Adaptive Gamut Mapping Method Based on Image-to-Device

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Abstract

This paper describes Gamma-Compression Gamut Mapping Algorithm based on the concept of Image-to-Device. Considering the relations of color gamut boundaries between the devices (such as printers, displays) and image source, the proposed method adjusts the distribution of image colors fitting to the output device gamut. The mapping algorithm is applied to adjust the distribution of image colors on Chroma-Lightness planes after 6 main hue leaves are divided.

During the psychopsysical experiments in which the proposed method is compared with the conventional Device-to-Device methods, the proposed method works better for color appearance matching between the test image on CRT screen calibrated with sRGB standard and printed hardcopy image after mapping.

Introduction

On the process of digital color reproduction, a key feature is the use of gamut mapping techniques[1] to adjust the different color gamuts between displays and printers. However, most of the current gamut mapping techniques are based on the concept of Device-to-Device, which is negligent of the image's color distribution.

Even though the concept of device-independence has gradually been applied to many color management system in image input and output devices, it is not enough to solve the color appearance problems between different devices, in particularly between the monitor image and the hardcopy image. Color appearance error between these 2 devices comes from the difference in their color gamut sizes. Usually the monitor's color gamut is wider than printer's color gamut. To resolve this problem, the establishment of a gamut mapping method, based on the concept of image-dependence is necessary. Then the non-linear compression Gamut Mapping Algorithm, which is based on the concept of Image-to-Device, is proposed by coupling the hue-division method with the gamut-compression coefficient γ.

Gamut Mapping Algorithms

The proposed Gamma-Compression Gamut Mapping Algorithm (Gamma-Compression GMA) is preformed based on the following set of equations:

$$t = o \cdot \left(\frac{s}{i}\right)^{\gamma}; \qquad (1)$$

for cases (a) and (b) of Figure.1

$$t = o_2 + \left(o_1 - o_2\right) \cdot \left(\frac{s - i_2}{i_1 - i_2}\right)^{\gamma}; \qquad (2)$$

for case (c) of Figure.1

The distance from the determined point **p** to the source color is represented by **s**. And the distance from **p** to the target color is represented by **t**. The distance from **p** to input gamut is represented by **i** (or $\mathbf{i}_1$, $\mathbf{i}_2$ in case (c)), and the distance from **p** to output gamut is represented by **o** (or $\mathbf{o}_1$, $\mathbf{o}_2$ in case (c)). The gamut-compression coefficient γ must be set between 0 and 1 (but the actual range will be determined by the experiment).

By drawing color gamut boundaries on the C*-L* plane in terms of input data and output device, 3 different cases appear, as shown in Figure 1. In the cases (a) and (b), the input data gamut is completely enclosed by the output device gamut. Then Eq (1) is used to compress the source colors along a given line toward the determined point **p** on the L* axis.

In case (c) of Figure 1, the input gamut is not enclosed by the output gamut, but instead cross over each other. Eq (2) is used to compress the source colors along a given line toward the determined point **p** on the C* axis.

In this experiment, the Device-to-Device (D-D) mapping is performed by GMA from the input display gamut (Device 1) toward the output printer gamut (Device 2). And the Image-to-Device (I-D) mapping is performed by GMA from the source image gamut (Image) toward the output printer gamut (Device).

However, if only the output printer gamut is used, the clipping method is applied to keep the color distributions undisturbed inside the printer gamut, while the gradations of colors outside the printer gamut are sacrificed.

Experiment

Two kinds of images from CD-ROM is used for testing the above algorithms. One is natural image, and the other is CG image. Since both images include high chromatic and out-of-gamut colors, the differences between the CRT image and the printed hardcopy image are easily distinguished.

In the CIELab space color data with equal interval are generated and transformed into corresponding XYZ tristimulus values and sRGB values on CRT monitor.

Here, 1675 color chips formed from the Lab values on the sRGB monitor are printed by Epson PM-750C inkjet printer. The XYZ tristimulus values are measured with spectrophotometer and then transformed into CIELab space.

The sRGB values of the test images are also transformed into XYZ tristimulus values, and the color distributions of the images in CIELab space are obtained (see Figure 2).

Dividing the Lab distributions into subjective colors of red, green, blue, cyan, magenta and yellow, the data of devices and image sources are separated into 6 main hue leaves. These 6 C*-L* planes are shown in Figure 3. Then the GMAs are applied to each hue leaf plane.

After completing the hue-division of devices and image sources, 16 color points with equal intervals are selected along a given line with end points being the determined point **p** on the L* axis and the maximum chroma point of image source **c**. This maximum chroma point **c** is usually located on the image gamut function. Then those 16 color points are converted into the corresponding sRGB signals, and the clipping GMA and 6 Gamma-Compression GMAs (with γ values set to 1.0, 0.9, 0.8, 0.7, 0.6, 0.5) are applied to these sRGB signals, with results in the production of 7 color charts by inkjet printer (see Figure 4).

The XYZ tristimulus values of all printed color charts after mapping are measured with spectrophotometer and then analyzed on C*-L* planes.

The measured results of blue color charts are shown in Figure 5. The clipping method will allow printed images to lose their gradations on the high chroma-lightness field, but may remain more details on the other areas of the image. Since the color distribution by the clipping method is limited just to the inside of the image gamut, it will be used as a reference to find the fitting range for γ when comparing with the distributions of 6 I-D Gamma-compression GMAs (see Figure 5).

Both I-D, D-D Gamma-Compression GMAs (with γ set to 1.0, 0.8, 0.5) along with clipping GMA are applied to natural image and CG image. This produces totally 14 hardcopies (7 GMAs * 2 images).

Monitor's white point was set to the chromaticity near CIE Illuminance D65 with a peak luminance of 80 cd/m^2. The printed hardcopies after mapping are viewed in a light box with the same color temperature and peak luminance as monitor's set. CRT monitor was calibrated to near sRGB standard.[2]

A psychopsysical experiment was carried out to make a comparison of color appearance matching between the original CRT image and the printed hardcopies after mapping. A paired-comparison technique was used and both images were appraised by 12 observers in a dim viewing surround where the level of ambient illumination was approximately 64 lux. Using Thurstone's law of comparative judgement, the data from the psychopsysical experiment were analyzed to generate interval scales (Z-score values).

Results

According to the γ value estimation experiment, the color distributions of I-D Gamma-Compression GMA with γ values of 0.7~0.9 seem to be near that of clipping GMA, omitting the high chroma-lightness field.

Also, the evaluation results of the psychopsysical experiment show that clipping method and I-D Gamma-compression GMA of $\gamma = 0.8$ are superior to other methods for natural image's mapping, whereas clipping method has the best result in all methods for CG image's mapping.

If γ is set within the range of 0.7~0.9 for I-D gamma-compression GMAs, better graduations of printed natural images could be obtained.

Although clipping method causes the image to lose some colors located outside the printer gamut, it can preserve higher chroma of printed images after mapping. For this reason, clipping method gives better appearance for CG image's mapping.

Conclusion

The optimizing method to estimate the fitting gamut-compression coefficient γ of Gamma-compression GMA is proposed. I-D Gamma-Compression GMA with γ values of 0.7~0.9 work better for natural images, whereas clipping GMA works well for CG image. If the image's graduation is preferred (as in the purpose of most of the natural images), I-D Gamma-compression GMA is superior to the conventional methods based on the D-D concept. If the high-chroma image (like CG images) is preferred, clipping method will be a better choice for use.

Reference

1 J'an Morovic and M.Ronnier Luo,*Gamut mapping algorithms based on psychophysical experiment*, *Proc*. 5th IS&T/SID CIC , pg. 44-49 (1997).

2 *A Standard Default Color Space for the Internet-sRGB*, http://www.w3.org/Graphics/Color/sRGB

Biography

Chen Hung-Shing received his B.S. degree in Graphic Arts Engineering from Chinese Culture University, Taipei, Taiwan, R.O.C, in 1990. During 1995-1997, he currently holds a M.S. degree in Printing Image Engineering from Chiba University, Japan. Since April 1997, he has been studying toward his PhD course at Chiba University's Graduate School of Science and Technology. His research interests include color gamut mapping, digital printer and color management technologies for multi-media.

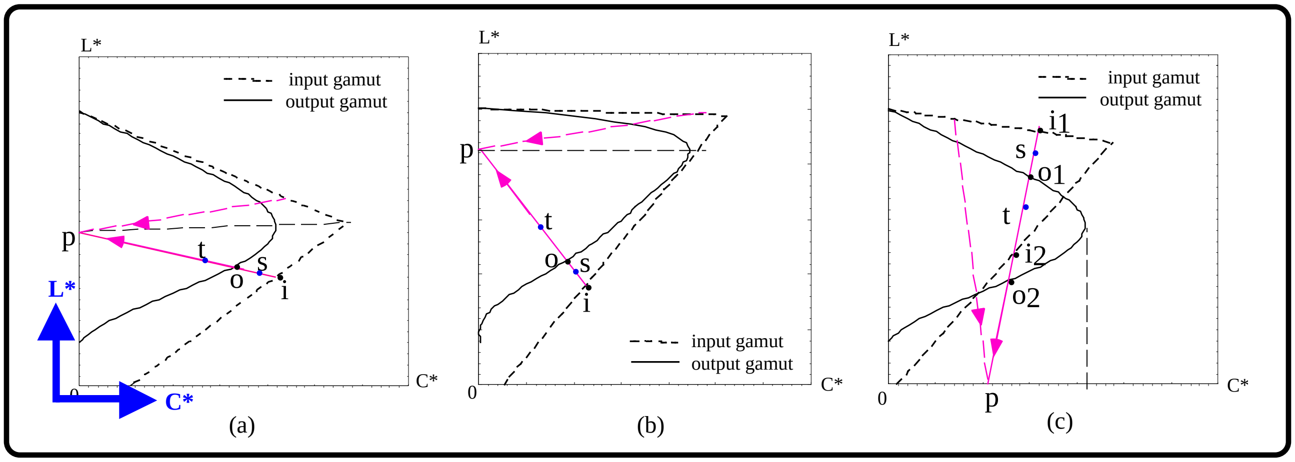


Figure.1 Overview of the relationships between input gamut and output gamut

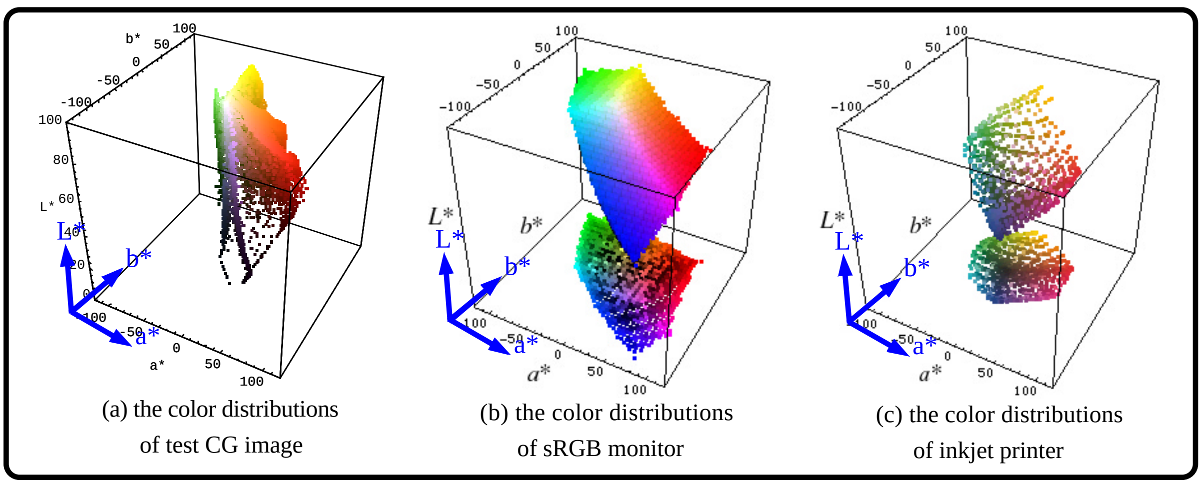


Figure.2 Overview of the color distributions of the CG image and devices in CIELab space

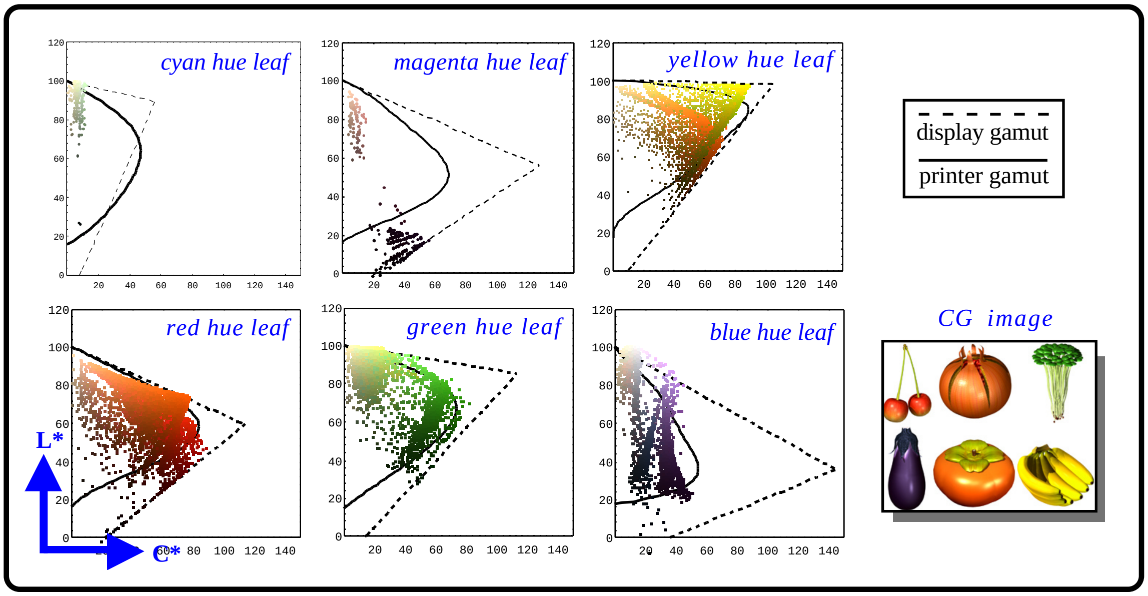


Figure.3 Six C-L* planes of test CG image by hue-division*

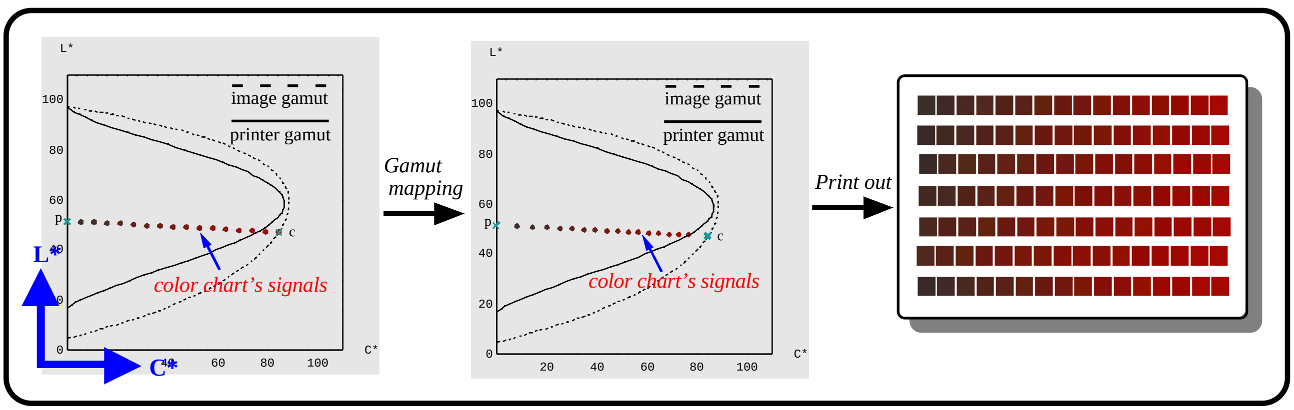
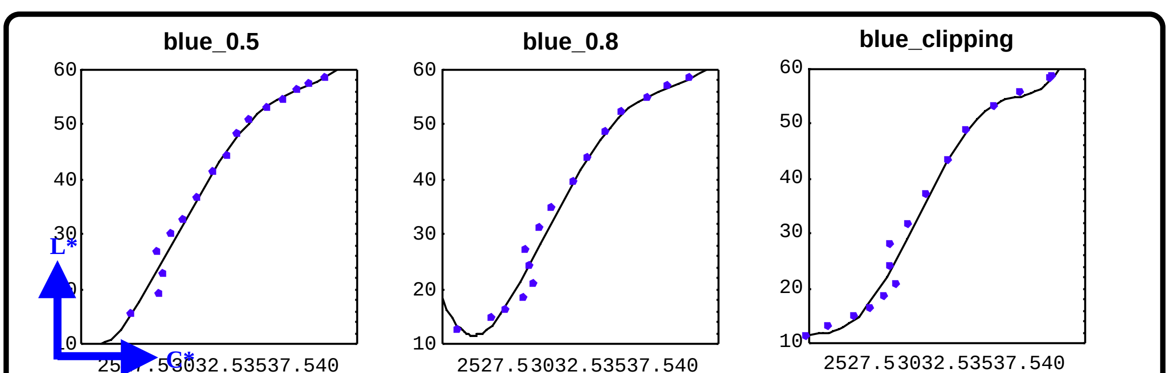


Figure.4 A set of printed color charts for estimating the fitting gamut coefficient γ



(a) blue color chart mapped by γ = 0.5

(b) blue color chart mapped by γ = 0.8

(c) blue color chart mapped by clipping GMA

Figure.5 Color distributions on C-L* plane of blue color chart mapped by clipping GMA and Gamma-Compression GMA of γ = 0.5 and 0.8*