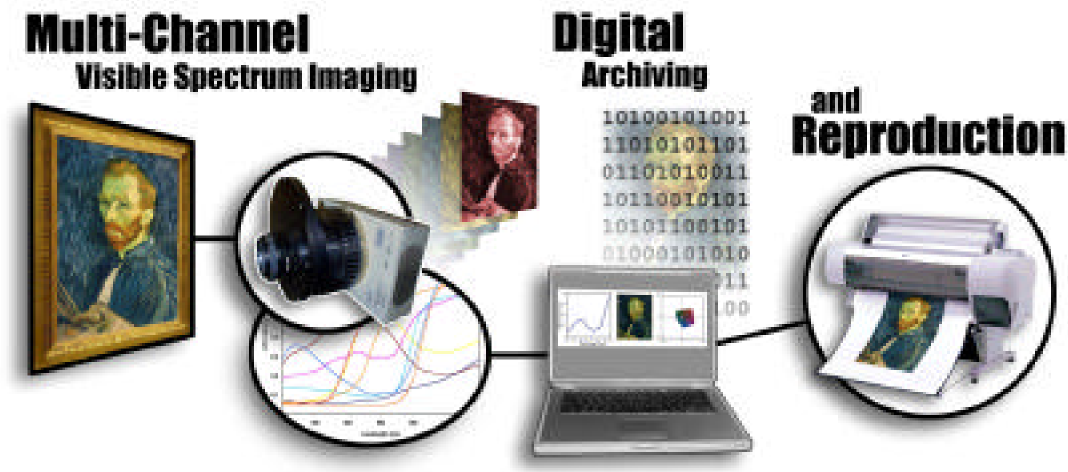

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Simulation of spectral estimation of an oil-paint target under different illuminants

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Abstract – This report describes the performance of spectral estimation by computer simulation of 68 oil paints using a transformation matrix from digital counts to reflectance factor derived using eigenvectors derived from an GretagMacbeth ColorChecker color rendition chart in order to evaluate the appropriateness of available illuminants in multi-channel visible spectrum imaging. The wavelength range from 380 to 730 nm was sampled in intervals of 5 nm.

Experimental - The camera signals were simulated using a camera model consisting of the spectral sensitivity of the Quantix camera (considering Gain 2, 5000 Mhz readout speed, Nikon 50 mm lens and a IR cut-off filter) measured recently, the spectral transmittances of five filters (consisting of a combination of Schott filters for each channel), the spectral reflectance of the considered object (either the oil-paint target or the ColorChecker) and the spectral power distributions of 14 illuminants. The oil-paint target was produced by Ross Merrill and consisted of a number of commonly-used oil paints mixed with titanium white. Three of the illuminants were measured from a GretagMacbeth Spectralight viewing booth using the PhotoResearch PR-704 spectroradiometer that gives measurements from 360 to 780 nm in intervals of 4 nm. The three illuminants in the viewing booth consist of tungsten, daylight (filtered tungsten) and fluorescent lamps. The spectral power distribution of five high-pressure discharge lamps were provided by Prof. Janos Schanda and they consist of one standard high pressure sodium lamp, one colour enhanced high pressure sodium lamp and three types of high pressure metal halide lamps. Broadband fluorescent (color-matching) lamps, Illuminant F7, daylight, warm white deluxe and cool white deluxe also were used. Three illuminant sensitivities provided by Robin Myers: Buhlite Softcube Model SC-150 0° no diffuser manufactured by Buhl Lights; Solux 36° manufactured by Tailored Lighting and HMI lamp were also considered in the calculations. HMI (a registered trademark of Osram) is a special form of metal halide arc lamp with many individual spectral lines combined to form a quasi-continuous spectrum of energy. The relative spectral power distributions of the lamps are shown in Figure 1a–1e. Except for the viewing booth tungsten and daylight, colour enhanced high-pressure sodium lamp, and the HMI lamp, all other lamps presented spikes in the spectra. The transmittances of the filters are shown in figure 2.

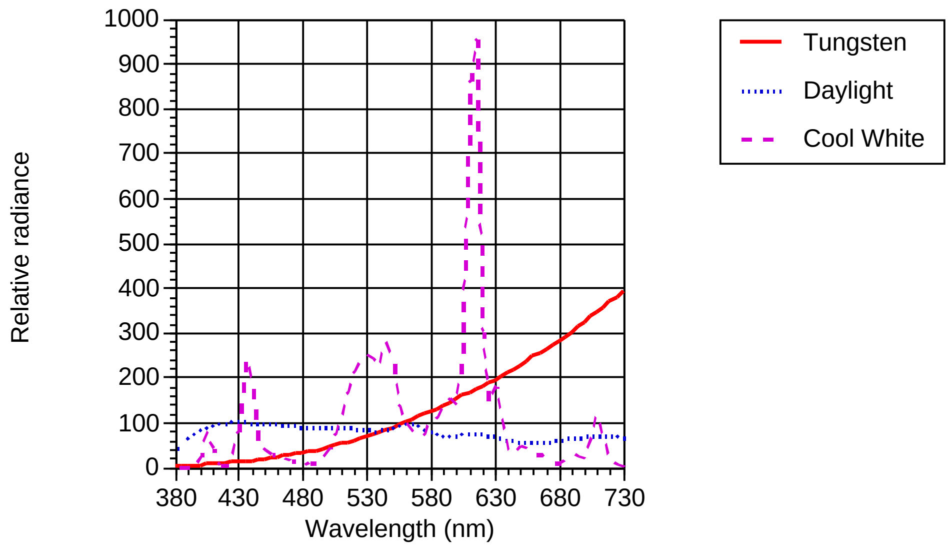


Figure 1a. Relative spectral radiance of light booth lamps used in the experiment.

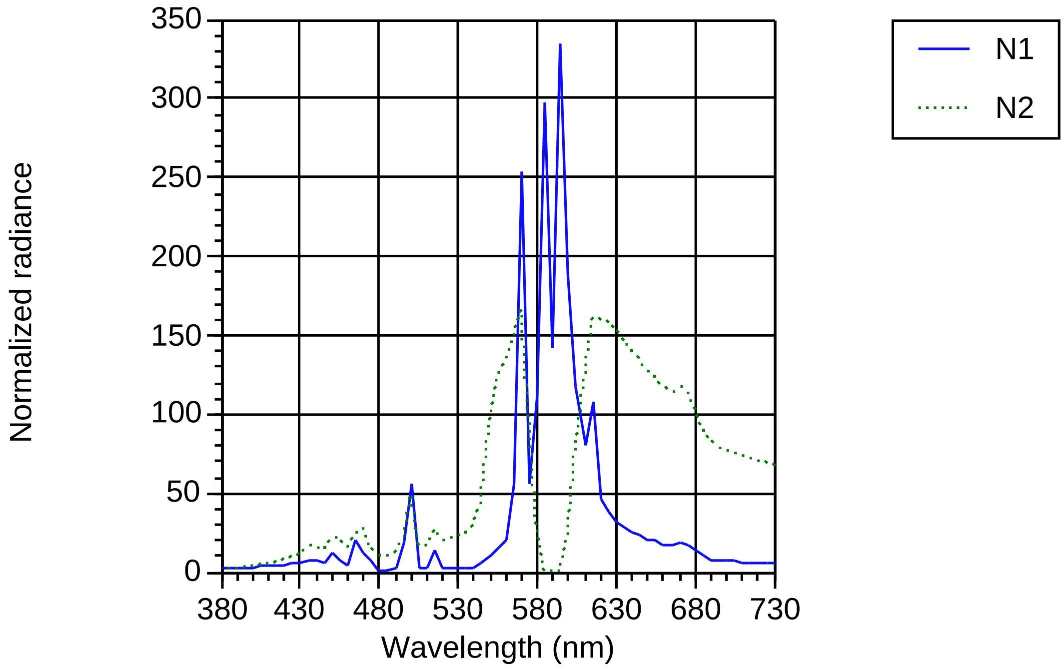


Figure 1b. Relative spectral radiance of the high pressure sodium lamps used in the experiment. NA1 – standard high pressure sodium lamp, NA2 – colour enhanced high pressure sodium lamp.

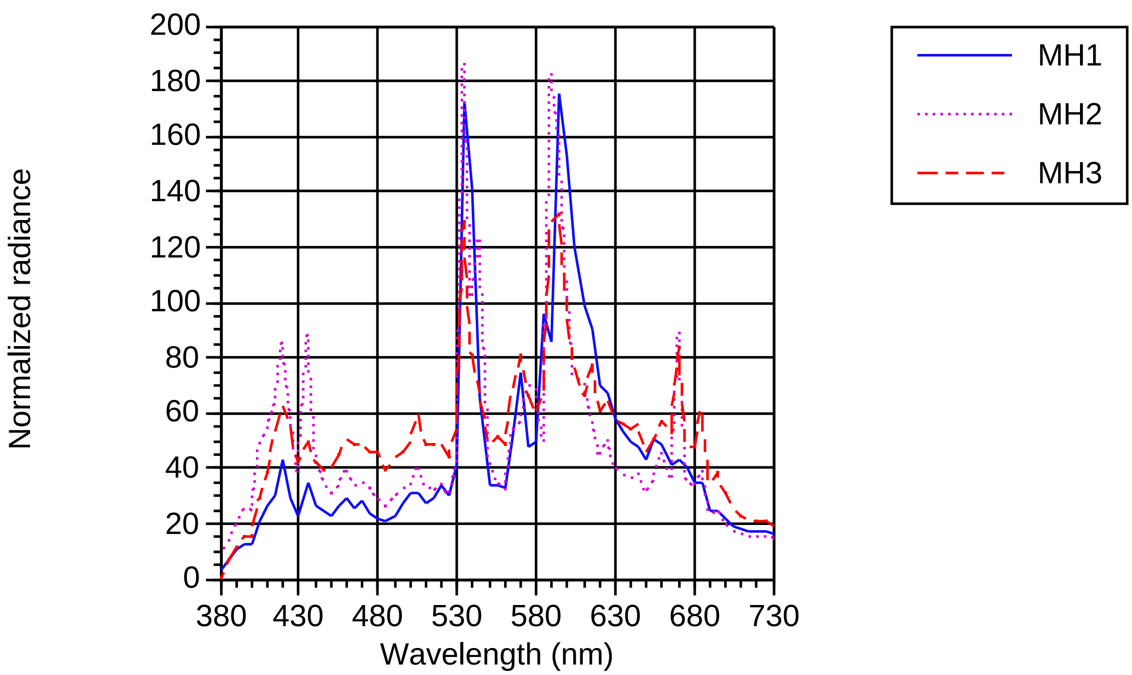


Figure 1c. Relative spectral radiance of the metal halide lamps used in the experiment. MH1 to H3 – Metal halide lamps.

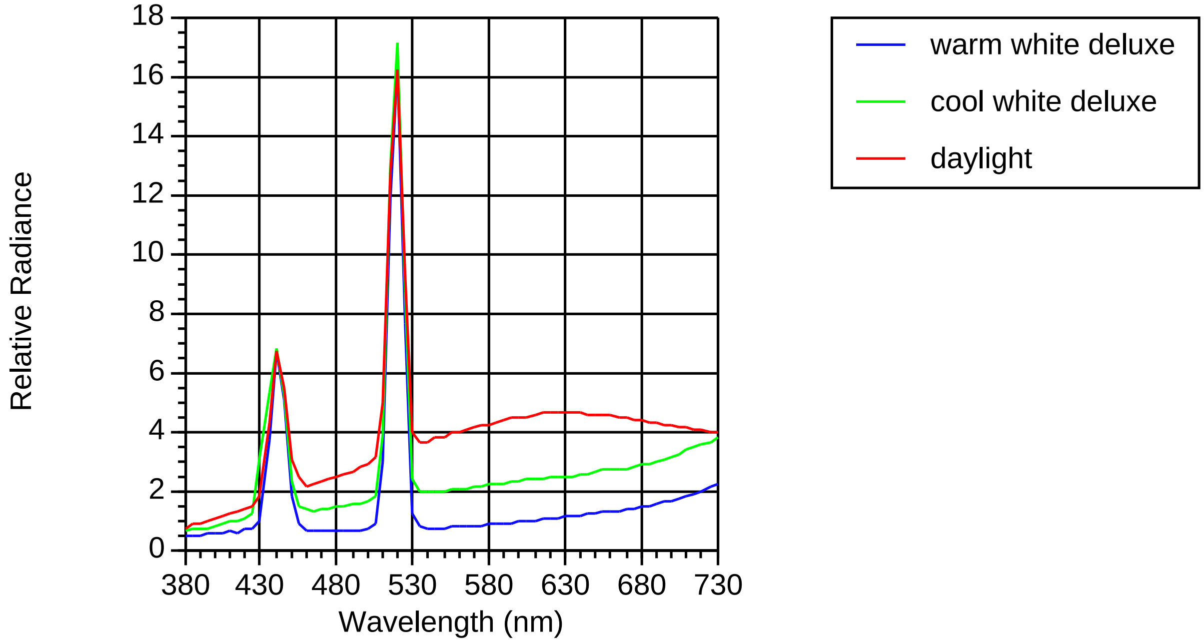


Figure 1d. Relative spectral radiance of fluorescent illuminants used in the experiment.

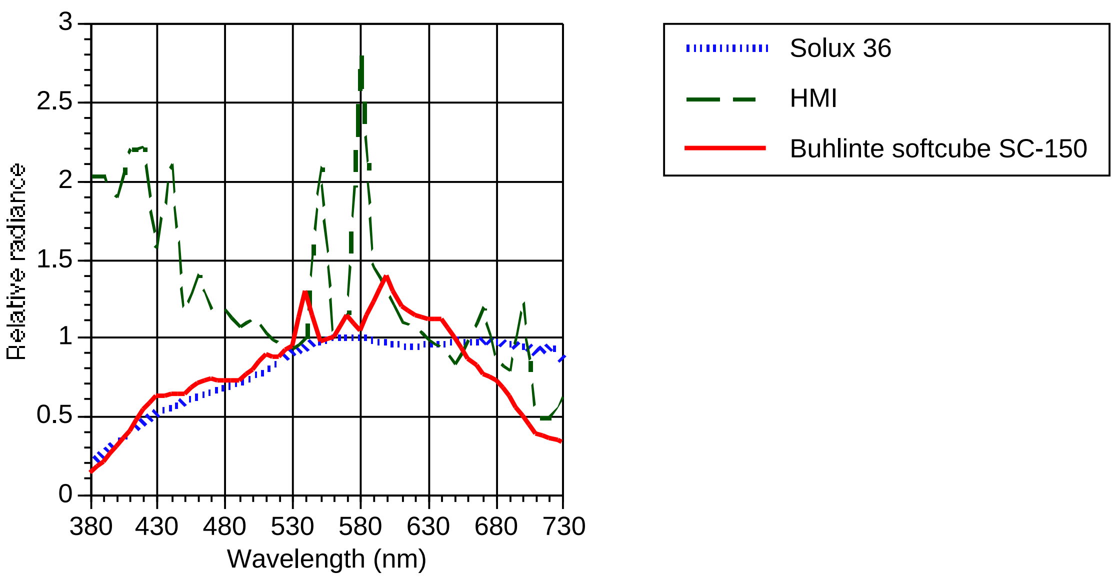


Figure 1e. Relative spectral radiance of three illuminants used in the experiment; Buhlite Softcube Model SC-150 0° no diffuser manufactured by Buhl Lights; Solux 36° manufactured by Tailored Lighting and HMI lamp.

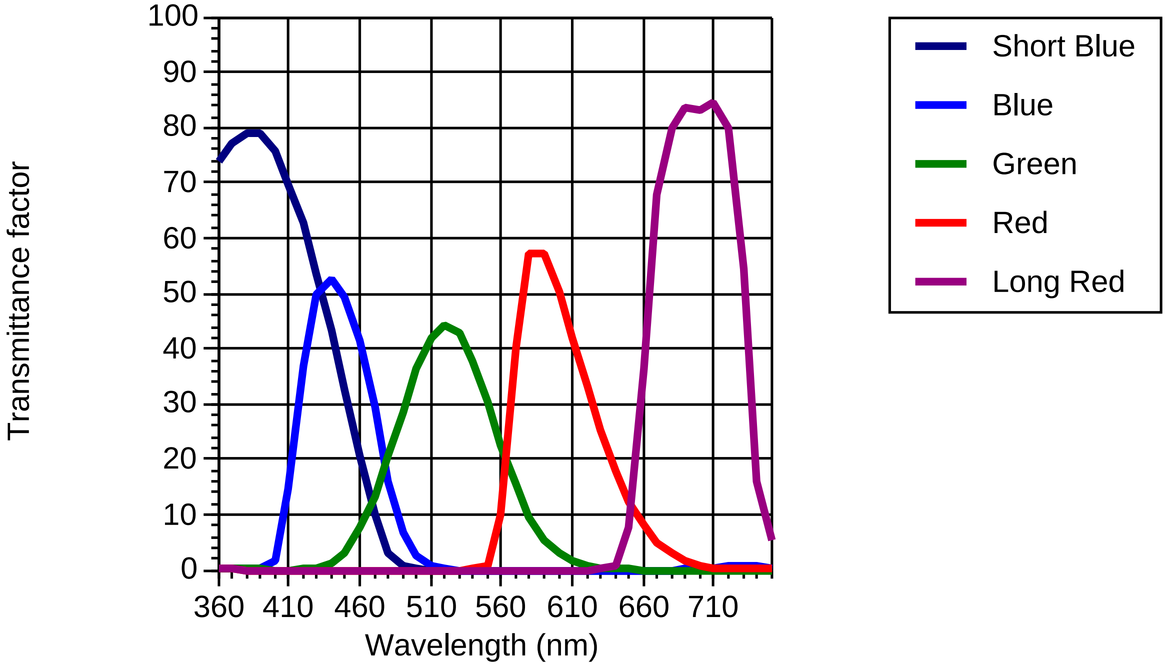


Figure 2. Spectral transmittance of the filters used in the simulation.

The spectral sensitivity of the Quantix camera as measured by Jae-Chul Shin is shown in Figure 3a. In his measurements, he used a monochromatic light generated using a tungsten lamp having very low throughput in the low-wavelength. More recently, Ellen Day remeasured the spectral sensitivity of the Quantix camera using a monochromator with a Xenon lamp that has higher power distribution in the blue region of the spectra. The newly measured spectral sensitivities are shown in Figure 3b. The spectral sensitivity shown in Figure 3b was used in these simulations.

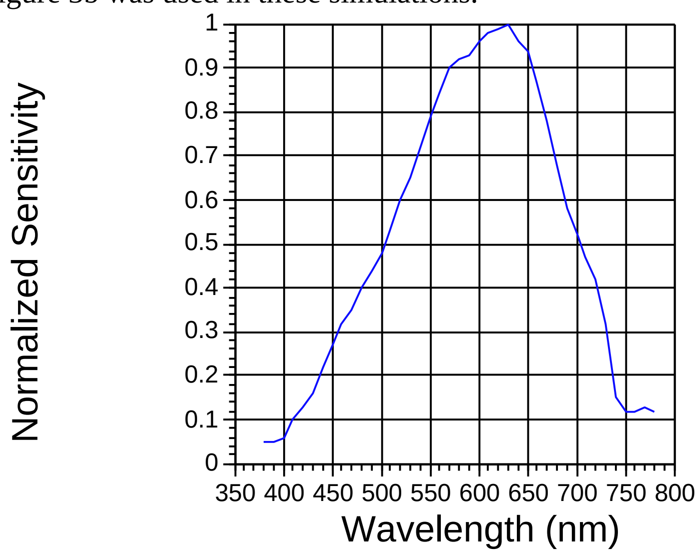


Figure 3a. Normalized spectral sensitivities of the Quantix imaging system measured by Jae-Chul Shin.

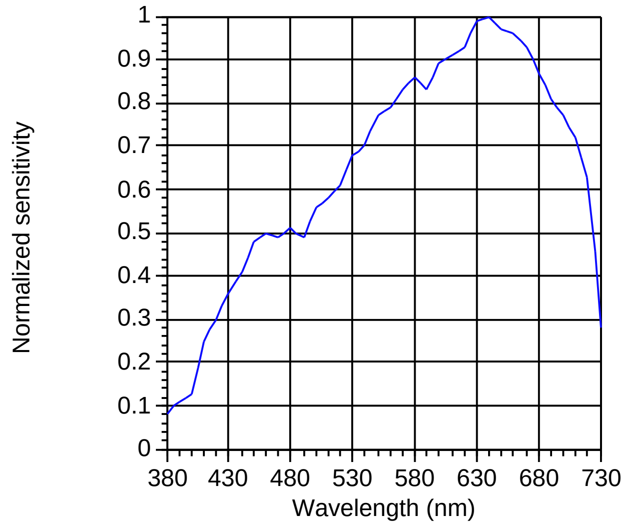
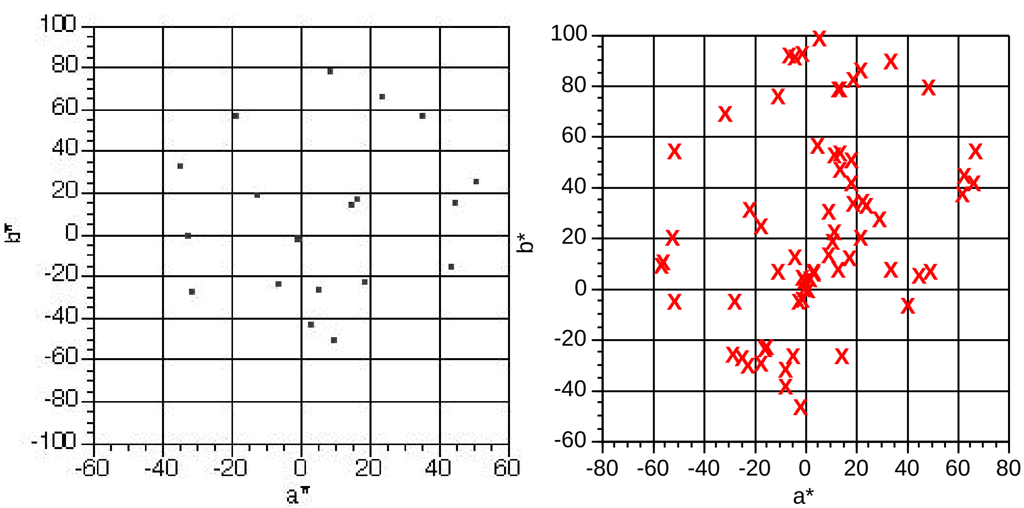


Figure 3b. Normalized spectral sensitivities of the Quantix imaging system measured by Ellen Day and Shuxue Quan.

The colorimetric plots (CIELAB, D50 illuminant and 2 degree observer) of the targets considered in the experiment are shown in Figures 4. The *Ross Target* consists of oil painting targets, painted by Ross Merrill, head of conservation at the National Gallery of Art, Washington, DC, created using 68 pigments dispersed in linseed oil representing blues, greens, yellows, reds, earth colors, browns and radiant colors commonly used by artists. Each chromatic paint was mixed with titanium white to increase the spectral selectivity.



a) ColorChecker *a* x b **   *b) Ross target a* x b**

Figure 4. Colorimetric plots for the targets (under D50 illuminant, 2° observer).

All the spectral data were interpolated in order to have a sampling in intervals of 5 nm from 380 to 730 nm. All the spectral measurements of the targets were performed using the GretagMacbeth SpectroEye 45/0 spectrophotometer.

Five eigenvectors were derived from the ColorChecker and they were used to derive a transformation from the simulated digital signals under a test illuminant to ColorChecker spectra. The derived transformation were used to estimate the spectral reflectance of each patch of the *Ross Target* from their simulated digital counts under the same illuminant used to derive the transformation. The accuracy of the spectral estimation was evaluated in terms of CIE94 (D50 illuminant and 2 degree observer), spectral reflectance factor rms error and Fairman's metamerism index (CIE94, between D50 and A, 2 degree observer).

Results

The results of the estimation are shown in Table I.

Table I. Results of the spectral estimation accuracy comparing measured and estimated spectral reflectances.

Lamps	Booth tungsten	Booth daylight	Booth F2	F7 Warm white	F7 Cool white	F7 daylight
ΔE94 mean	0.7	1.4	1.8	1.5	1.1	1.2
ΔE94 min	0.07	0.2	0.1	0.1	0.09	0.09
ΔE94 max	3.0	6.4	9.7	23.8	6.0	6.5
Rms mean	0.035	0.035	0.037	0.036	0.035	0.035
Rms min	0.014	0.013	0.014	0.014	0.013	0.014
Rms max	0.124	0.125	0.124	0.118	0.119	0.121
MI mean	0.7	0.7	1.3	1.2	0.7	0.6
MI min	0.09	0.05	0.09	0.06	0.04	0.06
MI max	3.7	3.5	34.9	33.2	3.1	2.7

Lamps	NA1	NA2	MH1	MH2	MH3
ΔE94 mean	2.3	1.6	1.2	1.3	1.1
ΔE94 min	0.2	0.3	0.2	0.2	0.1
ΔE94 max	8.0	6.9	5.8	6.9	5.0
Rms mean	0.037	0.036	0.035	0.035	0.035
Rms min	0.015	0.012	0.014	0.014	0.014
Rms max	0.121	0.124	0.119	0.119	0.118
MI mean	0.6	0.7	0.7	0.7	0.6
MI min	0.04	0.09	0.07	0.07	0.07
MI max	2.7	3.2	2.7	2.5	2.8

Lamps	Buhlite	Solux 36°	HMI
ΔE94 mean	1.1	1.2	1.3
ΔE94 min	0.09	0.1	0.1
ΔE94 max	6.0	6.4	6.6
Rms mean	0.035	0.035	0.035
Rms min	0.013	0.014	0.013
Rms max	0.119	0.121	0.124
MI mean	0.7	0.6	0.6
MI min	0.04	0.06	0.03
MI max	3.1	2.7	3.5

A – Tungsten, Day – daylight, CW – Cool white fluorescent, NA1 – standard high pressure sodium lamp, NA2 – color enhanced high pressure sodium lamp, MH1 to MH3 – Metal halide lamps, MI – Metamerism index, rms – root means square error.

Figures 5a to 5n show the ΔE94 histogram for D50 illuminant and 2 degree observer.

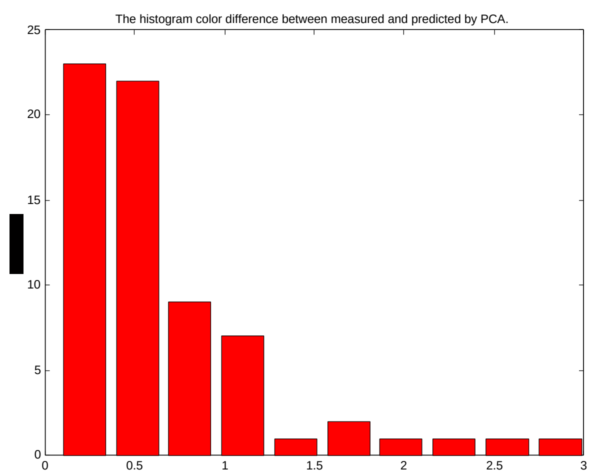


Figure 5a. ΔE94 histogram for D50 illuminant and 2 degree between original and estimated Ross target spectral reflectances from digital counts simulated under tungsten lamp.

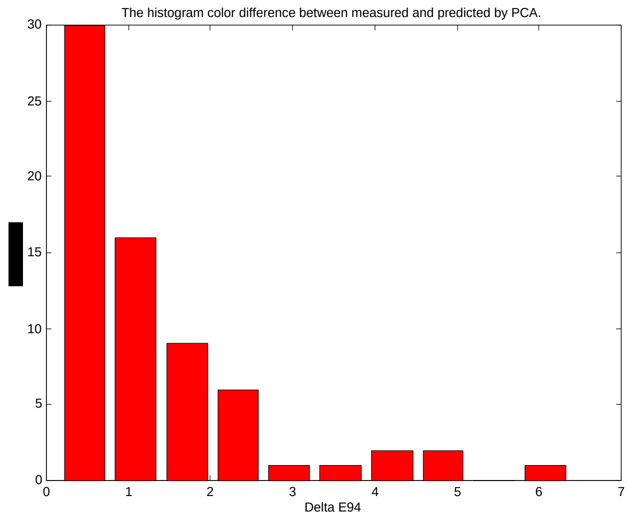


Figure 5b. ΔE94 histogram for D50 illuminant and 2 degree between original and estimated Ross target spectral reflectances from digital counts simulated under daylight (filtered tungsten) lamp.

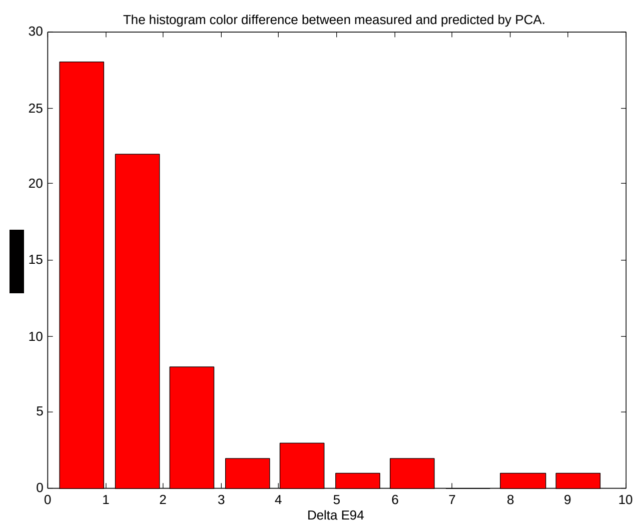


Figure 5c. ΔE94 histogram for D50 illuminant and 2 degree between original and estimated Ross target spectral reflectances from digital counts simulated under fluorescent lamp (F2).

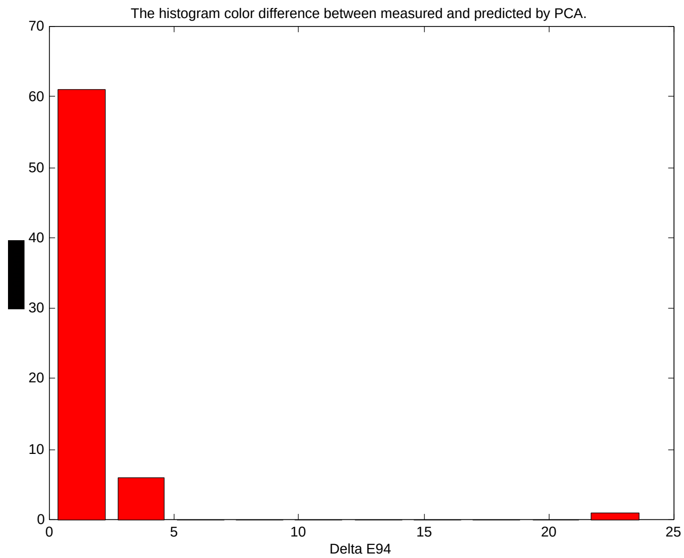


Figure 5d. ΔE94 histogram for D50 illuminant and 2 degree between original and estimated Ross target spectral reflectances from digital counts simulated under fluorescent lamp (F7 warm white).

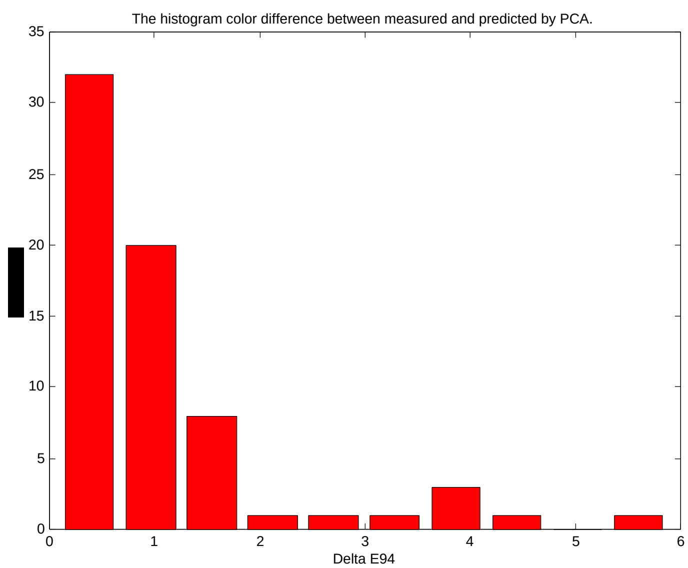


Figure 5e. ΔE94 histogram for D50 illuminant and 2 degree between original and estimated Ross target spectral reflectances from digital counts simulated under fluorescent lamp (F7 cool white).

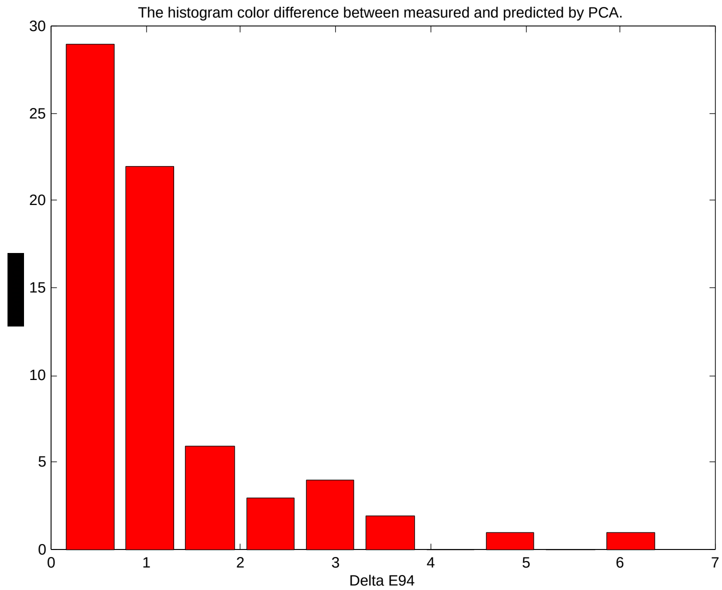


Figure 5f. ΔE94 histogram for D50 illuminant and 2 degree between original and estimated Ross target spectral reflectances from digital counts simulated under fluorescent lamp (F7 daylight).

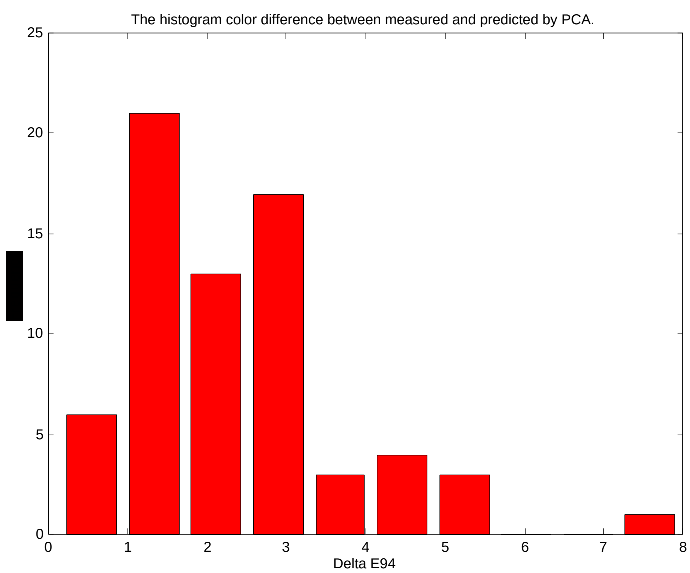


Figure 5g. ΔE94 histogram for D50 illuminant and 2 degree between original and estimated Ross target spectral reflectances from digital counts simulated under standard high-pressure sodium lamp.

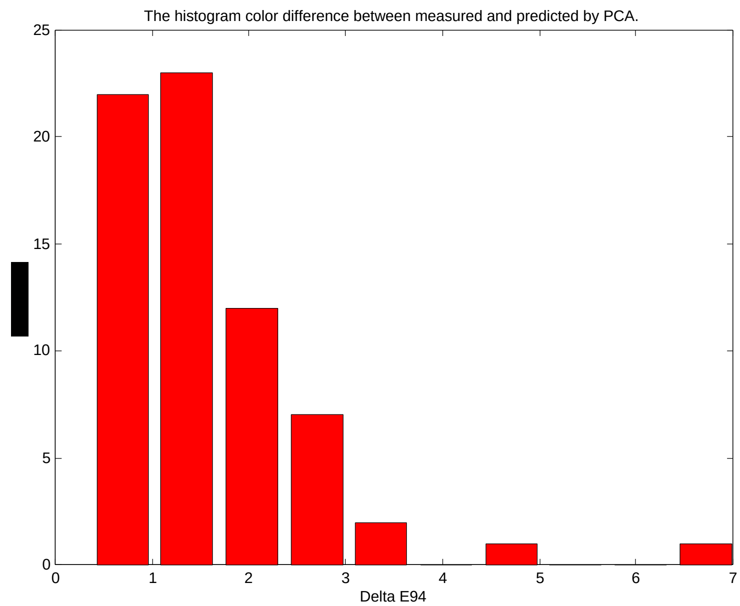


Figure 5h. ΔE94 histogram for D50 illuminant and 2 degree between original and estimated Ross target spectral reflectances from digital counts simulated under color enhanced high-pressure sodium lamp.

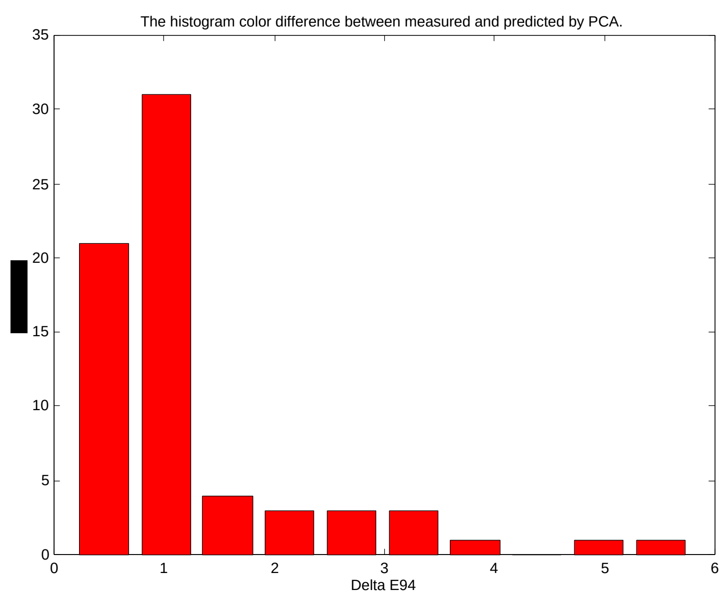


Figure 5i. ΔE94 histogram for D50 illuminant and 2 degree between original and estimated Ross target spectral reflectances from digital counts simulated under metal halide lamp 1.

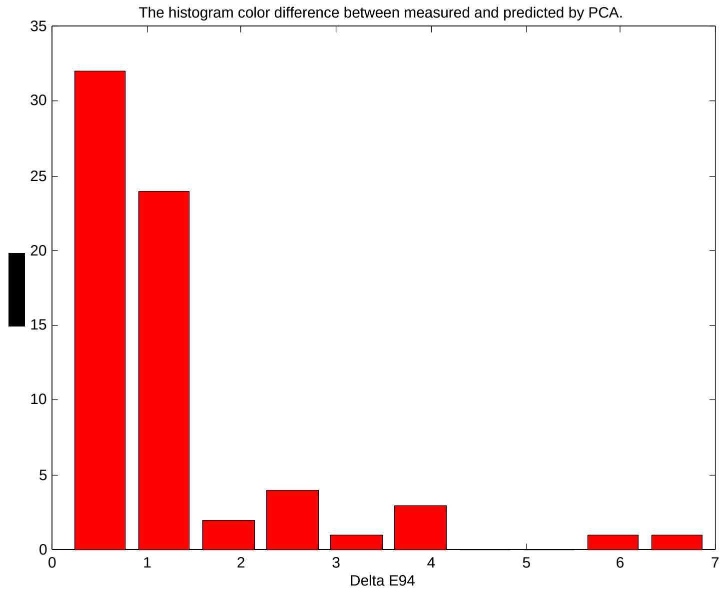


Figure 5j. ΔE94 histogram for D50 illuminant and 2 degree between original and estimated Ross target spectral reflectances from digital counts simulated under metal halide lamp 2.

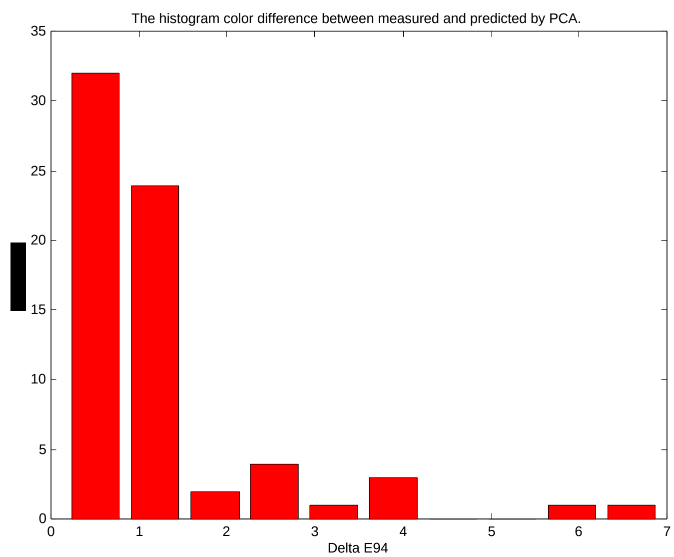


Figure 5k. ΔE94 histogram for D50 illuminant and 2 degree between original and estimated Ross target spectral reflectances from digital counts simulated under metal halide lamp 3.

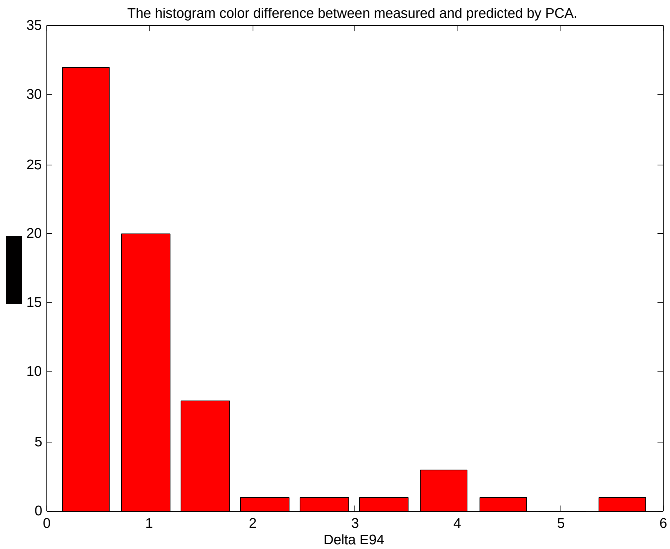


Figure 5l. ΔE94 histogram for D50 illuminant and 2 degree between original and estimated Ross target spectral reflectances from digital counts simulated Buhlite Softcube Model SC-150 0°.

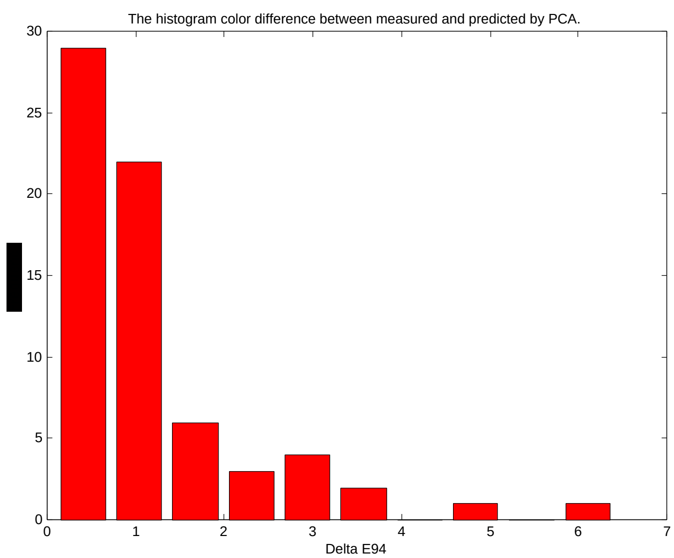


Figure 5m. ΔE94 histogram for D50 illuminant and 2 degree between original and estimated Ross target spectral reflectances from digital counts simulated under Solux 36°.

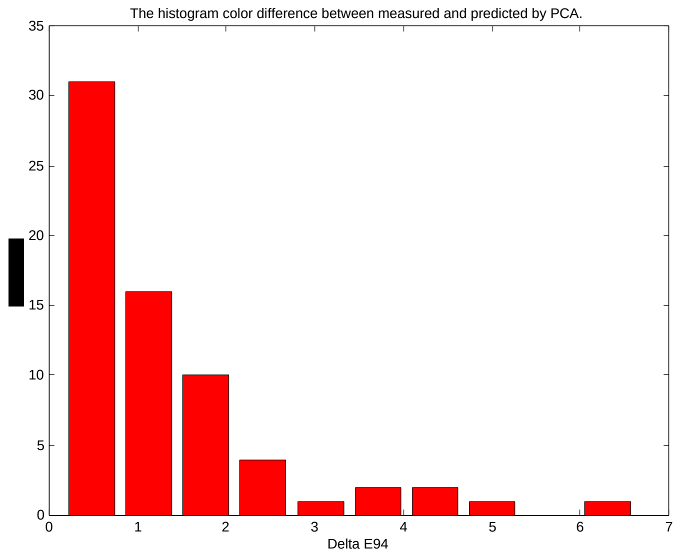


Figure 5n. ΔE94 histogram for D50 illuminant and 2 degree between original and estimated Ross target spectral reflectances from digital counts simulated under HMI.

Discussion – From our results, there are not really dramatic difference on the selection of illumination on the accuracy of spectral estimation since we are using broadband imaging capture. However, from the Table I we found that illuminants with very spiky spectra such as Cool White and Warm White Deluxe lamps produced very high maximum metamerism indices. Although we cannot infer conclusive results, the smoothness of the light source might have an influence on the spectral estimation accuracy. Significantly large ΔE94 was observed for the spiky illuminants for colors like cobalt blue, permanent green light, cadmium reds, naphtol red and violet radiant. They are all colors that present a steep transition in spectra whose estimation seems to be compromised by the presence of spiky illuminants. Besides color accuracy in spectral estimation and spectral composition of the lighting we should also consider other concerns such as:

I. Short and long term stability (HMI and other arc lamps are rather noisy sources while tungsten lamp are quite stable).

II. Fading effect on artwork (excessive ultraviolet and infrared radiation can be harmful for artwork during long exposures)

III, Cost and availability (it would be convenient to use familiar lamps already available in museums).