Gamut Mapping in a Composite Color Space

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Abstract

In recent years, many approaches have been addressed for gamut mapping. Different color spaces and different gamut mapping methods were investigated to improve gamut mapping accuracy or to achieve perceptual pleasing result. The effects of different color spaces (i.e. CIE L*a*b*, CIE L*u*v*, CIECAM97s, Munsell color system, and other non-standard color spaces) on gamut mapping have been addressed in many publications. However, most of these papers are based on gamut mapping in a single color space. Zeng presented a gamut mapping approach using multiple color spaces to solve problems or limitations in gamut mapping in a single color space. By this approach, several color spaces are chosen to perform gamut mapping in different regions to solve some color space problems. In this paper, another approach will be addressed to solve similar color space problems and also to perform some color preference mapping.

Although gamut mapping using multiple color spaces solves some gamut mapping problems, it makes implementation more complicated than gamut mapping using a single color space. It requires a gamut mapping object for each color space, and it also requires additional parameters to decide what color space(s) to select and additional function(s) for smooth transaction from one color space to another. In order to apply the approach of gamut mapping in multiple color spaces but still preserve the simplicity of gamut mapping in a single color space, another approach, which is gamut mapping in a composite color space, was developed. A composite color space is defined as a color space derived from the combination of several color spaces with different weightings in different gamut regions. For the gamut mapping in a composite color space to achieve similar result as that in multiple color spaces, a composite color space and one gamut mapping object are created to replace several gamut mapping objects and transaction functions for gamut mapping. The implementation of gamut mapping in a composite color space is exactly the same as that of gamut mapping in a single color space except that a special color space is applied to replace a regular color space. The composite color spaces that were tested are the linear combinations of standard color spaces, such as CIE L*a*b*, CIE L*u*v*, CIECAM97s, etc.

Our analysis shows that gamut mapping in a composite color space is not mathematically exactly equivalent to the gamut mapping in multiple color spaces. However, very close gamut mapping results are achieved with properly defined transaction functions. Our experimental showed that constructing printer ICC profiles using gamut mapping under a composite color space achieved similar result as that with gamut mapping under multiple color spaces in correcting blue shift problem for monitor RGB to printer CMYK color conversion.

1. Introduction

In cross-media color reproduction, gamut mapping is an essential step. In recent years, many researchers have addressed different approaches for gamut mapping.[1-13] These approaches involve two aspects: what color space to use, and what algorithms to be applied for gamut mapping. This paper addresses color space aspect only. It is very clear that gamut mapping performed in different color spaces produce different result. CIE XYZ color space is not a uniform color space and should not be used for general color difference comparison, compression, and gamut mapping. CIE L*u*v* color space is not as uniform as CIE L*a*b* color space, so it is mostly avoid to be used as far as CIE L*a*b* color space can be applied. CIE L*a*b* color space has become one of the most popular color space for color science research in color calibration, color image compression, and gamut mapping. However, CIE L*a*b* color space has serious hue non-linearity in blue region which shift color from blue to purple for monitor to printer gamut mapping. Different approaches have been developed to fix the problem. The most popular one may be to shift hue in blue region before gamut mapping. Another approach is to modify CIE L*a*b* color space so that its hue is more linear in blue region, or to develop a new color space for gamut mapping. CIE CAM97s is a color space that includes advanced color appearance model for image color transformation, and it has more linear hue in the blue region than CIE L*a*b* color space. Although good perceptual blue can be produced for the gamut mapping in CAM97s color space, it exaggerates chroma for dark colors thus shifts the black point far off the gray axis. This makes many gamut mapping algorithms functioning improperly. CIE L*u*v* color space was superior to many other color spaces for the gamut mapping in blue region.[2] However, CIE

L*u*v* color space is not as uniform as CIE L*a*b* color space, and there is color shift in skin tone and reddish orange regions by using CIE L*u*v* color space for gamut mapping. Munsell color system was also reported to be visually non-uniform due to the improper setup in psychophysical experiments. It seems that there is no perfect color space for gamut mapping in the entire color gamut.

Zeng proposed applying multiple color spaces for gamut mapping to solve the color space problem that a color space performs well for part of the color gamut but not good for other regions of the gamut. By this approach, if a color space is good for a certain region, and another color space is good for the other part of the gamut, gamut mapping could be performed by using both color spaces, and a smooth transaction function is applied to control the weight used in each color space. In the region that a color space performs good, the weight would be high. In the region that a color space performs poor, the weight would be small or minimized. Although this approach solves some color space problems, it makes implementation more complicated than gamut mapping in a single color space. It requires a gamut mapping object for each color space, and it also requires additional parameters to decide what color space(s) to select and additional function(s) for smooth transaction from one color space to another. In this paper, a different approach will be presented to preserve the simplicity of gamut mapping in a single color space and also to apply the idea of the gamut mapping in multiple color spaces. It achieves result similar to the approach using the multiple color spaces gamut mapping, but the implementation is much simpler. It is easier to apply more than two color spaces for gamut mapping. It also has additional advantage for the implementation of color preference mapping. By this approach, a special color space, which is called composite color space in this paper, is built. The composite color space is the combination of a few color spaces. The combination may be linearly, and the weighting of a color space in a certain region is decided based on its performance. If the gamut mapping in a color space achieves best result than that using other color spaces in a certain region, the weighting for this color space in this region should be maximized. If the gamut mapping in a color space is inferior to gamut mapping in a certain region, its weighting for this color space in this region should be minimized. An example of using composite color space approach for gamut mapping is described in the following sections.

2. Constructing a Composite Color Space for Gamut Mapping

If a color space performs very well for some regions of a device gamut, but does not performs well for other regions of the device gamut, should we discard this color space? The answer is no. By constructing a composite color space, we can use the part of this color space that achieves good gamut mapping result, and find another color space (or more than one color space) to fill the regions in which this color space does not perform well. An example to apply composite color space is to correct the blue shift for gamut mapping under CIE L*a*b* color space. The composite color space could be comprised by both CIE L*a*b* color space and CIE L*u*v* color space as shown below.

$$Y = w \cdot f(X) + (1 - w) \cdot g(X) \qquad (1)$$

where X is a color in CIE XYZ color space, Y is the output color, w is a weighting factor, f(X) is a function to convert CIE XYZ values to CIE L*a*b* values, and g(X) is a function to convert CIE XYZ value to CIE L*u*v* value. The weighting factor w is defined to be a function of hue angle as shown in Fig. 1. The x-axis is hue angle defined in CIE L*a*b* color space. Fig. 1 shows that CIE L*a*b* color space is the dominant color space in this composite color space and CIE L*u*v* color space is applied only in the blue region. It may be argued why CIECMA97s is not used instead to solve the blue shift problem. The reason comes from the construction of the colorimetric table, BToA1 tag, of printer ICC profiles for the conversion from CIE L*a*b* to printer device color space. ICC requires preserve colorimetric values for colors inside the printer gamut. Using CIE L*a*b* color space for the colorimetric rendering intent is a straightforward solution. But the blue colors in the out-of-gamut region need special processing to produce good blue. Besides the problem that CIE CAM97s exaggerates chroma of dark colors as described in the previous section, gray colors in CIE L*a*b* color space (a* = b* = 0) are converted to colors with non-zero chroma in CIE CAM97s color space. Due to these problems, the complexity of gamut mapping is often increased by using CIE CAM97s in the colorimetric rendering intent. In fact, using a composite color space simplifies the implementation for the gamut mapping for the colorimetric rendering intent. And there is no advantage of using CIE CAM97s for the gamut mapping in this rendering intent for constructing printer ICC profiles.

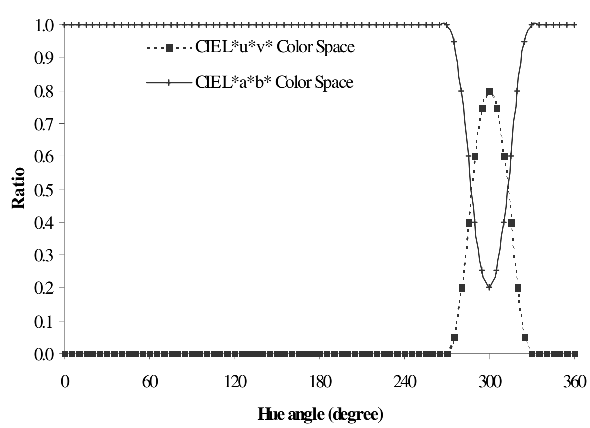

Figure 1. Ratios for the gamut mapping in two color spaces to eliminate blue shift in printer ICC profiling

Moroney reported that the green hue constancy of CIECAM97s color space is likely not as good as other color spaces.[14] It is very easy to solve this problem by using the composite color space approach for gamut mapping. At the stage of composite color space construction, a better-performed color space could be applied to replace CIECAM97s color space in the green region.

3. Experimental Result and Discussion

A Hewlett-Packard DeskJet 930C inkjet printer was used to print samples on this experiment. Plain paper, inkjet premium inkjet paper, and glossy paper were tested. ICC profiles were created for the color transformation. sRGB to CMYK conversion was performed by linking an sRGB ICC profile with a printer ICC profile.

Three categories of gamut mapping methods were tested:

- Gamut mapping under CIE L*a*b* color space,
- Gamut mapping under CIECAM97s color space, and
- Gamut mapping under a composite color space.

In this experiment, the composite color space was formulated by the linear combination of two color spaces as described in the section 2. The goal of using it is to solve the blue shift problem on monitor to printer gamut mapping. It has been proved that CIE L*u*v* color space performs very well for the gamut mapping in the blue region, so the color conversion is dominated by CIE L*u*v* color space in the blue region. As a color moves off the blue region, the weighting for CIE L*u*v* color space decreases smoothly, and the weighting for CIE L*a*b* color space increases simultaneously.

The experiment shows that blue is mapped to purple for the gamut mapping under CIE L*a*b* color space. If a composite color space is constructed by the linear combination of both CIE L*a*b* color space and CIE L*u*v* color space, allowing CIE L*u*v* color space to be dominated in the blue region and CIE L*a*b* to be dominated in other regions, the blue shift problem disappears. This approach is very useful for the gamut mapping to construct a BToA1 tag table (the colorimetric rendering table for the conversion from the profile connection space to the printer color space) in printer ICC profiling. The CIE L*a*b* color space is a dominant color space for the gamut mapping, and CIE L*u*v* color space is applied for the gamut mapping in the blue region so that out-of-gamut blue colors are not mapped to purple.

The gamut mapping under CIE CAM97s color space does not have blue shift problem. However, if the chroma of the black point is not close to zero, the CIE CAM97s chroma becomes very large. This increases the difficulty for gray balancing. For colorimetric rendering intent, it gains nothing for using CIE CAM97s color space.

In run-time gamut mapping applying to a smart CMM, if CIE L*a*b* color space is used for gamut mapping in most of gamut region and a different color space is used for the gamut mapping in the blue region, the gamut mapping will be performed faster than using another color space, such as CIE CAM97s or Mlab (a color space derived from the Munsell color chips).[15] Creating a composite color space using CIE L*a*b* as a dominant color space and another color space for the blue region for gamut mapping will greatly improve the linking time for a smart CMM.

Gamut mapping using a composite color space could also be applied for color preference mapping. For monitor to printer color reproduction, skin-tone usually needs special adjustment for preference reasons. By using the composite color space approach, a composite color space is constructed to convert measured target data into a composite color space. This composite color space is modified so that skin tone color is calculated differently. An input color is converted into a composite color using this modified composite color space for gamut mapping. With this gamut mapping approach, the skin-tone color can be adjusted easily.

4. Conclusions

A composite color space approach was developed for gamut mapping to solve the limitation of gamut mapping under a single color space. A composite color space was constructed for the gamut mapping to create a BToA1 tag in the printer ICC profiling. This approach is simple and the process is fast. It is suitable for implementing in a smart CMM for real-time gamut mapping. Some color preference mapping, such as skin-tone preference adjustment can also be incorporated into a composite color space to simplify the gamut mapping implementation.

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Biography

Huanzhao Zeng is a color scientist in the Color & Imaging Group at Inkjet Publishing Division of Hewlett-Packard Company. He received his M.S. degree in Imaging Science from Rochester Institute of Technology in 1996 and his M.S. degree in Color Science from Chinese Academy of Sciences in 1990. His research interests include device color calibration, gamut mapping, ICC color management, system color architecture, and digital halftoning.