Color Rendition with Variable Point Interpolation

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Abstract

Because of the rapid growth in electronic color publishing, it becomes more important to develop a color correct algorithm to minimize the color errors caused from the gamut mismatch, quantization and non-linearity characteristics between image devices. Recently, some 3-D (3-Dimensional) interpolation algorithms were introduced and most of them are lacking the flexibility of adopting different LUTs (Look Up Table) and interpolation algorithms to correct the non-uniformity of color space and to fit the reception of human vision. This paper presents a new algorithm of color transformation with non-fixed points interpolation method to deal with color correction in non-uniform color space.

In this algorithm, the non-uniformity of color space is associated with the membership function of modern fuzzy theory. Based on the association of fuzzy rules, color rendition can be achieved with LUTs and mixed mode variable point interpolation method. According to the pictorial image coordinate in the non-uniform color space, different LUTs and 1, 2, 3, 4, 5, 6, 7, or 8 points interpolation will be selected. By considering the nonlinearity and the different resolution requirement of color correction under the human appearance-based model, the color reproduction model is established in the LUT. With the fulfillment of the scheme, it can reduce the computational costs by a large factor comparing the conventional direct color mapping method and it can improve the color matching accuracy of the 3-D interpolation techniques. The colorimetric simulation of this algorithm illustrates a satisfac-tory performance. It is estimated that mean square color difference, delta Erms, between two color images will be less than 6. This algorithm is verified by various output samples produced by this new method. The color printing samples using this new algorithm are compared with the outputs using traditional 3-D interpolation technique and the results indicates a great improvement. It is proved to be a less cost and more flexible scheme for electronic color publishing.

Introduction

During the process of color reproduction, color space transformation and color correction are always the important keys to obtain a good color matching between the original image and the reproduction. Until now, there are many methods presented to do this.[1-8]

The most common method is software mathematical model. It can perform any color space transformation and complicated color correction computation. This method can obtain the most precise result, however, the calcula-tion is too slow to deal with a color picture with lots of data. On the contrary, hardware solution becomes the only possible way to obtain the real time conversion. Direct color mapping method[6] with frame memory is a general way to complete the color space transformation and color correction within one step LUT conversion. But this method needs 50 MB memory used as LUT, it is not very appropriate to be used in the DTP (Desk Top Publishing) applications such as facsimile, scanner, printer, copier, or other embedded systems. So, these methods described above are not able to process the image in real time or the cost for the hardware circuit implementation is expensive as well.

In order to reduce the memory of LUT and realize realtime processing, 3-D LUT combined with 3-D interpolation technique seems to be the better way than those methods mentioned above to be used in modern DTP application environment. There are many interpolation algorithms are developed till now, for example, CUBE[3] and TETRAHEDRON[5] algorithms — etc. But, under the consideration of human visual response i.e. human color perception, all of these algorithms are lack of the flexibility to adopt different interpolators and LUTs to adjust the color correction accuracy according to the non-uniformity of chromatic space.

A new method is proposed here to achieve the *appearance equivalence* between the original image and the reproduction with the mixed mode variable point interpolation. Based on the tolerance analysis of human vision and the coordinates of color image point in the colorimetric space, the acceptable color factor, A.F., derived from the *Appearance Equivalence Model is* designated and 1, 2, 3, 4, 5, 6, 7, or 8 neighbor points are selected. With this algorithm of variable point interpolation, color matching can be achieved by using fewer calculation time. Finally, the result of color rendition experiment is within the acceptable tolerance of human perception in comparison with the conventional fixed point interpolation method.

Background

With the MacAdam-Ellipses experiment (1942) about visual threshold values of perceptible color differences plotted in CIE 1931 chromaticity diagram, it reveals that the variation of color tolerance depends on where the color coordinates locate in the chromaticity diagram. For example, color coordinates near grass green area have larger color tolerance than those in the sky blue area under x-y plane. However, the color tolerance near the green area is smaller than in the sky blue area under the x-Y or y-Y plane. Moreover, neutral color nears the center of the chromaticity diagram has the smallest color tolerance for the reason that the human visual response is very sensitive to the deviation of neutral color. Because of this, it is necessary to adjust the color appearance signal based on the attributes of color area.

For the purpose of associating the attributes of different color area, the LCH (Light, Chroma, Hue) coordinate system under CIE-L*a*b* color space is adopted. In this color space, the lightness and the chroma of the pictorial image are separately manipulated so that the tint can be controlled without changing the light and shade. As shown in Fig. 1, the relationship of LCH coordinate system with CIE-L*a*b* color space is defined as follows:

$$L = L^*$$
$$C = (a^{*2} + b^{*2})^{1/2} \quad (1)$$
$$H = \tan^{-1} (b^*/a^*)$$

By the analysis of human vision experiments, the characteristics of noticeable color difference in LCH coordinate system can be concluded. Fig. 2 illustrates that as L is increased, the relative change of color tolerance caused by L (i.e. delta L) is increased too. In other word, delta L is only a function of L. Also the delta C is only a function of C as shown in Fig. 3. In Fig. 3 and Fig. 4, the change of C or H will influence delta H. Namely, delta H is a function of both C and H. The permissible maximum tolerances for metric chroma deviation, metric hue angle deviation, and metric lightness deviation are 8, 5, and 5 times with respect to neutral color.

With the analysis of Fig. 2, 3, and 4, the membership functions of L, C, and H (denoted MF. (L), MF. (C) and MF. (H),respectively) can be created as shown in Fig. 5, 6, and 7. The acceptable color factor, A. F. used to determine how many lattice points are selected for interpolation can be defuzzied by the following equation:

$$A.\,F. = S_l * MF.\,(L) + S_c * MF.\,(C) + S_h * MF.\,(H) \quad (2)$$

where

S_l, S_c, and S_h are the contribution coefficients for LCH MF. (L), MF. (C) and MF. (H) are the membership functions of L, C, and H

In the traditional fixed-point CUBE and TETRAHEDRON interpolation methods, the interpolator compensates the output data O (P) between lattice points are as follows:

$$O\,(P) = \text{Summation of } W_i * O\,(P_i) \quad (3)$$

where

W_i denotes the linear interpolation weight for the volume ratio of *i*-th lattice point with respect to P

i = 1-8 for CUBE interpolation method
= 1-4 for TETRAHEDRON interpolation method

Now the mixed mode variable point interpolator can determine how many lattice points it needs for the color adjustment based on the comparison of acceptable color factor A.F and the weighting factor W_i as follows:

IF (A.F. <= W_i) THEN P_i is available
ELSE P_i is not available

Different color image point has different A.F., so the output data O(P) is obtained from the interpolation of available lattice points.

Experiment

A configuration of the experimental system is shown in Fig. 8 which conceptually depicts the color reproduction scheme of this new method. This experiment has been done by using 24 bits color signal (8 bits for each R, G, B). The 24 bits color signal is divided into upper 12 bits signal (4 bits for each R, G, B) and lower 12 bits signal (4 bits for each R, G, B). The upper bits are used as the input address of 3-D LUT and the lower bits are to determine the weighting factor for each lattice point on sub-cube. The major objective of the experiment is to compare the new variable point interpolator with the conventional fixed point interpolator. The simulation results by different interpolation methods are list on the Table 1 and Table 2.

Conclusion

An advanced method for adaptive color appearance equivalence has been proposed and proven to work effectively in practical color imaging. It can discriminate from the image a color area and determine the tolerance attributes to maintain the color balance from the view point of human vision. In this system, once the LUT has been made, then 3-D interpolation is done at high speed. Therefore, any kind of color space conversions are possible whenever they are complicated and nonlinear. The LUT stores the output data only at coarse lattice points and needs only a small, low cost memory capacity. Moreover, the calculations of the LUT for the different devices can be quickly done by software in advance, then a variety of color signal processing operations can be realized by the quick change of LUT (RAM) contents.

References

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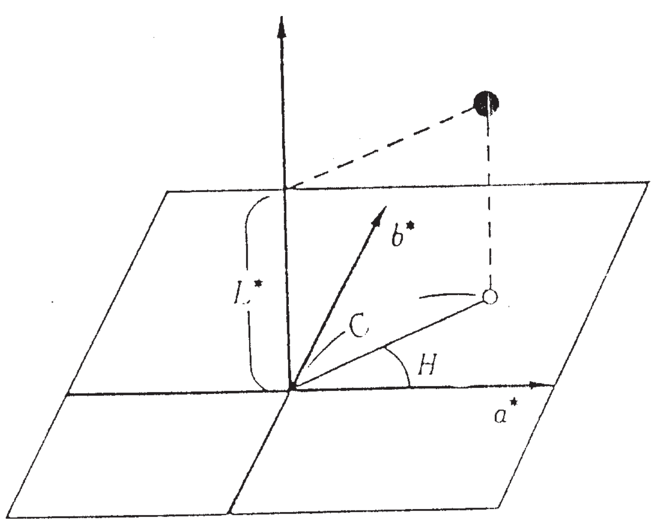

Figure 1. L-C-H coordinate system

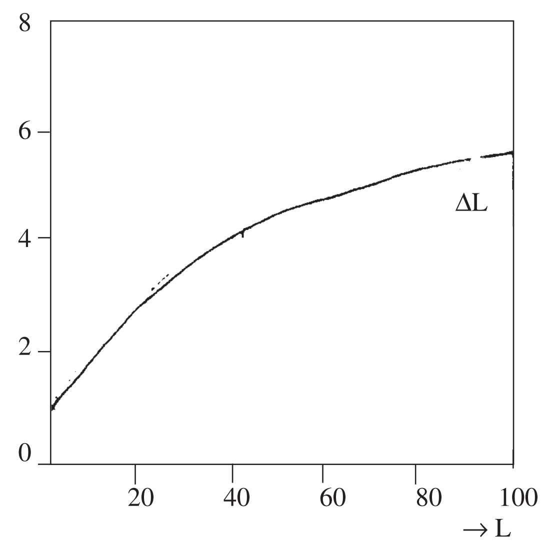

Figure 2. Relative changes of color tolerance delta L vs. L

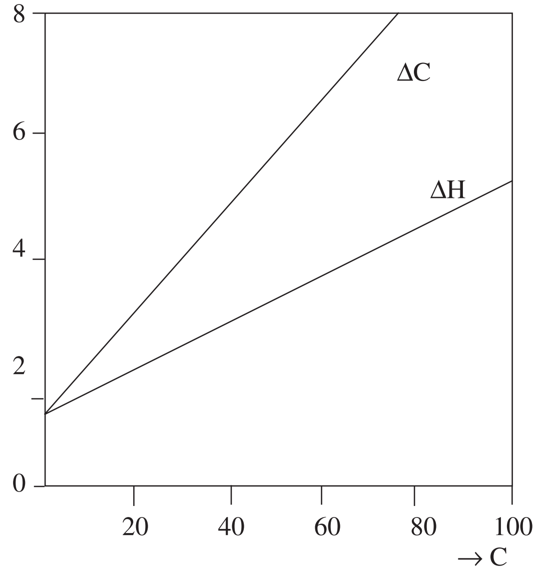

Figure 3. Relative changes of color tolerance delta C vs. C, delta H v.s. C

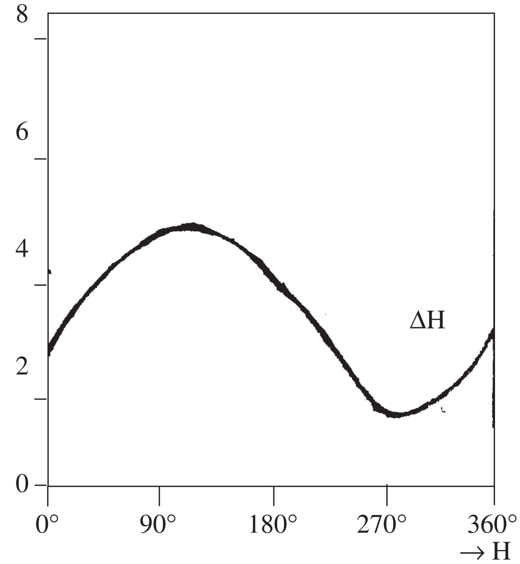

Figure 4. Relative changes of color tolerance delta H vs. H

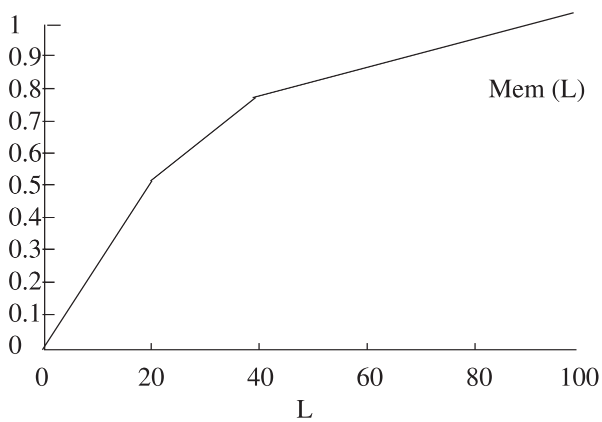

Figure 5. Membership function of L

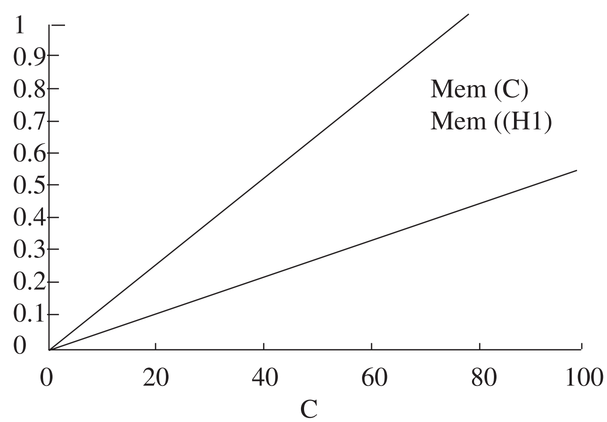

Figure 6. Membership function of C

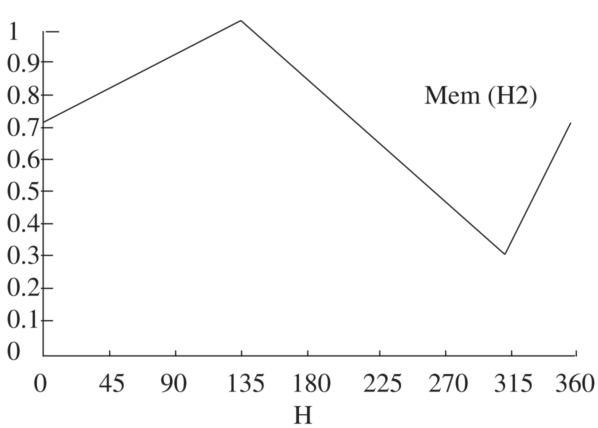

Figure 7. Membership function of H

Table 1. Color Scanner Correction Experiment

Color Scanner Correction Experiment				
	Computation	**Cube**	**Fuzzy**	**Tetrahedron**
delta E	5.48	6.21	6.67	8.41
points		8	4.46	4
*Before Correction delta E = 19.92				

Table 2. NTSC-RGB TO CIE-LCH Experiment

NTSC-RGB to CIE-LCH Experiment			
	Cube	**Fuzzy**	**Tetrahedron**
delta E	4.65	4.96	6.85
points	8	5.78	4

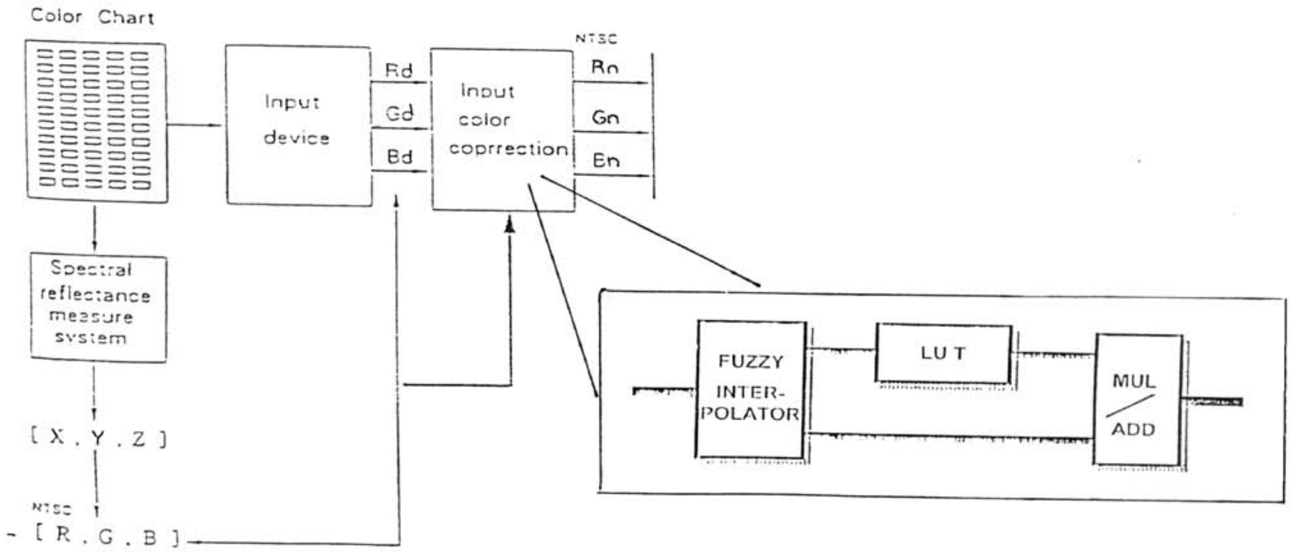

Figure 8. Configuration of experiment system