A Versatile 3D Gamut Mapping Adapted to Image Color Distribution

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

Abstract

We have been proposed a ***GBD*** (Gamut Boundary Descriptor) 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. We presented a method of image-dependent gamut compression using ***r-image*** and introduced image-dependent gamut expansion using histogram stretch. This paper examines how to decide which should be applied, compression or expansion, for gamut mapping in reference to the each ***r-image*** of image and device. When the most of ***r-image*** pixel values for image are greater than those for device in entire region and around middle lightness region, a gamut compression is necessary. On the other hand, if they are smaller than those for device in middle region and mainly located at lower region of lightness, a gamut expansion is desirable. The numerical gamut comparison by ***r-image*** to decide compression or expansion is tested for typical image samples. The paper reports the experimental results in both compression for wide gamut and expansion for unsaturated narrow gamut.

Introduction

Gamut Mapping between display and print images is a most typical application. Current gamut mapping algorithm (GMA) is mostly addressed to compress the out-of-gamut colors into the inside of printer gamut.[1,2] 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. 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.[6,7,10,12] The proposed system selects the compression GMA or expansion GMA whether the image gamut is obviously larger or extremely smaller than printer gamut. Figure 1 illustrates the process diagram of the proposed GMA. We proposed a method for comparing the gamut between image and device, where the device and image color distributions are divided into small segments by discrete polar angle. There, the maximum radial vectors for image and device are extracted and compared in each segment. The gamut shell is described as the simple radial distances, called ***r-image***.

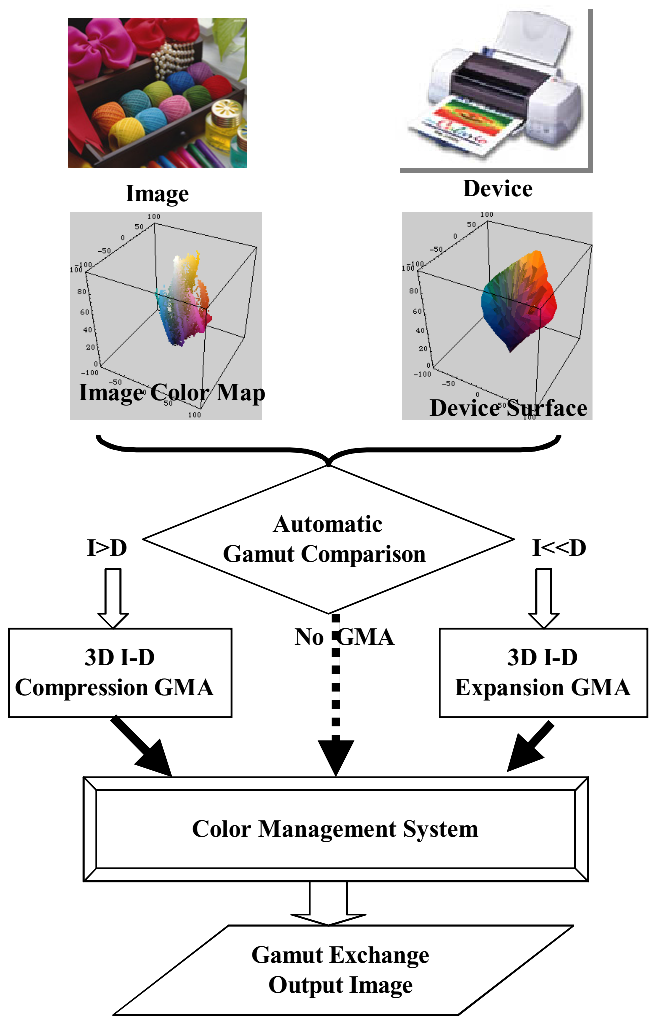


Figure 1. Diagram of proposed gamut mapping system

The image and device gamut boundaries are quickly compared between polar angle segments and both gamut are automatically compared. In the compression GMA, the source colors are mapped into the inside of printer gamut based on the I-D 3D gamut. This compression GMA is to use the relations in only two vectors in each divided segment. While in the expansion GMA, the image gamut is stretched to a target in lightness and chroma histograms.

Automatic Gamut Comparison

Gamut Boundary Descriptor

We have developed an automatic gamut surface extraction algorithm from a random color distribution[4,5,8]. The random color distributions of source image in the CIELAB space are segmented by a constant polar angle step, that is, $\Delta\theta$ in hue angle and $\Delta\phi$ in sector angle between a color vector and the lightness axis. The gamut center was set at a neutral point $[L^*_0, a^*_0, b^*_0] = [50,0,0]$.

$$\theta = \tan^{-1} \frac{b^* - b^*_0}{a^* - a^*_0} \tag{1}$$

$$\varphi = \tan^{-1} \frac{L^* - L^*_0}{\left[(a^* - a^*_0)^2 + (b^* - b^*_0)^2\right]^{1/2}} \tag{2}$$

We define the radial matrix $\boldsymbol{r}_{gamut}$ whose element is given by the maximum radial vector in each polar angle segment[8]. The magnitude of radial vector $\boldsymbol{r}_{jk}$ is given by the norm

$$\left\| r_{jk} \right\| = \left[\left(L^*_{jk} - L^*_0\right)^2 + \left(a^*_{jk} - a^*_0\right)^2 + \left(b^*_{jk} - b^*_0\right)^2 \right]^{1/2} \tag{3}$$

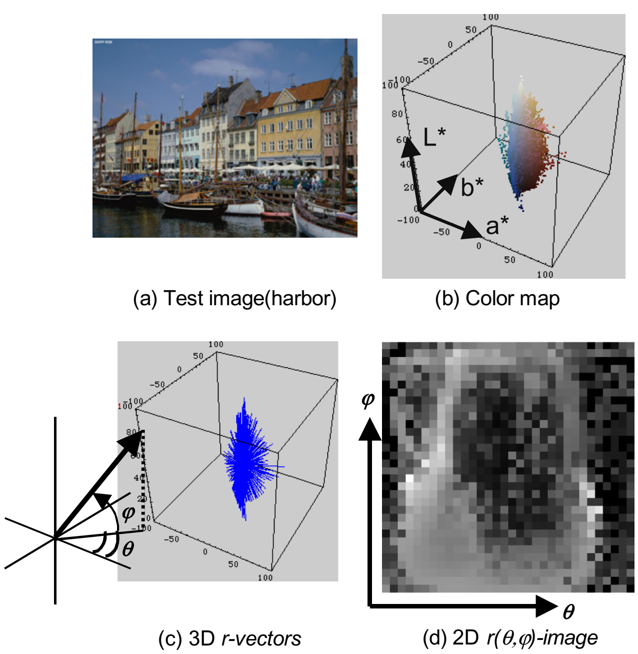


Figure 2. Gamut surface of "harbor"

Figure 2 (a) and (b) show the sRGB test image "harbor" and its color map in CIELAB. The extracted maximum radial vectors are shown in Fig. 2(c). We proposed to replace the 3D radial vectors 2D distance array arranged in rectangular lattice point (j,k), called ***r-image***. Figure 2(d) shows the ***r-image*** represented as a 2D gray scale image segmented in 32×32 discrete angles.

Gamut Comparison

Twelve test images shown in Fig. 3 were used to compare with gamut size of printer. Figure 4 shows a result of gamut comparison between images and dye ink-jet printer.

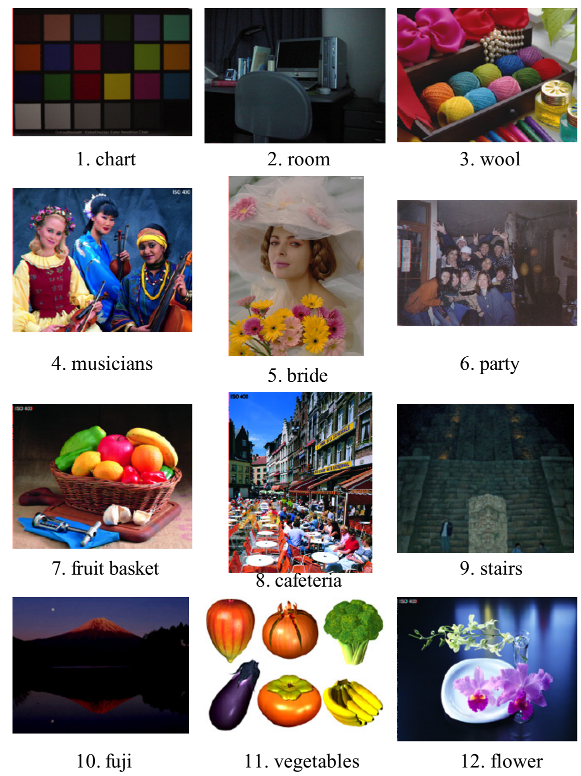


Figure 3. Twelve images are used to compare with gamut

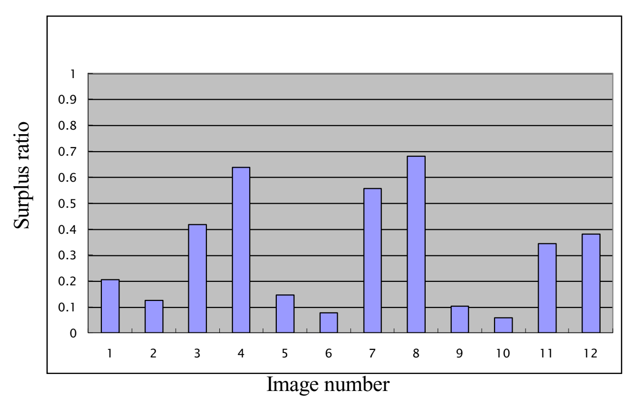


Figure 4. Image gamut surplus ratio for dye ink-jet printer

This figure shows ***r-image*** pixel values for image were greater ratio than those for device in entire 32×32 regions. Obviously, in the image 3, 4, 7, 8, 11 and 12, each image are greater than those for printer in entire region. A compression GMA is necessary in these images. However, other images are not clear to need compression, expansion or not both. Therefore it was divided by three regions in lightness. Figure 5 shows the result of 32×10 upper regions, 32×12 middle regions and 32×10 lower regions. In the image 3, 4, 7, 8, 11, 12 and 5, images are greater than those for printer in middle region. On the other hand, image 1, 2, 6, 9 and 10 are greater than printer's in lower region but smaller than printer's in middle region. In these images, expansion GMA is required.

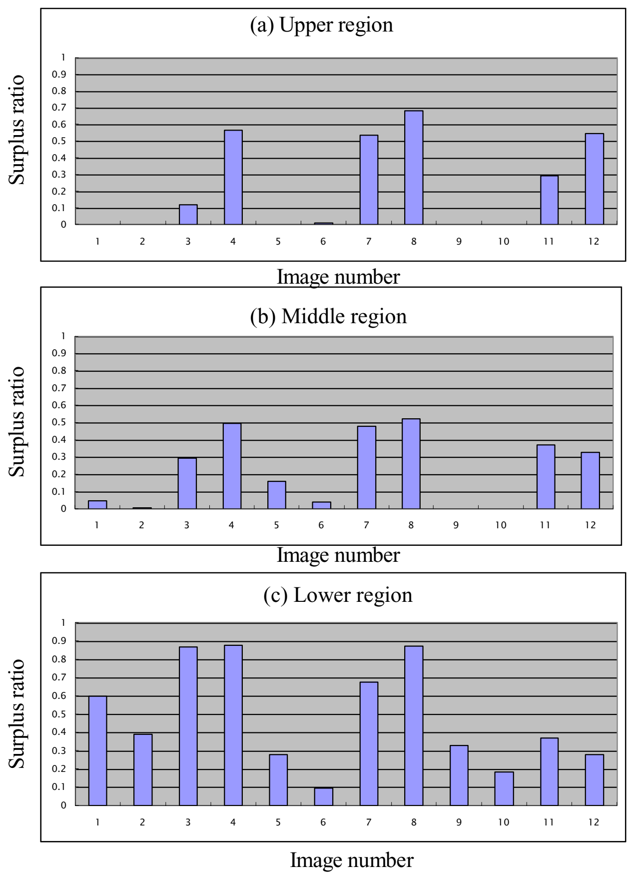


Figure 5. Image gamut surplus ratio of three lightness region for dye ink-jet printer

Gamut Compession

In CIELAB space, a source color ***s*** is mapped to target ***t*** along the mapping line toward focal point ***p*** referencing to the image gamut boundary ***i*** and output device gamut boundary ***o*** as given by the following vector notations.

$$\overrightarrow{pt} = \overrightarrow{po} \cdot \left(\frac{\overrightarrow{ps}}{\overrightarrow{pi}} \right)^{\gamma} \tag{4}$$

where γ represents the gamma-compression coefficient. The GMA works as linear compression for γ=1, and as nonlinear compression for $0<\gamma<1$[3].

In the design of GMA, the mapping direction to a focal point is very important. To keep the natural lightness, a mapping into the multi-focal points is desirable. We took the control parameters, $\boldsymbol{p}_{lower}$ and $\boldsymbol{p}_{upper}$ into account to setting the multi-focal points.[9, 11] Image and printer lightness are divided by polar angles under $\boldsymbol{p}_{lower}$ and over $\boldsymbol{p}_{upper}$, and by the parallel segments between $\boldsymbol{p}_{lower}$ and $\boldsymbol{p}_{upper}$.

This compression GMA is to use the relations in only two vectors in each divided segment.

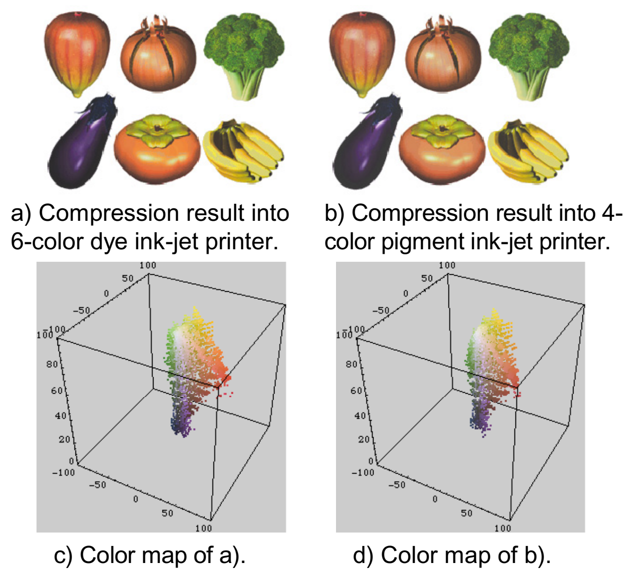


Figure 6. Image11 by gamut compression and its color map

Figure 6 shows the compression GMA results for test image 11. In Fig. 6-a), image was compressed into inside of 6-color dye ink-jet printer gamut, and in Fig 6-b), image was compressed into inside of 4-color pigment ink-jet printer gamut. Each color map is shown Fig. 6-c) and 6-d). The result clearly shows that the compression GMA give the better image appearances.

Gamut Expansion

The major objective of gamut expansion is to recover the degraded colors taken under insufficient illumination or faded colors after long preservation. It is difficult to restore the lost original colors exactly, but possible to recover the pleasant colors by gamut expansion. 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.

Histogram equalization is useful to expand the reduced monochrome image, but it causes unnatural and unbalanced color appearance. We introduced Gaussian histogram specification.[6,7,10] This specification was an effective candidate to create the natural and pleasant images. However, the target histogram has not always a single peak but multiple peaks.

In order to perform natural and pleasant expansion automatically, we propose an image gamut expansion method based on the histogram stretching. The histogram stretching automatically expands the degraded image to the natural and pleasant images. To simplify the process, the histograms of luminance and chrominance are expanded separately in CIELAB space as the following steps.

(1) RGB to LAB conversion
(2) histogram stretching for L component
(3) Segmentation of chroma component
(4) histogram stretching for chroma component

In the original histogram p1(L), highest value ***a*** is expanded higher, and lowest value ***b*** is lower. As a result, the original histogram p1(L) is expanded p2(L). (See Fig.7)

$$p2(L) = p_m \frac{p1(L) - a}{b - a} \qquad (5)$$

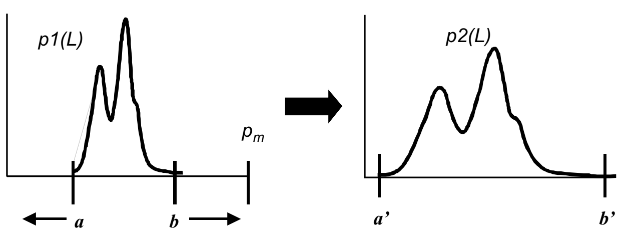
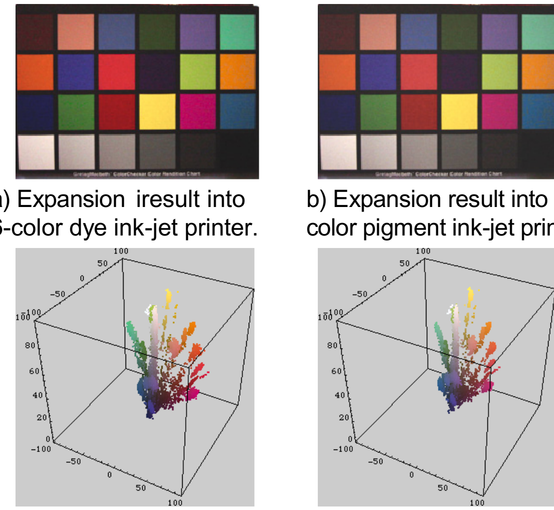


Figure 7. Histogram stretching

After the histogram stretching of *L*, the chrominance components are segmented into *m* divisions by ΔH in hue angle *H*. Then chroma *C* of each division is expanded by histogram stretching as same as *L* without changing color hue.

Figure 8 shows an improved image 1 by gamut expansion using histogram stretching. In Fig. 8-a), image was expanded to gamut of 6-color dye ink-jet printer, and in Fig 8-b), image was expanded to gamut of 4-color pigment ink-jet printer. Each color map is shown Fig. 8-c) and 8-d). The chroma was segmented to 16 ΔH division. The image 1 taken in dim light was dramatically improved to comfortable image with the bright and vivid colors.



a) Expansion iresult into 6-color dye ink-jet printer.
b) Expansion result into 4-color pigment ink-jet printer.
c) Color map of a).
d) Color map of b).

Figure 8. Image 1 by gamut expansion and its color map

Conclusion

This paper proposed how to decide which should be applied, compression or expansion, for gamut mapping in reference to the each ***r-image*** of image and device. When the most of ***r-image*** pixel values for image were greater than those for device in entire region and around middle lightness region, a gamut compression is necessary. On the other hand, if they were smaller than those for device in middle region and mainly located at lower region of lightness, a gamut expansion is desirable. The numerical gamut comparison by ***r-image*** to decide compression or expansion was tested for typical image samples. Two different GMAs were introduced, one for compression from wide to narrow and the other for expansion from narrow to wide gamut. We could design the 3D compression and expansion GMA for printer gamut. Both algorithms were based on the common concept of "***image-dependent***". Future works will be continued to find on the human visual appearance tests.

References

1. J. Morovic and M. R. Luo, *Col. Res. Appl.* 26,pp.85-102 (2001).
2. L.W.MacDonald, M.R.Luo, *Color Imaging,* John Wiley & Sons (1999).
3. H. S. Chen and H. Kotera, *JIST*, 46, pp.44-63 (2002).
4. R. Saito and H. Kotera, *Proc. IS&T's 17th NIP*, pp.454-457 (2001).
5. R. Saito and H. Kotera, *Proc. ICIS'02, TOKYO*, pp.407-408 (2002).
6. H. Kotera, et al, *Proc. PICS Conf. '01*, pp. 288-292 (2001).
7. H. Kotera, et al, *Proc. AIC Color '01*, pp. 227-228 (2001).
8. H. Kotera and R. Saito, *Proc. 9th IS&T/SID CIC*, pp.56-61 (2001).

9. R. Saito and H. Kotera, *Proc. IS&T's 18th NIP*, pp.608-611 (2002).
10. R. Saito and H. Kotera, *Proc. IS&T's 19th NIP*, pp.812-815 (2003).
11. R. Saito and H. Kotera, JEI, 13, in printing (2004).
12, B. H. Kang, et al, Proc. 9th IS&T/SID CIC, pp.158-162 (2001).
13, E.D.Montag, M.D.Fairchild, Proc. 6th IS&T/SID CIC, pp.57-61 (1998).

Biography

Ryoichi Saito received his B.S. degree in Image Science from Chiba University in 1983 and a Ph.D. from same University in 2004. 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.