ETRGB: An Encoding Space for Artwork Imaging

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Abstract

Fluorescent, iridescent, interference, and metallic colorants are part of a modern artist's palette. These materials produce colors far exceeding conventional absorbing and scattering colorants. Current encoding spaces, even so-called wide gamut, cannot accurately encode such modern materials. A new encoding space, ETRGB, has been developed that extends both chromatic and photometric dimensions. ET is an abbreviation for Extended Tristimulus. The chromaticites of the space are the apices of the 1931 xy chromaticity diagram. The photometric range is from 0 – 2 luminance factor, 0 – 130L. Its white point is CIE Illuminant D50. Nonlinear encoding is based on CIE L*. The extended photometric range is equivalent to 15-bit encoding when compared to current systems. An imaging experiment of an interference-pigment coating demonstrated its usefulness compared with ProPhotoRGB.*

Introduction

Presently, there are two guidelines for image archiving, Metamorfoze [1] and FADGI [2]. They recommend encoding using eciRGBv2 and AdobeRGB(1998), respectively. Both are "output referred" based on CRT display technology. AdobeRGB(1998) is likely the most common encoding space when archiving artwork. Some museums have begun using large color-rendering gamuts such as ProPhotoRGB, ProStarRGB (ProPhotoRGB matrix and L* tone response curve), and CIELAB.

These various encoding spaces were not designed for artwork imaging and it has been assumed that artist materials encode without error. This assumption may be incorrect given the wide range of materials used in artist paints including conventional absorbing and scattering colorants, metallic flakes made using bronze, copper, zinc, stainless steel, nickel, graphite, and aluminum, fluorescent dyes, and iridescent and interference pigments made using thin film technology. A computational analysis [3] revealed that sRGB, eciRGBv2, and AdobeRGB(1998) primaries with D50 white point have an insufficient rendering gamut for conventional and fluorescent paints, shown in Figure 1 for a combined set of two different varnished acrylic paint systems, fluorescent paints, and the Pointer colors. (CIECAT02 was used to transform the Pointer colors from illuminant C to D50.) ProPhotoRGB and ProStarRGB had insufficient rendering gamuts for the fluorescent colors. We expect the other non-conventional artist paints to also be problematic. As a consequence, a new encoding space for artwork imaging is described.

RGB or Lab

The first decision was whether to simply use Lab encoding since its encoding gamut is very large. However, if a white point other than D50 is desired, there is not a way to encode this information since profiles are not written for Lab encoding. Also, RGB spaces are more familiar and are common working spaces for visual editing. Thus, the new encoding space is an RGB space.

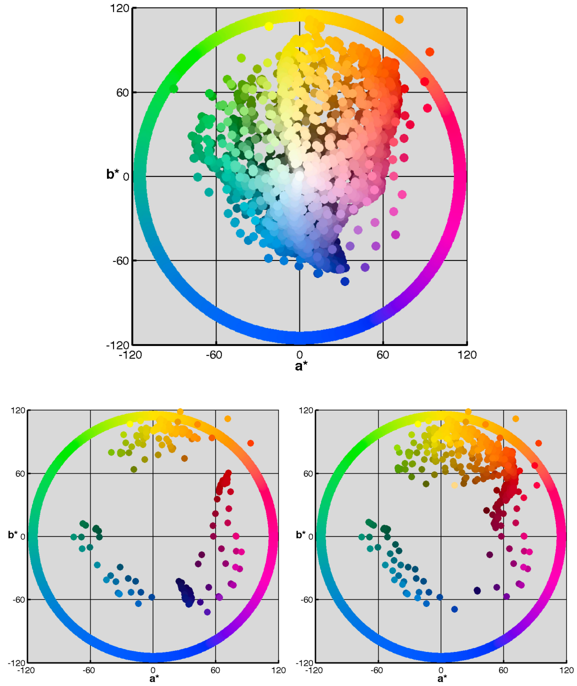


***Figure 1**. (a) Colorimetric coordinates of two paint systems, Pointer colors, and fluorescent paint. Out of gamut colors for (b) eciRGBv2 and (c) AdobeRGB(1998) encoding.*

Null Viewing Conditions

There are no specifications for display white point, contrast ratio, display black point, display colorimetry, ambient illumination spectral power distribution, illuminance, and chromaticities, and display surround. This is an encoding space that does not have an equivalent display.

Bit Depth

The new encoding system is considered a "wide-gamut" system and accordingly, images should only be stored using 16 bits or greater per channel.

RGB Primaries

Any RGB encoding system is defined, in part, by each channel's chromaticities (i.e., x,y or u',v'). Their definition can be based on display standards, e.g., eciRGB and sRGB, or more empirically, e.g., ProPhotoRGB and WideGamutRGB. In the past, one of the key considerations is minimizing the chromaticity area where values exceed some set of chromatic stimuli. However, this criterion loses relevancy once bit depth is 16 bits or greater. The only primaries guaranteed to encompass all chromatic stimuli are the apices of the 1931 chromaticity diagram: (0,0), (0,1), (1,0), forming a right triangle. These primaries were selected for the new encoding system. The SMPTE arrived at the same conclusion in their 2006 standard for encoding digital cinema distribution masters [4].

White Point

This encoding system will be used for color management as an ICC profile. The ICC profile connection space (PCS) defines CIE Illuminant D50 and the 1931 standard observer as its white point. Accordingly, this white point was selected for the new encoding system, leading to the following tristimulus matrix converting from RGB to XYZ:

Table 1. ***Tristimulus values each primary and D50 white point.***

	R	G	B	White
X	0.964	0	0	0.964
Y	0	1	0	1
Z	0	0	0.825	0.825

Extending Input Range

The input range for existing encoding systems is 0 – 1 where X/X_n, Y/Y_n, and Z/Z_n equal 1.0 (white-point normalization where subscript n indicates the tristimulus values used for the normalization). This limit is reasonable for most colors. However, metallics and goniochromatic colors can easily exceed this limit. It was decided to extend the range of white-point normalized tristimulus values from 1.0 to 2.0, the maximum encoding range for tristimulus values within ICC profiles. Thus the range is 0 to 65535.0/32786.0 (1.999969482421875).

Non-Linear Encoding

Even with 16 bits, it is advantageous to encode data nonlinearly. For very dark colors, linear encoding can lead to quantization errors [5]. One option is to use CIEDE2000 to develop a nonlinear function where there is equal color differences between each of the 65,536 values. However, the S_L function of CIEDE2000 has the least consistent agreement between datasets used to develop CIEDE2000 [6]; thus this option was rejected. The CIE L* function is still the most reliable function relating luminance factor with lightness. Furthermore, its use is increasing for image encoding, e.g., ProStarRGB and eciRGBv2. Although a 2.4 gamma is similar to L*, L* is still a better fit by a factor of over five when comparing performance using the original visual data. Another advantage of L* is it's explicit slope term for near-black colors. Although this was developed to avoid negative L* values, it also serves as a linear term to avoid an infinite slope at 0. Thus the L* function was selected.

The L* constants of 116, 16, and 903.3, were rescaled such that normalized tristimulus data ranging from 0 to 2 would map to L* values of 0 to 100. The resulting constants are 89.13, 12.29, and 694.04 based on a scaling of 0.7683.

16-bit has an encoding range of 0 – 65,535. The scalar was further adjusted so that a luminance factor of 1.0 was as close as possible to an integer value before rounding (0.7683383). The numerical data are listed in Table 2 for normalized tristimulus data between 0 and 2. At 1.0 and 2.0, the 16-bit floating-point values are 50,353.05 and 65,534.92, both numbers quite close to integers and not a source of round-off error. Extending the range has a small effect compared with the usual range of 0 – 1. For a perfect reflecting diffuser (1.0), the encoding range is 77% of the full range. This corresponds to 15.6 bit encoding (2^15.62 – 1 = 50353.05).

Table 2. ***Non-linear encoding of normalized tristimulus values.***

Norm. XYZ	Floating point 0-1	Floating point 0-65535	% of full range
0	0.00	0.00	0%
0.001	0.01	454.84	1%
0.01	0.07	4527.47	7%
0.1	0.29	19054.82	29%
0.2	0.40	26101.62	40%
0.3	0.47	31044.78	47%
0.4	0.53	34980.03	53%
0.5	0.58	38303.19	58%
0.6	0.63	41208.02	63%
0.7	0.67	43805.57	67%
0.8	0.70	46166.12	70%
0.9	0.74	48337.30	74%
1.0	0.77	50353.05	77%
1.1	0.80	52238.52	80%
1.2	0.82	54012.91	82%
1.3	0.85	55691.27	85%
1.4	0.87	57285.62	87%
1.5	0.90	58805.74	90%
1.6	0.92	60259.72	92%
1.7	0.94	61654.31	94%
1.8	0.96	62995.23	96%
1.9	0.98	64287.37	98%
2.0	1.00	65534.92	100%

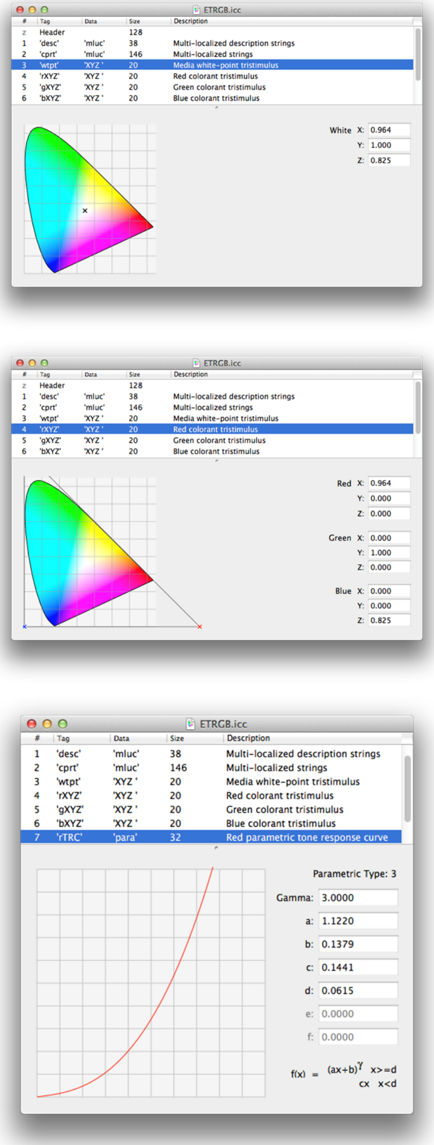
ETRGB

This new encoding system is called ETRGB, where E refers to "extended" and T refers to "tristimulus." Although this is a nonlinear encoding of XYZ tristimulus values, it remains an RGB-type color space from an imaging perspective.

Table 3. ***Forward and inverse (profile) encoding constants for the non-linear function.***

	Image forward encoding	Profile inverse encoding
Gamma	0.333333333	3
a	0.891272426	1.121991404
b	0.122934128	0.137931034
c	6.940371388	0.144084508
d	0.008856452	0.061467064

The forward and inverse encoding constants for the non-linear function are listed in Table 3. A parametric curve was used rather than a 1,024 entry LUT to avoid quantization errors. The image encoding constants are the scaled (L*/100) function values. The inverse constants are the reciprocals of the forward encoding except for d (0.061467064). This value corresponds to the forward encoded value at an input of 0.00885. Screenshots of the ICC version 4 profile are shown in Figure 2. The constants were rounded to four places past the decimal point. The same non-linear function is used for all three channels.



ETRGB.icc

#	Tag	Data	Size	Description
z	Header		128	
1	'desc'	'mluc'	38	Multi-localized description strings
2	'cprt'	'mluc'	146	Multi-localized strings
3	'wtpt'	'XYZ '	20	Media white-point tristimulus
4	'rXYZ'	'XYZ '	20	Red colorant tristimulus
5	'gXYZ'	'XYZ '	20	Green colorant tristimulus
6	'bXYZ'	'XYZ '	20	Blue colorant tristimulus

White X: 0.964
Y: 1.000
Z: 0.825

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Red X: 0.964
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6	'bXYZ'	'XYZ '	20	Blue colorant tristimulus
7	'rTRC'	'para'	32	Red parametric tone response curve

Parametric Type: 3
Gamma: 3.0000
a: 1.1220
b: 0.1379
c: 0.1441
d: 0.0615
e: 0.0000
f: 0.0000

$$f(x) = \begin{cases} (ax+b)^{\gamma} & x>=d \\ cx & x<d \end{cases}$$

***Figure 2**. Screenshots of ETRGB ICC profile.*

Numerical Evaluation

One of the paint system's CIELAB values was extended by defining a line segment from L* = 50, $C^*_{ab} = 0$ to each coordinate defined by L* and C^*_{ab}, and extending the line by 10%, resulting in coordinates thought to encompass most conventional artist materials [3]. Any colors with negative tristimulus values or luminance factor greater than 1.0 were excluded, resulting in 1,723 coordinates. Comparisons were made between the floating-point data and data rounded to 16 bits, and 16-bit data modified by adding 1 count to R and B and subtracting 1 count from G. The ±1 count represents quantization uncertainty. CIEDE2000 color differences were calculated between the floating point and encoded data for ProPhotoRGB and ETRGB, listed in Table 4. We often find the 90th percentile the most important metric because it avoids outliers and color differences are not normally distributed, reducing the usefulness of the mean. The color differences are imperceptible for pictorial imagery [7]. Thus, the new encoding system does not add noticeable quantization error compared with another wide-gamut space, ProPhotoRGB.

Table 4. CIEDE2000 values for the extended glossy paint dataset.

	16 bit encoding			±1 count uncertainty		
	Mean	90th	Max	Mean	90th	Max
ProPhotoRGB	0.02	0.00	1.92	0.03	0.01	1.92
ETRGB	0.03	0.08	0.87	0.04	0.08	0.85

Imaging Experiment

An imaging system consisting of a Sinar 86H 48 MP back, RePro body, eShutter, and HR100 lens, and a single Broncolor strobe placed 45° from the object plane was used to image a Xrite ColorChecker Classic and a drawdown of ChromaFlair Blue/Red interference paint, supplied by JDSU, mounted on black foamcore, and white foamcore. The drawdown was attached to the foamcore as a curve to reveal both interference colors. The strobe energy was set so that the ColorChecker white had an average green signal of 7670 (out of a possible 16,383); this was equivalent to a perfect reflecting diffuser having 8-bit data of 128. Under-exposing a diffuse white is common practice when imaging paintings containing metal, such as gold leaf. The image data were converted to floating point, divided by the white image data (flat fielding), and rescaled so the white had a value of 0.9 (near the luminance factor of this sample measured with 45/0 geometry). A transformation matrix was derived from RGB to XYZ using the ColorChecker data minimizing average CIEDE2000. The XYZ data were used to encode 16-bit images in ProPhotoRGB and ETRGB. The ETRGB image was converted to ProPhotoRGB in Photoshop using absolute colorimetric rendering to facilitate visual comparisons with the ProPhotoRGB encoded image. The images are shown in Figure 3. The red color is much more visible with the ETRGB encoding than the ProPhotoRGB encoding, confirming the advantage of ETRGB for modern artist materials.

Conclusions

A new encoding has been developed for image archiving of cultural heritage. The new scheme, ETRGB uses the apices of the 1931 chromaticity diagram as its RGB primaries, a D50 white point, and L* type nonlinear encoding where white-point normalized tristimulus values between 0 and 2 map to between 0 and 1. ETRGB can encode all colorants and their mixtures used by artists including fluorescent and goniochromatic colors. Preliminary testing imaging a ChromaFlair paint drawdown revealed that the new encoding scheme was superior to ProPhotoRGB.

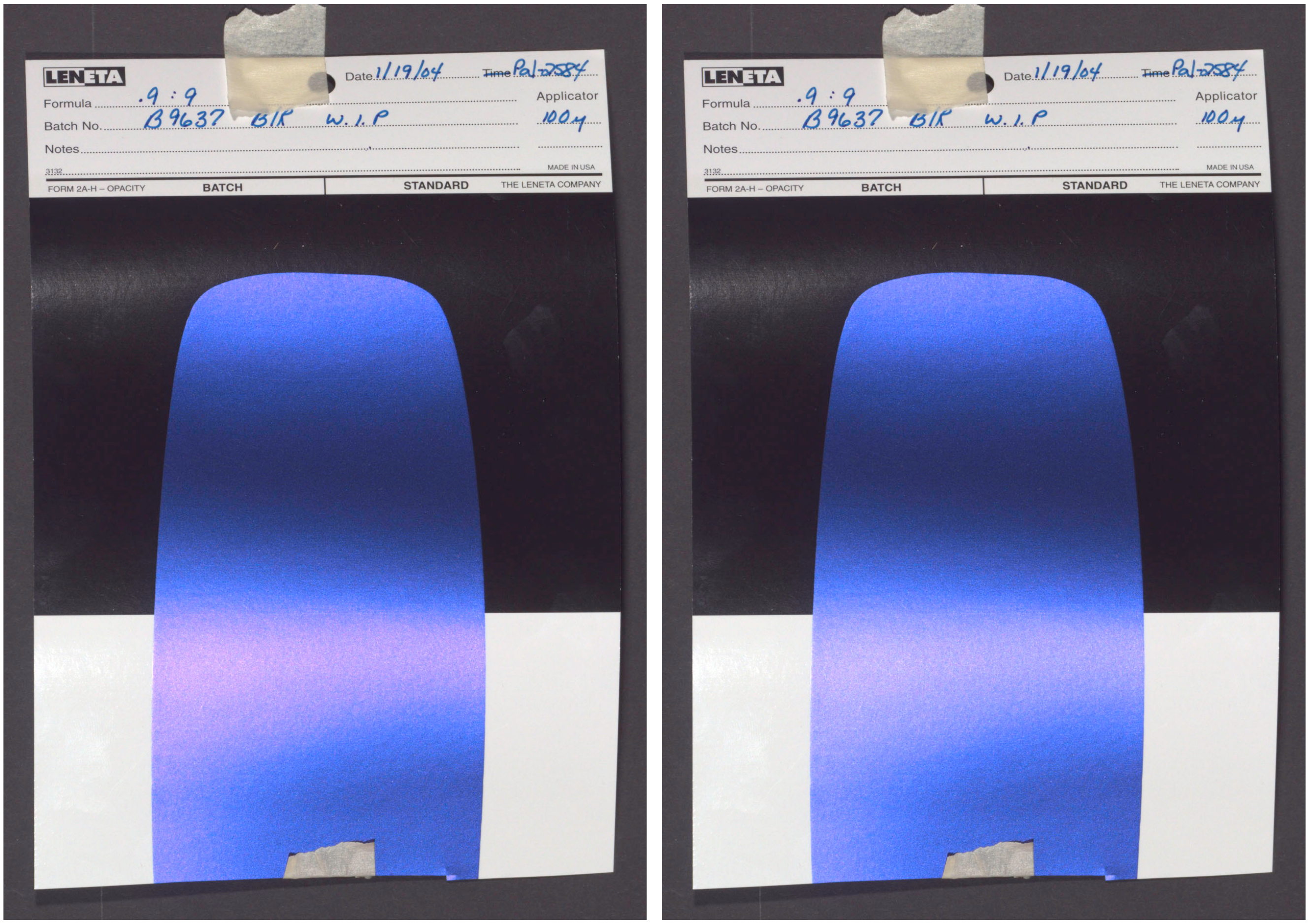

Figure 3*. Chromaflair interference coating rendered using ETRGB (left) and ProPhotoRGB (right). (Images are rotated 90° counterclockwise relative to lighting.)*

References

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