White-point independent RGB Primaries for Color Image Encoding

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Abstract

We present a method to calculate sets of RGB primaries that are white-point independent and have suitable gamut properties when evaluated with regards to surface colors. These primaries can be used as a basis for defining an output-referred color encoding intended for print applications. The resulting RGB sensors are sharp, i.e. de-correlated, emphasizing again that for imaging applications, the choice of a chromatic adaptation transform based on sharp sensors might be most appropriate.

Introduction

There are a number of RGB color encodings with different characteristics (primaries, transfer function, white-point, viewing conditions, quantization) proposed and/or standardized by the imaging industry today, optimized for different purposes within the color imaging workflow. Most define a fixed adopted white-point, usually D50 or D65. However, the adapted white-point of scenes can vary greatly due to different lighting conditions, and images are viewed under different illuminants. It is therefore necessary to apply chromatic adaptation transforms to represent images in these different encodings, and to accommodate for different viewing conditions. As a result, several chromatic adaptation transforms might be applied to an image before it is finally displayed or printed.

There are several chromatic adaptation transforms (CATs) described in the literature, most based on the von Kries model [1]. Recent research [2,3,4] has shown that for imaging applications, a linear CAT is sufficient to predict corresponding colors under different illuminants. In this model, CIE tristimulus values are linearly transformed by a 3x3 matrix **M** to derive RGB sensor responses under the first illuminant. The values of **M** are transform dependent. The resulting RGB values are independently scaled to get the post-adaptation sensor responses R'G'B' under the second illuminant. The scaling coefficients are based on the ratio of the illuminants' sensor responses. To obtain CIE tristimulus values X'Y'X' under the second illuminant, the R'G'B' are then multiplied by $\mathbf{M}^{-1}$, the inverse of matrix **M**. Equation (1) describes a matrix notation of this concept:

$$\begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = [\mathbf{M}]^{-1} * \begin{bmatrix} R'_w/R_w & 0 & 0 \\ 0 & G'_w/G_w & 0 \\ 0 & 0 & B'_w/B_w \end{bmatrix} * [\mathbf{M}] * \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \quad (1)$$

Quantities R_w, G_w, B_w and R'_w, G'_w, B'_w are computed from the tristimulus values of the first and second illuminants, respectively, by multiplying the corresponding XYZ vectors by **M**.

We found that there are RGB sensor responses with gamut properties that make them suitable for defining a color encoding. Such RGB encodings can be considered to be white-point independent, because the image RGB values are equal to the post-adaptation sensor responses (after linearization, if necessary). From the standpoint of chromatic adaptation, the image RGB values are an appearance description. When transforming these RGB values to the corresponding color XYZ values for a particular adopted white chromaticity, the scaling for the destination adopted white is applied to the matrix that transforms from RGB to XYZ. This matrix is obtained by pre-multiplying matrix $\mathbf{M}^{-1}$ by the RGB scaling from an equi-energy adopted white to the destination adopted white. Likewise, converting XYZ values for a particular adopted white to the RGB appearance description involves applying the inverse of the matrix that is used to transform from the RGB values to the adopted white XYZ values. It can be assumed that color image processing would become computationally "cheaper," and quantization errors would be minimized if images were encoded based on RGB primaries that exhibit such favorable chromatic adaptation behavior.

Experiment

Through a spherical sampling technique described previously [5], a large number (~2500) of XYZ to RGB transforms (**M**) were found that are not statistically significantly different from CMCCAT2000 in predicting corresponding colors. The goal here is to find among them the RGB to XYZ transforms ($\mathbf{M}^{-1}$) and the corresponding RGB primaries that wholly enclose the gamut of optimal surface colors [6] while minimizing the "waste" of encoding colors outside of the surface gamut. Using surface colors to define the target gamut implies that the resulting color encoding is optimized for print reproduction, i.e. it falls into the class of output-referred color encodings. However, the method presented here works with any target gamut, and can be used to find the optimal RGB primaries for any encoding intent.

A set of RGB values describing the RGB cube surface was transformed to XYZ using $\mathbf{M}^{-1}$, which was pre-multiplied by the RGB scaling to D50. Note that for the RGB to XYZ transformation matrices $\mathbf{M}^{-1}$ to be white-point preserving, the row sums of the matrices need to be equal to unity.

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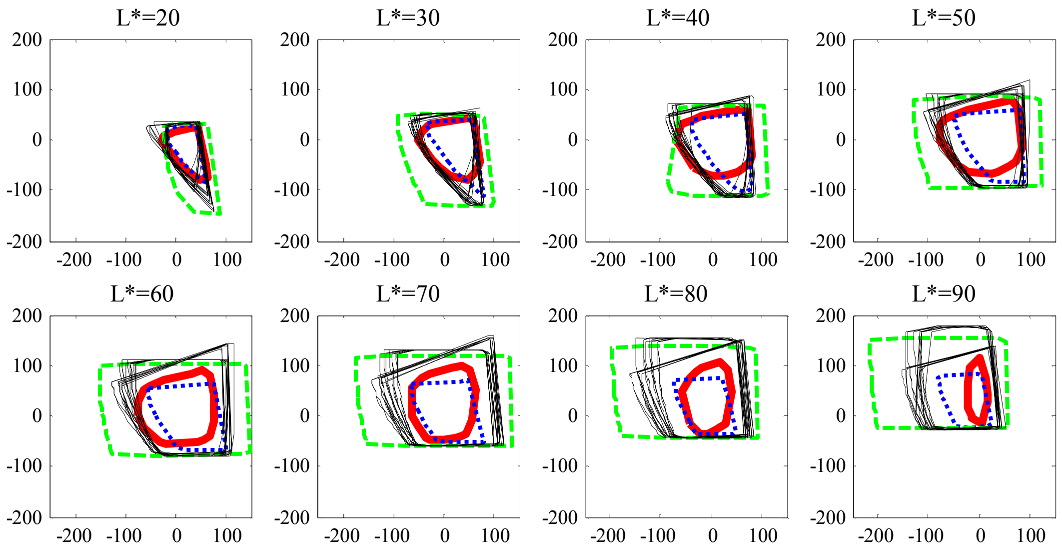

*Figure 1: a*b* gamuts at different levels of L*: surface (—), 20 best RGB (-), ROMM/RIMM (--), ITU-R.BT 709 (…)*

The resulting XYZ values were transformed to CIE L*a*b* under D50 and compared to the surface gamut. For an interval of L*=5, between L*=15 and L*=90, the coverage of the surface gamut *(encodable gamut)* and the percentage of the total gamut that the surface gamut occupies *(useful gamut)* was calculated. A larger encodable gamut implies that more of the surface gamut is contained within the RGB encoding gamut. A larger useful gamut suggests that less L*a*b* values outside of the surface gamut is encodable.

The percentages of encodable and useful gamut were calculated by comparing the convex hull at each level of L*. The intersections of surface and tested gamut was obtained through a sequential angular method, where the considered areas were calculated with a polygon area function whose main steps are a Delaunay triangulation of the considered polygon, followed by the extraction of the polygon's area from the triangle areas.

For comparison, the gamuts of the equi-energy ROMM/RIMM RGB to XYZ and ITU-R.BT 709 to XYZ transforms were also considered. The mean encodable gamut, calculated over the different L* values, is 99.97 percent and 73.9 percent and the useful gamut 30.8 and 79.4 for ROMM/RIMM and ITU-R.BT 709, respectively. These two transforms have been considered previously as chromatic adaptation transforms, and it was found that they do not perform as well as the most popular CATs [7].

In Figure 1, the gamuts of the 20 "best" transforms, i.e. the ones that resulted in the largest useful gamuts, are plotted at different levels of L* and compared to the surface, ROMM/RIMM and ITU-R.BT 709 gamuts. The mean encodable gamuts for the plotted transforms are ≥ 91.6 and the useful gamuts are ≥ 49.5 percent.

In Figure 2, the corresponding RGB sensor sets are plotted. Compared to CMCCAT2000, the optimal RGB sensors in terms of gamut coverage are much more de-correlated than the CMCCAT2000 sensors.

Conclusion

We have presented a method to calculate a set of white-point independent RGB primaries that have good surface gamut coverage properties, which makes them suitable as basis to define an output-referred color encoding intended for print reproduction. However, there are other properties to color encodings, such as hue constancy, that need to be investigated before a final selection of the primaries can be made.

We have also shown that the corresponding RGB sensors are much more de-correlated than the CMCCAT2000 sensors. These sensors are similar to the prime color sensors obtained by investigating gamut size and visual efficiency [8]. They also emphasize again that for imaging applications, the choice of a CAT based on sharp sensors might be most appropriate.

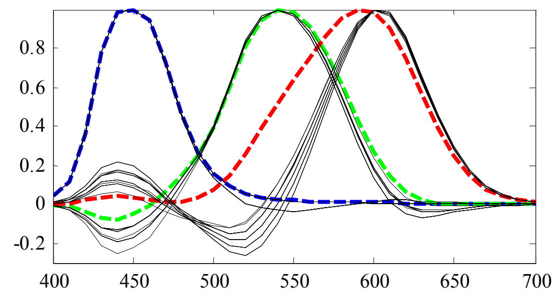

Figure 2: 20 RGB sensor sets (-) that resulted in the largest useful gamuts, compared to CMCCAT2000 (--).

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