Spectral Imaging of Matisse's *Pot of Geraniums*: A Case Study

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Abstract

The accuracy of color image-acquisition systems is most often evaluated using test targets of uniform color patches imaged under optimal conditions. In artwork imaging, system performance is judged visually, comparing the art with images rendered for display or print. Because the surface properties of the art may not be uniform, the spectral properties of the pigments may be different than the test targets, the sizes may be different, renderings are often metameric to the art, taking and viewing lighting geometries may be different, and the museum observers are more experienced than scientists in judging color accuracy visually, color accuracy as determined on a visual basis may be quite different than target performance. Therefore, an experiment was performed where a spectral-imaging system, designed for scientific purposes under laboratory conditions, was taken to a museum and tested in its photographic and conservation departments. The work of art evaluated was Henri Matisse's *Pot of Geraniums*. Spectral and colorimetric comparisons were made between *in situ* small aperture spectrophotometry and imaging. The average performance was $3.7\Delta E_{00}$ and 3.1% spectral RMS; this was similar to an independent verification target of typical artist pigments applied to a canvas board. Viewed in close up, this level of accuracy yielded reasonable color matching for images rendered for display and print. Viewed overall, the matching quality worsened, a result of using diffuse lighting during image acquisition. Renderings appeared "flat" and reduced in perceived contrast. This indicates that when creating an image archive for both scientific and visual purposes, it will be necessary to use both directional and diffuse lighting geometries.

Introduction

Spectral imaging in the visible wavelength range offers tremendous opportunities in increasing the information content of a digital representation compared with trichromatic imaging. A research program is underway at the Munsell Color Science Laboratory to develop spectral imaging systems for museums.[1] A growing body of research has been performed, summarized by Hardeberg[2] and Day.[3] Much of this research has been computational (*i.e.*, simulation), or in a laboratory under carefully controlled conditions. In addition, test targets with planar surfaces of uniform spatial properties have been the dominant objects, although there has been some effort in combining spectral and goniophotometric imaging. This paper describes the use of spectral imaging in a real-world environment, the photographic department of a museum. There were several goals. The first was to compare spectral reflectance data acquired using imaging techniques with *in situ* small-aperture reflection spectrophotometry. The second was to learn what types of appearance attributes were most important to reproduce when rendering images, either in print or display, when viewed by curators and conservators. The third was to image paintings rather than test targets and understand the unique requirements when dealing with cultural heritage. The fourth was to learn about color-matching-accuracy requirements of museum personnel.

Painting

Pot of Geraniums (National Gallery of Art 1963.10.41, Chester Dale Collection) was painted in 1912 by Henri Matisse. The painting is a very-well known example from his Nice, France period. It is an oil painting on linen, measuring 41.3 x 33.3 cm. It is unvarnished and has a fairly matte surface. The paint topography is smooth, although brushmarks are clearly seen. Thus, in direct lighting, one observes impasto with faint specular highlights. An image is shown in Figure 1. This painting was selected for study because of its range of colors and pigments, particularly cobalt blue, matte surface, and small size.

A GretagMacbeth Eye-One was used to measure 43 uniform colored positions on the painting as noted in Figure 1. This instrument was selected because of its portable, lightweight, and ease of use characteristics. A polyester template with a small hole was used to protect the painting. A digital image of the template following measurement was used to approximately record the measurement position. The spectral reflectance spectra are plotted in Figure 2.

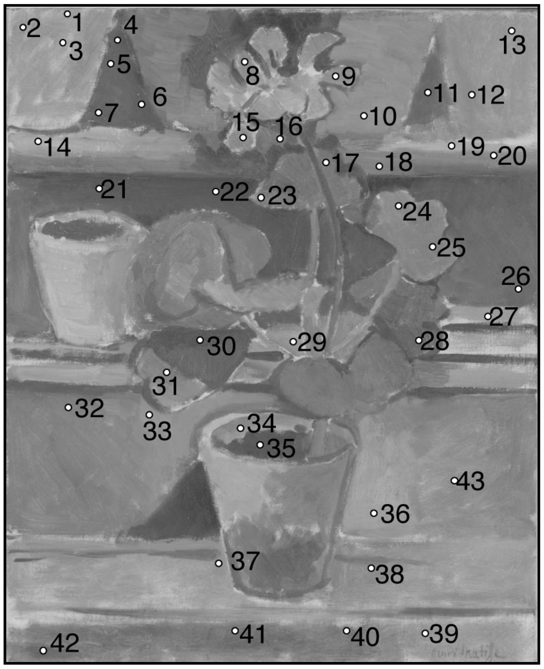

Figure 1. Henri Matisse, Pot of Geraniums, 1912 (National Gallery of Art 1963.10.41, Chester Dale Collection).

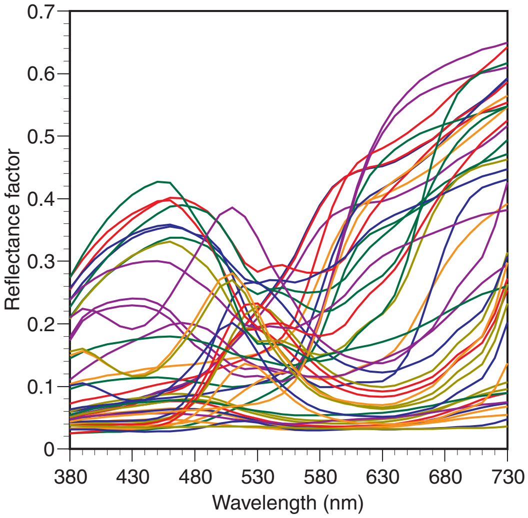

Figure 2. In situ *measurements of* Pot of Geraniums.

Imaging System, Calibration, and Verification

Photography Studio

Spectral measurements, image capture, and image display were performed in the photography studio of the National Gallery of Art, Washington, DC. We were aided by the museum photographic and conservation staff to ensure the painting was not adversely affected by the experiment.

Camera

A Roper Scientific Photometrics Quantix 6303E monochrome digital camera using a cooled grade 3 Kodak 2048 x 3072 pixel CCD model KAF-6303E was used as the digital camera. The sensor was coupled with a Cambridge Research Institute liquid-crystal tunable filter (LCTF) and Rodenstock 105 mm enlarger lens. 12-bit linear-photometric data were recorded. 31 bands were collected corresponding to wavelength centroids of 400 – 700 nm in 10 nm increments.

Lighting

A pair of Elinchrom Scanlite Digital 1000 tungsten-halogen lights affixed with Chimera Softboxes illuminated the object plane at 45° to the surface normal. The goal was to provide spatially uniform diffuse illumination, often used when imaging paintings for scientific analyses.[4]

Calibration and Verification Targets

Typical of any optical device, calibration is required. The goal was to develop a transformation that converted raw image data to spectral reflectance factor. Two calibration targets were used. The first was the Gretag-Macbeth ColorChecker DC. This target has 239 samples reasonably distributed in color space. However, its range of pigmentation is limited, particularly for blues. Accordingly, we produced a separate target of 56 blues using artist acrylic paints including cobalt and ultramarine pigments. As a verification target, samples were made of typical artist's pigments using the Gamblin Conservation Colors. Each pigment was mixed with titanium white at two different concentrations and applied to a canvas board. All the targets were measured using an integrating sphere spectrophotometer with specular component excluded, approximating the lighting system geometry as much as possible. An L* = 70 gray poster board, larger than the image area, was used to digitally flat field the image plane. For every wavelength centroid, images were collected of the gray card, the three color-targets, the painting, and with the shutter closed.

Calibration Transformation

Each image plane was corrected for fixed pattern noise and lack of lighting uniformity using image subtraction and division in the usual manner. Each pixel corresponding to the calibration color targets was assigned a measured spectral reflectance factor. Using a generalized pseudo inverse (*PINV* function in Matlab), a 31 x 31 matrix transformation was derived from 230,640 pixels. Using the individual pixels rather than their average for each color sample improved spectral accuracy significantly. This method included image noise in similar fashion to methods such as Wiener filtering. A visualization of the matrix transformation is shown in Figure 3. This matrix is accounting for differences in bandwidth between the LCTF and spectrophotometer, wavelength calibration, unwanted transmittance in out-of-band regions such as at 400 nm, and the small range of digital signals for the Halon. Greater details of this method are described in reference 5.

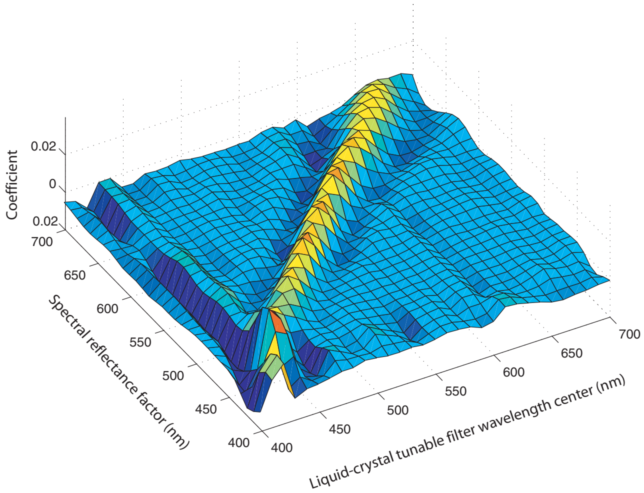

Figure 3. Visualization of the matrix transformation.

The spectral data generated by spectrophotometry and imaging were analyzed for spectral accuracy using spectral reflectance RMS and an index of metamerism between illuminants D65 and A using a parameric correction to D65 and CIEDE2000, and colorimetric accuracy using CIEDE2000 for D65, summarized in Table I. The 2° observer was used for all calculations. These results were reasonable and typical of the accuracy levels we achieve in the laboratory. The spectral fits were excellent; the image-based spectra well tracked the unique features of each sample as measured with a bench-top spectrophotometer. (See reference 5 for plots.) We continue to be surprised how quite small spectral differences result in appreciable colorimetric differences, reinforcing the need for improved metrics for spectral reproduction.[6]

Table I. Comparisons between spectrophotometry and imaging for the various calibration (ColorChecker DC and blue acrylics) and verification (Gamblin Conservation Colors) targets.

Targets	ΔE_{00}	RMS (%)	Metameric Index (ΔE_{00})
Color Checker DC	2.6	2.6	0.5
Blue Acrylics	1.7	1.4	0.4
Conservation Colors	3.3	3.5	0.5

In Situ Analyses

Based on the spectrophotometer's specified measurement aperture and images of the measurement locations, an image mask was made for the painting. The spectral reflectances of pixels within the mask were averaged and compared with the direct measurements. In some cases, the image-based spectral data were quite different than the direct measurements. One of the difficulties during the *in situ* measurements was keeping the polyester template in position following the removal of the spectrophotometer. Shifting the mask for these cases improved accuracy. For this publication, position discrepancies were not corrected.

The spectral and colorimetric accuracy is listed in Table II. Spectral plots are shown in Figure 4. The average accuracy was similar to the independent verification target. However, the maximum differences were larger. The spectral "fingerprints" were well estimated in nearly all cases and could be used as an analytical tool for conservation science, in similar fashion to other spectral measurements such as Raman and X-ray fluorescence. Since this comparison has not been published by other researchers and this is the first time we have performed this comparison, we cannot judge the quality.

Table II. Comparisons between direct and image-based spectrophotometry for *Pot of Geraniums*.

	ΔE_{00}	RMS (%)	Metameric Index (ΔE_{00})
Average	3.7	3.1	1.1
Maximum	14.2	13.3	8.8
Standard Deviation	3.0	2.7	1.4

Image Rendering

Having a spectral image, CIE tristimulus values can be calculated for any light source and observer, standardized or otherwise. While at the museum, we wanted to render the painting for display to ensure we had performed the imaging and data storage correctly. The studio was not set up for softcopy comparisons with imaged art. We had two illumination choices, the camera-taking tungsten lights or daylight-fluorescent ceiling lights of low illuminance. The display available to us was a Macintosh-controlled CRT with a native white point of 9300 K. We had a telespectroradiometer and were able to colorimetrically characterize the display to an average accuracy of less than $1\Delta E_{00}$. We could use the display in one of two ways. The first was the usual color management approach. We could use a color appearance model to account for differences in white point chromaticity and luminance and compensate for partial adaptation between the display and painting.[7] The other choice was to treat the characterized display as a visual colorimeter and display the absolute colorimetry for the selected light source and observer. We were using this approach for a visual experiment to judge the color and spatial image quality of several spectral estimation techniques, including the one used in this experiment.[3, 8] Because we had very limited time and had not incorporated a color-appearance model into our workflow, we used the later approach. Because the camera-taking illuminance was so much greater than the display, we decided to illuminate the painting with the ambient fluorescent lights. In this manner, we had similar luminance and white point chromaticities.

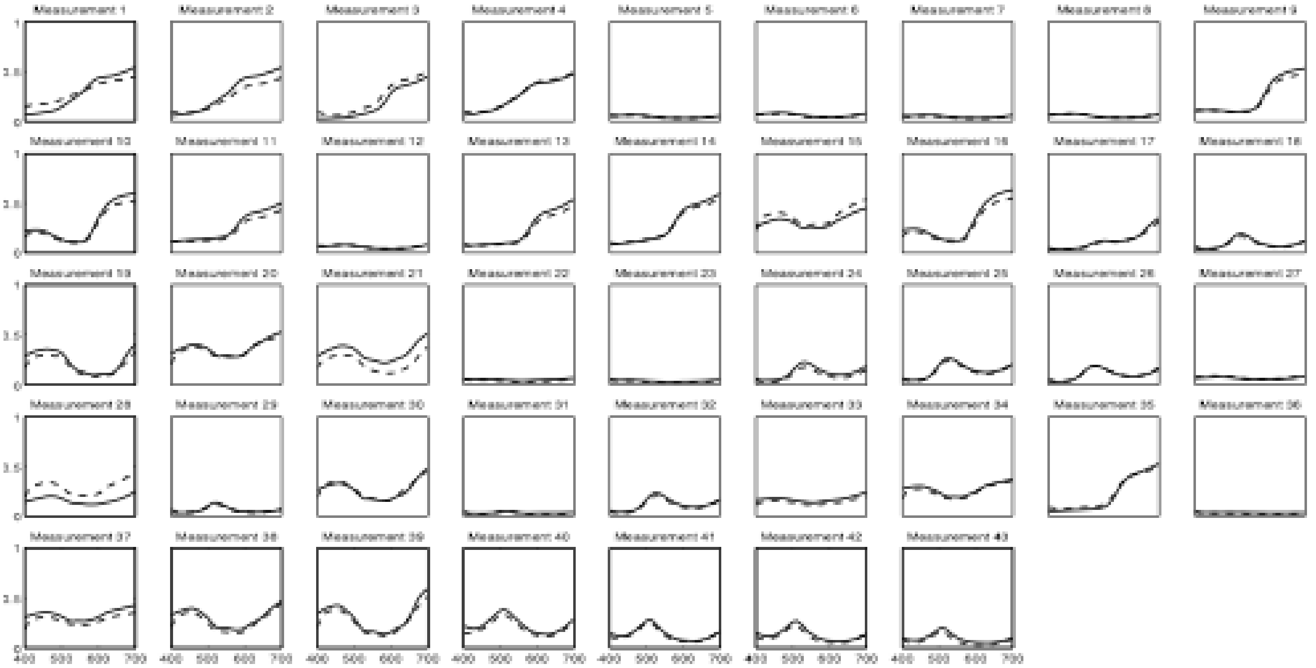

Figure 4. Spectral reflectances of Pot of Geraniums. Solid lines indicate in situ spectrophotometry; dashed lines indicate image based estimates.

In our software, we could select any CIE daylight illuminant. We first rendered the painting for D65 and the 2° observer using Matlab as the processing environment. We had overlooked that it was impossible to close all the dialog boxes; as a consequence, there were image areas with the native white point visible on the display. This resulted in the image looking yellowish. As a simple expedient, we re-rendered the image for D93, thereby matching the white points. Since the viewing was successive binocular, we hoped that the painting had reasonable color constancy between daylight-fluorescent and D93. The final digital signals were boosted in contrast by 1.25γ to compensate for the dim surround display viewing conditions.[7] The color accuracy was, surprisingly, quite good when comparing various color passages. The overall image looked “flat.” This was caused by using highly diffuse camera-taking illumination. The rendered image was also compared with a positive photographic transparency. The spectral-based reproduction had better color accuracy while the photograph was more pleasing and “life like.” The later system used more directional lighting.

Upon return to RIT, we rendered the painting for D50 and the 2° observer and made a glossy print using a well-profiled proofing printer using the ICC absolute color rendering intent. (Very few of the painting’s colors were outside the printer’s color gamut.) During our next visit to the Gallery, we compared the print and painting side-by-side in the painting conservation studio under a combination of natural daylight on a partly cloudy day and ambient 6500 K fluorescent daylight. (The specific CCT was not known.) Again, the color accuracy was reasonable when viewing areas of the painting in detail. It was clear that the conservators had very stringent color-matching criteria. Moving back and comparing the print and painting on an overall basis, the appearance matching quality decreased. Although the conservation studio lighting was largely diffuse, it was still possible to see brushmarks and some specular highlights in the painting as we are constantly moving our eyes and heads. The print, of course, could not mimic this. The camera-taking lighting geometry was developed to minimize the effects of surface properties on color. In this fashion, if we repeat the imaging, we expect the images to be nearly identical. If the imaging goal is to have a spectral record to evaluate ageing and transit effects and perform analytical analyses, this is the appropriate lighting. If the goal is to create images that match the appearance of the painting, this geometry is inappropriate. Conservators were viewing the print with the latter goal. The lack of topographical information reduced the perceived contrast of the printed reproduction and gave it the “flat” appearance.

Conclusions

A spectral-imaging case study was performed in a museum environment. Thirty-one-band images were transformed to spectral reflectance factor images using a target-based transformation. Spectra based on digital imaging were compared with direct spectrophotometry. The results were reasonable and will provide a benchmark when using techniques that sub-sample the visible spectrum and rely on estimation approaches or other approaches. A key issue in this study was lighting geometry. Since this system is intended as an analytical instrument, we used diffuse lighting to minimize the influence of surface attributes on measured spectral reflectance. However, museum personnel are accustomed to viewing images for documentation. Ideally, a work of art should be imaged using both diffuse and directional lighting. One can then render an image for either optimal appearance or optimal scientific analysis.

When creating an image archive, it is clear that printed reproductions will be used as the main quality criterion rather than tables of color differences, spectral plots, or images rendered for display. As a consequence, lighting geometry becomes the critical factor, as we have discussed. A second critical factor is the quality of the printer profile. If our main research is to create an imaging system, but the quality is judged on prints, any accuracy limitations of the printer will be associated with the image-acquisition accuracy. Clearly, we will have to provide demonstrations of the accuracy of the input and output systems, independently.

The imaging system was optimized for spectral accuracy. It is becoming clear that colorimetric accuracy is more important than spectral accuracy. Thus we may modify our transformation approach in order to improve colorimetric accuracy for a specific illuminating and viewing condition.

When rendering the spectral image while at the Gallery, we recognized the difficulties in establishing standardized conditions for visually evaluating digital imaging of cultural heritage. This reinforced our philosophy of using objective measurements to evaluate color-reproduction accuracy and that visual editing should not be part of the workflow when creating image archives of cultural heritage.[9]

The success of any color-reproduction system for museum applications depends on a clear understanding of the imaging goals, tradeoffs between analytical and perceptual renderings, and cooperation between museum and academic constituencies.

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Acknowledgments

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Biography

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