Three-dimensional Gamut Mapping Method Based on the Concept of Image-dependence

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Abstract

Three-dimensional (3D) Gamma-Compression Gamut Mapping Algorithm (GMA) is proposed. Currently Gamma-Compression GMA has been designed to work in two-dimensional (2D) Lightness-Chroma planes segmented by primary and secondary color hues. The advanced 3D GMA is expected to work without color segmentation.

This paper describes a 3D GMA based on the concept of Image-to-Device (I-D). Considering the color gamuts' relations between the devices (i.e. printers, monitors) and source image, the Gamma-Compression GMA is applied to the 3D shell shapes in CIEL*a*b* space. 3D shell shapes of devices and image source are formed by connecting the edgy color points located at their gamut surfaces. The surface polygons are built up from these most outside color points, and true seamless 3D mapping is performed.

1. Introduction

On the process of cross-media color reproduction, a key feature is the use of gamut mapping techniques 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 (D-D), which is negligent of the image color distributions.

Although the researches on 2D GMAs in Lightness-Chroma plane are brisk, the ideal GMA is requested to work directly in 3D uniform color space. Hence, the development of 3D GMA based on the concept of image-dependence or image-to-device is necessary.

When 3D GMA is designed, the following factors should be taken into account. (1) 3D description of color gamut, (2) the type of mapping, (3) the direction of mapping, and (4) the intersection points on gamut surface.

The paper represents (1) 3D color gamut of source image and printing media, (2) the Gamma-Compression GMA[1], (3) mapping directions toward multi focal points, and (4) the intersection points on the gamut surfaces of source image and printer.

2. Gamut Mapping Algorithms

2.1. The Description of Color Gamut
A. Devices' Gamut

Initial data sets of {a*, b*, L*} are generated with equal intervals of Δa*=1, Δb*=1, ΔL*=5 in the ranges of -120 $\leq$ a* $\leq$ 120, -120 $\leq$ b* $\leq$ 120, and 0 $\leq$ L* $\leq$ 100 respectively. The corresponding initial RGB data have been limited within the sRGB[2] range and located between 0 and 1. Thus the corresponding {a*, b*, L*} values filling the sRGB space are used to define sRGB monitor's gamut.

The wireframe gamut of sRGB monitor is shown in Figure 1-(a). It is formed by extracting the surface points from the generated color distributions. Here, sRGB monitor's color distributions are segmented into m lightness planes and n hue leaves (m*n divisions). Then color points having the maximum chroma at each hue leaf represent the gamut surface points. In the example of Figure 1-(a), *23*36* divisions (*23* lightness planes and *36* hue leaves) are used, and 23*36 surface points are obtained. After adding 2 points of top and bottom, CRT color gamut has been formed by the 2*m*n triangles with these m*n+2 surface points.

The printer gamut is obtained based on the measurements of color chips. The color chips from the data sets of {a*, b*, L*} are printed on superfine paper by Epson PM-750C inkjet printer. XYZ tristimulus values of the printed chips are measured with Gretag spectrophotometer and then transformed into CIEL*a*b* values. As well, the 3D wireframe gamut shape has been formed by segmenting the measured color points into *m* lightness planes and *n* hue leaves and extracting the surface points with maximum chroma (see Figure 1-(b)).

B. Image's Gamut

Because the color distributions of source image are random, the method of *L-h* (lightness-hue) segmentation is applied to get the surface points. If *m*n* divisions (*m* lightness divisions and *n* hue divisions) are used to divide the image color distributions into *i* segments, the division number *j* in each *L-h* subspace and the number *q* of surplus points are calculated as ; *j* is the greatest integer for $j \leq i / (m*n)$ and $q = i - m*m*j$. After discarding the *1st to q*-th surplus points with the minimum distance to the centroid, the image color distributions can be segmented into *m*n* number of *L-h* subspaces.
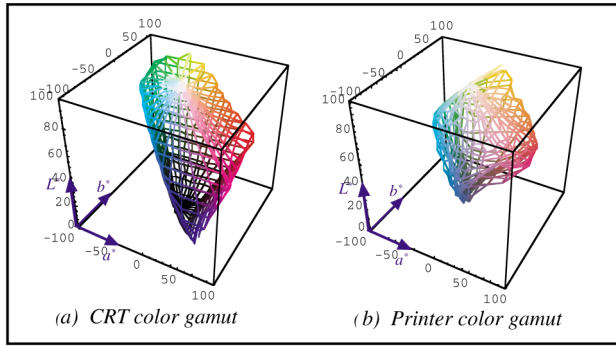
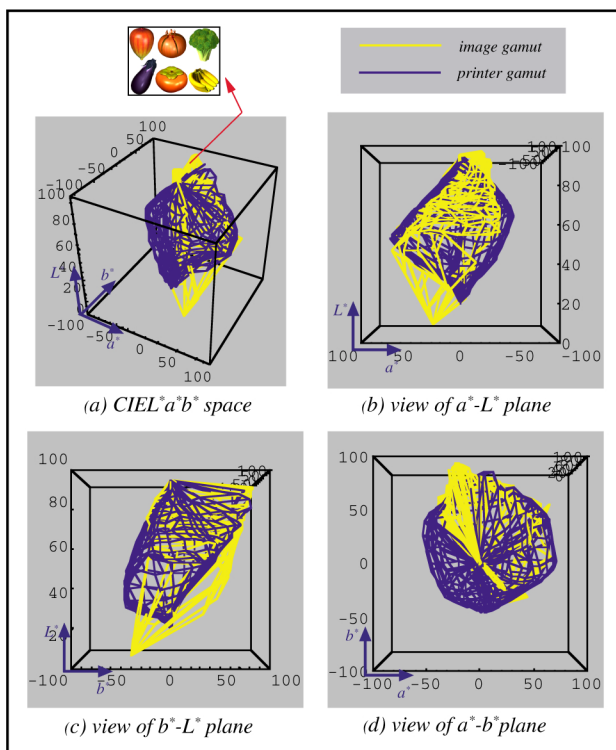*Figure 1. 3D color gamuts of monitor and printer (23*36 divisions).*

Figure 2. An example of 3D color gamut of image and printer in CIEL*a*b* space.

The *m*n* number of surface points of image can be regarded as the color points having the maximum distance to image centroid in each *L-h* subspace. Then adding 2 points of top and bottom, image color gamut has been formed according to these *m*n+2* points. An example of 15*15 divisions for image source is shown in Figure 2.

2.2. Gamma-Compression GMA

The basic 2D Gamma-Compression GMA[2] given by Eq. (1) is directly applied to 3D model in CIEL*a*b* space.

$$\vec{pt} = \vec{po} \cdot \left(\frac{\overline{ps}}{\overline{pi}} \right)^\gamma \qquad (1)$$

Here, *s*, *t*, *o* , *i* and *p* represent the positions of input color, target color, the output gamut, the input gamut and the focal point in CIEL*a*b* space respectively. γ represents the gamma-compression coefficient. The GMA works as linear compression for γ=1, and as nonlinear compression for 0<γ<1. The optimum range of γ for 2D Gamma-Compression GMA in CIEL*a*b* space was reported to lie around 0.8.

2.3. 3D Gamut Mapping Direction

As well known, gamut mapping directions are dependent on the positions of focal points. The colors out-of-image gamut are mapped toward the multi focal points. In this study, a method called *Image Lightness Division* (**ILD**) is utilized to decide the focal points.

An example of image lightness division is shown in Figure 4. To maintain gray balance of the image after mapping, the *n* number of the focal points are selected on L* axis and **ILD** method is applied to the divided lightness values of the image. All of the image's L* values are divided into *n* intervals, where every interval includes the same number of *k* samples. Thus *n* focal points {*p_i*}; i=1~n are decided as the lightness centroid in each L* interval. *p_i* is calculated as follows.

$$P_i = \frac{\sum_{j=1}^{k} L_{ij} f_{ij}}{\sum_{j=1}^{k} L_{ij}}, \quad i = 1 \sim n \qquad (2)$$

where *L_{ij}* represents the *j-th* lightness value in the *i-th* interval, and *f_{ij}* represents the occurrence frequency of lightness *L_{ij}*.
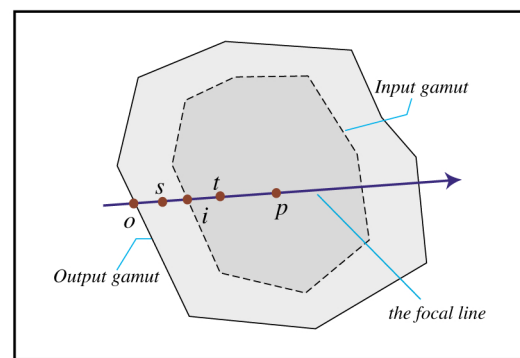

Figure 3. Overview of the relationships between input gamut and output gamut.

2.4. Intersection Points on Gamut Surface

For each color gamut of source image and printer, the gamut surface is composed of *2*m*n* triangles according to *m*n+2* surface points. Here only one intersection point is

calculated on the surface triangle where the focal line passes through.

As shown in Figure 5, *p* and *s* represent the positions of foal point and input color respectively, and Q_1, Q_2, ... , Q_n represent all of the intersection points. The values of Q_1, Q_2, ... , Q_n can be found from the common solutions of the focal line $\overleftrightarrow{sp}$ and the plane equation where the surface triangle is located on. When a focal line $\overleftrightarrow{sp}$ passes through the polygon (color gamut surface), 4 kind of relationships will be yielded. If *p* is located inside of polygon (like Figure 5-(a) or (b)) the intersection point Q_1 is desired. If *p* is located outside of polygon (like Figure 5-(c) or (d)) the intersection point Q_1 is desired.
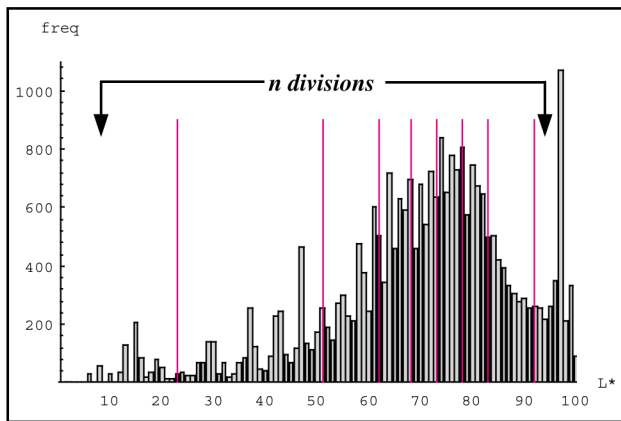

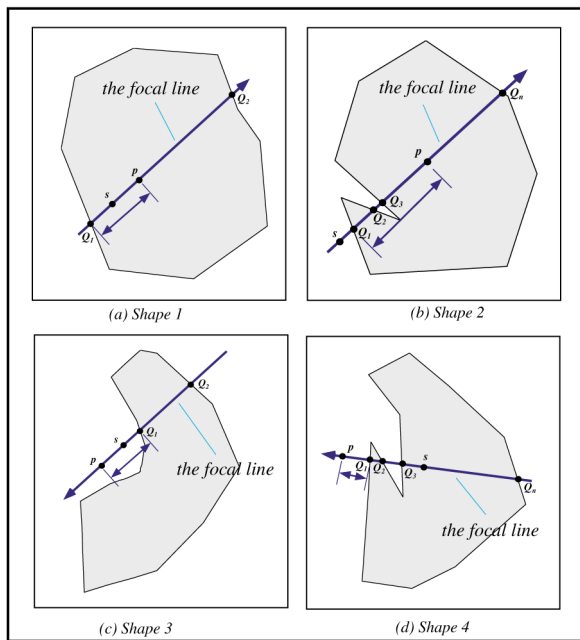*Figure 4. An example of image's divided lightness histogram*

Figure 5. The relationship between the polygon (color gamut) and the intersection points $Q_1, Q_2, ..., Q_n$.

3. Experiment

[Step 1] Two kinds of images from CD-ROM are used for testing the above algorithms. One is natural image "balloon", and the other is CG image "fruits & vegetables" (see Figure 5).

To perform the Gamma-Compression GMA based on image-dependence in CIEL*a*b* space directly, 3D color gamuts of image and printer are formed as given in Section 1. The image's reference white is regarded as the same setting as sRGB monitor, and printer's reference white must be calibrated to paper white which is illuminated by CIE Illuminant D_{65}. The tops of image and printer gamut are placed at the same position (near the point of {0, 0, 100} in CIEL*a*b* space).

[Step 2] By seeking for the intersection points on gamut surface as given in Section 2.4, the positions of input color *i* and output color *o* in Eq. (1) are determined. The intersection point Q_1 shown in Figure 5 represents the position of *i* for image gamut or *o* for printer gamut.

A comparison experiment between the mappings by multi focal points method and by a single focal point method has been carried out. Three kind of lightness divisions by *ILD* method in Section 2.3 (*n* is set to 15, 22, 30) are used to decide the mapping direction and 2 kind of the fixed positions (L*=75, 85) on L* axis are selected.

By setting the gamma-compression coefficient (γ=0.8), the target colors *t* in Eq. (1) after mapping is obtained.

The hardcopies mapped by 3D Gamma-Compression GMA are also compared with the ones by 2D Gamma-Compression GMA.

[Step 3] In the hardcopies, the color correction is indispensable to convert RGB data into CMY signals. In this study, the color correction LUTs embedded in ColorSync profiles are applied to RGB to CMY conversion.

[Step 4] Monitor's white point is set to the chromaticity near CIE Illuminant D_{65} with a peak luminance of 80 cd/m². The printed hardcopies after mapping are viewed in a light booth with the same color temperature and peak luminance as monitor's set.

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

The examples of test image "fruits & vegetables" mapped by 3D Gamma-Compression GMA are shown in Figure 6-(b)&(d). In comparison with original color distributions in Figure 6-(a)&(c), the image's {a*, b*, L*} distributions after mapping are almost well shifted inside print gamut.

Figure 6. Two kinds of test images: the CG image of "fruits & vegetables" and the natural image of "balloon".
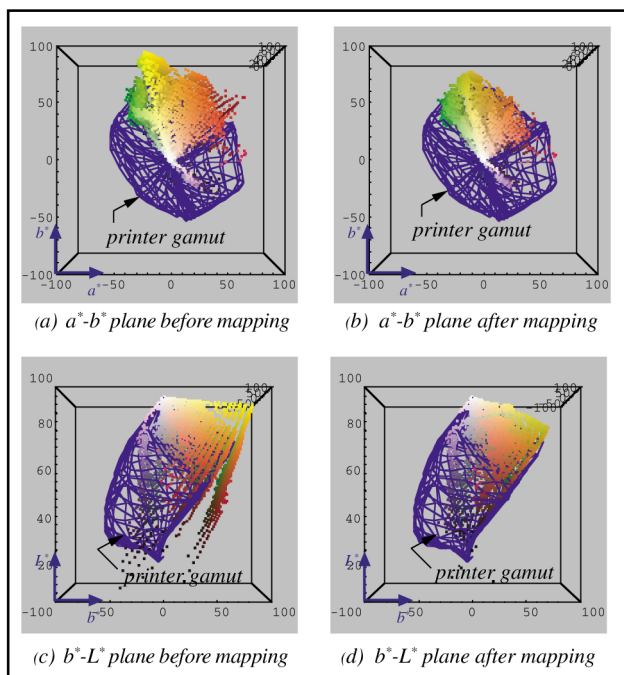

Figure 7. Image's color distributions before and after mapping in CIEL*a*b* space (viewing from +L* & +a* direction)

The mapping results by multi focal points **ILD** method give the better appearance than the results by the signal focal point method. The evaluation results in the psychophysical experiment show that the mapping by 3D Gamma-Compression GMA is superior to the mapping by 2D GMA when the appropriate number of lightness divisions are set.

5. Conclusions

3D Gamma-Compression GMA based on Image-to-Device is proposed. It is shown that the GMA coupled with 3D compression and **ILD** based on multi focal points resulted in the better rendition than 2D GMA. It is a key point that a true 3D GMA gives the seamless mapping without segmentations, then without causing unnatural artifacts as compared with that by 2D GMA in hue divided *L-C* planes.

However the yellow colors in image's high light ranges are tended to lose their chroma ingredient when **ILD** method is applied. The better **ILD** method considering the gamut relationships in between image and printer is under development.

6. Reference

1   Chen Hung-Shing, Minoru Omamiuda and Hiroaki Kotera, *Adaptive Gamut Mapping Method Based on Image-to-Devic*e, Proc. IS&T NIP15 , pp. 346-349 (1999).
2   A Standard Default Color Space for the Internet-sRGB, http://www.w3.org/Graphics/Color/sRGB

7. Biography

Chen Hung-Shing, he received a first class B.S. honors in Graphic Arts Engineering from Chinese Culture University, Taipei, Taiwan, R.O.C, in 1990. During 1995-1997, he hold his M.S. in Printing Image Engineering of Chiba University, Japan. Since April 1997 he is studying towards his PhD course at Graduate School of Science and Technology, Chiba University, Japan. His research interests include color gamut mapping, digital printer and color management technologies for multimedia.