Gamut Mapping Algorithm Suitable for Implementation to Device Profiles

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Abstract

We examined the performance of a gamut mapping algorithm in implementing a device profile for color management systems (CMS). To evaluate its performance, we focused on errors that would occur during transformation, using the device profile recording the gamut mapping.

In order to have a mapping method that would be suitable for implementation, we developed a new gamut mapping algorithm which we call "Chroma Proportional Clipping (CPC)". The algorithm we propose can preserve chroma and reproduce color tones while reducing errors through interpolation. The reproduction of chroma and tone was evaluated by subjective assessments, and the reduction of errors was evaluated based on color differences. In comparison with three conventional algorithms, CPC showed superior performance.

Background

Recent developments in computers and peripheral devices have made full-color image processing practical and easy. CMS is a software for correcting color signals for the purpose of matching displayed and printed colors.

One of the most difficult problems in connection with color matching is gamut mapping. The display gamut is larger than the printer gamut, and their shapes are very different as well. To print a displayed image while maintaining the same appearance, excellent gamut mapping is required.

CMS contain device profiles and a color matching module (CMM). The device profile describes the color characteristics of a certain device, and the CMM corrects the color signals according to these profiles.

The device profile for a color printer usually consists of a look-up table (LUT). The relationship between device independent colors and the device specific color signals, such as CIELAB and CMYK, are recorded in this table. For example, the CMYK values of 17×17×17 grid points in CIELAB uniform color space are recorded here. Usually, device color signals for both in-gamut colors and out-of-gamut colors are recorded in this table.

For constructing an LUT, a gamut mapping algorithm is required for determining the device-specific color signals of out-of-gamut colors. First, the algorithm maps out-of-gamut colors to in-gamut colors. The color signals for the corresponding in-gamut colors are then recorded as the appropriate color signals for the respective out-of-gamut colors. The results of the gamut mapping algorithm are in this way included into the LUT.

When interpolating from the LUT for transforming color signals, gamut mapping is performed simultaneously, as the gamut mapping algorithm is implemented into the LUT. Therefore, it is important that the gamut mapping algorithm provides good performance for interpolating from the LUT.

Conventional Method and Problems

Gamut mapping algorithms that perform a combination of scaling and clipping generally show good performance(1). Clipping means that all out-of-gamut colors are clipped onto the boundary of the destination (printer) gamut. After scaling, in-gamut colors remain unchanged. Conventional clipping algorithms are as follows:

1. Minimizing color differences (Figure 1): out-of-gamut colors are mapped to the closest color(2).
2. LCLIP (Figure 2): out-of-gamut colors are clipped to the boundary maintaining the same hue and lightness.(3)
3. Chord clipping (Figure 3): out-of-gamut colors are moved to the point on the lightness axis that has the same lightness as this color while providing the highest chromaticity at the given hue.(4)

Still, all of these algorithms are to some degree problematic with respect to the following points:

1. A loss of detail occurs in some regions and the chroma and lightness is reduced for some colors.
2. In-gamut colors near the boundary of the printer gamut change after being transformed by LUT interpolation.

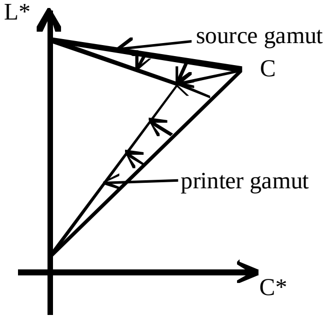

Figure 1. Minimizing color differences.

The algorithm for minimizing the color difference (see Figure 1) transforms the colors near point C to the same color. In this case, the detailed information of these colors is lost. An LCLIP algorithm greatly reduces the chroma of some colors. Chord clipping is relatively good with respect to the first issue.

The second issue is a new way of evaluating gamut mapping. Gamut mapping and color transformation are performed by a method of interpolation, such as trilinear interpolation. Through the interpolation, in-gamut colors near the boundary of the printer gamut change.

Figure 4 shows an example of a change in the in-gamut color near the boundary of the printer gamut. The LUT records device color signals, such as the CMYK value of a color "x". Color "x" is the result of gamut mapping of the grid point color "o".

Therefore, the device-specific color signal of color "+" is interpolated using the device-specific color signals of the colors "x" and "o", not only by using the device-specific color signal of color "o". The result of this interpolation is a signal that corresponds to the color "*". Consequently, the result after interpolation is inferior to the result of the original algorithm. The degree of change depends on the difference between the colors "o" and "x". This change might unexpectedly reduce the chroma of vivid colors, especially of yellow.

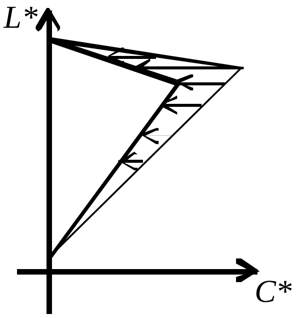

Figure 2. LCLIP.

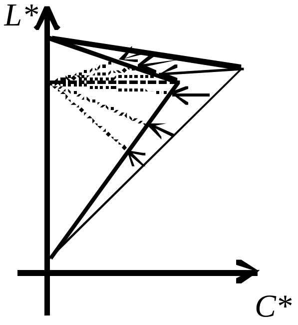

Figure 3. Chord clipping.

Proposed Solution

To avoid unexpected reductions in chroma as far as possible, the changes in the out-of-gamut colors near the boundary should be small. To minimize these changes, out-of-gamut colors should be mapped to the closest color. This approach corresponds to the algorithm for minimizing the color difference. However, this approach alone would lead to the problem that the detailed information of some colors was lost.

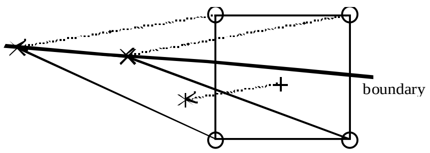

Figure 4. Unexpected change of in-gamut color.

Gamut mapping should ideally both reproduce the tone and reduce the changes in the out-of-gamut colors near the boundary. Of course, the chroma should be preserved as well.

To fulfill these requirements, we propose a new gamut algorithm, which is called "Chroma Proportional Clipping (CPC)". CPC basically maps colors as shown in Figure 5: Out-of-gamut colors are shifted towards points on a line between the highest chroma in the printer gamut and the point on the lightness axis which has the same lightness. The points on this line are defined in proportion to the ratio of a mapped color chroma and the highest chroma of the source (display) gamut. This prevents unexpected reductions in chroma as the mapping direction of the out-of-gamut colors is orthogonal relatively to the boundary of the printer gamut.

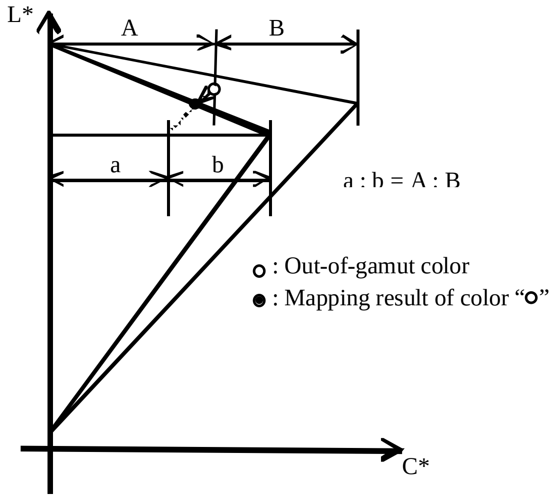

Figure 5. Basic concept of the CPC algorithm.

However, there are two problems in connection with this algorithm: The first problem is that a great loss in the lightness of some colors occurs. The algorithm maps the peak point (the highest chroma) in the source gamut to the peak point in the printer gamut. Colors, such as green, where the lightness difference between the peak points of two gamuts is large will loose a great amount of lightness.

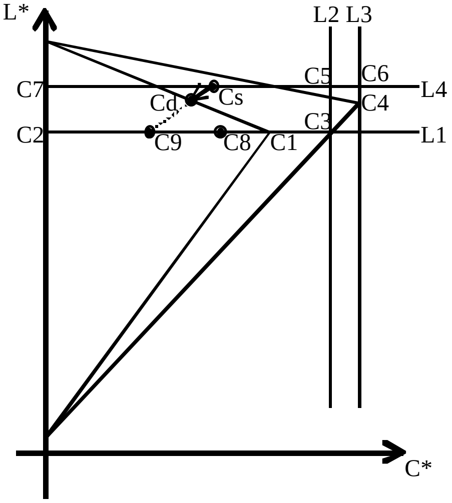

Figure 6. Overview of the CPC algorithm.

We solved this problem by changing the mapping direction according to the lightness difference between the peak points. When the difference is relatively large, the direction is shifted more toward the lightness axis.

The second problem is that the details of high chroma colors are distorted. This is caused by the shift of the mapping target points. We solved this problem by mapping high chroma colors towards the same point.

The CPC algorithm, which incorporates the solution to the above two problems, is shown in Figure 6. Cs denotes the out-of-gamut color of a printer and Cd denotes the color mapped by the CPC.

1. The algorithm maps variations in lightness so that the minimum and maximum of the two gamuts are mapped onto each other.
2. At a hue of Cs, the line L1 is created between color C1, which has the highest chroma in the printer gamut, and color C2 on the lightness axis, which has the lightness as this color. The point on the line L1 which has the highest chroma of the display gamut is defined as C3.
3. A line L2 is created that is parallel to the lightness axis and goes through the color C3. A line L3 is created that is parallel to the lightness axis and goes through the color C4, which is the color with the highest chroma in the display gamut.
4. A line L4 is created that is parallel to line L1 and goes through the color Cs. The point where L2 and L4 intersect is defined as point C5. The point where L3 and L4 intersect is defined as point C6. The point where L4 and the lightness axis intersect is defined as point C7.
5. A point C8 on the line L1 is defined with the following equations. In this connection, L^*_{C1} and L^*_{C4} denote the L* value of C1 and C4, respectively.

$$\begin{aligned}&\text{if } L^*_{C1} - L^*_{C4} < 60\\ &\text{then } |C2C8| : (60-(L^*_{C1} - L^*_{C4})) = |C2C1| : 60\\ &\text{else}\\ &\qquad C8 = C2 \qquad (1)\end{aligned}$$

6. A point C9 on line L1 is defined with the following equation.

$$\begin{aligned}&\text{if } |C7Cs| < |C7C5|\\ &\text{then } |C7Cs| : |CsC6| = |C2C9| : |C9C8|\\ &\text{else } |C7C5| : |C5C6| = |C2C9| : |C9C8| \qquad (2)\end{aligned}$$

7. The color Cs is shifted towards the point C9 and clipped to the boundary of the printer gamut.

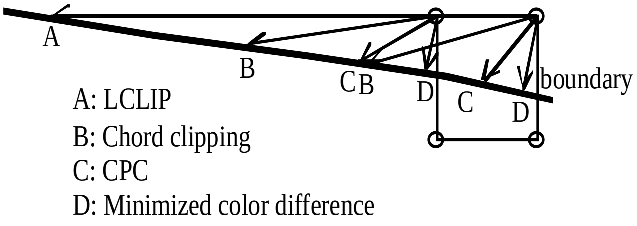

Figure 7. Change of grid point near boundary.

Figure 7 shows the change of grid points near the boundary of the color yellow according to each algorithm. With CPC, the change of the grid points is relatively small.

Evaluation

We evaluated the performance of the proposed algorithm, CPC, with the following two methods:

The performance with respect to preserving chroma and reproducing tone was evaluated by subjective assessments. An image displayed on the computer screen was compared with the printed image according to a quality scale (Table 1). We used 6 photographic images that were to be evaluated and had 6 people evaluate them. All images included very colorful regions, such as fruits, flowers or painted objects. Preservation of chroma and tone for these regions is a difficult task. Figure 8 shows the steps of this evaluation.

Color differences that were generated by interpolation were evaluated as well. Figure 9 shows the steps of this evaluation.

In this part of the evaluation, we used "relative colorimetry", a technique that was adopted from the ICC 3.4 specification(5). The colorimetry (X_{rel}, Y_{rel}, Z_{rel}) was derived from the following equations: (X_{abs}, Y_{abs}, Z_{abs}) denotes an absolute colorimetry value that was measured under a D50 light source for reflective objects. (X_{d50}, Y_{d50}, Z_{d50}) denotes a tristimulus value of D50 light source, and (X_{mw}, Y_{mw}, Z_{mw}) denotes an absolute colorimetry value for the media white point.

$$X_{rel} = X_{abs}\,(X_{d50}/X_{mw}) \qquad (3)$$

$$Y_{rel} = Y_{abs}\,(Y_{d50}/Y_{mw}) \qquad (4)$$

$$Z_{rel} = Z_{abs}\,(Z_{d50}/Z_{mw}) \qquad (5)$$

Table 2 shows the results of the subjective assessment. It shows clearly that CPC was the most effective algorithm.

Table 3 shows the maximum color differences that were obtained by interpolation. Applying CPC results in the second smallest difference in color. This result indicates that the change of in-gamut colors through interpolation is relatively small.

Table 1. Quality Scale for Subjective Assessment.

5	The same
4	Slightly different
3	Different
2	Definitely different
1	Very different

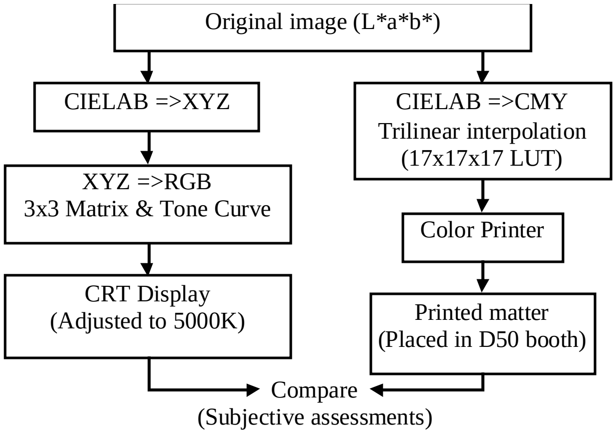

Figure 8. Process of subjective assessments.

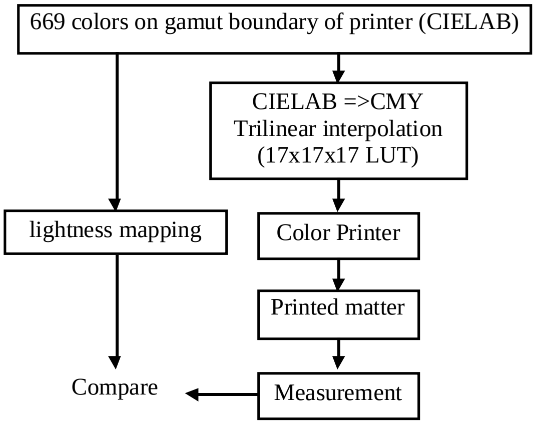

Figure 9. Evaluation of color differences.

Table 2. Results of Subjective Assessment.

Algorithm	Result
Proposed CPC algorithm	3.3
Minimized color differences (hue unchanged)	2.8
LCLIP	2.9
Chord clipping	3.1

Table 3. Color Difference After Interpolation.

Algorithm	Result
Proposed CPC algorithm	14.2
Minimized color differences (hue unchanged)	8.1
LCLIP	54.4
Chord clipping	31.6

Conclusion

We developed a gamut mapping algorithm called "Chroma Proportional Clipping (CPC)", which is suitable for implementing device profiles. We evaluated this algorithm in two ways and confirmed that it preserves chroma and reproduces tone. It also reduces the change of in-gamut colors due to interpolation, a result which was verified by evaluating the resulting color differences. The results indicate that CPC is superior to conventional methods.

References

1. J. Morovic, To Develop A Universal Gamut Mapping Algorithm - Literature survey, Design Research Centre, University of Derby, (1997).
2. M. C. Stone, W. B. Cowan, and J. C. Beatty, Color Gamut Mapping and the Printing of Digital Color Images, *ACM Trans. Graphics*, **7**, 249-292, (1998).
3. J. Morovic and M. R. Luo, Cross-Media Psychophysical Evaluation of Gamut Mapping Algorithms, *AIC Color97* Kyoto, 594-597, (1997).
4. L. W. MacDonald and J. Morovic, Assessing the Effects of Gamut Compression in the Reproduction of Fine Art Painting, *Proceedings of the IS&T/SID Color Imaging Conference, Color Science, Systems and Applications*, 194-200, (1995).
5. ICC Profile Format Specification Ver. 3.4, http://www.color.org/, (1997).