Development of XYZ/sRGB-SCID and Color Gamut Compression

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Introduction

Today, personal computers are prevailing not only for business use but into home broadly and deeply. Digital input and output devices such as digital camera, CRT monitor, LCD, scanner, printer, etc., are also rapidly improving, making digital imaging environments a reality where ordinary people can easily handle digital images. At the same time, improvement of image quality is also strongly expected. Under such a trend, standard images play more and more important roles in the related study and development exemplified by the evaluation of image processing techniques including device and algorithm, the evaluation of image quality, etc.

Among the new work items of ISO/TC130/WG2, preparation of new standard images succeeding ISO12640 (CMYK-SCID) is now being discussed. More specifically, two sets of standard images defined in two color spaces, one being Lab-SCID defined in a D50 color space representing the viewing and evaluating condition for reflection prints such as printed matter and photograph, and the other being XYZ/sRGB-SCID defined in a D65 color space representing the viewing and evaluating condition for images on display devices.

As for image preparation, the Swiss team is in charge of the former set while the Japanese team is in charge of the latter (Figure 1).

The present paper describes XYZ/sRGB-SCID.

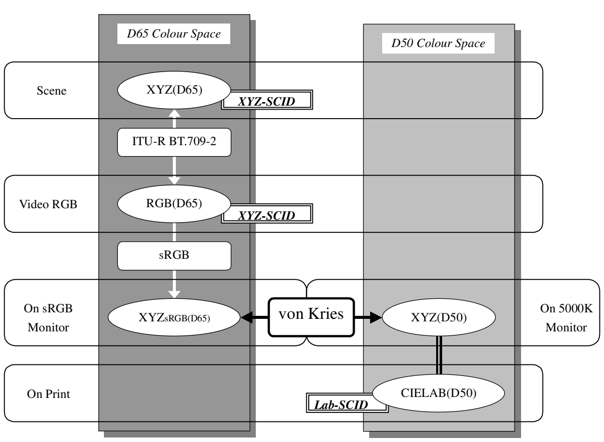

Figure 1. Relationship between D65 and D50 color space.

Features of Image Data of XYZ/sRGB-SCID

Color Space

XYZ/sRGB-SCID, which aims to be applicable to the standardization of not only printed matters but displayed images, has been developed with a premise of various images such as natural images, computer graphics, business graphics, etc., to be displayed on monitors.

To meet the above premise, the ITU-R BT.709-2[1] for various video devices has been adopted as the image capturing norm, and sRGB which will soon be standardized as the monitor display norm[2,3] to ensure a high degree of consistency from image input to monitor output (Figure 2).

As ITU-R BT.709-2 and sRGB both assume the color temperature of D65, the present images are defined in a D65 color space; accordingly the XYZ image data are regarded as describing scenes illuminated with D65 light sources. The RGB image data have been derived so as to be interpreted as such obtained by applying the ITU-R BT.709-2 transformation to the XYZ image data.

It should be noted that the RGB images can be displayed on sRGB monitors without further transformation. It is thus concluded that the RGB images in XYZ/SCID are RGB standard images in the ITU-R BT.709-2/sRGB imaging systems.

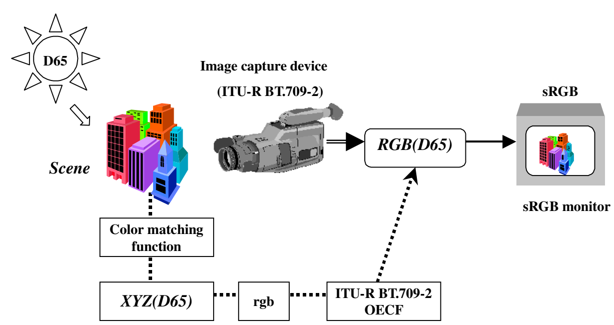

Figure 2. Relationships among the original scene, XYZ, RGB and sRGB monitor.

Image Contents and Image Data Specifications

In order to cope with the future multi-media society in a full use of internet, digital archive, etc., XYZ/sRGB-SCID consists of eight natural scene images and seven synthetic images comprising four computer graphics, one business graph and two color charts.

As for the natural scene images, those containing objects suited for image quality evaluation in a well-balanced manner have been chosen with reference to the notes for image quality evaluation described in CMYK-SCID.

On the other hand, the computer graphics are synthetic, pictorial images, some being three-dimensional with shadows and the other being two-dimensional without shadows. The business graph includes a bar chart, a circle graph, letters, etc., all widely used for presentation, etc.

Table 1 Specifications of image data.

File name	Descriptive name	Height (pixels)	Width (pixels)	Color Space	Bits depth	Characteristics
N1	Woman with glass	4096	3072	XYZ	16-bits	Human skin tone
				RGB	8-bits	
N2	Flowers	3072	4096	XYZ	16-bits	Color reproduction
				RGB	8-bits	
N3	Fishing goods	4096	3072	XYZ	16-bits	Image sharpness
				RGB	8-bits	
N4	Japanese goods	3072	4096	XYZ	16-bits	Wide color gamut
				RGB	8-bits	
N5	Field fire	3072	4096	XYZ	16-bits	Color reproduction
				RGB	8-bits	
N6	Pier	3072	4096	XYZ	16-bits	Fine geometrical patterns
				RGB	8-bits	
N7	Threads	3072	4096	XYZ	16-bits	Wide color gamut
				RGB	8-bits	
N8	Silver	4096	3072	XYZ	16-bits	Gray reproduction
				RGB	8-bits	
S1	Teapot	360	480	XYZ	16-bits	3D-CG
				RGB	8-bits	
S2	Fukusuke	1536	2048	XYZ	16-bits	3D-CG
				RGB	8-bits	
S3	Cat	1536	2048	XYZ	16-bits	2D-CG
				RGB	8-bits	
S4	Sports	2048	1536	XYZ	16-bits	2D-CG
				RGB	8-bits	
S5	Business-graph	1536	2048	XYZ	16-bits	Business graph
				RGB	8-bits	
S6	Color chart	1332	2736	XYZ	16-bits	Step tablets
				RGB	8-bits	
S7	Color vignettes	2608	4256	XYZ	16-bits	Vignettes
				RGB	8-bits	

The color charts are test images designed for the quantitative evaluation of output devices, consisting of primary, secondary and tertiary color step tablets and vignettes.

The gradation depth of the individual image data is 8 bits/color for RGB and 16 bits/channel for XYZ. Each image has a unified aspect ratio of 4:3 (or 3:4) except the color charts. In particular, the natural scene images are of high resolution consisting of 4096 x 3072 pixels.

Applications

The RGB image data provided with such characteristics can be widely used for the evaluation of the color reproduction characteristics of imaging systems, the evaluation of color image output devices, and the evaluation of coding techniques associated with the storage and transmission of high resolution image data, etc., while the XYZ image data can be used for experiments on color appearance models, etc., since the both image data are consistent and reliable as high resolution digital data sources.

Image Data Preparation for Xyz/Srgb-Scid

As for the natural scenes of XYZ/sRGB-SCID, each original scene was shot with a 4 x 5 inches color reversal film, which was then scanned with a drum scanner of a high S/N to obtain 4K x 3K image data quantized to 12bits. Further, these data were used to calculate the XYZ values of the recorded film image.

On the other hand, XYZ values are regarded as those describing scenes illuminated with D65 light sources according to the definition of ITU-R BT.709-2. If the distribution of light reflected by such a scene could be captured with an imaging device having the ideal spectral sensitivities defined by ITU-R BT.709-2, then it would be possible to obtain the scene XYZs via the transformation between XYZ and RGB. However, from a practical point of view, production of an electronic imaging device provided with the ideal spectral sensitivities and a sufficiently high resolution is almost impossible. It is also unrealistic to measure the reflection spectra of individual points throughout a real scene.

Thus, to obtain XYZ data representing real scenes, the following approach was adopted which can deal with natural images of high resolution under the precisely defined color space of the present standard.

According to the definition of ITU-R BT.709-2, the linear rgb values are linearly related to the scene brightness. Such linear rgb values can be obtained as follows. First, the colors recorded in a color transparency are transformed to XYZs linear to the scene brightness by using the γ characteristics of the reversal film. After the XYZs thus obtained are subjected to an exposure correction treatment so as to achieve an optimized display lightness on monitors, they are used to derive linear rgb values defined by ITU-R BT.709-2.

Though the final XYZs are different from those of the original scene illuminated with D65 light sources, they can be regarded as those corresponding well to the scene, as they are linearly related to the scene brightness.

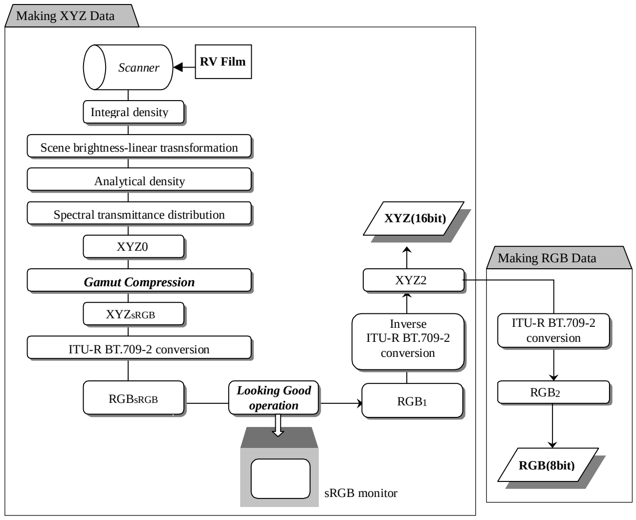

Figure 3. Image data processing flow

However, it must be kept in mind that the device-dependent color characteristics of the color reversal film has been modified by an operation to impart a subjectively favorable appearance to the display image on the sRGB monitor, and further by gamut compression.

In the next section, details of the data derivation will be described.

Figure 3 illustrates such an image data processing flow.

Image Scanning

Each of the eight, 4"x 5" color transparences having captured natural scenes is scanned with a drum scanner described in Table 2 to store the images in digital form.

Table 2 Main features of the scanner.

Manufacturer, Product Type	Dainippon Screen Co., SG-1000 (modified)
Scanning Aperture	25 microns square
Density Resolution	0.001 at D<2.5
A/D Conversion	Analog density signals were quantized to 12bits/channel

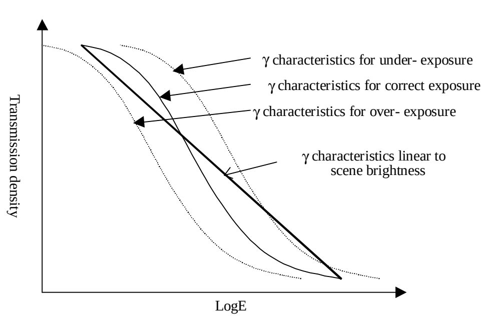

Figure 4. γ characteristics of the color reversal film used for image capture.

The resulting data consist of transmission density values quantized to 12bits/channel.

Transformation of Integral Density to Analytical One

Via the inverse transform of the γ characteristics of the reversal film, the data gathered with the scanner are converted to those linearly related to the scene brightness (Figure 4).

The resulting integral density data, Di,r, Di,g and Di,b are first converted to analytical ones, Da,r, Da,g and Da,b.

The conversion matrix **Ak, l** has been calculated in advance for each kind of reversal film.

$$\begin{pmatrix} Da,r \\ Da,g \\ Da,b \end{pmatrix} = \mathbf{Ak,l} \begin{pmatrix} Di,r \\ Di,g \\ Di,b \end{pmatrix} \quad (1)$$

Calculation of Spectral Transmittance Distribution

By using the Lambert-Beer's law, the spectral transmittance of each pixel is calculated;

$$T(\lambda) = 10^{[-\Sigma\, Da,i \times DDi(\lambda)]} \quad (2)$$

wherein i = r, g or b, and DDi(λ) represents the spectral density distribution exhibited by the individual dyestuff existing alone.

Tristimulus Value

Tristimulus values XYZ0 are calculated by using a D65 light source and the color matching functions. In the following formulae, S(λ) is the spectral energy distribution of the light source,[4] and X(λ), Y(λ) and Z(λ) are the color matching functions.[5]

$$X0 = 100\,(\Sigma\, S(\lambda)T(\lambda)X(\lambda)\,)/\,\Sigma\, S(\lambda)Y(\lambda)$$

$$Y0 = 100\,(\Sigma\, S(\lambda)T(\lambda)Y(\lambda)\,)/\,\Sigma\, S(\lambda)Y(\lambda) \quad (3)$$

$$Z0 = 100\,(\Sigma\, S(\lambda)T(\lambda)Z(\lambda)\,)/\,\Sigma\, S(\lambda)Y(\lambda)$$

Gamut Compression

As all the colors of the images must be reproduced on sRGB monitors without any further transformation, the color gamut thereof has been compressed to such that sRGB monitors can reproduce; in other words, the XYZ values representing each standard image must be within the color gamut of ITU-R BT.709-2.

Since the color gamut of color transparencies differs from that of ITU-R BT.709-2 in general, the XYZ to RGB transformation yields certain colors not reproducible with sRGB monitors if the image data are not subjected to a gamut compression. Among various methods treating the data outside the reproducible color gamut, we have adopted one to be described below.

Outline of Gamut Compression

In order to carry out a gamut compression in the CIELAB color space, the data XYZ0 are transformed to the

CIELAB. Separately, the following two regions are provided within the ITU-R BT.709-2 color gamut (Figure.5)
(1) An original color region where no color change takes place with the present gamut compression, and
(2) A compressed color region where colors outside the ITU-R BT.709-2 color gamut as well as close to its boundaries are present as the results of the present gamut compression.

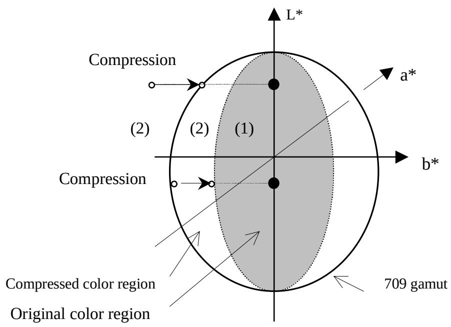

Figure 5. Conceptual illustration of gamut compression.

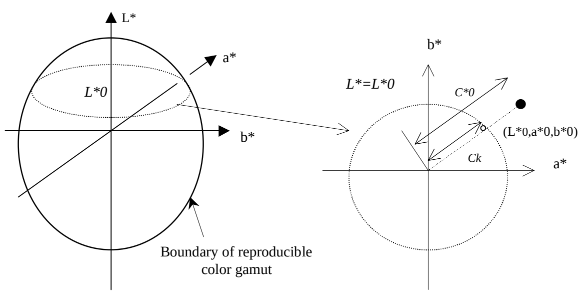

Figure 6. Examples of data lying outside and inside of the reproducible color gamut.

When the Lab data lie in the original color region, they are conserved as they are. When the Lab data lie in the compressed color region, chroma is compressed so as to keep lightness and hue unchanged.

Algorithm

Step1; The XYZ_0 data are transformed to the CIELAB data $\boldsymbol{V}_{lab}$(i,j) where i and j represent the spatial coordinates of pixel.

$$\boldsymbol{V}_{lab}(i,j)=(L0^*,a0^*,b0^*) \tag{4}$$

Further, the following two formulae are used to derive chroma C^* and hue angle θ^*.

$$C0^*(i,j)=\{a0^*(i,j)^2+b0^*(i,j)^2\}^{1/2}$$
$$\theta0^*(i,j)=\tan^{-1}(b0^*(i,j)/a0^*(i,j)) \tag{5}$$

Then, the CIELAB data $\boldsymbol{V}_{lab}$(i,j) is expressed in terms of chroma and hue as,

$$\boldsymbol{V}_{lab}'(i,j)=(L0^*,C0^*,\theta0^*) \tag{6}$$

Step2; Using the lightness data L_0^* and the hue data θ_0^* of the pixel in concern, the chroma data C^*_k of the boundary for ITU-R BT.709-2 with the same L_0^* and θ_0^* is calculated.

Then, the chroma data C^*_0 of the pixel in concern is normalized with the calculated chroma C^*_k.

$$P(i,j)=C0^*(i,j)/\,Ck^*(i,j) \tag{7}$$

Step3; The boundary point P_x of the original color region and compressed one as described outline is illustrated in Figure 7.

The histogram of the normalized chroma is obtained by performing the above calculation for all the pixels.

A peak is identified that lies below but closest to 1.0 in the histogram. Such a peak defines the mapping boundary (Figure 7).

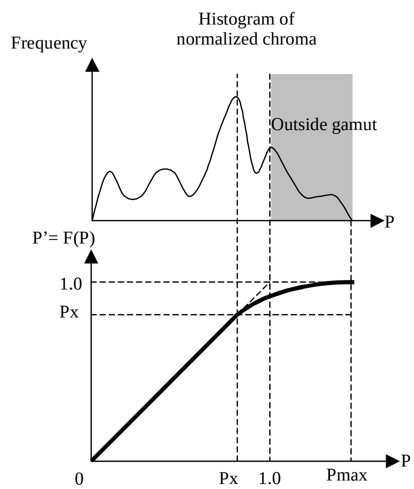

Figure 7. Example of compression function.

Step4; The compression function F(P) must satisfy the following conditions, where P_{max} is maximum data of normalized chroma:

1. $F(P_{max}) = 1.0$
2. At the mapping boundary P_x,

$$\partial F(Px)/\partial Px = 1.0 \tag{8}$$

3. For $0 \le P \le P_x$, F(P) = P, and
4. For $P_x < P \le Pmax$, F(P) increases smoothly and monotonically.

By making use of the compression function defined above, the normalized chroma of the pixel in concern after compression P' is calculated from its normalized chroma P. Then, the chroma value C^*_1 after compression can be obtained by

$$C1^*(i,j)=P'\,Ck^*(i,j) \tag{9}$$

By the transformation of C^*_1 to XYZ, one finally completes color mapping onto the reproducible gamut of ITU-R BT.709-2 color space.

Definitions in ITU-R BT.709-2 and XYZ/RGB transformation

The primary colors and the white of ITU-R BT.709-2 are defined by the following color coordinates in Table 3:

Table 3 CIE color coordinates for ITU-R BT.709-2 reference primaries and CIE standard illuminant.

	Red	Green	Blue	D65
x	0,6400	0,3000	0,1500	0,3127
y	0,3300	0,6000	0,0600	0,3290
z	0,0300	0,1000	0,7900	0,3583

Then, the transformation from XYZ(D65) to linear rgb values is performed by

$$\begin{pmatrix} r \\ g \\ b \end{pmatrix} = \begin{pmatrix} 3.2410 & -1.5374 & -0.4986 \\ -0.9692 & 1.8760 & 0.0416 \\ 0.0556 & -0.2040 & 1.0570 \end{pmatrix} \begin{pmatrix} 0.01 & 0 & 0 \\ 0 & 0.01 & 0 \\ 0 & 0 & 0.01 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \quad (10)$$

Further, the opto-electronic characteristic function (OECF) of video cameras is defined as follows;

$$V' = \begin{cases} 1.099 \times V^{0.45} - 0.099 & 0.018 \le V \le 1.0 \\ 4.50 \times V & 0.0 \le V < 0.018 \end{cases} \quad (11)$$

$$V' = R, G, B$$

$$V = r, g, b$$

wherein r, g and b are the linear rgb values of the original scene, and R, G and B are the non-linearly transformed RGB video signals.

Data processing to make the appearance of each image displayed on an sRGB monitor subjectively favorable

As the present standard is aiming to be used in a broad range of applications not only for high-end but also low-end users, each image is expected to have a subjectively favorable quality. Thus, it must satisfy the requirement of looking subjectively favorable on monitors as well as in the form of hardcopy (Looking good).

For that purpose, we have taken the following steps; transformation of the XYZ values compressed within ITU-R BT.709-2 color gamut onto the RGB color space defined by ITU-R BT.709-2, “Looking good” operation of the resulting data to secure a subjectively favorable appearance under sRGB monitor display conditions, and inverse transformation of ITU-R BT.709-2 to derive XYZ values.

The “Looking good” processing mainly consists of lightness (exposure) correction, color saturation enhancement, etc.; the processing parameters have been determined by subjective evaluation of each image.

XYZ/RGB Data Description

XYZ image data

The XYZ image data were normalised by the XYZ values for D65 white, and expressed as 16bit data;

$$X_{16bit} = 65535\ X/X_{65}$$

$$Y_{16bit} = 65535\ Y/Y_{65} \quad (12)$$

$$Z_{16bit} = 65535\ Z/Z_{65}$$

wherein, X_{65},Y_{65} and Z_{65} represent the tristimulus values of D65.

RGB Image Data

The RGB image data were obtained by first converting the XYZ, via ITU-R BT.709-2 transformation, to non-linear RGB data, which were multiplied by 255 to obtain 8bit data without sign;

$$R_{8bit} = 255\ R$$

$$G_{8bit} = 255\ G \quad (13)$$

$$B_{8bit} = 255\ B$$

R_{8bit}, G_{8bit} and B_{8bit} all were rounded to the nearest integers.

Ending Remarks

The image data preparation for XYZ/sRGB-SCID now under study in ISO/TC-130/WG2 has been described.

The present standard images are widely applicable to the evaluation of the color reproduction characteristics of imaging systems, the evaluation of color image output devices, and the evaluation of coding techniques associated with the storage and transmission of high resolution image data, etc., as they are of guaranteed, consistent quality.

To facilitate its early and extensive use, the present standard is now being made into JIS(Japanese Industrial Standard). Specifically, a part of the XYZ/sRGB-SCID images will be distributed in the summer of 2000.[NOTE1]

NOTE.1

The JIS version of XYZ/sRGB-SCID does not include N6 to N8 images. Those who are interested in them may refer to Standard HIgh Precision Pictures (SHIPP) [6] which are based on the same color space as the present standard and which include N6 to N8.

References

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