derived from statistical analyses of artist paints and a five-step grey scale. This target was compared with those commonly used when calibrating spectral-imaging systems. An Esser TE221 scanner target, GretagMacbeth ColorChecker DC, GretagMacbeth ColorChecker Color Rendition Chart, and the prototype target were used as both calibration and verification targets using a modified commercial color-filter-array digital camera as a spectral-imaging device. When evaluating a verification target made from 30 different pigments, the prototype target had equivalent performance. Thus for spectral imaging, the spectral properties are more important than the number of samples or its colorimetric range of colors.

1. INTRODUCTION

The performance of spectral imaging is drastically impacted by the choice of the calibration target. There are several conventional calibration targets that are used for spectral imaging; these include the Esser TE221 scanner Test Chart (Esser), the GretagMacbeth ColorChecker DC (CCDC), and the GretagMacbeth ColorChecker Color Rendition Chart (CC).[1] Sample inclusion criteria may be spectral (Esser), color gamut (ColorChecker DC) or both (ColorChecker). Tsumura, *et al.* [2] have introduced a technique based on the vector angle and vector distance as criteria for selecting 100 samples from 1000 simulated artist oil colors as a calibration target for spectral imaging. DiCarlo, *et al.* [3] have developed an emissive calibration target included 16 light-emitting diodes at various wavelengths.

Mohammadi, *et al.* [4] have shown that the performance of the reconstruction of spectral reflectance beyond a threshold quality metric became independent of the number of samples in the calibration target. A series of calibration targets has been selected from a dataset using agglomerative hierarchical cluster analysis. The dataset included all the spectral reflectance factors of the conventional targets listed above and a separate target of 56 artist-acrylic blues including cobalt and ultramarine. The results showed that target performance was more a function of its spectral properties rather than the number of samples in the calibration target.

Color accurate and non-metameric retouching are significant issues for paintings conservators with a large number of available pigments. Mohammadi, *et al.*[5] and Berns, *et al.*[6] have developed a set of nine pigments selected from 30 Gamblin Conservation Colors using Kubelka-Munk[7] turbid media theory. These pigments are quinacridone red (PV 19), cadmium red medium (PR 108), phthalocyanine blue (PB 15:2), cobalt blue (PB 28), cadmium yellow medium (PY 37), Indian yellow (PY 83), venetian red (PR 101), phthalocyanine green (PG7), and chromium oxide green (PG 17). These selected pigments can be used as a dataset instead of the 30 pigments with reasonable accuracy.

The results of cluster analysis and the selected pigments using Kubelka-Munk theory led to the idea of fabricating a new calibration target for spectral imaging. Mohammadi, *et al.*[8] determined that a chromatic pigment at its maximum chroma can predict mixtures of that pigment with the white pigment extremely well. This means that a chromatic pigment with this specification could be a reasonable sample for representing the spectral properties of a pigment at various concentrations, and as such, would replace the usual practice of color ramps for calibration targets.

2. CALIBRATION AND VERIFICATION TARGET

In order to make a physical calibration target, Golden[9] Fluid Acrylics artist paints were employed. The paints with the most similar spectral properties to the nine Gamblin paints were selected. A sample with the maximum chroma was made for each pigment and grey ramp at five lightness levels using carbon black and titanium white.

Thus the prototype calibration target contained 14 samples, referred to as the EXP target (for experimental). The spectral reflectance measurements of the EXP are shown in Figure 1. The EXP, Esser, CCDC, CC, and a target containing typical artist's pigments using Gamblin Conservation Colors (Gamblin) were used as calibration and verification targets for evaluating the performance of spectral imaging system. All the targets were measured using a GretagMacbeth Color XTH, specular component excluded in the wavelength range of 360 to 750 nm in intervals of 10 nm with a small aperture.

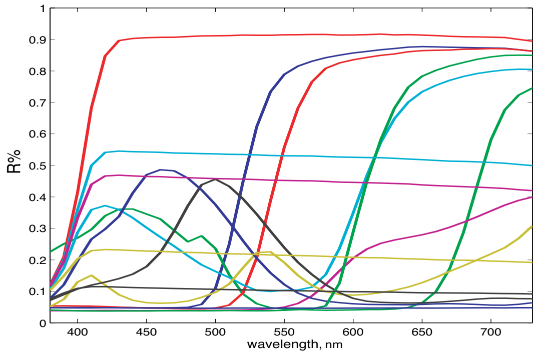

Figure 1. Spectral reflectance factors of EXP target.

3. SPECTRAL IMAGE ACQUISITION

Images of the targets and a uniform grey background were captured using a modified Sinarback 54 digital camera in its "four-shot" mode. The Sinarback 54 is a three channel digital camera that incorporates a Kodak KAF-22000CE CCD with a resolution of 5440×4880 pixels. Berns, *et al.*[10] have modified this camera by replacing its IR cut-off filter with clear glass and fabricating two filters used sequentially, resulting in a pair of RGB images. For this experiment, a pair of Elinchrom Scanlite 1000 lights positioned at 45^0 angles were used, producing a correlated color temperature of 2910 ^{0}K. All images were digitally flat fielded using the grey background followed by image registration.

Spectral reflectance factor was estimated from linear photometric camera signals by a matrix transformation:

$$\hat{\mathbf{R}} = \mathbf{T} \cdot \mathbf{D} \qquad (1)$$

where $\hat{\mathbf{R}}$ is the vector of estimated reflectances, $\mathbf{D}$ is a digital count vector, and $\mathbf{T}$ is the transformation matrix. The transformation matrix was derived using the measured spectral reflectance factors and the captured digital counts for each calibration target. A SVD-based pseudo inverse technique was used to derive the transformation matrix.

4. RESULTS AND DISCUSSION

The imaging colorimetric and spectral performance for each targets as either a calibration or verification target are tabulated in Tables 1 and 2. A target consisting of 14 samples was also made by a random selection from CCDC based on a uniform probability distribution. The random sampling procedure was repeated 50 times, as well as the calibration and verification analyses; the reported results are an average of the 50 evaluations. Since the selected pigments and transformation were performed spectrally, the emphasis is on spectral rather than colorimetric performance. In order to compare the performance of the different calibration targets in estimating different verification targets, one-way ANOVA and a multi-comparison statistical tests were performed. The confidence interval of the performance of each calibration target for estimating the CC, Gamblin, and EXP targets are plotted in Figure 2. When confidence limits overlap, the mean results are not statistically different. The statistical and spectral results show that the EXP target is significantly different from the CC and the CCDC for estimating the CC. All the calibration targets are not significantly different for estimating the Gamblin, an independent oil paint verification target. The average 4.4 RMS% and 2.4 ΔE_{00} of the EXP with just 14 patches for estimating the Gamblin was comparable with the performance of the other calibration targets. Although all the targets performed similarly in estimating the EXP, the extent of overlapping confidence intervals for CC and CCDC compared with the EXP were slight, suggesting that the EXP can also be a reasonable verification target for spectral imaging. These results prove that calibration target performance is more a function of spectral properties rather than the number of samples in the calibration target. The performance of the random target also demonstrates this issue. Since it was selected 50 times randomly from CCDC, the performance for predicting this verification target is in the range of the performance of the CCDC for predicting itself.

Table 1. Spectral RMS% performance of spectral imaging for each listed calibration targets in estimation of each listed verification targets.

				Verification Target				
		N	Stat.	**Esser**	**CCDC**	**Gamblin**	**CC**	**EXP**
Calibration Target	**Esser**	**283**	Mean	2.2	2.8	3.8	3.4	3.7
			90th percentile	3.5	5.8	7.2	5.6	8
	CCDC	**240**	Mean	2.9	2	4	2.6	4.1
			90th percentile	4.6	3.2	6.5	3.6	6.9
	Gamblin	**56**	Mean	2.9	2.8	3	3.6	3.9
			90th percentile	4.7	5.2	5	5.8	6.8
	CC	**24**	Mean	3.2	2.7	4.6	2.2	4.3
			90th percentile	4.8	5	7.8	3.1	7.9
	EXP	**14**	Mean	3.5	3.2	4.4	4	2.3
			90th percentile	6.9	5.8	7.3	6.3	3.2
	Random	**14**	Mean	3.5	2.7	5	3.5	4.9
			90th percentile	6	5	8.8	6.1	9.4

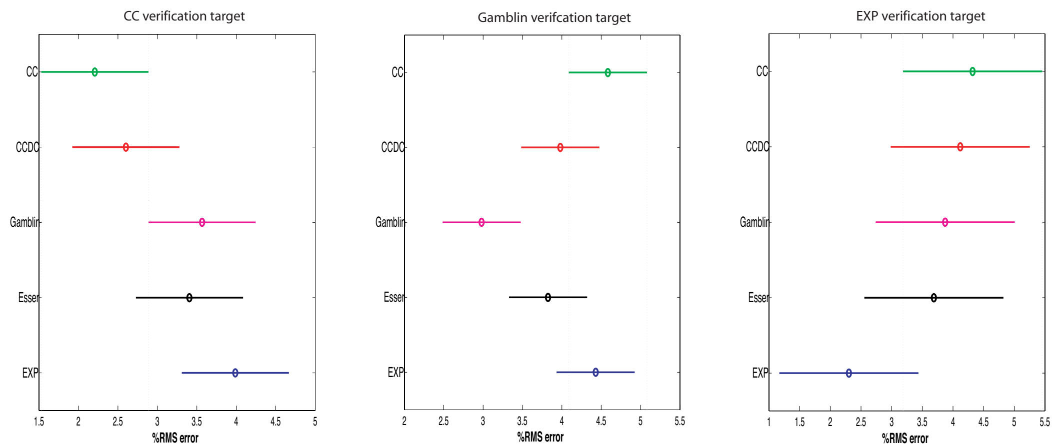

Figure 2. Statistical comparison of the average spectral %RMS for estimation of different calibration targets. The verification target from left to right are CC, Gamblin, and EXP.

Table 2. The average CIEDE2000 colorimetric performance of spectral imaging for each listed calibration targets in estimation of each listed verification targets.

			Verification Target				
	N		**CC**	CCDC	Gamblin	Esser	EXP
Calibration Target	**283**	Esser	2.8	2.1	2.3	1.4	1.9
	240	CCDC	1.7	1.6	2.3	2.2	2.1
	56	Gamblin	2.4	2.1	1.9	1.8	2.2
	24	**CC**	1.3	1.8	3.1	2.7	2.7
	14	EXP	2.7	2.1	2.4	1.7	1.2
	14	Random	2.4	2	3	2.7	3

5. CONCLUSIONS

Researchers involved in high-accuracy colorimetric or spectral imaging well imagine that the number of samples in a calibration target is less important than the spectral properties of the colorants used to create the target. This hypothesis was confirmed experimentally at, perhaps, the limiting case of nine chromatic samples.

The imaging system used tungsten-halogen lighting. It is expected that the performance can improve using different lighting[10] and more complex color processing[11], both routinely used at the Munsell Color Science Laboratory when imaging cultural heritage. Future testing will explore this. This prototype target may be a very effective verification target to evaluate the color quality of image archives of paintings. This target would certainly be an improvement over the usual practice of including a color-separation guide.

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