Gamut Mapping Method Adaptive to Hue-divided Color Distributions

Chen Hung-Shing, Minoru Omamiuda and Hiroaki Kotera
Graduate School of Science and Technology, Chiba University
Chiba, Japan

Abstract

This paper describes Image-to-Device Gamma-Compression Gamut Mapping Algorithm based on the concept of image segmentation. Two image segmentation methods, hue-leaf division and image clustering, are combined with the proposed mapping algorithms. The image color distributions on Chroma-Lightness planes are adjusted to fit to the output device gamut in terms of image's gradation preferred or image's chroma preferred.

Three typical mapping methods, (1) Device-to-Device Gamma-Compression, (2) Image-to-Device Gamma-Compression and (3) Clipping Compression, are applied to the segmented images.

The psychophysical experiment shows the evaluation results depend on not only the image segmentation methods, but also the image contents and the gamut functions. And, if the image's gradation is preferred, Image-to-Device Gamma-Compression GMA is superior to the conventional methods based on the Device-to-Device concept. If the high-chroma image is preferred, Clipping Compression will be a better choice for use.

Introduction

On the process of digital 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, which is negligent of the image's color distributions.

Even though the concept of Device Independent Color has gradually been applied to many color management systems in image input and output devices, it is not enough to solve the color appearance problems between different devices, in particularly between the monitor image and the hardcopy image. Under the operating surrounding of the same color temperature and luminance, color appearance mismatch between these 2 devices comes from the difference in their color gamut sizes. Usually the monitor's color gamut is wider than the printer's color gamut. To resolve this problem, the establishment of a gamut mapping method, based on the concept of image-dependence, is necessary.

Besides the optimums of geometrical mapping directions,[1,2] the performances in image segmentation and image gradation scaling also affect gamut mapping's results. The Gamma-compression GMA (in Gamut Mapping Algorithm), which is based on the concept of Image-to-Device, is proposed by coupling in the image segmentation method with the gamut-compression coefficient γ.

Gamut Mapping Algorithm (GMA)

One of the gamut mapping technologies called CARISMA[3] (Colour Appearance Research for Interactive System Management) was confirmed to perform well for images' gamut mapping.[4]

The proposed Gamma-Compression GMA,[5] which is developed from CARISMA, is preformed based on the following set of equations :

(1) $$t = o \cdot \left(\frac{s}{i}\right)^{\gamma}$$; for cases (a) and (b) of Figure 1

(2) $$t = o_2 + (o_1 - o_2) \cdot \left(\frac{s - i_2}{i_1 - i_2}\right)^{\gamma}$$; for case (c) of Figure 1

The distance from the anchor point **p** to the source color is represented by **s**. And the distance from **p** to the target color is represented by **t**. The distance from **p** to input gamut is represented by **i** (or $\mathbf{i}_1$, $\mathbf{i}_2$ in case (c)), and the distance from **p** to output gamut is represented by **o** (or $\mathbf{o}_1$, $\mathbf{o}_2$ in case (c)). As proposed in the previous study,[5] the optimal gamut-compression coefficient γ is set between 0.7 and 0.9.

By drawing color gamut boundaries on the C*-L* plane in terms of input data and output device, 3 different cases appear, as shown in Figure 1. In cases (a) and (b), the input gamut is completely enclosed by the output gamut. Then Eq (1) is used to compress the source colors along a given line toward **p** on the L* axis.

In case (c) of Figure 1, the input gamut is not enclosed by the output gamut, but instead cross over each other. Eq (2) is used to compress the source colors along a given line toward **p** on the C* axis.

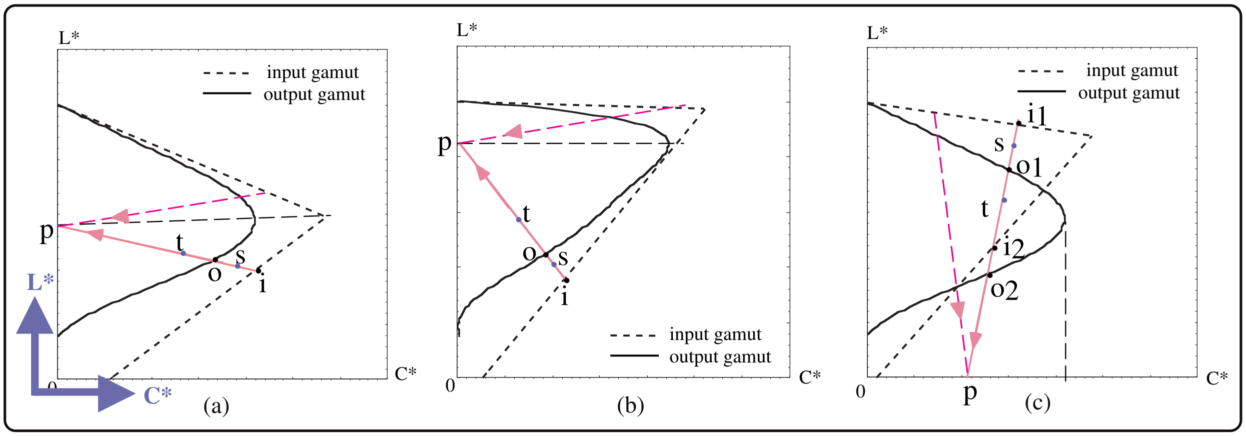

Figure 1 Overview of the relationships between input gamut and output gamut.

The anchor point **p** in case (a) represents the intersection between the line passing through the 2 gamut cusps and L* axis, and **p** in case (b) is the crossing between the line (which is parallel to C* axis) passing through the input gamut cusp and L* axis. **p** in case (c) is the point on C* axis which has half of the input gamut maximum chroma.

In this experiment, the Device-to-Device (D-D) mapping is performed by GMA from the input display gamut (Device 1) toward the output printer gamut (Device 2). And the Image-to-Device (I-D) mapping is performed by GMA from the source image gamut (Image) toward the output printer gamut (Device).

However, if only the output printer gamut is used, the Clipping Compression is applied to keep the color distributions undisturbed inside the printer gamut, while the gradations of colors outside the printer gamut are sacrificed.

Image Segmentation Methods

Two image segmentation methods, hue-leaf division and image clustering, are applied to GMAs. The former technique can be operated more efficiently, and the latter performs well when extracting the ambiguous colors from the original image, such as skin color or sky color.

The hue-leaf division method divides the image color distributions into 6 main hue-leaves of red, green, blue, cyan, magenta and yellow according to their corresponding hue angle ranges. This technique allows for observation of the changes of the image segmented colors during the gamut mapping process.

On the other hand, image clustering is one of the most important ideas of proposed Object-to-Object color matching technique[6]. By using Euclidian, Mahalanobis distance or Bayesian decision rule based on the maximum likelihood principle and settings the clustering parameters (such as the initial color centers, the thresholding area ratio and iteration times), pictorial image can be successfully segmented into different object areas with clustered color distributions.

If the segmented channels divided by image clustering include 2 hue leaves or more, then the hue-leaf division method may be used after image clustering.

Gamut Functions

The gamut functions of the segmented image and devices are defined as follow: C*-L* distributions (the color distributions plotted on C*-L* planes) of segmented image or devices are divided by equal L* intervals (e.g. $\Delta L = 4$). Within each segmented L* intervals, the maximum chroma points of the divided C*-L* distributions are extracted. For finding the fitting curves, the least-squares method is used to fit these maximum chroma points. Then the gamut functions $\boldsymbol{F}_i$ (i = 1~n, n represents the segmented numbers) can be obtained where most of the segmented colors are included inside the curves.

Experiment

As shown in Figure 2, the gamut mapping procedures are described as follows:

Steps 1 & 2 Two kinds of images (see Figure 3) from CD-ROM are used for testing GMAs. One is natural image (balloon), and the other is CG image (fruits & vegetables). Since both images include high chromatic and out-of-gamut colors, the differences between the CRT image and the printed hardcopy image are easily distinguished.

Based on the conditions of Tables 1 & 2, the segmented number n of the hue-leaf division was 6. And for image clustering, n = 9 for natural image, and n = 8 for CG image.

Step 3 sRGB color data of the segmented images from step 1 are transformed into CIELab space. Next, the C*-L* distributions ${}_{img}\boldsymbol{D}_i$ (i = 1~n) are plotted and their gamut equations ${}_{img}F_i$ (i = 1~n) are calculated on the C*-L* planes.

Since the relations between image and devices must be considered, the divisions of monitor and printer colors corresponding to segmented image channels are also necessary.

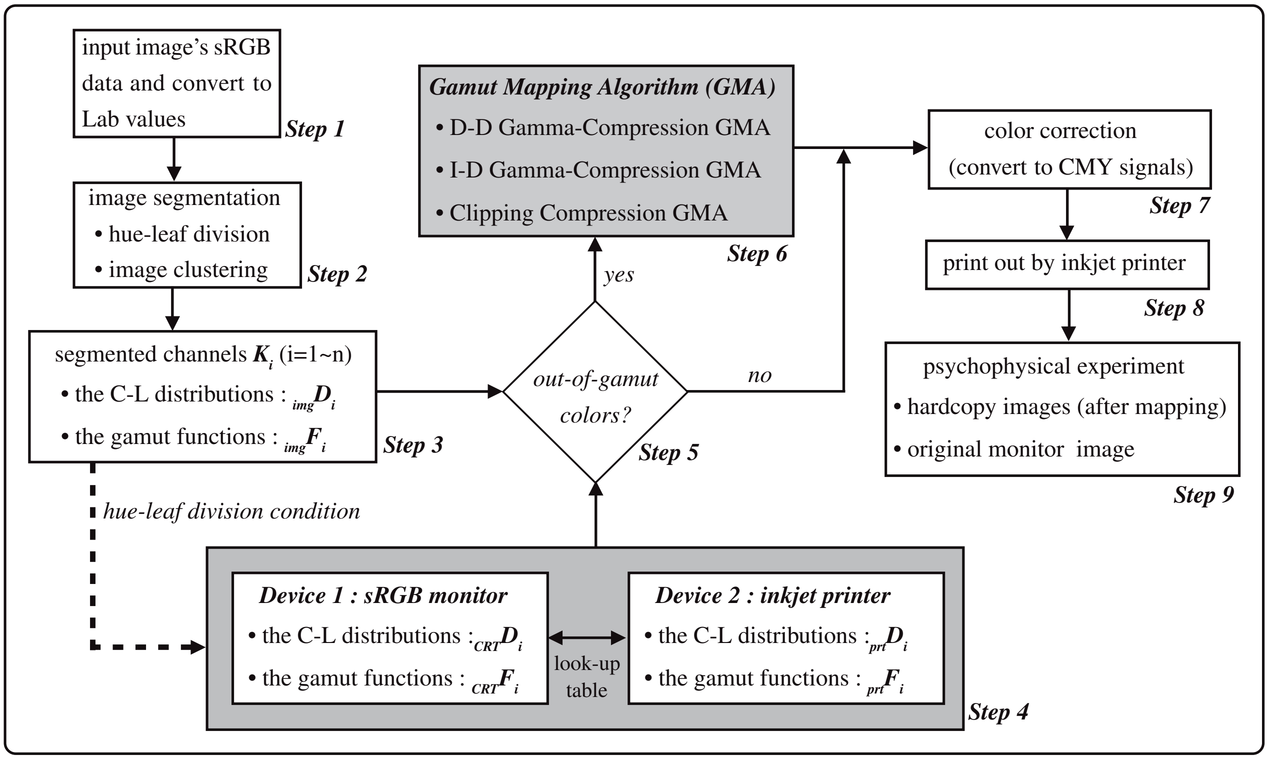

Figure 2 Flow diagram of gamut mapping process.

Figure 3 Two kinds of test images: "fruits & vegetables" (CG image) and "balloon" (natural image).

Table 1. The segmented hue-leaves by using the hue-leaf division

Hue-leaf	*Angle range*
red	0 ~ 80 & 355 ~ 360 degrees
yellow	80 ~ 115 degrees
green	115 ~ 185 degrees
cyan	185 ~ 245 degrees
blue	245 ~ 320 degrees
magenta	320 ~ 355 degrees

Table 2. The segmented conditions by using the image clustering.

Statistical classifier	Bayesian decision rule
Initial color's center numbers and Lab positions	***64*** inside the image gamut in Lab space
Iteration times	***2*** (for natural image) ***3*** (for CG image)
Threshold (area ratio)	***0.04*** (for natural image) ***0.02*** (for CG image)
Segmented numbers	***9*** (for natural image) ***8*** (for CG image)

Step 4 The display colors, similar to the image colors on the monitor, are luminous colors produced by additive color mixing. These display colors can be approximately calculated with the 3 x 3 matrix to transform sRGB color data to tristimulus values in terms of Grassmann's law.[7] Thus the display's C*-L* distributions $_{CRT}D_i$ (i = 1~n) are segmented into the same hue-angle ranges as the previously divided image ranges (see cases (a) and (b) of Figure 4).

Since the color reproduction mechanism of hardcopy is rather complicated than luminous color and estimation of hardcopy colors is not easy. In this experiment, a look-up table is used to exchange the Lab values between sRGB monitor and inkjet printer (see cases (b) and (c) of Figure 4). Each hardcopy's C*-L* distributions $_{prt}D_i$ (i = 1~n) corresponding to the same segmented parts of monitor device are obtained using the look-up table.

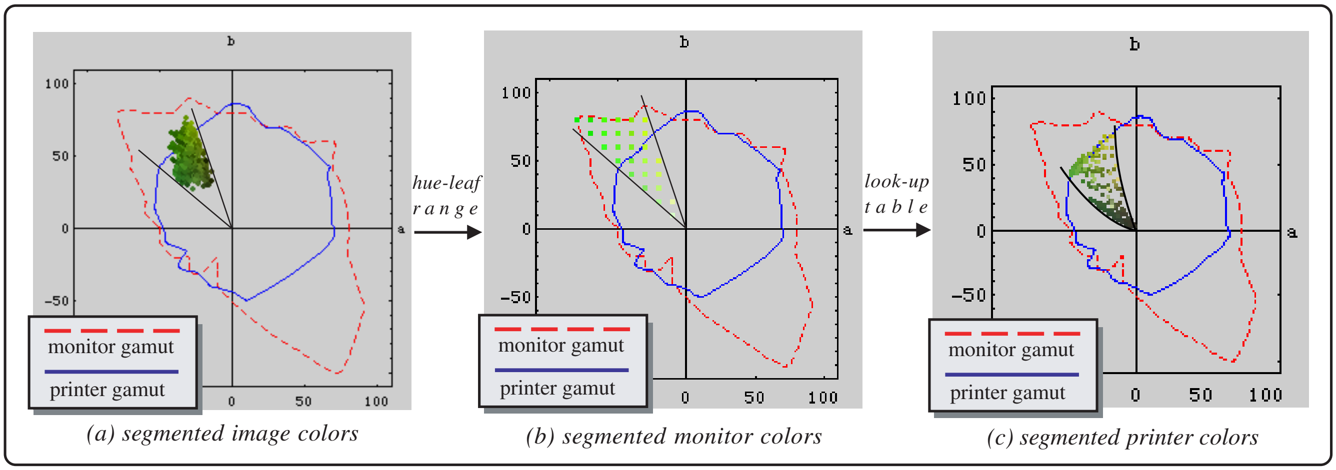

Figure 4 The hue-leaves of segmented image and devices. The hue-shift problem occurring in segmented printer colors is solved by using look-up table.

After getting the Lab values in each devices' segmented parts, the monitor gamut equations ${}_{CRT}\boldsymbol{F}_i$ (i = 1~n) and the printer gamut equations ${}_{prt}\boldsymbol{F}_i$ (i = 1~n) can be calculated on their C*-L* planes.

Step 5 Lab color data with equal interval within the sRGB range are generated and transformed into corresponding XYZ tristimulus values and sRGB values on CRT monitor.

Here, 1675 color chips formed from the Lab values on the sRGB monitor are printed by Epson PM-750C inkjet printer. The hardcopies' XYZ tristimulus values are measured with spectrophotometer and then transformed into CIELab space.

To determine whether the segmented image has out-of-gamut colors, the image's C*-L* distributions ${}_{img}\boldsymbol{D}_i$ and printer gamut equations ${}_{prt}\boldsymbol{F}_i$ are compared on the C*-L* planes. If the segmented images have the colors outside the printer gamut equations, gamut compression is performed for the hue-leaves having out-of-gamut colors. If the segmented images are inside the printer gamut equations, then the gamut compression is not necessary (proceed to step 7).

Step 6 Three kinds of gamut mapping methods are applied to the segmented images. D-D Gamma-Compression GMA is used with both the display and printer gamut equations for compressing the segmented image colors. I-D Gamma-Compression GMA is used with the image and printer gamut equations for compressing the segmented image colors. In this experiment, the gamut-compression coefficient γ is set to 0.7 for natural image and 0.8 for CG image. Then Clipping Compression GMA is used only with printer gamut equations for compressing the segmented image colors (see Figure 5).
After these signals are compressed by the 3 GMAs, their corresponding XYZ tristimulus data are sent to step 7.

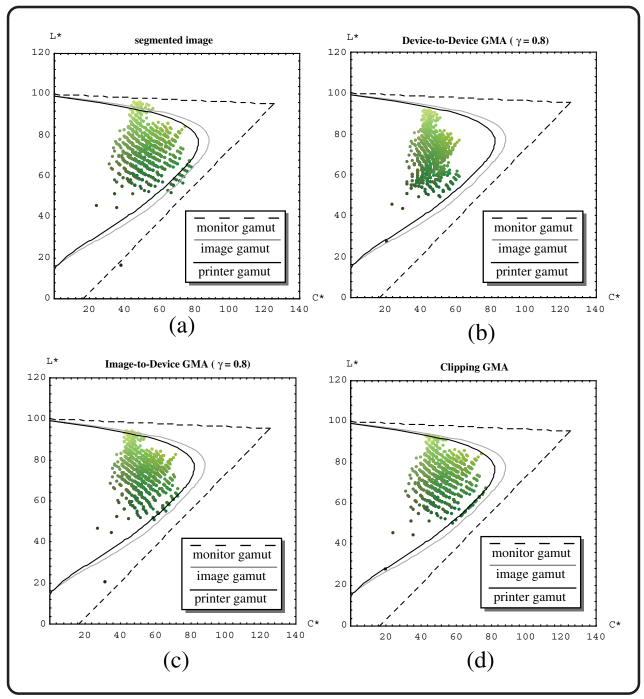

Figure 5 The examples of original segmented image and their C^*-L^* distributions mapping by 3 kinds of GMAs: (a) original segmented image, (b) D-D $_{\gamma=0.8}$ GMA, (c) I-D$_{\gamma=0.8}$ GMA and (d) Clipping Compression GMA.

Steps 7 & 8 Several methods can be used for hardcopy's color correction which converts XYZ tristimulus into CMY data. For example, Neugebauer functions in terms of halftone printing, color masking functions in terms of color photographic density and the use of look-up table. In this study, the look-up table embedded in ColorSync profiles are applied to convert XYZ tristimulus to CMY data. Then the hardcopies are printed out by inkjet printer in step 8. This produces a total of 12 hardcopies (3 GMAs x 2 segmentations x 2 images).

Step 9 Monitor's white point is set to the chromaticity near CIE Illuminance D65 with a peak luminance of 80 cd/m^2. The printed hardcopies after mapping are viewed in a light box with the same color temperature and peak luminance as monitor's set. CRT monitor is calibrated to near sRGB standard.[7]

A psychophysical experiment was carried out to make a comparison of color appearance matching between the original CRT image and the printed hardcopies after mapping. A paired-comparison technique is used and 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).

Results

The evaluation results of the phychophysical experiment shows that I-D$_{\gamma = 0.7}$ GMA with hue-leaf division is superior to other methods for natural image, whereas both Clipping Compression GMA and I-D$_{\gamma = 0.8}$ GMA with image clustering give the better results for CG image (see Figures 6 and 7).

Because the image clustering method doesn't always guarantee to segment the image channels into enough numbers of color, it doesn't give the better results than hue-leaf division or natural image. For case (a) of Figure 8, the out-of-gamut blue colors segmented by hue-leaf division affect all blue colors while mapping. But for case (b) of Figure 8, the out-of-gamut blue colors segmented by image clustering affect the segmented colors which lacks middle to hightlight areas of blue colors.

Although the Clipping Compression can retain higher chromatic colors, it tends to make the image gradations discontinuous. For the CG image's gradation, the mapping result of I-D$_{\gamma=0.8}$ GMA was better than Clipping Compression GMA.

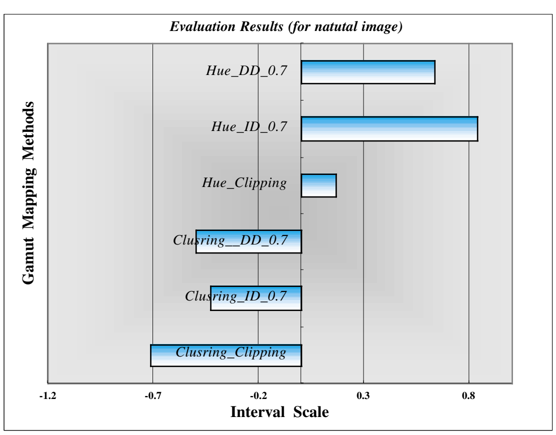

Figure 6 The evaluation results for natural image.

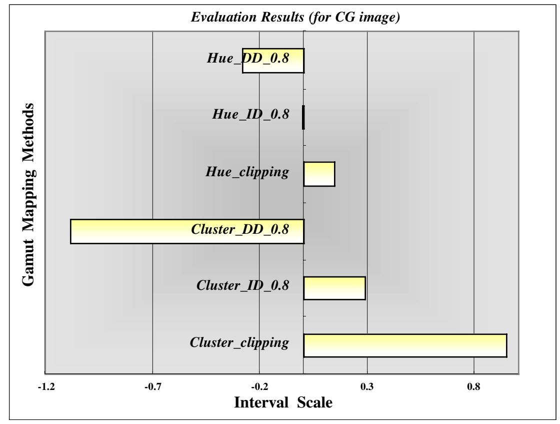

Figure 7 The evaluation results for CG image.

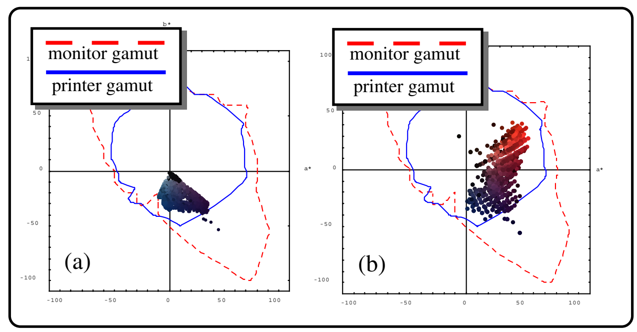

Figure 8 The natural image channels having out-of-gamut blue colors segmented by (a) hue-leaf division , and (b) image clustering.

By setting the look-up table values between monitor colors and printer colors, the hue-shift problem, in particularly blue colors, could be resolved successfully.

Conclusions

Image-to-Device GMA coupled the image segmentation with image gradation scaling is proposed. The mapping results depend on not only the image segmentation methods, but also the image contents and the gamut functions.

The choices of GMAs are dependent on the intents which the images have. If the image's gradation is preferred (for most of the natural images), Image-to-Device Gamma-Compression GMA is superior to the conventional methods based on the Device-to-Device concept. If the high-chroma image (for most of the CG images) is preferred, Clipping Compression method will be a better choice.

By well setting the look-up table values between monitor colors and printer colors, the hue-shift problem in gamut mapping process is resolved successfully.

Reference

1. Katoh N. and Ito m., Gamut mapping for Computer Generated images (II), *Proc. 4th IS&T/SID CIC* , pp. 126-129 (1996).
2. C. S. Lee, K. M. Kim, E. J. Lee and Y. H. Ha, Gamut mapping using variable anchor points, *IS&T/SPIE Conference on Color Imaging* (1999).
3. Johnson A. J., Luo M. R, Lo M. C, Xin J. H., Rhoded P. A, Aspects of Colour Management, part 2 Characterisation of Four-Colour Imaging. *Color Research and Application* (1998 b).
4. J'an Morovic and M.Ronnier Luo, Gamut mapping algorithms based on psychophysical experiment, *Proc. 5th IS&T/SID CIC* , pp. 44-49 (1997).
5. Chen Hung-Shing, Minoru Omamiuda and Hiroaki Kotera, Adaptive Gamut Mapping Method Based on Image-to-Device, *Proc. IS&T NIP15* (1999).
6. Hiroaki Kotera, Chen Hung-Shing and Tetsuro Morimoto, Object-to-object color mapping by image segmentation, *IS&T/SPIE Conference on Color Imaging* (1999).
7. *A Standard Default Color Space for the Internet-sRGB*, http://www.w3.org/Graphics/Color/sRGB