Faithful Color Printing for Computer Generated Image Syntheses With Highly Saturated Component Inks

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Objective and Background

We have already developed technology to produce accurate and realistic Computer Graphics (CG) images that can aid color design work[6].

This stems from the desire that accurate color images is to be used in design work to evaluate colors and finishing materials in addition to the uses for recording or making presentation materials.

If this CG image can be reproduced not only on a CRT but also on paper by Color Printing System (CPS), its effect could be immeasurable.

Conventional Research on Color Gamut and Its Problems

Chromaticity of automotive exterior color distributed in ranges from high saturated blue to high saturated red area.

On the other hand, conventional CPS does not provide sufficiently wide color gamut for automotive exterior color, because conventional CPS normally uses only three component colors, yellow, magenta, cyan or four colors with black added to these three.

Conventional Research on Color Reproduction and Its Problems

Many reports on color reproduction by CPS are easily found, but none of them refers to usable color levels for color design[1,2].

Commercial CPS was evaluated by Takaoka to know the level of its color reproduction[7]. The experiment has revealed that average color difference between desired color and output color was about $E^*_{ab} = 32$. This color reproduction level is not suitable for design purpose.

Our Objects

The following describes the requirements for color reproduction method which can be used as a tool to evaluate colors and materials.

Requirement 1. Wide Color Reproduction Gamut CPS should be able to reproduce required high saturated colors that has not been achieved by a conventional CPS.

Requirement 2. Faithful Color Reproduction CPS should have color reproducibility to the level of color difference, $E^*_{ab} < 1$, to permit faithful reproduction of desired colors.

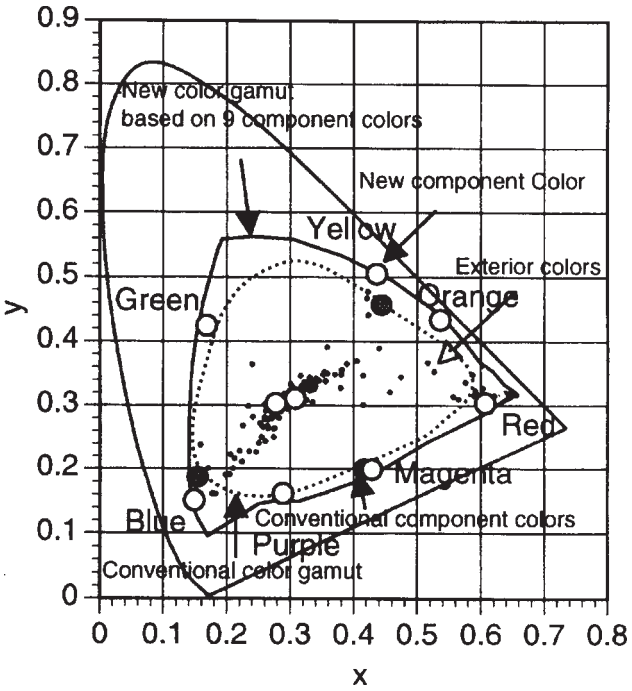

Figure 1. Color distribution of automotive exterior paint in (x, y) *chromaticity diagram*

Results

Widened Gamut with Multiple Ink Method

Color gamut was expanded about 35% in comparison to conventional CPS's gamut by using 'multiple ink method (MIM)'. This MIM is a method which is getting attention these days using multiple ink[4]. 9 component colors such as red, orange, yellow, green, blue, purple, magenta, black and gray was used in order to widen color reproduction range (Figure 1). Black and gray were used as achromatic colors, because they express the changes in lightness and darkness as smoothly and clearly as possible.

Faithful Color Reproduction with Neural Network

We have applied Neural Network in order to solve color reproduction. Various color combinations were experimented with, and the result of **G**reen, **B**lue, blac**K** is explained here.

Sample Data and Learning

Each one of (G, *B, K*) is gradated in five five stages, namely 0, 63, 127, 191, and 255 to make 125 sets of sample data. And each one of the sample colors is measured to obtain the tristimulus values, X_i, Y_i, Z_i (i = 1, 2, . . . ,125) as follows.

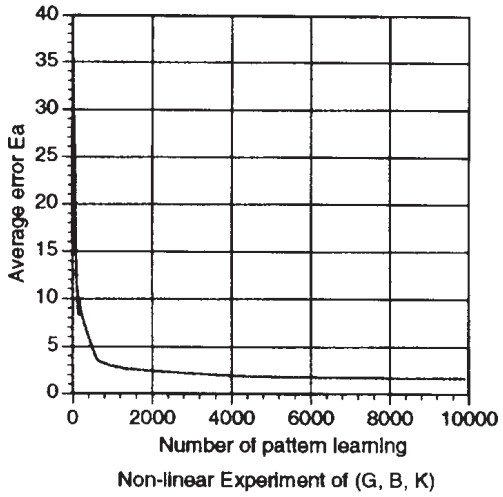

Figure 2. Pattern learning and average error. Non-linear experiment of (G, B, K)

G B K	→	X Y Z
(0, 0, 0)		(X_1, Y_1, Z_1)
(0, 0, 63)		(X_2, Y_2, Z_2)
(0, 0, 127)		(X_3, Y_3, Z_3)
(0, 0, 191)		(X_4, Y_4, Z_4)
. . . . .		
(255, 255, 255)		(X_{125}, Y_{125}, Z_{125})

For this, all input (G_i, B_i, K_i), and teaching (X_i, Y_i, Z_i) signals may be given. Then, (G_i, B_i, K_i) for any one of (X_i, Y_i, Z_i) can be obtained.

Result of Learning with Neural Network

Figure 2 is the result of learning 125 units of sample data. Uniform random numbers for the initial values of coupling coefficient and offset were given. There were four layers with 3 units in each layer.

The average error for 10,000 cycle tests between the result of learning and converged values was as follows:

$$E_a = 1.688.$$

Figure 3 shows the changes of X for changes of measuring points of (G, B, K). The five graphs show the curves for changes of K in 0, 63, 127, 191, and 255 stages. (•) dots are the measuring points.The curves on each graph are drawn with B as parameters. Horizontal axis

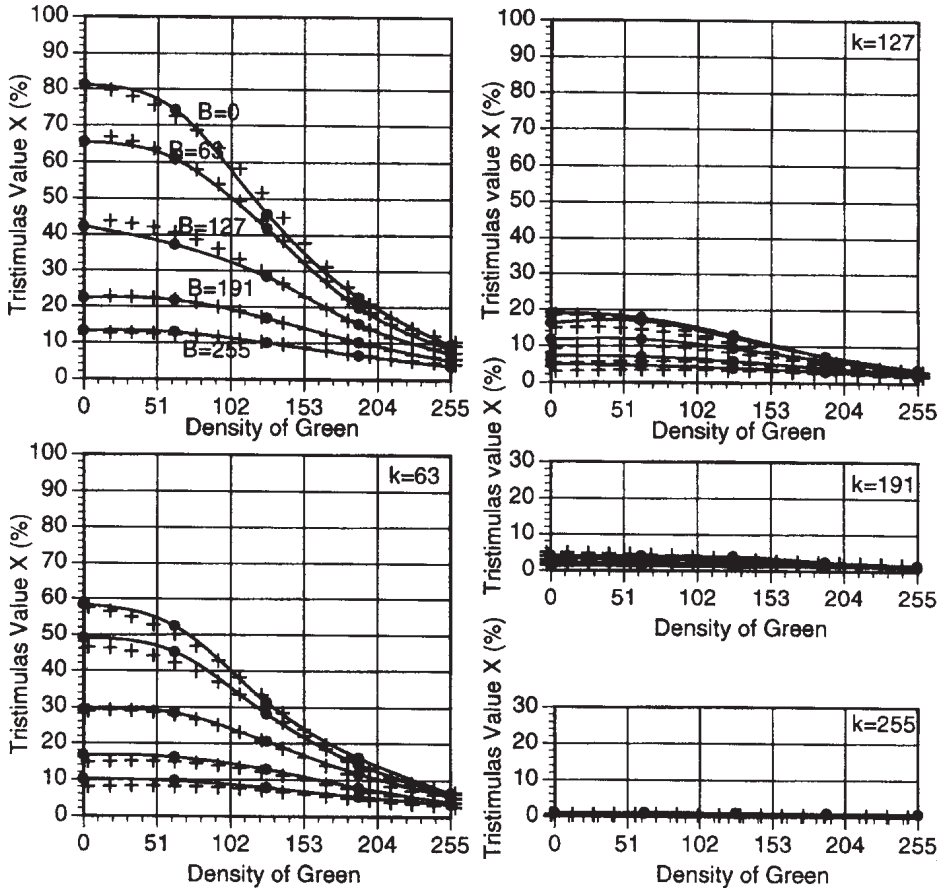

Figure 3. Relationship between result of experiment (*G, B, K*) *and X* (• *is measuring data, + is estimated by neural network)*

is G and vertical axis X. G and B like K were varied in 0, 63, 127, 191, and 255 stages. Each measuring point (•) was connected by a spline curve.

Cross points (+) were estimated on the Neural Network. The separation values of B, K= 0, 63, 127, 191, 255 and G = 0, 25, 50, 75, ..., 250, were used for calculation. It can be said that the curve is approximated by Neural Network well.

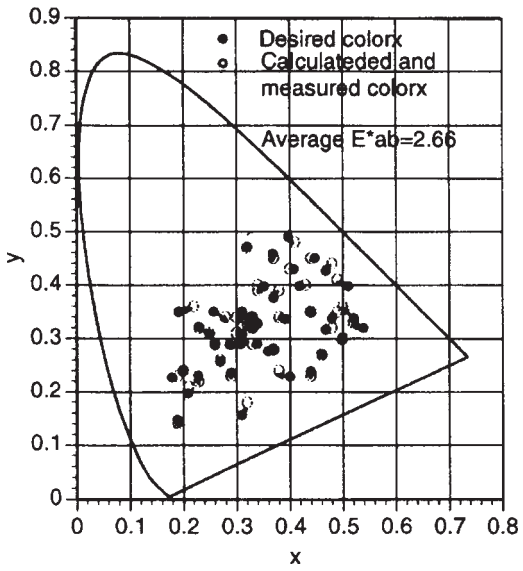

Figure 4. Result of color reproduction

Result of Color Reproduction

Figure 4 is the result of color reproduction based on our idea. The average color difference,

$$E^*_{ab} = 2.66$$

was obtained. The color difference over the color gamut of most commonly used automotive exterior colors was within 1. This level is quite sufficient for design work.

Why Neural Network was Applied?

Good points of Neural Network. Capable of Highly Precise Approximation of Complex Non-linear Phenomenon[5]. The Neural Network is known for its capability to better approximate non-linear phenomenon. We applied its nature to non-linear color reproduction problem.

Capable of Infinite Outputs from Few Data. By leaning only 125 sample data which are composed by a pair of input and output signals, other input signals which are not in the sample data can be estimated to find output signals.

Smaller Calculation Time. Learning of three colors combination took only a few minutes for convergence to take place.

Why Conventional Methods was not Applied?

Conventional color reproduction does not provide the sufficient color quality accuracy because of following reasons.

1. Failure of Approximate Non-linear phenomena
   Complex phenomena which can not be expressed by equation are simply formulized.
2. Too Much Number of Data
   Conventional CPS uses more than •4000 data.
3. Substantial Calculation Time

To be more stringent on above two for higher color quality, tremendous time is required, and it is not just economically feasible for conventional CPS.

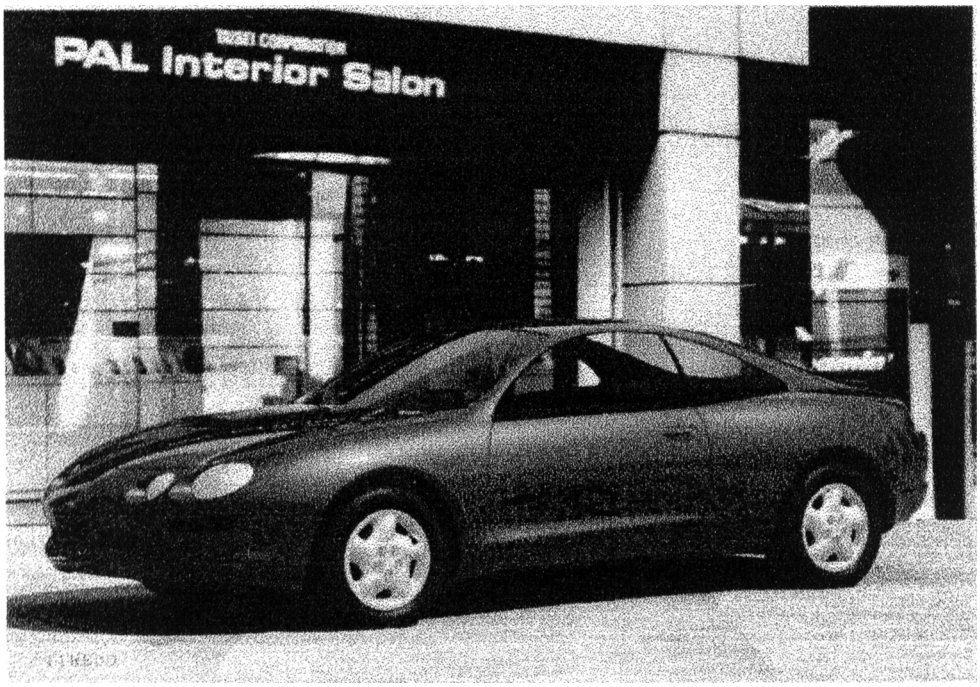

Figure 5. Example of Output

Impacts

Wide color reproduction gamut and faithful color reproduction that will meet the requirements of design work has been attained. This development has brought a drastic improvement over color reproduction gamut and reproduction which was difficult for conventional color printing system.

Figures 5 is the printout of an example of our inhause CAD (Color CAD System) output[3]. For A3 size paper printout time was about 30 minutes. No antialiasing was made for this printout.

Prior Publication

The contents described the present summary have not been published and presented in any journals or at any conferences.

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