Black Color Replacement using Gamut Extension Method

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Introduction

Besides having cyan, magenta and yellow colorants, most of color printers include at least one extra colorant, black (K) in order to increase the density for shadow colors and to reduce colorants for printing shadow colors.[1] There are numerous advantages of using GCR (Gray Component Replacement) technique: the chief advantages are (1) extension of color gamuts, especially of denser black, (2) improvement of image definition, and (3) substitution of relative inexpensive black ink to more costly colored inks.[2]

Unlike gamut compression studies, gamut extension is mapping from narrower original gamuts to wider reproduction gamuts.[3,4] In this study gamut extension method was used in increasing color gamut, the major benefit of using black ink. In new method, black replacement is done in device-independent color space, and gamut is extended with increasing lightness reproducible range (CIE L or J) and increasing chroma range, sequentially. In addition, observer experimental data of gamut extension studies was used for searching optimal black replacement.*

Two different evaluation experiments, quantitative and qualitative, were carried out. In quantitative experiment, color gamuts were compared between methods of existing GCR methods in commercial color printers and of this study. Furthermore lightness contrast values, i.e., reproducible lightness range, were compared. In qualitative evaluation (psychophysical), color imaging experts compared reproductions through two different methods. The results show new method outperforms existing black color replacement method.

Gray Component Replacement

Gay component replacement has been defined as a technique in color printing where the neutral or gray component of a three-color image is replaced during reproduction with a certain level of black ink, the least predominant of the three primary inks is used to calculate a partial or total substitution by black, and the color components of that image are reduced to produce a print image of a nearly equivalent color to the original three-color print.[5,6]

There are numerous advantages of using GCR as below[1]:

1. To make the control of ink balance of the cmy colors less critical and to enhance immunity of metamerism
2. To extend the color gamut, especially the production of denser blacks
3. To improve image definition, especially in the shadow detail
4. To substitute a relatively inexpensive black ink for a portion of the more costly colored inks
5. To reduce the ink consumption and loading, which allows for better ink rapping and drying.

In this study optimized extending gamut is focused in process of black color replacement.

Gamut Extension

Experimental tool (GUI) used in the colour imaging manipulation experiment of gamut compression was also applied to the study of gamut extension. Two experiments were conducted, *Experiments GE1* and *GE2*. *Experiment GE1* was designed to acquire observer data on the extension of gamuts in terms of colour pleasantness, hence only one initial image was shown and then adjusted (extended) by observers using the computer-controlled interactive software.

Many plots were generated to examine the relationship between the initial and reproduction images in the same manner like the data analysis used for investigating gamut compression in the previous studies.[7,8] The reproduction images were then calculated by averaging each observer data for each image. These images were used to represent the mean visual results.

A GEA (Gamut Extension Algorithm), GEA-1, was developed to model the observer experimental data from *Experiment GE1* and its coefficients for lightness and chroma extension were derived using the least square technique. Five variations, i.e., GEA2-6, took the structure of GEA1 and increased the amount of chroma extension so as to verify (1) the amount of extension that the observers have applied was indeed sufficient and (2) they were too cautious with their modifications in the *Experiment GE1*. In *Experiment GE2*, the GEA-1 and its five variations (GEA-2, 3…6) were evaluated using a pair comparison method together with the average observer images obtained in *Experiment GE1*. These optimized extension methods were used in extending color gamut by adding black ink.

Gamut Extension Based Black Extraction

Procedure Overview

One advantage of adding black colorant is extending color gamut. K adding method developed in this study is carried out in CIECAM 02 (CIE Color Appearance Model 2002), that is *Jab* system. As lightness reproducible range, i.e., minimum J is decreased, is extended, find the maximum chroma range and check the reproduction possibility in terms of adding black ink and device characterization model.

Gamut extension method[3] is also used both decreasing and increasing lightness and chroma values for enhancing image quality by adding K. Detail algorithm procedures are as below:

Step 1: Find lowest J

DO

J-△J (△J: constant): decrease reproducible lightness.

1. Calculate Jab→XYZ (3C) using device characterization model
2. Calculate actual substitution ratio based upon the GCR degree vs. J function.
3. Substitute K density, that is $D_{(4c)}=\{D_{(3c)} - D_{(min\ 3c*GCR)}\} + D_{(K\_Interpolated)}$; K density is obtained based upon 1-D LUT of black.

UNTIL

4-C extended gamut is not smaller than 3-C gamut boundary in any r. (r=Euclidean distance from mid-point of lightness, J=50, onto gamut surface).

Step 2: Extend r

Find the possible largest r on the basis of extended lightness range from Step 1 above.

When extending lightness and chroma range GEA (Gamut Extension Algorithm) method is used. The relationship between input and output lightness and chroam was obtained through psychophysical experiments. Twelve observers took part in these experiments. Before the main experiment, a training session was conducted to verify the experimental procedure and their understanding of lightness, chroma and hue attributes. Each observer took a training session for one hour. On average, each image took between 25 to 50 minutes to complete. Four images used earlier were again used. This experiment was conducted twice for each image.

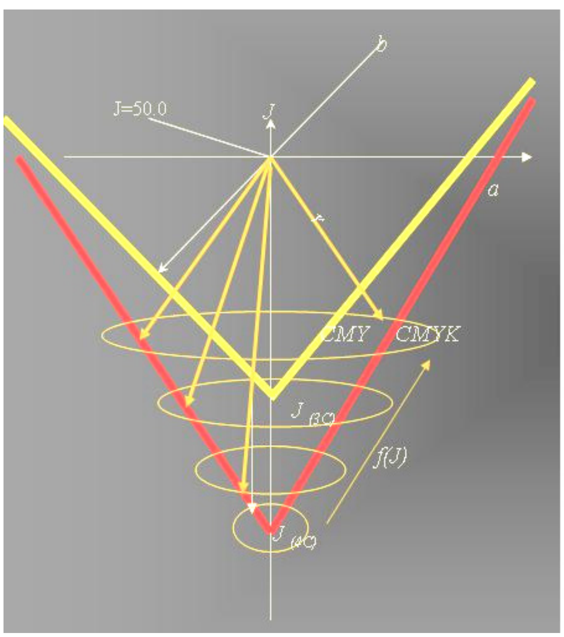

Figure 1. Black addition algorithm process

Seventy-six plots were again generated to study the relationship between the initial and observer reproduction images. The reproduction images were calculated by averaging each observer's data pixel-by-pixel for each image. A systematic pattern for lightness was found for all four of the images tested. Following equations were used in extending gamut by adding K.

STEP 1: A Linear Lightness Mapping

A linear lightness mapping is defined in the following equation.

$$J_r = 1.02J_o - 4.44 \qquad (1)$$

where subscripts o and r denote the original and reproduction.

STEP 2: A Linear Chroma Mapping

Two different chroma extension models with different coefficient according to each GEA are given below:

[*Case 1*]

$C_r = aC_o$

where

$a = 1.57$

[*Case 2*]

if (C_o<= 23.0)

then $C_r = C_o$

else

$C_r = a\,(C_o\text{-}23.0) + 23.0$

where $\alpha = 2.05$.

For images including skin tone, Case 2 is used in chroma extension and Case 1 is applied to the other cases, respectively.

Experimental

Two different type experiments, i.e., quantitative and qualitative, were designed in order to evaluate performance of new black color replacement method.

In the first quantitative analysis, gamut volume through commercial printers and new black addition algorithms were calculated. Inkjet and CLBP printers were used in this experiment. Figure 2 shows average distance from mid-point (J=50, a=0, b=0) to gamut surface through two different methods. This shows new algorithm can give larger reproducible range by adding black colorant.

In the second quantitative experiment, reproducible lightness ranges were compared. Figure 3 shows this results and black addition algorithm can provide wider lightness range comparing with existing method. The same color printers were used in this analysis.

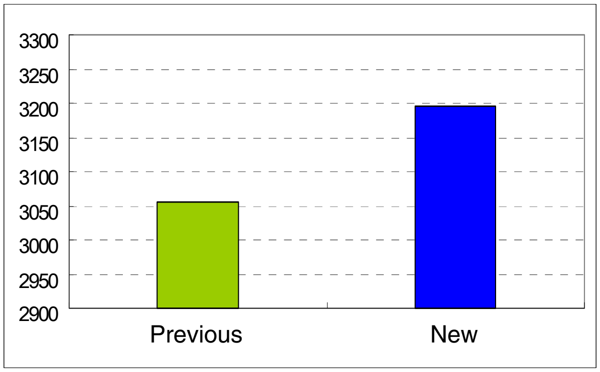

Figure 2. Performance evaluation (gamut volume)

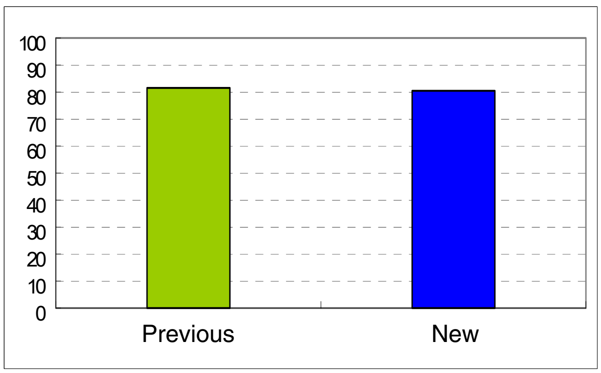

Figure 3. Performance evaluation (lightness contrast)

In qualitative psychophysical experiment, ten observers took part in this experiment using the pair comparison technique. A training session was arranged for the observer group. In the main experiment, a pair of images was shown to each observer and their task was to select which of the two give better image quality, i.e., correctness and pleasantness.

The higher the z-score, the higher degree of image quality judged by observers (see *Figure 4*). The 95% confidence interval for each z-score was calculated. It can be seen that *new black addition algorithm* performed better than existing methods.

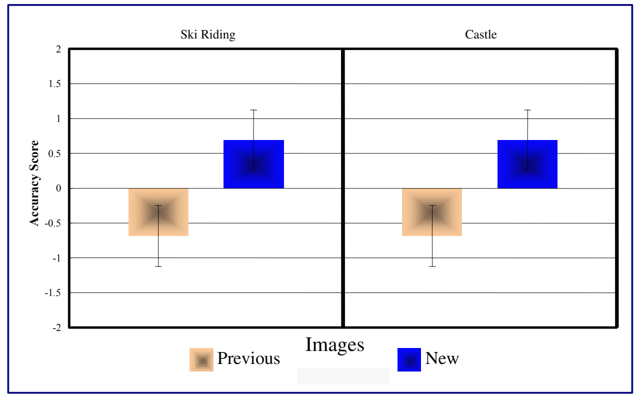

Figure 4. Performance evaluation (psychophysical experiment)

References

1. H. R. Kang, Color Technology for Electronic Imaging Devices, SPIE (1997).
2. H. Zeng, , "3-D color separation maximizing the printer gamut," color imaging VIII: processing, hardcopy and applications, edited by R. Eschbach and G. G. Marcu: 260-267 (2003).
3. B. H. Kang, "Gamut extension modeling based on observer experimental data," Proceedings of the 9th Color Imaging Conference:158-162 (2001).
4. G. J. Braun, A Paradigm for Color Gamut Mapping of Pictorial Images, Ph.D. Thesis, RIT (1999).
5. F. Sigg, " On second though let' s call it GCR," Rochester Institute of Technology, Technical and Education Center Newsletter, Vol 12:5-6 (1984).
6. R. Fishch, " Gray component replacement: the scanner connection," Proceedings of Taga: 511-538 (1988).
7. B. H. Kang, M. S. Cho, J. Morovic and M. R. Luo, "Gamut compression analysis based on observer experimental data," Proceedings of 7th Color Imaging Conference: 295-300 (1999).
8. B. H. Kang, M. S. Cho, J. Morovic and M. R. Luo, "Gamut compression algorithm development on the basis of observer experimental data," Proceedings of 8th Color Imaging Conference: 268-271 (2000).

Author Biography

Byoung-Ho Kang received his M.Sc. degree in Computer Science from the University of Georgia in 1993 and Ph.D. degree from Colour & Imaging Institute, University of Derby in 2001, respectively. He has worked at Computer Graphics team, the Electronics Telecommunications Research Institute, Korea from 1989 to 2004. From 2004 he joined to imaging solution program team, SamSung Advanced Institute of Technology.