3D Gamut Comparison between Image and Device for Gamut Mapping

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Abstract

This paper proposes a simple and easy method for 3D gamut comparison between image and device. In the previous paper, we reported *3D I-D GMA* (Image-to-Device Gamut Mapping Algorithm) is a best way to make the appearance matching between display and print images. A quick decision whether each pixel is located at inside of the device gamut or not, is necessary to execute *3D I-D GM*. In this paper, both 3D image and device gamut shells are shaped as polygon meshes in the segmented discrete polar angle (θ_i, φ_j) by extracting the most outside points from the random color distributions of source image. The image and device gamut boundaries are quickly compared between polar angle segments and the pixels located at the outside of device gamut are automatically separated. *3D I-D GMA* has been executed by mapping the image color points into the inside of device gamut shell referencing to the surface points on the corresponding polar segments.

A variety of image gamut shapes are compared with that of inkjet printer and experimental results in 3D Image-to-Device GMA are reported.

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, many of the current gamut mapping algorithm (GMA) are based on the concept of Device-to-Device (D-D),[1] which is negligent of the image color distributions. The saturation and gradation losses will happen after the mapping, because the image color distributions don't always fill the entire monitor gamut. While, the Image-to-Device (I-D)GMA uses the image gamut boundary, then it can suppress such losses in minimum.[2]

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. We proposed 3D I-D GMA[3]. It is shown that the GMA coupled with 3D compression and multi focal points resulted in the better rendition than 2D GMA. 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, It spent a lot of time for the calculation and need a complex algorithm, because all intersection points are calculated for the multi focal points on the surface of both image and printer gamuts where the focal line passes through.

In this paper, we propose a new simple and easy method for comparing the gamut between image and device. Both color spaces are divided by polar angle (θ_i, φ_j). The most out-side points from the center in polar division are extracted, and both gamuts are compared by the each representative vector. *3D I-D GMA* has been executed by referencing to the each representative vector.
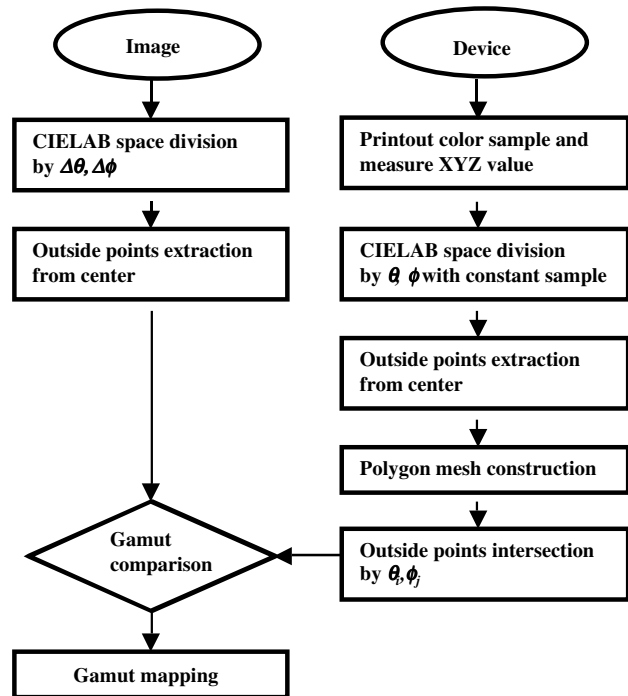

Figure 1. Flow diagram of 3D gamut comparison.

Comparison of Divided Gamut Space

Figure 1 shows the flow diagram of 3D gamut comparison between image and device. The random color distributions of source image on the CIELAB space are divided by the

uniform polar angle $(\Delta\theta, \Delta\phi)$. For image representative vector, the most outside points are extracted from image center in each divided segments. While, printer gamut shells are shaped as polygon meshes by extracting the most outside points for the color distributions in the segmented non-uniform polar angle (θ, ϕ) to include the constant samples. For printer representative vector, the most outside points are extracted by the discrete polar angle (θ_i, ϕ_j) from image center. Where polar angle θ and ϕ are calculated by Eq.1 and Eq.2[4].

$$\theta = tan^{-1}\left(\frac{b*-b*_0}{a*-a*_0}\right) \quad (1)$$

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

$;(L*_0, a*_0, b*_0)$=image center.

Results of Compared Gamut

Figure 2 shows the example of gamut comparison results. Original image are (a) "bride", and compared between image and ink-jet printer gamut are (b). Each gamuts are divided with 16*16 segments by polar angle θ and ϕ. In figure (b), dark segments represent the outside of printer gamut and light segments are the inside of printer gamut. The image and device gamut boundaries are quickly compared between polar angle segments and the pixels located at the outside of device gamut are automatically separated.
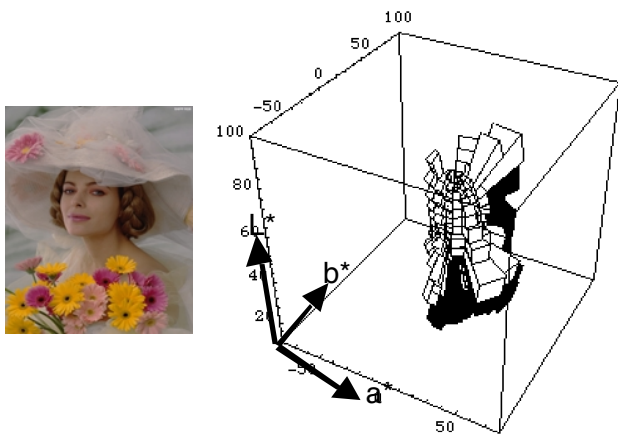
(a) original image   (b) comparison of image and printer

Figure 2. Comparison results of image and printer gamut.

Application to 3D I-D GMA

GMA to single-focal point

Figure 3 shows the overview of the GMA to single focal point. In segmented CIELAB space, a source color s is mapped to target t along the mapping line toward focal point p referencing to the image representative vector $\vec{pi}$ and output device representative vector $\vec{po}$. Where $\vec{pi}$ and $\vec{po}$ do not exist on the same focal line. It's GMA is given by the following vector notation.

$$\vec{pt} = \vec{po} \cdot \left(\frac{\vec{ps}}{\vec{pi}}\right)^{\gamma} \quad (3)$$

Here γ represents the gamma-compression coefficient[2]. The GMA works as linear compression for $\gamma = 1$, and as nonlinear compression for $0 < \gamma < 1$.
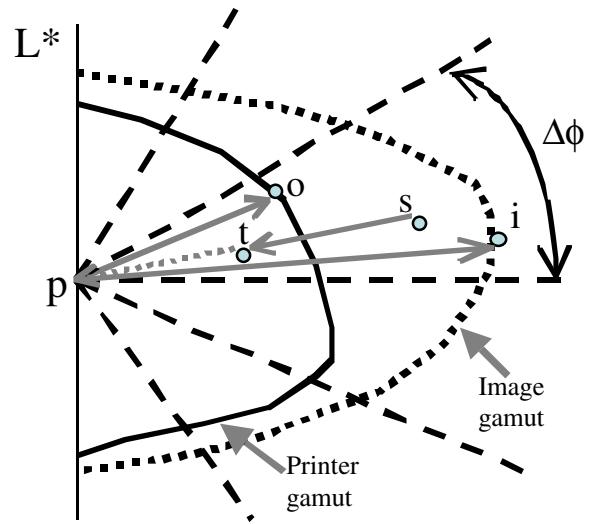

Figure 3. Overview of the GMA to single focal point.

GMA to Multi-Focal Point

In the mapping into a single-focal point used in the typical 2D GMA, lower the lightness reappearance is fatal to the image quality. To keep the natural lightness, a mapping into the multi-focal points is desirable. We take into account the media used in the experiment by having as parameters the minimum L* point p_{lower}, which is the point where slope is changed, and the maximum L* point p_{upper}. Image and printer lightness divisions are divided by polar angles under p_{lower} and over p_{upper}, and by the parallel segments between p_{lower} and p_{upper}. Figure 4 shows the overview of the GMA to multi-focal points with two convergent lightness points.
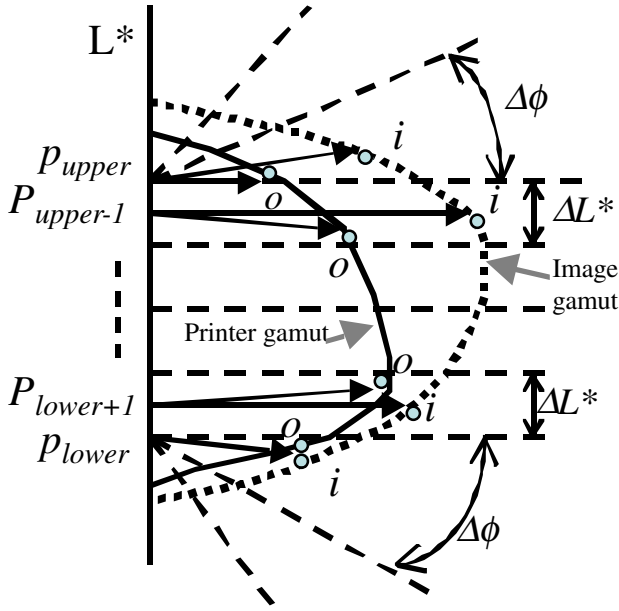
Figure 4. Overview of the GMA to multi focal point.

Experimental Results

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.

The examples of test image "fruits & vegetables" mapped for the GMA to single-focal point are shown in figure 5. By setting the gamma-compression coefficient (γ = 0.8), the target colors t in Eq.(3) after mapping is obtained. Each image and printer gamuts are divided with 16*16 segments by polar angle θ and ϕ. In the case of the single-focal point GMA, a result is affected by the position of a focal point. Figure 5 (a) shows GMA to a focal point {L*,

a*, b*}={80, 0, 0}, and (b) shows that of {L*, a*, b*}={40, 0, 0}. Shown figure (a), the image was reproduced the lighter color appearance and has unnatural artifact in part of 'eggplant'. While, in figure (b), 'eggplant' was reproduced better but the whole image was reproduced the darker color appearance and has unnatural artifacts in part of 'onion' and 'persimmon'.

(a) GMA to focal point {L, a*, b*}={80, 0, 0}*

(b) GMA to focal point {L, a*, b*}={40, 0, 0}*

Figure 5. Experimental results for the GMA to single-focal point.

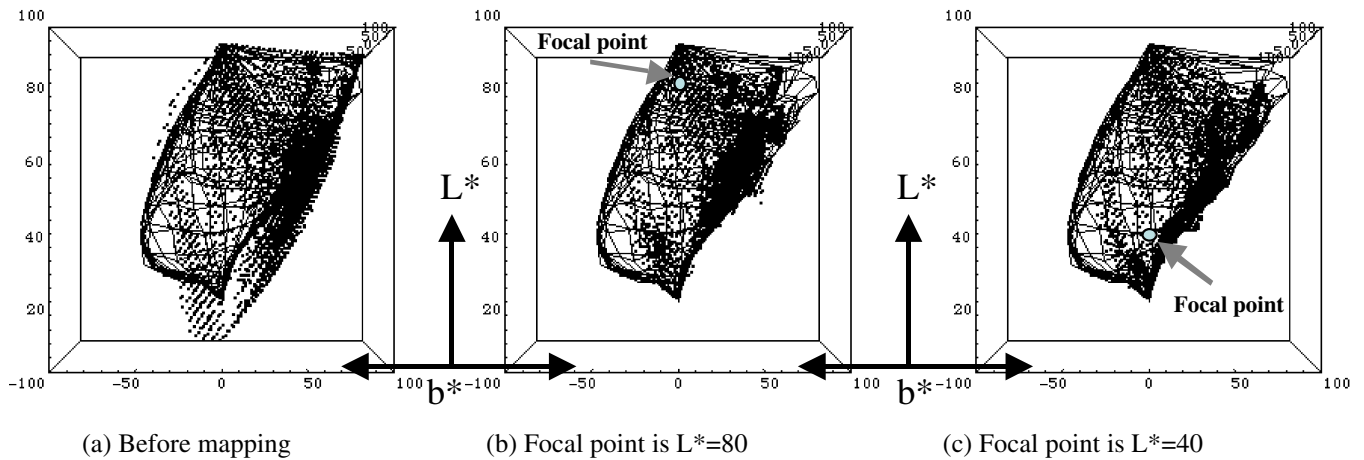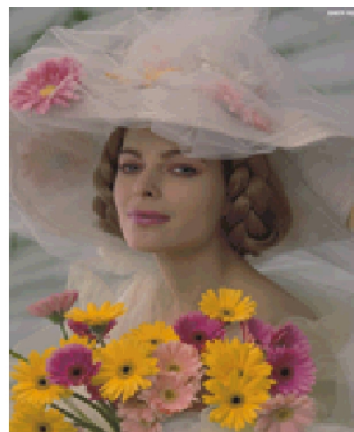(a) Before mapping   (b) Focal point is L*=80   (c) Focal point is L*=40

Figure 6. Before and after mapping color distribution on L-b* plane with printer gamut (wire frame).*

(a) GMA result of 'fruits & vegetables'.

(b) GMA result of 'bride'.

Figure 7. Experimental results for the GMA to multi-focal points.

Figure 6 shows the before and after mapping color distribution with the printer gamut. In comparison with original color distributions in figure 6(a), the image's distributions after mapping are shifted inside printer gamut, and focal point L*=80 is shifted in upper side and L*=40 is in lower side of printer gamut.

The examples of test image "fruits & vegetables" and "bride" mapped for the GMA to multi-focal points are shown in figure 7. Each image and printer gamuts are divided with 16 segments by polar hue angle θ, and 16 segments by lightness (4 segments by polar angle φ under $L^*_{lower} = 40$, 8 segments by parallel between L^*_{lower} and L^*_{upper}, and 4 segments by polar angle φ over $L^*_{upper} = 80$). Both image were reproduced good color appearances without unnatural artifacts.

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 judgment, the data from the psychophysical experiment are analyzed to generate interval scales(z-score values).

The evaluation results in the psychophysical experiment show that the mapping results by the GMA to multi-focal points method give the better appearance than the results by the single-focal point method.

Discussion and Conclusion

We proposed a simple and easy method for 3D gamut comparison between image and device. The image and device gamut boundaries are quickly compared between polar angle segments and the pixels located at the outside of device gamut are automatically separated. **3D I-D GMA** has been executed by mapping the image color points into the inside of device gamut shell referencing to the surface points on the corresponding polar segments. A variety of image gamut shapes were compared with that of inkjet printer and experimental results in 3D I-D GMA were reported.

A result of 3D I-D GMA is affected by the position of focal points. The better multi-focal points method considering the gamut relationships in between image and printer is under development.

References

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Biography

Ryoichi Saito received his BS degree in Image Science from Chiba University in 1983. Since 1983, he has been working on direct plate making, digital image processing and color reproduction at Chiba University.