3D Image-to-Device Gamut Mapping Using Gamut Boundary Descriptor

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Abstract

3D I-D GMA (Image-to-Device Gamut Mapping Algorithm) is an ideal way to map the display image to the inside of printer gamut. A quick decision whether each pixel is located at inside of the device gamut or not, is necessary to execute 3D I-D GMA. We proposed a new gamut boundary descriptor for comparing the gamut between image and device by discrete polar angle (θ, ϕ). The gamut shell is described as the simple radial distances, *r-image*. In this paper, we try to research the optimum r-image for 3D GMA. The printer gamut shell is desirable a smooth and a precise surface. Its gamut shell is examined to shape by polygon mesh and *Overhauser Spline* Fanctions. The 3D I-D GMA using r-image is considered by the case of the single and the multi focal points. 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.

Introduction

Many of the gamut mapping algorithm (GMA) have been proposed in 2D L-C planes.[1] So far, 3D GMA is not major but a few works have been reported.[2-4] However, these are based on the concept of Device-to-Device (D-D). The color information 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.[5] 3D I-D GMA is an ideal way to map the display image to the inside of printer gamut keeping the minimum loss in color information.[6] 3D GMA, however, spent the calculation for many hours and needed a complex algorithm to obtain the intersection points of each gamut surfaces. In the previous paper, we proposed a new simple and easy method for comparing the gamut between image and device.[7-9] Both color spaces are divided by polar angle (θ, ϕ). The most out-side points are extracted and both gamut are compared in each segment. The gamut shell is described as the simple radial distances, *r-image,*[8] and we try to execute 3D I-D GMA by referencing to the each *r-image.*[10] The printer gamut shell is desirable a smooth and a precise surface. In this paper, its gamut shell is examined to shape by polygon mesh and *Overhauser Spline* Fanctions. A concrete method is stated to the following chapters.

Color Gamut Description

The random color distributions of source image on the CIELAB space are divided by the uniform polar angle, hue angle θ and lightness angle ϕ. Letting the image color center be [L_0^*, a_0^*, b_0^*], the radial distance is measured from the center as

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

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

$$r = \sqrt{(L^*_i-L^*_0)^2+(a^*_i-a^*_0)^2+(b^*_i-b^*_0)^2} \quad (3)$$

The image radial vector is picked up the points with the maximum radial distance in every segment divided by (θ, ϕ).

The printer gamut shell is obtained from the measurements of color chips. Its gamut is extracted the most outside points in the partitioning un-even division to include the constant samples.[7] The simple way to render color gamut is the formation of the polygon meshes with triangular patches. In figure 1 (a), 18*16 θ-ϕ segments are used to obtain surface points and gamut shell is formed by the 2*18*16 triangles.

To obtain more smoothly gamut shell, we used a seamless gamut shell composed of *Overhauser Spline* Fanctions.[6,11] This surface P(u,v) based on double para-meters u and v on the surface is calculated by Eqs. 4 to 6.

$$P(u,v) = \sum_{i=0}^{3}\sum_{j=0}^{3} N_i^3(u)N_j^3(v)V_{ij}, \quad 0 \le u < 1; \quad 0 \le v < 1 \quad (4)$$

$$N^3(x) = \begin{bmatrix} x^3 & x^2 & x & 1 \end{bmatrix} \cdot M_{CR}, \quad x = u,v \quad (5)$$

$$M_{CR} = \frac{1}{2} \begin{bmatrix} -1 & 3 & -3 & 1 \\ 2 & -5 & 4 & -1 \\ -1 & 0 & 1 & 0 \\ 0 & 2 & 0 & 0 \end{bmatrix} \tag{6}$$

where V_{ij}(I=1,2,3,4; j=1,2,3,4) represents the matrix of 16 control points. Figure 1 (b) shows a gamut shell formed by the *Overhauser Spline* Fanctions.

Then, the printer radial vector is computed the intersection points on the surface by the discrete polar angle (θ_i, ϕ_j). Figure 2 shows (a) the example of printer's radial vectors array extracted polygon mesh surface, r-image. The difference of radial vectors between polygon mesh and *Overhauser Spline* Fanctions shown in figure 2(b).
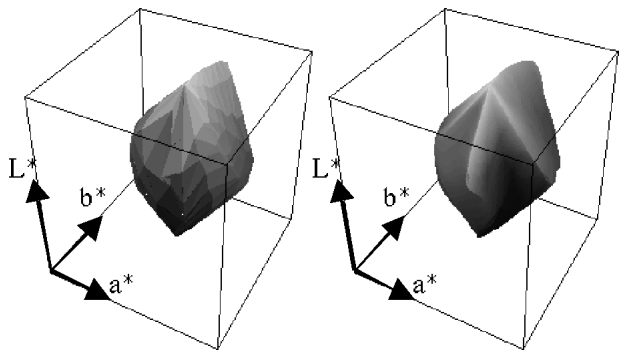
(a) Polygon mesh.   *(b) Overhauser Spline Fanctions.*

Figure 1. Printer gamut shell formed by extracted points.
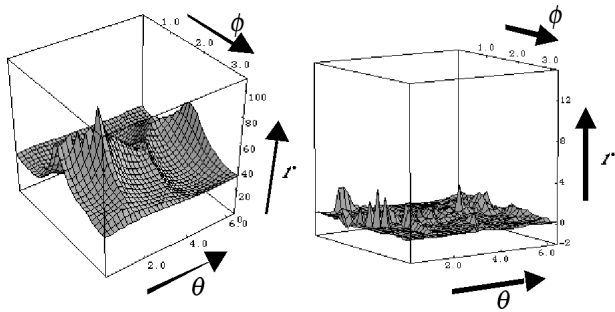

(a) Printer r-image.   *(b) Difference between polygon and Spline.*

Figure 2. Printer r-image and difference by the formation method.

Application to 3D I-D GMA

Figure 3 (a) 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 radial vector *pi* and output device radial vector *po*. Here, *i* and *o* mean image and output device gamut, respectively. Each of *pi* and *po* do not exist on the same focal line.

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}. While, during two points, these division is parallel. Figure 3 (b) shows the overview of the GMA to multi-focal points with two convergent lightness points.
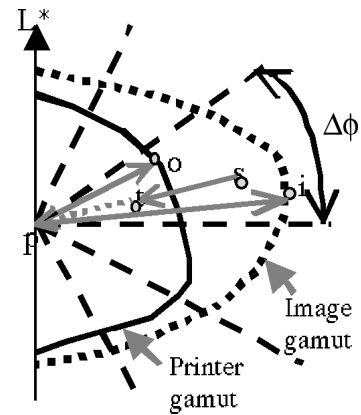
(a) The GMA to single focal point
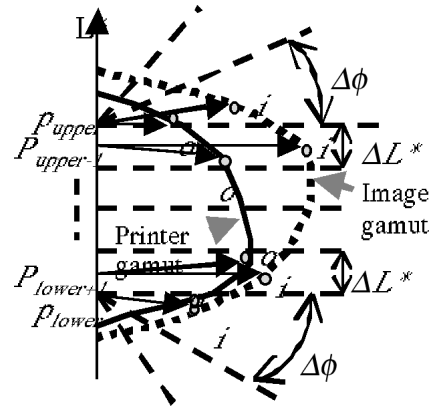
b) The GMA to multi focal point.

Figure 3. Overview of the two GMA.

This GMA is represented by the following vector notation.

$$\vec{pt} = \vec{po} \cdot \left(\frac{\vec{ps}}{\vec{pi}} \right)^{\gamma} \tag{7}$$

Here γ represents the gamma-compression coefficient.[5] This GMA works as linear compression for $\gamma = 1$, and as nonlinear compression for $0 < \gamma < 1$.

Experimental Results

Figure 4-5 shows the examples of r-image for images. Figure 4(a) is the CG image "fruits & vegetables", 4 (b) and 4 (c) also show its r-image by single- and multi focal.

Figure 5(a) is the standard image "wool", 5 (b) and 5 (c) are also its r-image by single- and multi focal. The r-image by single focal is constructed by θ and ϕ with 32*32 segments at the image center [L*,a*,b*=50,0,0].
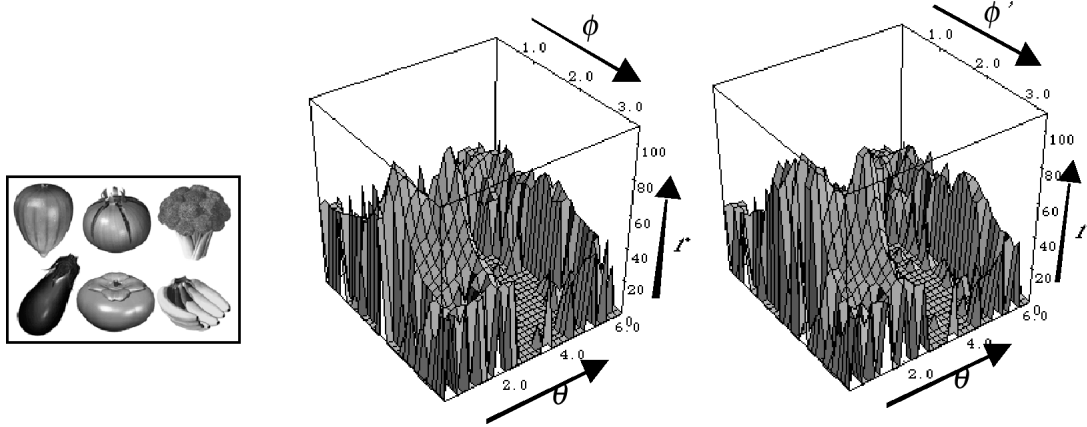
a) CG image "fruits and vegetables".   *(b) r-image by single focal.*   *(c) r-image by multi focal.*

Figure 4. CG image and its gamut shell by r-image.
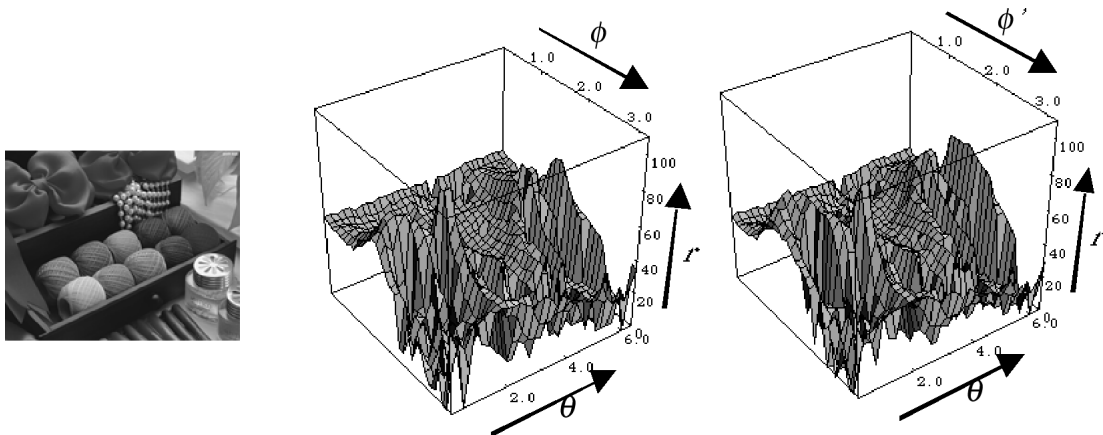
(a) Standard image "wool".   *(b) r-image by single focal.*   *(c) r-image by multi focal.*

Figure 5. Standard image "wool" and its gamut shell by r-image.

The r-image by multi focal points is also constructed by polar hue angle θ with 32 segments. But in lightness angle, it is each 10 segments over p_{upper} and under p_{lower}, 12 segments between both points by parallel. In each figure, it has a little difference between single focal (b) and multi focal (c). In figure 4 (b) and (c), the radial distance of CG image is noticeably larger at low θ side (Orange to Yellow region), but it is very smaller at middle θ side (Green to Cyan region) than that of printer in figure 2 (a). While in figure 5 (b) and (c), the radial vector of image "wool" is larger on the whole than that of printer.

In the hardcopies, the color correction is indispensable to convert RGB data into CMY signals. In this study, the nonlinear color correction functions are applied to RGB to

CMY conversion. Figure 6 (a) shows the result of CG image "fruits&vegetables" calculated by 3D I-D GMA for single focal points. As comparison, the result calculated by 3D D-D GMA is shown in Fig. 6 (b). It is shown that gradation loss has few results calculated by I-D than the result of D-D.

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 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). An example of an evaluation experiment is shown in Figure 7. The device formation method of polygon mesh was used in this experiment. In this case, the multi-focal points method generally give the better appearance, and γ=0.5 is more better result. While, the single-focal point method were worst results.

Conclusion

We proposed a new method for 3D gamut comparison between image and device. The image and device gamut boundaries are quickly compared between both r-image extracted polar angle segments. In device gamut, gamut shell formed by both polygon mesh and *Overhauser Spline* Fanctions are considered. 3D I-D GMA has been executed by mapping the image color points into the inside of device gamut shell referencing to the r-image with both single- and multi- focal point. A variety of image gamut shapes were compared with that of inkjet printer and experimental results in 3D I-D GMA were reported.

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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.
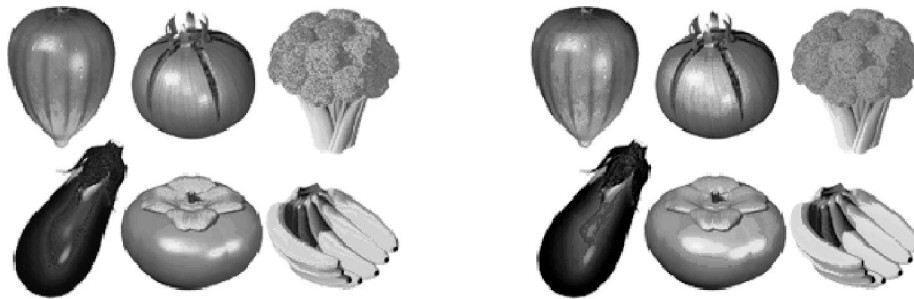
(a) Result of 3D I-D GMA by single focal (γ=0.8) (b) Result of 3D D-D GMA by single focal
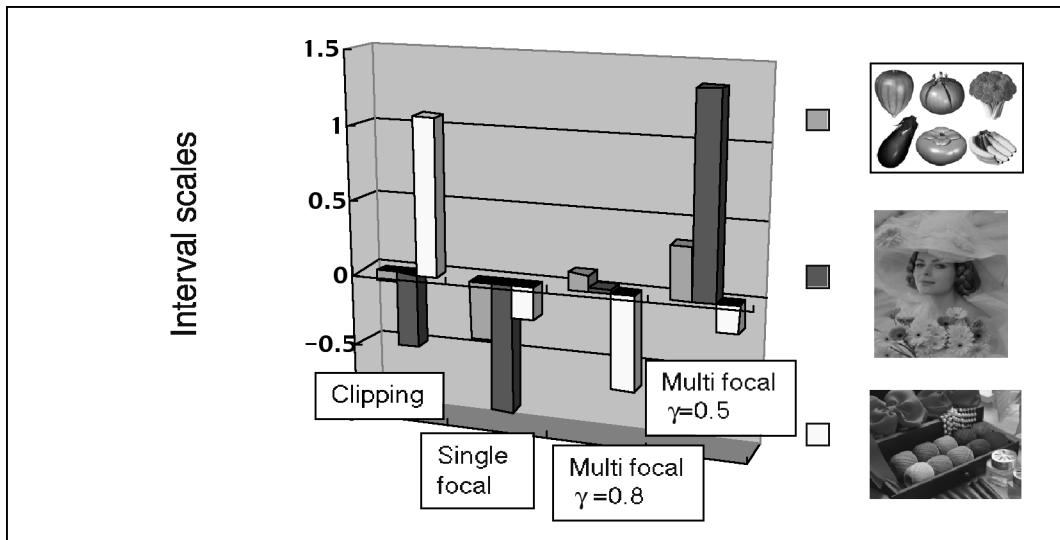
Figure 6. The Mapping result of CG-image "fruits&Vegetables"

Figure 7. An example of psychophysical experiment.