Color Coordinate Systems for Accurate Color Image Editing Software

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Abstract

Software for accurate color image editing can be more efficient if it uses basic Color Coordinate System, where Brightness, Chroma, and Hue are tied to quantities that:

- *Have clear physical meaning;*
- *Are independent from color capturing devices or color reproduction devices;*
- *Are adopted for accurate color editing.*

We use ideas from J. Cohen and G. Wyszecki in the construction of the Fundamental Color Space, and introduce three new Color Coordinate Systems to describe the color vectors:

- *Euclidean DEF, where E = F = 0 for grey color;*
- *BCH, where Brightness, Chroma and Hue are spherical coordinates of color stimulus;*
- *Bef, which is a new type of chromatic coordinate system.*

The advantages of these Color Coordinate Systems are illustrated with algorithms for the most popular editing tools: brightness, contrast and saturation. Unlike most popular color image editing software, our editing tools provide users with an instrument for independent modification of each parameter and do not change chromatic coordinates when brightness or contrast is changed.

Introduction

The efficiency of color image editing software depends on the choice of basic CCS (Color Coordinate System). However, CCS that is effective for one editing procedure might be less effective for other. Thus, we offer a collection of correlated CCSs and indicate where each of them is mostly effective.

Any color image editing software has Brightness, Contrast, and Saturation control which usually imitate corresponding adjusting knobs of a Color TV. However, it should be mentioned, that functionality of those knobs

- Correspond to mid 20 century scope of engineering;
- Adjusting one of parameters affects all three of them;
- A person should be experienced enough in order to get a result equivalent to a simple expocorrection with a set of sequential control operations.

Usually **B** (Brightness), **C** (Chroma) or **S** (Saturation), and **H** (Hue), should be used only for non-quantitative references to physiological sensations and perceptions of light. But developers of algorithms for Color Image Editing Software are obliged to find a way to describe stimulus characteristics numerically. In the present time, there are several different formulas in use for B, C, and H calculation. However, all of them:

- Are based on nonlinear CCS, so modification of exposition time for the same subject leads to not only B change, but also C and even H as well;
- Depend on hardware used for color-capturing (reference white point for CIE L*a*b*) or color-reproduction (monitor for HSB);
- Are not adjusted for high dynamic range imaging (HDRI);
- Don't have clear physical meaning.

For considered CCS we use the following definitions for Brightness, Chroma and Hue:

- B – a norm of a color vector S;
- C – an angle between the color vector S and an axis D - color vector representing Day Light (for example D65, D55, EE etc.);
- H– is the angle between the orthogonal projection of the color vector S on the plane orthogonal to the axis D and an axis E - the orthogonal projection of a color vector, corresponding to some fixed stimulus (for example, a monochromatic light with wavelength 700 nm), on the same plane.

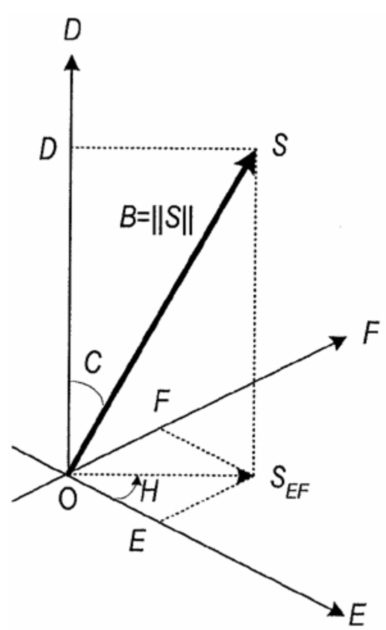

Figure 1. Color Coordinate Systems DEF and BCH

Figure 1 illustrates the relationship between values D, E, and F, coordinates of the vector S in an orthogonal coordinate system DEF, and parameters B, C, and H, which might be considered as spherical coordinates of the vector S in BCH coordinate system. Depending on a chosen specification for D and E definition, we can get different variations of DEF CCS and, therefore, variations of corresponding BCH CCS.

Linear CCS DEF2

If each coordinate of two stimuli mix is equal to a sum of corresponding coordinates of those stimuli, the coordinate system is a Linear CCS. Only Linear CCS may be used for image resize because the use of non-linear CCS (such as sRGB IEC/4WD 61966-2-1 or CIE L*a*b*) for image resize lead to violation of energy conservation law and result in visual image artifacts.

The primary linear CCS in Colorimetry is CIE XYZ. There are two standards: CIE XYZ 1931 and CIE XYZ 1964, which basis vectors span different subspaces. Graphic applications and standards usually use CIE XYZ 1931, so we follow that tradition and use CIE 1931 data to design our linear CCS DEF2. Digit "2" indicates 2º Standard Colorimetric Observer.

We want the new coordinate system to be orthonormal, and there are many ways how to reach this goal. For DEF2 design we use the following restrictions:

- $D > 0$ and $E = F = 0$ for standard Day light D_{65};
- $E > 0$ and $F = 0$ for monochromatic stimulus with 700 nm wavelength;
- $F > 0$ for yellow stimulus;
- CCS DEF2 is an orthonormal coordinate system with J. Cohen metrics [2].

These restrictions unambiguously determine coordinate transformation between CIE XYZ 1931 and DEF2

$$\begin{pmatrix} D \\ E \\ F \end{pmatrix} = \begin{pmatrix} 0.2053 & 0.7125 & 0.4670 \\ 1.8537 & -1.2797 & -0.4429 \\ -0.3655 & 1.0120 & -0.6104 \end{pmatrix} \cdot \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \quad (1)$$

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} 0.6712 & 0.4955 & 0.1540 \\ 0.7061 & 0.0248 & 0.5223 \\ 0.7689 & -0.2556 & -0.8645 \end{pmatrix} \cdot \begin{pmatrix} D \\ E \\ F \end{pmatrix} \quad (2)$$

It is appropriate to mention here that XYZ is essentially non-orthonormal system (with J. Cohen metrics), as it could be seen from the transition matrix (1). Thus, vector e_Z (0.4670, -0.4429, -0.6104) is about twice shorter, than e_X (0.2053, 1.8537, -0.3655) or e_Y (0.7125, -1.2797, 1.0120), and an angle between e_X and e_Y is 142 °.

In DEF2, plane **D = 1** is convenient to depict Gamut of various image reproduction devices. For example, Figure 2 represents Gamut of sRGB monitor.

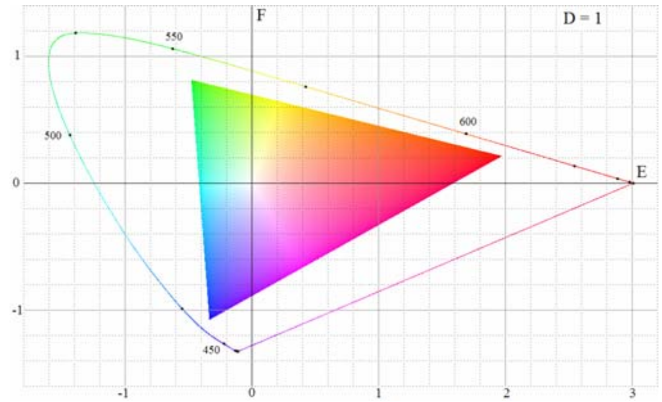

*Fig. 2. Plane **D = 1**. Gamut of sRGB monitor.*

Plane **Y = 1** is much less convenient for Gamut representation, if we take into account, that XYZ is not an orthonormal system. In this case Gamut of all visible colors looks unfamiliarly stretched (Fig.3).

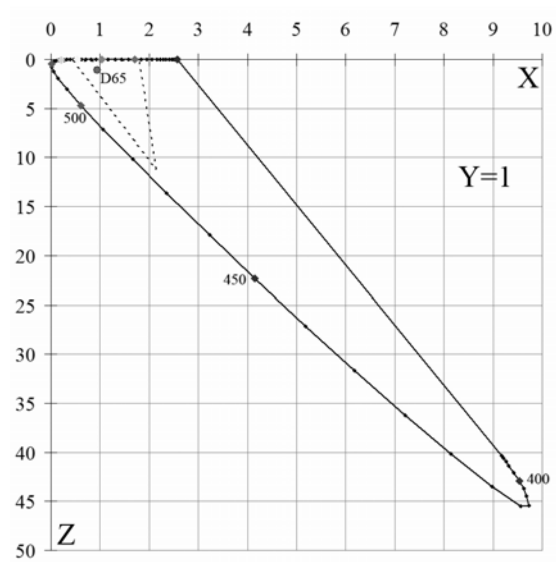

*Fig. 3. Plane **Y = 1**. Gamut of sRGB monitor (dotted line).*

CCS DEF2 might be recommended for algorithm development, such as:

- Resize;
- Transformation to other coordinate system;
- Some types of noise reduction algorithms.

Spherical CCS BCH

Variables B, C, and H defined in introduction are spherical coordinates correlated with D, E, F by the following equations:

$$B = \sqrt{D^2 + E^2 + F^2} \quad (3)$$

$$\begin{cases} D = B \cdot \cos C; \\ E = B \cdot \sin C \cdot \cos H; \\ F = B \cdot \sin C \cdot \sin H. \end{cases} \quad (4)$$

With this definition, Brightness, Chroma and Hue have a clear physical meaning, which helps effectively modify color image transformation algorithms.

Brightness Editing

Brightness modification should not affect stimulus chromatic coordinates. In CCS BCH it might be made as follows:

$$B' = f(B) \quad (5)$$

where *f(B)* is a non–negative function. For example,

$$B' = k \cdot B \quad (6)$$

where k is a positive number. In some graphic editors this transformation named as program exposure compensation.

Contrast Editing

Contrast modification should not affect stimulus chromatic coordinates. In CCS BCH it might be made as follows:

$$B' = f(B, B_0) \quad (7)$$

where $f(B,B_0)$ is a non–negative function. For example,

$$B' = B_0 \cdot \left(B / B_0 \right)^{\gamma} \quad (8)$$

where γ is a positive number, and B_0 is a chosen fixed level of brightness.

Saturation Editing

Saturation modification should affect neither stimulus Brightness, nor Hue. In CCS BCH it might be made as follows:

$$C' = g(C) \quad (9)$$

Where *g(C)* is some function.

For example, function *g(C)=C/2* decrease saturation twice (colors become more faded).

Hue Editing

Hue modification should affect neither stimulus Brightness, nor Saturation. In CCS BCH it might be made as follows:

$$H' = h(H) \quad (10)$$

where *h(H)* is some function.

Usually, in order to make this transformation graphic editors apply a turn on a fixed angle α. In CCS BCH Hue modification might be made with the following formula:

$$H' = H + \alpha \quad (11)$$

Color to monochrome transformation

Color-to-monochrome transformation should not affect Brightness. It can be made, for example, as follows:

$$C' = C_0 \quad (12)$$

$$H' = H_0 \quad (13)$$

where C_0 and H_0 are Chroma and Hue of the chosen color.

You can see from presented in the paper algorithms how simple calculations become with convenient CCS. Moreover, described coordinate system does not depend on a certain color reproduction device, and, thus, provides an opportunity to edit an image in the scope of all visible colors.

Chromatic coordinates and CCS Bef

Chromatic coordinates (x,y) and coordinate system Yxy are widely used for Gamut depicting and for the purpose of illustration of some color image transformations. Introducing similar coordinates in DEF is not appropriate because coordinates E and F might take negative values. We believe, that vector direction determined by its intersection with a unit sphere has more geometrical sense, than coordinates of its intersection with a plane. Thus, we introduce chromatic coordinates as follows:

$$\begin{cases} B = \sqrt{D^2 + E^2 + F^2}, \\ e = E / B, \\ f = F / B. \end{cases} \quad (14)$$

In this CCS *B* (Brightness), *e* and *f* are chromatic coordinates.

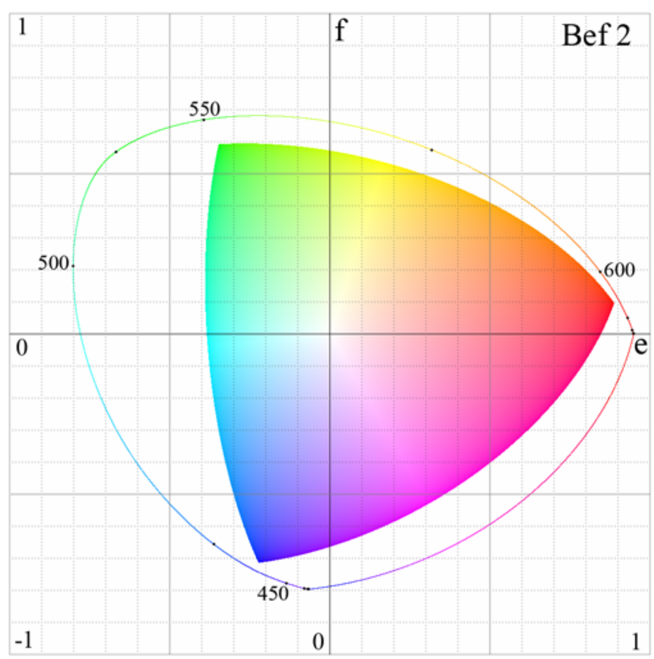

Fig. 4. Gamut of sRGB monitor in the plane ef

Figure 4 represents Gamut of sRGB monitor in the plane ef in Bef2 CCS.

Coordinate system Bef might be recommended for algorithm development in such area as:

- Image storing;
- Noise reduction;
- Transition from color to monochrome image.

Bef is interchangeable with BCH for all algorithms that preserve chromatic coordinates.

It has to be mentioned that, although all formulas and algorithms, described in the chapters, "Spherical CCS BCH" and "Chromatic coordinates and CCS Bef" do not depend on a chosen specification for D and E definition, the numerical output of the formulas depends on it, as well as Gamut representation.

References

1. Wyszecki G. & Stiles W. S., "Color Science, Concepts and Methods, Quantitative Data and Formulae", Second Edition, Wiley Inter Science, 2000.
2. Cohen J. B., "Visual Color and Color Mixture: The Fundamental Color Space", Univ. of Illinois Pr, (2000).

Author Biography

Sergey Bezryadin received MS in physics from the Moscow State University (1976) and PhD in physics and mathematics from the Moscow Institute of Electronic Technique (1982). Since 2001 he has worked in the KWE Int. Inc., San Francisco, USA.