Gamut Mapping for Computer Generated Images (II)

N. Katoh and M. Ito
Research Center, Sony Corporation, Tokyo, Japan

Abstract

Computer Generated (CG) images on a CRT monitor cannot be accurately reproduced on a hardcopy output when the gamut of the CRT monitor exceeds that of the printer. Such cases require that the out-of-gamut colors be mapped inside the output device's gamut while preserving the appearance of original image as much as possible. This technique is called gamut mapping. While several gamut mapping techniques have been suggested for the natural images,[1-7] techniques for CG images[8-9] have rarely been discussed.

In this paper, a three-dimensional gamut mapping technique for CG images is considered. A weighted color difference equation for lightness, chroma, and hue, along with normal CIE 1976 color difference equation[10] were used in the gamut mapping. Visual experiments were performed to evaluate the importance of these attributes in image appearance. Results showed that human visual system is most sensitive to lightness change, and least sensitive for chroma change. Surprisingly, for CG images, hue change was less noticeable than the lightness change.

Introduction

A number of recent color management systems (CMSs) on the market aim for device independent color environment, i.e., consistent colors across different media. However, present CMSs involve some technical problems, one of which is the gamut difference between devices. Among the variety of devices, the gamut difference is most noticeable between a CRT monitor and a hardcopy printer. For a typical printer, the gamut volume in CIELAB color space is only 50 to 80% of that of a typical CRT monitor. A monitor's gamut is wider especially in the green and blue hue regions and high-lightness region. Usually, CG designers generate images on CRT screen utilizing full gamut of the monitor, which include highly saturated colors. These colors are often not reproducible by the printer, which makes gamut mapping necessary and important for CG image processing.

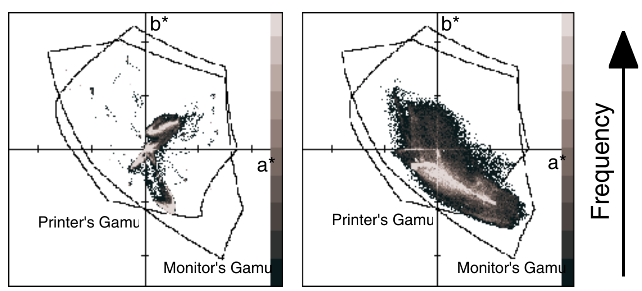
Conventionally, it was thought that chroma mapping with constant lightness and constant hue was the best method for natural image reproduction. However, recent studies indicate that two-dimensional, i.e., lightness and chroma, mapping techniques[4,6,7,8] have advantages over the one-dimensional, i.e., chroma mapping technique. In fact, in our previous study,[8] we found that lightness information is very important for the image contrast and that too much chroma mapping loses image vividness. In this paper, three dimensional gamut mapping technique is considered and evaluated whether it may be more appropriate for CG image processing.

Natural Images vs. CG Images

In Figure 1 below, pixel histogram of the above image is plotted on the graph below in an a*b* plane. Generally, natural images do not contain much of highly saturated colors. As seen in natural image on the left, most of the colors are distributed around the gray axis. On the other hand, since CG designers tend to utilize the full gamut of the CRT monitor when creating images, CG images often contain more saturated colors, as seen in the image to the right.

Natural Image

CG Image



Pixel distribution of natural ima

Pixel distribution of CG imag

Figure 1. Pixel distribution of natural image and CG image

Gamut Mapping

The human visual system has three attributes for color perception, i.e., lightness, chroma and hue. CIE/L*C*h is one color space that closely represents these attributes. In this color space, each attribute can be considered independently. In this paper, the CIE/L*C*h color space was utilized for the gamut mapping.

There are two main considerations in gamut mapping, i.e., 1) mapping direction and 2) mapping method. The first involves deciding the direction to where in color space out-of-gamut colors be mapped. The second considers the most effective way to compress those colors, either clipping or compression. The latter problem is highly dependent on image content. For example, if the pixel frequency of out-of-gamut colors in the image was very low, clipping would be preferred method to the compression. Therefore, only the former consideration is discussed in this paper. Mapping method was set to clipping, i.e., no mapping occurred for the in-gamut colors and out-of-gamut colors were mapped to the surface of the gamut. Out-of-gamut colors were mapped to the point that had the smallest color difference. A weighted color difference equation and the normal CIE 1976 color difference equation were used for the experiment.

The quantitative expression of the perceptual difference of the two colors is called the color difference: ΔE^*. CIE 1976 total color difference is defined as below.[10]

$$\Delta E^*_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*_{ab})^2 + (\Delta b^*_{ab})^2} \qquad (1)$$

and CIE 1976 a,b hue difference is gives as

$$\Delta H^*_{ab} = \sqrt{(\Delta E^*_{ab})^2 - (\Delta L^*)^2 - (\Delta C^*_{ab})^2} \qquad (2)$$

Therefore, CIE 1976 color difference can also be expressed as

$$\Delta E^*_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta C^*_{ab})^2 + (\Delta H^*_{ab})^2} \qquad (3)$$

ΔL^*, ΔC^*, ΔH^* denotes difference in lightness, chroma, and hue respectively.

A weighted color difference equation used in this experiment is shown below

$$\Delta E = \sqrt{\left(\frac{\Delta L^*}{Kl}\right)^2 + \left(\frac{\Delta C^*_{ab}}{Kc}\right)^2 + \left(\frac{\Delta H^*_{ab}}{Kh}\right)^2} \qquad (4)$$

Kl, Kc, Kh are mapping coefficients for each attribute. By changing these coefficients, the mapping direction could be controlled. For example, when *Kc* is larger than other two, the direction will be close to the one-dimensional chroma mapping, and when both *Kl* and *Kc* are larger than *Kh* , the direction will be close to two-dimensional mapping in lightness-chroma plane. When $Kl = Kc = Kh$, equation (4) becomes identical to the normal CIE 1976 color difference equation (1).

Visual Experiment

Visual experiments were performed to determine which attribute, i.e. lightness, chroma, and hue, is most important in image appearance. Six combinations of coefficients: (Kl:Kc:Kh) = (2:1:1), (2:2:1), (1:2:1), (1:2:2), (1:1:2), (2:1:2) and a normal color difference equation, i.e. (Kl:Kc:Kh) = (1:1:1) were used. Images using two-dimensional mapping techniques in lightness-chroma plane were omitted in the experiment. Images using a three-dimensional mapping technique with (Kl:Kc:Kh) = (2:2:1), which had the closest reproduction to the images mapped with two-dimensional lightness-chroma mapping technique, showed much better reproduction based on the experimenters' subjective judgment.

The three CG images shown in Figure 2 were used in the experiment.

Image A Image B Image C

Figure 2. Images used for the Visual Experiment (©Y. Kawaguchi)

The visual experiments were performed in a dark room to eliminate color appearance differences between the softcopy and the hardcopy. For both devices, the proximal field was set to white and the background was set to black. The CCT of both monitor's white point and the paper white was controlled between 6000K and 6500K and their luminance was controlled between 80cd/m^2 and 90cd/m^2. The CRT monitor and the light-booth were placed 90 degrees with respect to each other and a successive binocular matching technique was used for comparison.

Twenty-four observers (twenty-two males and two females) participated in the experiment. A paired comparison method was used. Observers compared original softcopy image to reproduced hardcopy images. A total of seven hardcopy images were used that are generated with different combinations of coefficients:(Kl:Kc:Kh) in equation (4). In each comparison, the observers first evaluated the softcopy image, and then evaluated a pair of hardcopy images. The observers were allowed to reevaluate the images as many times as necessary. The task was to indicate which of the hardcopy images matched to the softcopy image.

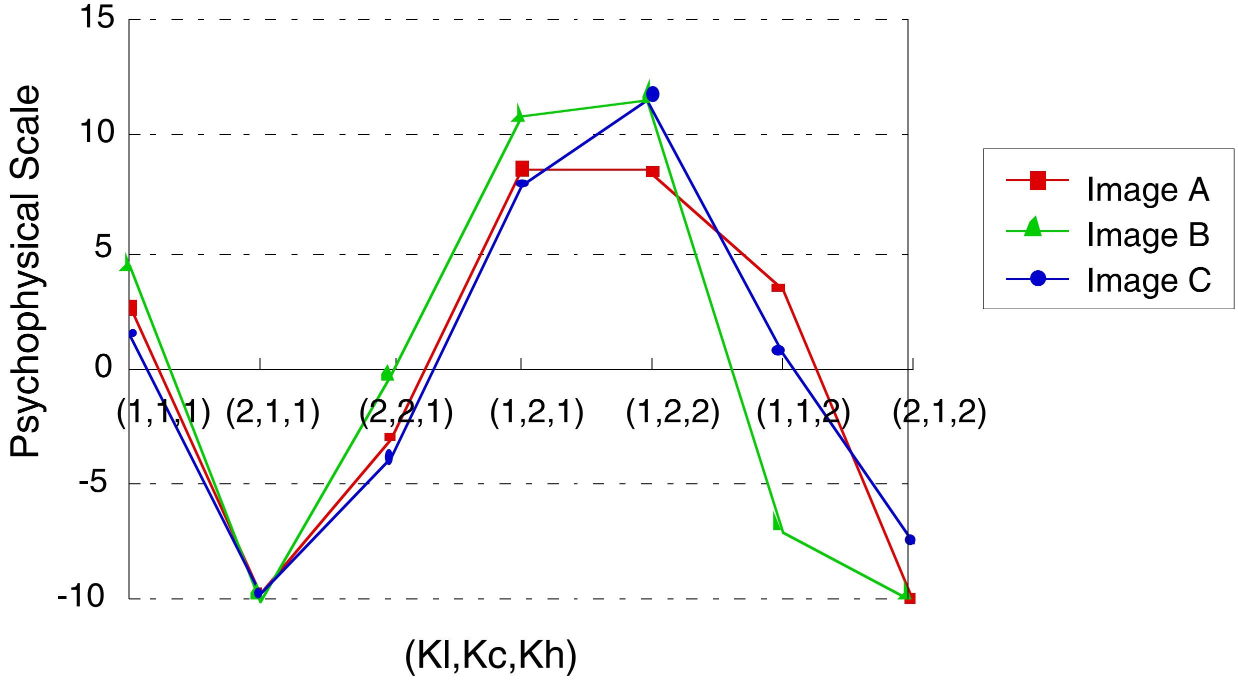


Figure 3. Result of Visual Experiment

Results and Discussion

The experimental result is shown in Figure 3 below. The abscissa represents the different combinations of coefficients and the ordinate shows the interval psychophysical scale calculated statistically from the experimental data. The higher value means that better matching was obtained between the original softcopy image and the reproduced hardcopy image.

The images with coefficients:(1:2:1) and (1:2:2) obtained the two highest scores, higher than images with coefficients:(1:1:1) which utilizes CIE 1976 color difference equation. This indicates that images mapped with large chroma mapping coefficient: *Kc* have good matching result. On the other hand, images with coefficients:(2:1:1) and (2:1:2) obtained two of the lowest scores. This indicates that images mapped with large lightness mapping coefficient: *Kl* have matching result. Therefore, gamut mapping with the coefficients $Kc \geq Kh \geq Kl$ would have the best matching result.

Conclusion

Gamut mapping using a weighted color difference equation was found to be superior to the mapping using normal CIE 1976 color difference equation. Experimental results indicated that human visual system is most sensitive to the lightness change and least sensitive to chroma change in terms of image appearance. Furthermore, as for CG images, hue change was less noticeable than the lightness change.

References

1. CIE Publ. No. 15.2, “Colorimetry, 2nd Ed.,” (1986).
2. M. C. Stone, W. B. Cowan, and J. C. Beatty: “Color Gamut Mapping and the Printing of Digital Image,” *ACM Trans. on Graphics,* Vol. **7***,* 249-292, (1988).
3. R. S. Gentile, E. Walowit, and J. P. Allebach, “A Comparison of Techniques for Color Gamut Mismatch Compensation,” *J. of Imaging Tech.,* Vol. **16**, 176-181, (1990).
4. E. G. Praiser, “An Investigation of Color Gamut Reproduction Techniques,” *IS&T Symp. on Electronic Prepress Technology—Color Printing*, 105-107 (1991).
5. Toru Hoshino, “Color Gamut Mapping Techniques for Color Hard Copy Images,” *SPIE proceedings Vol. 1909*, 152-164, (1993).
6. L. W. MacDonald, “Gamut Mapping in Perceptual Colour Space,” *Proc. IS&T/SID Color Imaging Conf.,* Vol. **1**, 193-196 (1993).
7. M.Wolski, J. P. Allebach, and C. A. Bouman, “Gamut Mapping: Squeezing the Most out of Your Color System,” *Proc. IS&T/SID Color Imaging Conf.,* Vol. **2**, 89-92 (1994).
8. M. Ito, N. Katoh, “Gamut Compression for Computer Graphic Images” *Extended Abstract SPSTJ 70th Anniversary Symposia on Fine Imaging,* 85-88, (1995).
9. W. E. Wallace and M. C. Stone: “Gamut Mapping Computer Generated Imagery,” *SPIE Vol. 1460*, 20-28, (1991).
10. E. D. Montag, M. D. Fairchild, “Simulated Color Gamut Mapping Using Simple Rendering Images,” *IS&T/SPIE Symp. on Electronic Imaging: Science & Technology*, (1996).