A Versatile Gamut Mapping for Various Devices

Ryoichi Saito and Hiroaki Kotera, Department of Information and Image Sciences, Chiba University, Chiba, Japan

Abstract

*GMA (Gamut Mapping Algorithm) is an essential technology to color appearance matching across the different devices or media. We have been introduced a design concept of 3D Image-to-Device GMA using compact GBD (Gamut Boundary Descriptor) and its extension into bi-directional versatile GMA with gamut compression from wide to narrow or gamut expansion from narrow to wide, depending on the image color distribution. Both algorithms were based on the common concept of "***image-dependent***". Until now, GMA was mainly accomplished that was mapped the image into the printer gamut. However, because the observation method of the image has various devices, a versatile GMA adapted to a variety of display devices is necessary. In this paper, the gamut of display devices (such as LCD(liquid-crystal display) and CRT(cathode ray tube), etc) and printer devices (such as ink-jet- and toner-based-printer) was discussed in CIELAB space, and the versatile GMA was presented that image was well adapted to each device gamut using compact GBD.*

Introduction

On the process of cross-media color reproduction, a key feature is to use the gamut mapping techniques to adjust the difference in color gamut between displays and printers. We proposed a ***Image-to-Device (I-D) 3D Gamut Mapping algorithm (GMA)*** by introducing the quick gamut comparison.[1-3] To perform the 3D ***I-D GMA*** in effective, a simple and compact Gamut Boundary Descriptor ***(GBD)*** is necessary. We have been proposed a ***GBD*** for comparing the gamut between image and device in discrete polar angle segment divided by ($\Delta\theta$, $\Delta\varphi$) in CIELAB space. The gamut shell is described as the simple radial distances, called ***r-image***. This ***GBD*** represents a monochromatic 2D image whose pixel denotes the radial vector magnitude arranged in discrete integer address. This simple presentation makes it easy to compare the point-to-point gamut sizes between image and device. Current GMA is mostly addressed to compress the out-of-gamut colors into the inside of printer gamut.[4,5] Indeed, the highly saturated gamut images such as CG images on monitor are necessary to be compressed to make the appearance matching to print. However, the printer gamut has been much expanded with the improvements in printing media and devices. Sometimes, the pictures even if taken by digital camera, only fill the narrow gamut ranges as compared with wide gamut media such as hi-fi inkjet print and hoped to be corrected to vivid colors. On the other hand, electronic technology is replacing our old way of communicating faster than ever. People tend to read more on their personal PC than printing papers. Hence, source image doesn't always fill the entire device gamut, and sometimes its' gamut need to be enlarged to get the better color renditions. Because the observation method of the image has various devices, a versatile GMA adapted to a variety of display devices is necessary. We have presented a method of image-dependent gamut compression using ***r-image*** and introduced image-dependent gamut expansion using histogram stretch.[6]

This paper proposes a histogram rescaling in reference to the each ***GBD*** of image and device is automatically applied for gamut mapping. The paper reports the experimental results in both compression for wide gamut and expansion for unsaturated narrow gamut.

Histogram Rescaling Using GBD

We have developed an automatic gamut extraction algorithm from a random color map. The source image in the CIELAB space are segmented by a constant polar angle step, that is, $\Delta\theta$ in hue and $\Delta\phi$ in sector. The gamut center was set at a neutral point $[L^*_0, a^*_0, b^*_0] = [50,0,0]$.

$$r_{gamut} = \lfloor r_{jk} \rfloor = \max\{r_i\}; \quad (j-1)\Delta\theta \le \theta_i \le j\Delta\theta \quad (k-1)\Delta\varphi \le \varphi_i \le k\Delta\varphi \tag{1}$$

We define the radial matrix $\boldsymbol{r}_{gamut}$ whose element is given by the maximum radial vector in each polar angle segment. The magnitude of radial vector $\boldsymbol{r}_{jk}$ is given by the norm

$$\|\mathrm{r}_{jk}\| = \left[\left(L^*_{jk} - L^*_0\right)^2 + \left(a^*_{jk} - a^*_0\right)^2 + \left(b^*_{jk} - b^*_0\right)^2\right]^{1/2} \tag{2}$$

We proposed to replace the 3-D radial vectors to 2-D distance array arranged in rectangular lattice point *(j, k),* named ***r-image.***[1-3]

In order to perform natural and pleasant gamut adaptation automatically, we propose an image gamut rescaling method based on the histogram stretching. The histogram rescaling method can easily adapt the image gamut to target device gamut setting corresponding lowest value and highest value. Figure 1 illustrates an explanatory model to gamut mapping based on the histogram rescaling.

The histogram rescaling automatically applies the degraded image and compresses the saturated image to the natural and pleasant images. The histograms of lightness and chroma are adapted separately in CIELAB space as the following steps.

1) RGB to LAB conversion,
2) Histogram rescaling for lightness component,
3) Segmentation of chroma component,
4) Histogram rescaling for chroma component.

In the original histogram *p(L)*, lowest value ***a*** and highest value ***b*** are expanded or compressed to target device gamut histogram using equation (3).

$$p(L)' = (T_h - T_l)\frac{p(L) - a}{b - a} + T_l \qquad (3)$$

where T_h and T_l are denote higher point and lower point of target device. After the histogram rescaling of L, the chroma components are segmented into m divisions by ΔH in hue angle H. Then chroma C of each division is expanded or compressed by histogram rescaling as same as L without changing color hue. The hue was segmented to 16 ΔH division in this experiment.

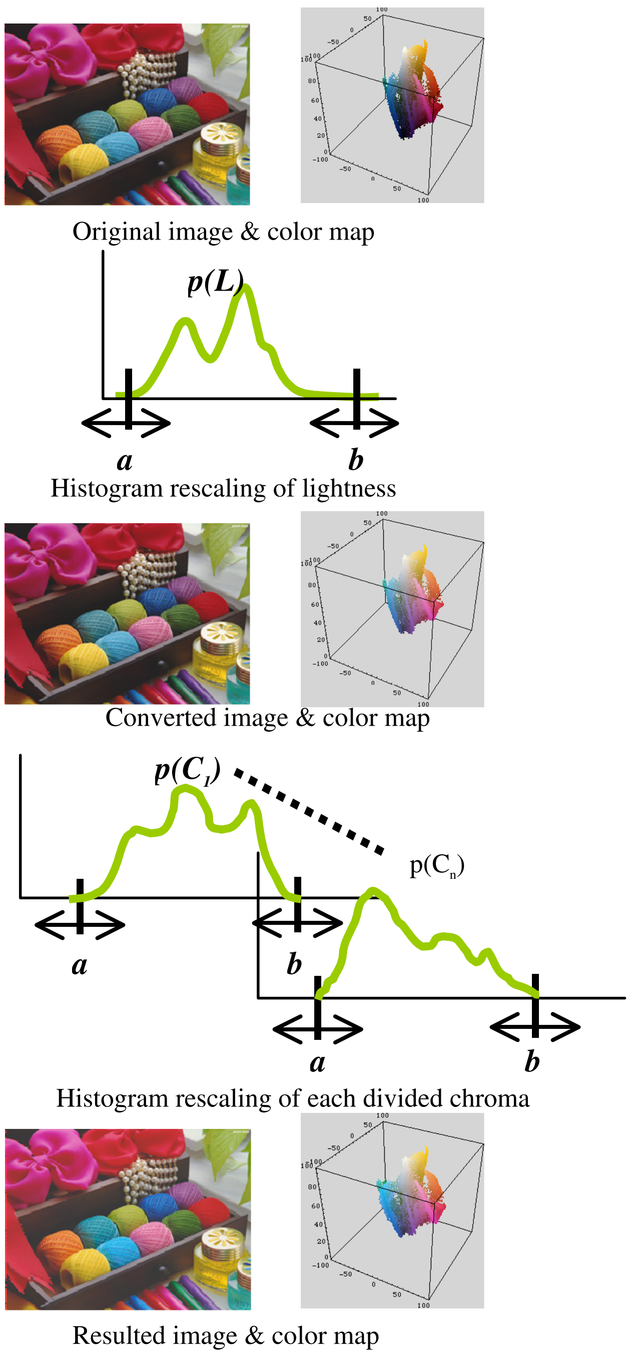


Figure 1. Schema of gamut mapping model based on histogram rescaling

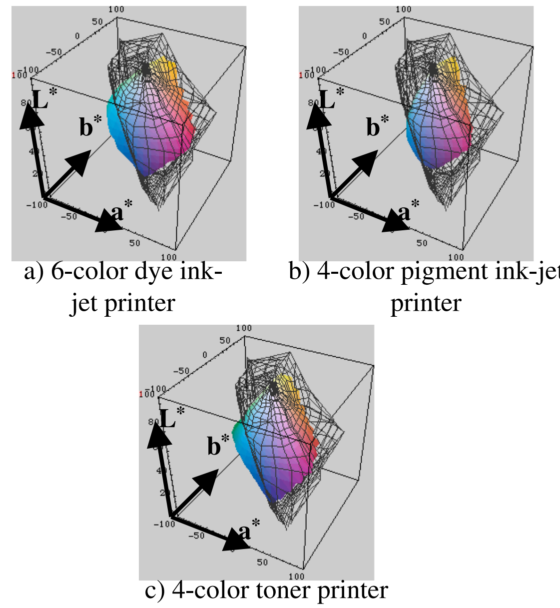


Figure 2. Printer gamut (solid) and sRGB gamut (wire frame) on CIELAB space

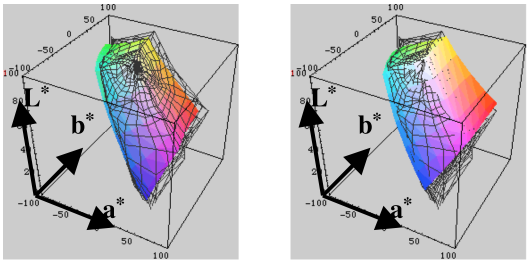
Experimental Results

Recently, the printer gamut has been much expanded with the improvements in printing media and devices. Figure 2 shows a measurement result of various printer color gamut on CIELAB space. There is two types ink-jet printer and a toner printer with wire frame of sRGB color gamut. The printer gamut is obtained from the measurements of color chips printed on superfine papers. XYZ tristimulus values of the printed chips are measured with a Gretag spectrophotometer. The sRGB gamut was generated a set of {a^*, b^*, L^*} with equal interval of Δa^*=5, Δb^*=5, in range of $-120<a^*<120$, $-120<b^*<120$, and $0<L^*<100$, respectively. The corresponding RGB data have been limited within the sRGB range and located between 0 and 1.

On the other hand, Liquid-crystal display (LCD) flat panels are becoming increasingly common as computer color displays due to their compact size and low power consumption.[7] LCD and cathode-ray tube (CRT) were evaluated through an experimental study. A number of spatially uniform color patches were displayed in the central region and measured using a Specbos 1200 spectroradiometer. All measurements were made at a 0 degree viewing angle and in a dark room with minimal stray light. Figure 3 shows a measurement result of both display color gamut on CIELAB space. These volumes on CIELAB were shown Table 1.

Table 1: Volume of Each Device

Each device	Volume
1. 6-color dye ink-jet printer	381666
2. 4-color pigment ink-jet printer	266361
3. 4-color toner based printer	428113
4. sRGB	765008
5. CRT	563564
6. LCD	667682



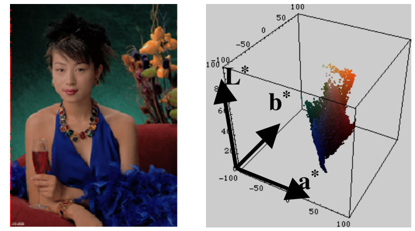
a) CRT display b) LCD display

Figure 3. Display gamut (solid) and sRGB gamut (wire frame) on CIELAB space

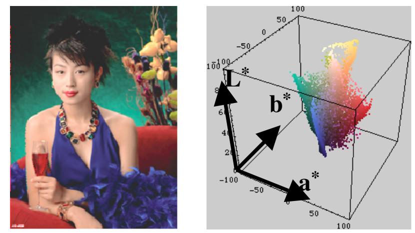
Each printer gamuts are obviously smaller than sRGB gamut but slightly larger in a part of cyan region. CRT gamut is similar sRGB gamut and slightly small. LCD gamut is a little smaller than sRGB gamut but larger in red-orange region.

Figure 4 shows test image "lady & glass" for one of narrow gamut image (a) and the GMA results (b) – (f) with their color maps. The image was expanded into inside of each device gamut. The result clearly shows that the expansion GMA gives individual image appearances. In CRT and LCD, "red sofa and wine" of test image was represented slightly different color image.

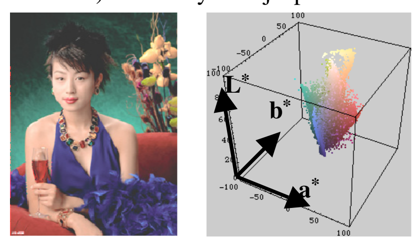
Figure 5 shows test image "musicians" for one of wide gamut image (a) and the GMA results (b) – (f) with their color maps. This image was compressed into inside of each printer device gamut, but it was expanded into inside of display device gamut CRT and LCD. And the result clearly shows that the GMA gives individual image appearances.



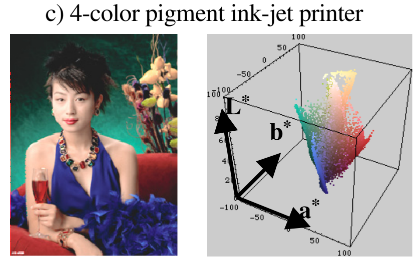
a) Original image "lady & glass



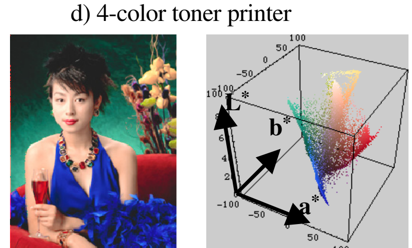
b) 6-color dye ink-jet printer



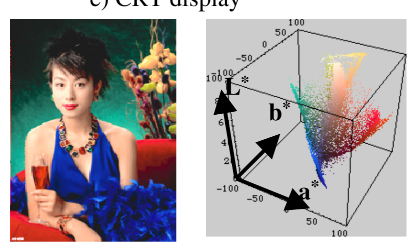
c) 4-color pigment ink-jet printer



d) 4-color toner printer

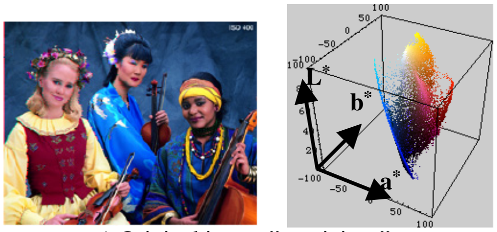


e) CRT display

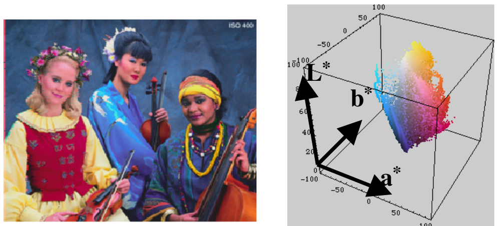


f) LCD display

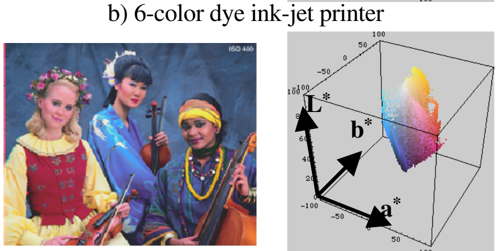
Figure 4. Test image "lady and glass" and GMA results



a) Original image "musicians"



b) 6-color dye ink-jet printer



c) 4-color pigment ink-jet printer

d) 4-color toner printer

e) CRT display

f) LCD display

Figure 5. Test image "musicians" and GMA result

Conclusions

This paper denoted a versatile gamut mapping adapted various devices. We proposed histogram rescaling for gamut mapping in reference to the each ***GBD*** of image and device. This model is automatically applied an expansion of degraded images and a compression of saturated images. We compared some printer devices' and monitor devices' color gamut with sRGB. A proposed GMA were performed for various devices and good image appearances were shown in experimental results. Future works will be continued to apply for the gamut mapping on another device, plasma-display-panel, LCD projector, etc.

References

1. R. Saito and H. Kotera, "Extraction of Image Gamut Surface and Calculation of its Volume", Proc. 8th IS&T/SID CIC, pp.330-333 (2000).
2. R. Saito and H. Kotera, "3D Gamut Mapping by Comparison between Image and Device Gamut Description", Proc. ICIS'02, TOKYO, pp.407-408 (2002).
3. R. Saito and H. Kotera, "Image-dependent three-dimensional gamut mapping using gamut boundary descriptor", Jour. Elect. Imaging, 13 (3) pp. 630-638 (2004).
4. J. Morovic and M. R. Luo, "Evaluating Gamut Mapping Algorithms for Universal Applicability", Col. Res. Appl. 26,pp.85-102 (2001).
5. L. W. MacDonald and M. R. Luo, Color Imaging, John Wiley & Sons (1999).
6. R. Saito and H. Kotera, "A Versatile 3D Gamut Mapping Adapted to Image Color Distribution", Proc. IS&T's NIP20, pp.647-651 (2004).
7. G. Sharma,, "LCDs Versus CRTs –Color- Calibration and Gamut Considerations", Proc. Of The IEEE,90, pp.605-622 (2002).

Author Biography

Ryoichi Saito received his B.E. and Ph.D. degrees in Image Science from Chiba University, Japan in 1983 and 2004, respectively. Since 1983, he has been working on direct plate making, digital image processing and color reproduction at Chiba University. His current research interest is image gamut description models and their application to 3-D gamut mapping and appearance matching across multimedia. E-mail:saito@office.chiba-u.jp