Artist Paint Spectral Database

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Abstract

Colorimetric and spectral gamuts are useful for the design of imaging systems such as display and print, to evaluate encoding errors for digital photography, for spectral reconstruction, and for lighting design. An artist paint spectral database was developed that includes spectra, colorimetry, eigenvectors, and optical data to produce additional spectra if desired. Nineteen acrylic-dispersion paints were sampled and Kubelka-Munk theory with the Saunderson correction was used to characterize each paint's optical properties. Each chromatic paint or hue-adjacent paints were mixed computationally with white and with black at a range of concentrations producing approximately uniform sampling in CIELAB. In total, there are 23 hues and one gray scale with 770 unique spectra.

Introduction

Colorimetric and spectral gamuts are useful for the design of imaging systems such as display and print, to evaluate encoding errors for digital photography, for spectral reconstruction, and for lighting design. Common gamuts include the Munsell Book of Color [1], the Natural Colour System [2], the MacAdam limits [3], the Pointer gamut of surface colors [4], the Li, et al. spectral database [5], the SOCS database [6], and the recent IES color-rendering spectra [7]. In this research, an artist paint spectral database was developed that includes spectra, colorimetry, eigenvectors, and optical data to produce additional spectra if desired.

Materials and Measurements

Nineteen Golden Artist Colors Heavy Body acrylic dispersion paints [8] were used to develop the database, listed in Table I. Acrylic paints were selected because of their quick drying times, ease of cleanup being water-based, and level of opacity. The specific paints were selected to sample the hue circle and when used directly from the tube, e.g., cadmium yellow, or when mixed with white, e.g., ultramarine blue, could achieve high chroma. The exception was cobalt blue; it was selected because of its unique spectral reflectance factor where at long wavelengths, it has high reflectance.

Each paint was applied to Leneta Form 3B Opacity Charts [9] using a 0.006" drawdown bar, the goal producing an opaque paint layer. For some paints, multiple drawdowns were applied, each at greater thickness, to achieve opacity. Each paint was mixed with white to produce a moderate to high chroma and also applied to the drawdown paper producing an opaque layer. The weight of each paint forming the mixture was determined using an Acculab scale with a precision of 0.005 g.

A Macbeth MS7000 integrating sphere spectrophotometer was used to measure total hemispherical spectral reflectance factor (SPIN). Each sample was measured four times with replacement and its average recorded from 380 – 750 nm in 10 nm increments.

Table I. Golden Artist Artist Colors Heavy Body acrylic-dispersion paints used to generate the database.

Paint	C.I. #
Titanium White	PW 6
Bone Black	PBk 9
Bismuth Vanadate Yellow	PY 184
Hansa Yellow Opaque	PY 74
Diarylide Yellow	PY 83
C. P. Cadmium Orange	PO 20
Pyrrole Orange	PO 73
C. P. Cadmium Red Light	PR 108
Pyrrole Red	PR 254
Quinacridone Red	PV 19
Quinacridone Magenta	PR 122
Dioxazine Purple	PV 23
Ultramarine Blue	PB 29
Cobalt Blue	PB 28
Cerulean Blue, Chromium	PB 36:1
Phthalo Blue (Red Shade)	PB 15:1
Phthalo Blue (Green Shade)	PB 15:4
Phthalo Green (Blue Shade)	PG 7
Phthalo Green (Yellow Shade)	PG 36

Optical Model

The opaque form of Kubelka-Munk (KM) turbid media theory [10–13] was used to predict the spectral reflectance factor of any paint mixture. The model's effectiveness was verified previously using Golden Artist Company Matte Fluid acrylic dispersion paints [14]. Each paint was characterized optically by calculating absorption and scattering spectra using the masstone-tint method [14]: the paint directly out of the tube (masstone) and mixed with white (tint) with known concentration.

KM theory requires internal spectral reflectance factor data, that is, spectral data inside the paint layer. This was achieved by compensating for the refractive index discontinuity at the paint and air interface using the modified Saunderson equations [15] with constants of $K_1 = 0.03$ (collimated), $K_2 = 0.65$ (diffuse) and $K_{instrument} = 1.0$ (SPIN), the constants derived previously [16].

Mixtures were varnished (or made glossy) computationally by setting $K_{instrument} = 0$ when transforming from internal to external reflectance factor. This approach was verified experimentally using Pyrrole Orange and Golden MSA glossy varnish.

Mixtures

Each chromatic paint was mixed computationally with white (tints) and with black (tones) resulting in 39 spectra for each color. The spectra and colorimetric coordinates (1931 observer, D50) of Cadmium Orange are plotted in Figure 1 as an example. With an increase in the amount of white, the short wavelength absorption decreases. With an increase in the amount of black, the long wavelength absorption decreases. The specific concentrations were selected to reasonably sample CIELAB.

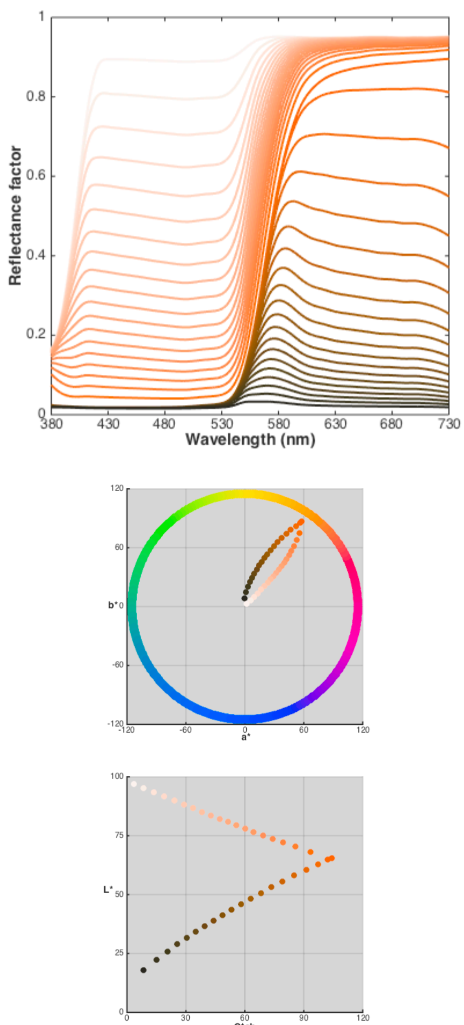

***Figure 1**. Computational mixtures of Cadmium Orange with Titanium White and with Bone Black. (The hue circle is shown as a guide to relating a*b* position with hue; it does not represent an outer gamut limit to CIELAB.)*

Spectral and Colorimetric Database

The set of paints did not completely sample CIELAB hue and additional spectra were produced by mixing Phthalo Green (Yellow Shade) and Bismuth Vanadate Yellow at three ratios, Phthalo Blue (Green Shade) and Phthalo Green (Blue Shade), and Quinacridone Magenta and Dioxazine Purple. In total there were 770 spectra. Their CIELAB coordinates are plotted in Figure 2. Note that most of the paints' tints and tones shift in hue, particularly the yellows, oranges, reds, and magentas. This is a result of the non-block-dye nature of these colorants where the transition from short to long wavelengths shifts with changes in white, clearly seen in Figure 2 for Cadmium Orange.

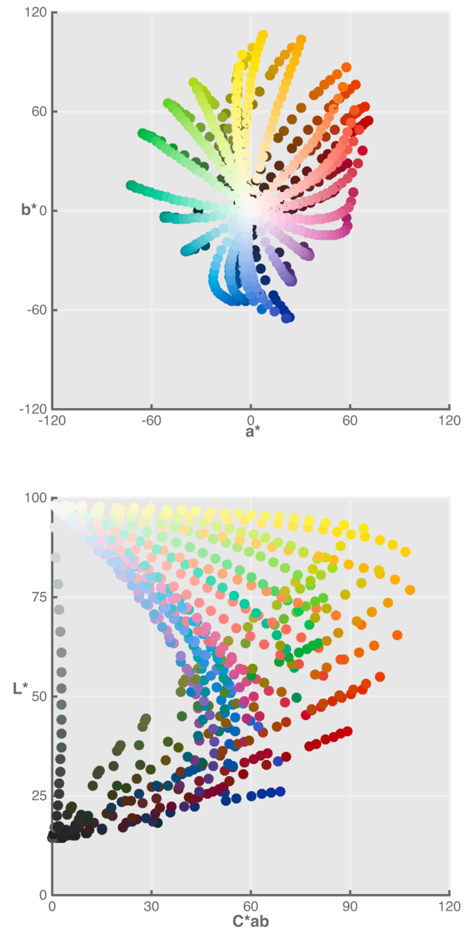

***Figure 2**. Complete spectral database plotted in CIELAB.*

Principal Component Analysis

Principal component analysis (mean subtracted) was performed on the spectra, the percent variance listed in Table II and the mean and first ten eigenvectors plotted in Figure 3. The small wiggle around 730 nm is a result of small uncertainty in the absorption and scattering properties of Bone Black. With each successive eigenvector, the number of oscillations increases, typical of PCA. There are many applications where three basis functions are useful as an approximation of the complete spectral dataset. A linear combination of the first three eigenvectors was sought that could reconstruct the mean, the result plotted in Figure 4. Five eigenvectors were necessary to reconstruct the mean with reasonable performance.

Table II. Variance and cumulative variance of the first ten eigenvectors.

Eigenvector	Variance	Cumulative % Variance
1	0.7392	73.9
2	0.1593	89.6
3	0.0769	97.5
4	0.0137	98.9
5	0.0056	99.5
6	0.002	99.7
7	0.001	99.8
8	0.0007	99.9
9	0.0006	99.9
10	0.0003	99.9

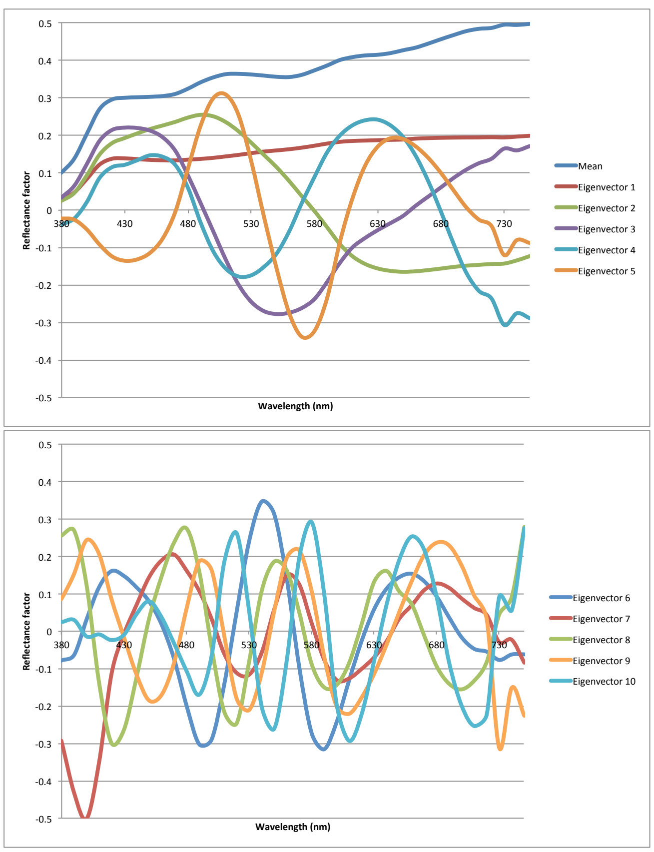

Figure 3*. Mean and first 10 eigenvectors.*

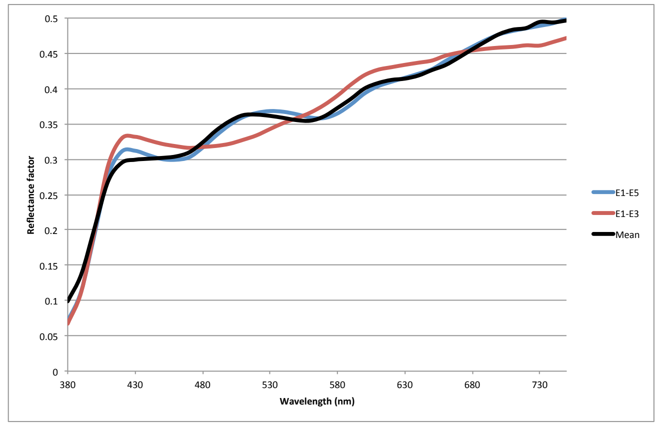

Figure 4*. Mean and its reconstruction using the first three and the first five eigenvectors.*

Encoding Error Example

The colorimetric coordinates of the database were transformed to sRGB, AdobeRGB(1998), and eciRGBv2. Any colors with linear RGB values less than zero or greater than unity will lead to encoding errors. These are plotted in Figure 5. As these are all display-based, subtractive primary colors, cyan, yellow, and magenta, are most commonly outside rendering gamuts [17]. sRGB demonstrates this for cyans and yellows. For all three encoding spaces, yellows and reds were beyond the rendering gamuts.

Conclusions

A spectral and colorimetric database of artist paints has been derived using Golden Artist Colors Heavy Body acrylic dispersion paints. The spectral, colorimetric, absorption and scattering, and eigenvector data will be available for downloading in a spreadsheet.

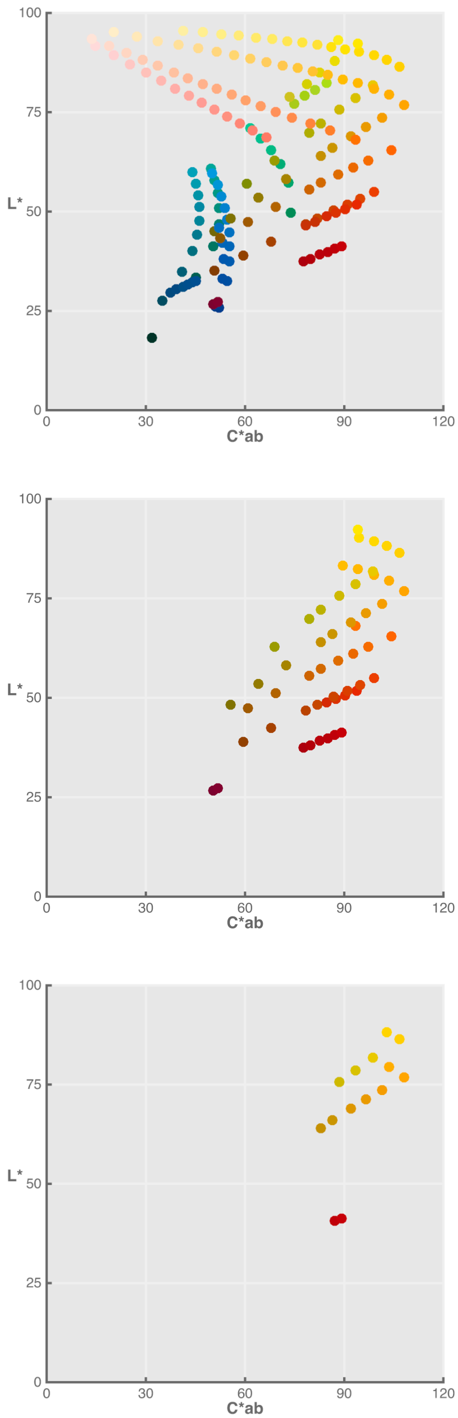

***Figure 4**. Colors outside of the color-rendering gamut of: (top) sRGB, (middle AdobeRGB(1998), and (bottom) eciRGBV2..*

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