An Approach to the Color Management among Color Devices

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Abstract

A new approach, in which several color scales are used, has been investigated. The approach has some advantages in comparison with a simple linear transformation. First advantage is an independent control of color hue. Next is an accurate color reproduction of neutral gray scale. Last is an independent control of color steps. These advantages are useful to design various kinds of color calibration and color management systems.

Introduction

In a color management system, a color correction of each color device is very important. In general, a color corrections is executed by technique using polynomials, higher order matrices or look up table and interpolation.[1,2,3] These polynomials, matrices, or look up tables can be determined as follows: Several color patches are prepared. These patches are measured with the spectrophotometer. And the exact tristimulus values (XYZ) or the values of the uniform color space (CIELAB) are obtained. On the other hand, the digital data, for example, RGB for scanners or monitors, CMY(K) for printers, are recorded. Then the coefficients of polynomials, elements of matrices, or members of look up table are calculated with statistical methods, such as mean square method.

However there are several problems in these methods. First problem is due to treating a color process as a black-box. That is to say, the relation of members of look up table and the practical color is not clear. So, members of look up table are determined by the statistical methods. Surely, the mean error is reduced. At the same time, there are also some errors for the important colors, such as vivid or bright colors and gray. So the reproduction of the aimed color is too difficult to achieve. And also it is impossible to realized the systematic control of the reproduction of colors. Because of these, it is useful for designing the color management systems to understand these relations. Second problem is due to using simple lattices which are convenient for digital circuits. As a result, the number of the measurement points or the data volume is increased to achieve a higher accuracy.

In this paper, we propose an approach to the color management among color devices, which have following characteristics.

1. The relation between members of look up table and the practical color is cleared.
   If the relation between members of the look up table and the practical color is cleared, it become easy to realized the systematic control of the reproduction of colors. And the systematic control method become an useful tool to predict the influence of the color change based on the visual characteristic of humans.
2. The number of the measurement points is small.
   We have estimated the color reproduction characters of the color devices. In this approach, the look up table have the information of the non-linearity and the interpolation is executed on the area where the linearity is good. As a result, the redundancy of data is reduced. And, the umber of measured points is reduced.

And the investigated approach is applied to the color reproduction between color devices. In this paper, it is applied to color reproduction between scanner and printer, or monitor and printers. And what is the good interfaces for color adjustment is also discussed.

Technical Approach

In this paper, a new approach to the color management among color devices is designed as follows:

1. Color hue and step are controlled independently.
   The relation between the look up table and the practical color is cleared. The interpolation of color is designed as modification of a part of the look up table doesn't influence other parts of it. As a result, color hue and step are controlled independently.
2. Neutral gray and chromatic color are separated.Neutral gray and chromatic color can be determined freely. And they are separated, so systematic color adjustment would be able to come true.

A concrete procedure to determine members of the look up table based on the new approach is described below:

Prepare color patches described as Figure 1. They have several scales form black to white, which include the neutral gay scale. In Figure 1, the color patches consisted of Red, Green, Blue, Cyan, Magenta, Yellow and Gray scales. Other color scales may be include to increase more accuracy. For example, orange scales etc. are used. It is confirmed in another experiment, in which several thousand color patches are measure, that these scales are inflection points upon the distribution of the chromatic diagram.

	A	B	C	D	E	F	G
1	wh	wh	wh	wh	wh	wh	wh
2							
3							
4							
5							
6							
7							
8							
9	C	M	Y	R	G	B	Gray
10							
11							
12							
13							
14							
15							
16							
17	bk	bk	bk	bk	bk	bk	bk

Figure 1. The color patch samples

Scale's number	Input values	Output values
Gary $_0$	(Ibk00,Ibk01,Ibk02)	(Obk00,Obk01,Obk02)
Gary $_1$	(Ibk10,Ibk11,Ibk12)	(Obk10,Obk11,Obk12)
Gary $_2$	(Ibk20,Ibk21,Ibk22)	(Obk20,Obk21,Obk22)
⋮	⋮	⋮
Gary $_N$	(IbkN0,IbkN1,IbkN2)	(ObkN0,ObkN1,ObkN2)
Red $_0$	(Ir00,Ir01,Ir02)	(Or00,Or01,Or02)
⋮	⋮	⋮
Red $_N$	(IrN0,IrN1,Irn2)	(OrN0,OrN1,OrN2)
yellow $_0$	(Iy00,Iy01,Iy02)	(Oy00,Oy01,Oy02)
⋮	⋮	⋮
yellow $_N$	(IyN0,IyN1,IyN2)	(OyN0,OyN1,OyN2)
⋮	⋮	⋮

Figure 2. The structure of the look up table

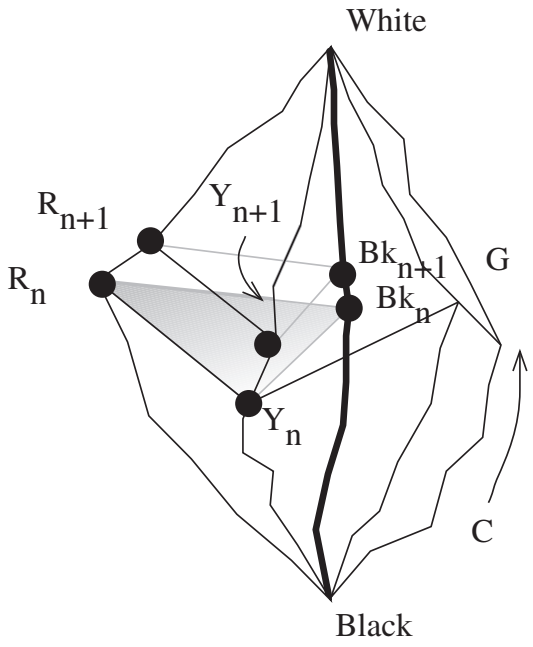

Figure 3. The model based on the approach

Measure the exact colorimetric values by means of spectrophotometer. In scanners, the color patches are measured. In monitor, the color patches on the display are measured. In printers, the printed color patches are measured. Here, N is a number of the patches.

$$\left[L_i^*, a_i^*, b_i^*\right] \text{ or } \left[X_i, Y_i, Z_i\right] \qquad \text{for } i = 1,....N$$

Record the RGB or CMY(K) values of the patches. In scanners, the values are scanners' response signals. In monitor, the values are displayed signals. In printers, the values are printed signals.

$$\left[R_i, G_i, B_i\right] \text{ or } \left[C_i, M_i, Y_i, \left(K_i\right)\right] \qquad \text{for } i = 1,....N$$

Make the look up table from exact colorimetric values and color signal values. Figure 2 shows the structure of the look up table. When signal values are converted into exact colorimetric values, input values of the look up table are color signal values, and output values of it are exact colorimetric values. In case of the conversion of exact colorimetric values into signal values, input values of the look up table are measured exact colorimetric values, and output values of it are recorded signal values.

Conversion Model and Interpolation

The look up table based on the new approach must be included the neutral gray steps. This causes a convenient effect, that is, once the gray steps are defined, the gray steps don't influence other steps and aren't be influenced by other steps. The model based on the new approach is shown in Figure 3. The gamut of chromaticity is divided into a plurality of pentahedrons or tetrahedrons, which have side of the neutral gray steps. Vertexes of each polyhedron have input values of the look up table or output values of it. We

suppose that the weight ratio of each vertexes of the input color space is equal to the one of output color space. In this supposition, interpolation based on the new approach is executed.

A concrete procedure to interpolate output signal values based on the new approach is described below:

Search a polyhedron which included point of input signal values inside.

Calculate volumes of internal tetrahedrons. A pentahedron is divided into 5 internal tetrahedrons, which have vertex of input signal values. In case of a tetrahedron, it is divided into 4 internal tetrahedrons.

See the look up table and select the output values of the searched polyhedron.

Interpolate output signal values from the output values of the searched polyhedron. The weight of each vertexes are the ratio of internal tetrahedrons' volumes.

The look up table is determined in this way. In case of this approach, the color scales of the look up table have direct connection with practical colors. So, if it is required to adjust each color scale individually, this can be achieved by handling the corresponding scale of the look up table. And each colors and steps are controlled independently. Especially, it is advantage that the gray steps are separated from other color steps.

Calculate and Color Reproduction Precision

We have confirmed precision of our approach by an experiment of evaluation which covers a whole gamut of chromaticity. The calculate and color reproduction precision are measured as following. First, two sets of color patches are prepared. One is a basic set for making the look up table based on the approach. It consists 119 colors (7 scales * 17 steps). Another is an evaluation set for measuring precision. It consists about 1000 colors except the basic set, witch covers a whole gamut of chromaticity. Second, the set of color patches are measured by means of spectrophotometer. In case of monitor, displayed colors are measured. In case of printer, printed colors are measured. Third, the look up table is made in the way based on the approach. Last, the calculated output signal values and the reproduced color are evaluated.

Table 1 shows the average of calculated error for each number of color patches when the approach is used. In case of the basic set for making the look up table, the error is 0 at Lab color space when the color is converted from RGB digital signal space to Lab color space. And the error is 0.9 at Lab color space when the color is converted from Lab color space to RGB digital signal space. The color difference was not recognized at the result of subjective evaluation experiment. In case of about 1000 colors except the basic set for making the look up table, the error is 3.4 at RGB digital signal space when the color is converted from RGB digital signal space to Lab color space. And the error is 10.7 at RGB digital signal space when the color is converted from Lab color space to RGB digital signal space. In this experiment, the evaluated color spaces are different in the direction of color conversion. Next experiment, in which the evaluated color spaces are equal, is executed.

Table 1. Average of Calculated Error for Each Number of Color Patches when the New Approach was Used. In Case of Conversion from RGB to Lab, Average Calculate Error is the Value in Lab Space. In Case of Conversion from Lab to RGB, Average Calculate Error is the Value in RGB Space.

direction of color conversion	basic set (119 color patches)	evaluation set –about 1000 color patches
RGB → L*a*b*	0.0	3.4
L*a*b* → RGB	0.9	10.7

Table 2 shows average color difference when digital signal RGB is converted Lab and Lab is converted digital signal RGB again. A sublimation printer, an ink jet printer and a silver halide type digital printer are used. In each case, the average color difference is less then 2 at Lab color space. The color difference is not recognized in a subjective evaluation.

Table 2. Average Color Difference, ΔE_{Lab}, for Each Number of Color Patches when the New Approach was Used. The number of color patches is more than 1000 except used for making the look up table.

printer type	average color difference
sublimation	1.9
ink jet	1.2
silver halide	1.5

Applying the Approach to the Color Reproduction

The approach is applied to the color reproduction from one color device to another one. The look up table based on the approach was made from measured values. If the look up table is not suitable, an adjustment is executed. Figure 4 shows the color adjustment panel. The look up table is adjusted with this panel. Each panel element is connected to the members of the look up table. It is equivalent to touch of the look up table that the panel element is touched. Since the relation of members of the look up table and the correspondent colors is cleared, the usage of the panel is easy. For example, if you want to adjust red-like color, choose the red scale button (A1) and the step buttons (A2). Enter values or color of the look up table into the boxes (from A3 to A6), or choose color in the picture (A7) by means of a pick up tool (A9). At the same time, an area (A11) which a color adjustment influence reaches, is shown on the adjusted picture (A8).

We have applied the approach to the color reproduction system composed of a scanner and a printer. Color patches are scanned, then RGB are recorded. And also they are measured by means of spectrophotometer. Printer's profile are also measured in the way based on the approach. Detail color adjustment is executed with the color adjustment panel. At the result of the subjective evaluation, the reproduced image is more correspondent to originals than one by a linear transformation.

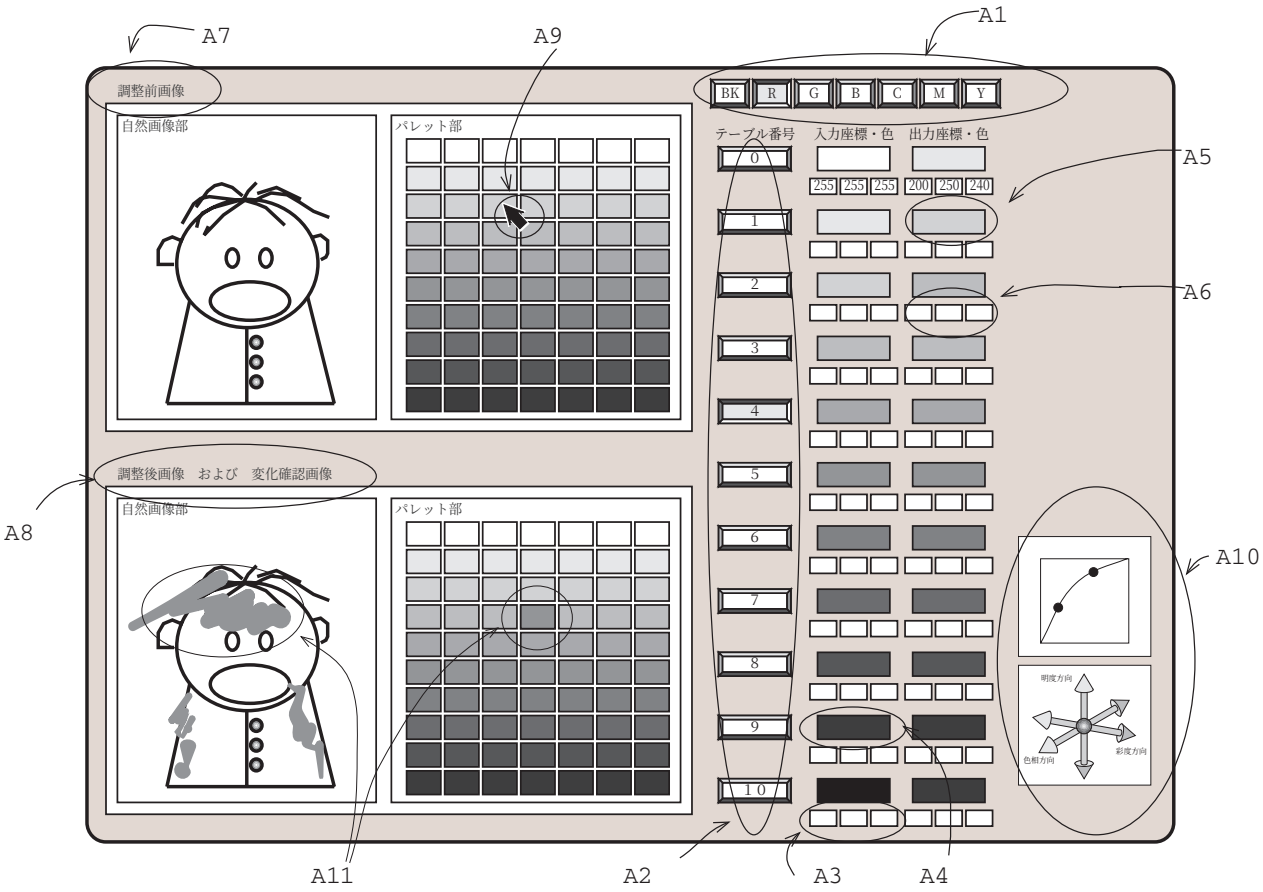

Figure 4. The color adjustment panel

Conclusions

We have been investigating a new approach to color reproduction among color devices. In this approach, a neutral gray scale and several color scales are adopted, and color hue and steps are controlled independently. And chromatic color and neutral gray are separated. It is easy to execute the color adjustment to refine the look up table for more accuracy of color correction, because the members of the look up table is directly connected to practical colors.

We applied the approach to color reproduction among real color devices. The average color difference is less than 2 at Lab color space in spite of the look up table of 119 colors member.

References

1. P. C. Hung, "Colorimetric calibration for scanners and media," SPIE, Vol. **1448** *Camera and Input Scanner Systems*, pp. 164 - 174 (1991).
2. P. Roetling, "Integrating scanners into color systems," *IS&T and SID's Color Imaging Conference*, pp. 92 - 94 (1993).
3. K. Kanamori, T. Fumoto and H. Kotera, "A Color Transformation Algorithm using PRISM Interpolation", *IS&T's 8th International Congress on Advances in NIP Technologies*, pp. 164 - 174 (1992).