A New Approximation Algorithm for Output Device Profile Based on the Relationship between CMYK Ink Values and Colorimetric Values

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Abstract

Due to the increasing of color picture applications, there is an increased color data exchange between various devices produced by different need to exchange data and predict the quality of color reproduction for manufacturers and the expected color reproduction in different types of rendering systems.

For these purposes, native device color spaces of specific devices must be converted to device independent color spaces, and vice versa.

Usually, the color reproduction in printers and process prints is implemented by using cyan, magenta, yellow, and black inks. The relationship between combinations of ink values and their measured colorimetric values is called the "characterization data", and these data are used to produce a LUT (LookUp Table) for the specific output device. This table is then embedded in the device to control its colorimetric results. Though crucial to control the printing quality, LUTs are rather large and producing them requires much labor.

In this research, the authors have used the ISO 12642 standard to produce color patches on several rendering systems, using various inks, papers and halftoning methods. Color characterization data was gathered in order to define the process control elements of the physical printing.

These results obtained can be summarized as follows;

1. Regarding the 3 color prints, three-dimensional colorimetric coordinates for color patches where the ink value of the one color (e.g. Cyan) is held fixed and others are arbitrary have a planar relationship and lie on a flat plane in the L*a*b* color space.
2. The planar relationship referred to in Result 1) can be observed for various hardcopies (e.g. process prints, laminate type proofs, toner images and inkjet prints).
3. The plane for a ink F can be expressed by the following equation.

$$L^* = \alpha(F) + \beta(F)a^* + \gamma(F)b^*$$
F: Ink value of Cyan, Magenta or Yellow

4. Coefficients of $\alpha(\ )$, $\beta(\ )$ and $\gamma(\ )$ can be approximated by quadric functions and their shapes have almost the same form regardless of rendering systems
5. Regarding the 4-color prints, the same relationship as 3-color prints can be observed when F and K values are fixed. When replacement of coefficients $\alpha(F)\rightarrow\alpha(F+K-Q)$, $\beta(F)\rightarrow\beta(F+K-Q)$, $\gamma(F)\rightarrow\gamma(F+K--Q)$ are performed, colorimetric coordinates for color patches of 4-color prints have a planar relationship referred to in Result 1).

Q (the " correction term") is defined by $Q=F\times K+\delta$ and is related to inks, ink values of C,M or Y and additional factor δ.

6. From the characteristics of Result 5, the rule on how to replace the color component by black ink can be made clear as follows;

F'(ink value remained) =
[F(ink value of 3-color print)-K(ink value of black) -δ] /(1-K)

7. The empirical validity of our analytical methods as described in these Results 1-6 has been confirmed for various prints including process prints, prints by copying machine, proofs and inkjet prints.

Using our results we are able to use a very small LUT to more accurately describe the output device profile. Also, we are able to provide rule of achromatic process on the basis of our theory and investigation works. Consequently, we believe this report will contribute to the color management technology.

1. Introduction

Although color reproduction technology varies; obtaining acceptable color reproduction requires;

Color appearance modeling
Colorimetric device characterization
Color gamut mapping

Appearance models account for differences in illuminating, viewing and cognitive conditions.

A colorimetric device characterization is a set of equations or a three-dimensional data set that converts between the device's color signal space (e.g. RGB, CMYK etc.) and the device-independent color spaces such as L* a* b*.

One of our research goals is to find a succinct definition for conversions between colorimetric data and recording data to the actual color reproduction process.

Gamut mapping often consists of a set of rules on how to map the gamut of color-appearance space of one device onto a second device.

Once the capturing device and recording process are identified, the three conversion stages, input device profile, gamut mapping and output device profile, are used to build a color management module in the form of a three dimensional color look-up table (CLUT).

This paper would like to provide a kind of output device profile which perform the translation between L* a* b* color space and CMYK color space.

For seven years, the ISO/TC130 (Graphic Technology) committee has been working to standardize the output device profile, including the printing process. Subsequently SWOP in the U.S.A., BVD/FOGRA in Europe and the Japan Color have applied efforts to create respective characterization data for printed materials. These characterization data are obtained by using the ISO 12640 SCID data and are possible to use in defining the color management system for process prints.

Our studies began with our participation in the Japan National Committee for TC130 (JNC) project for printing test and extended from process prints to various proofs.

In this paper, the method to obtain the device profile developed by us for both the process prints and the COLORART proof are explained on the basis of the relationship between CMY ink values and L* a* b* colorimetric values for 3-color prints.

Next, the efficacy of replacement of color ink by K (black ink) is investigated and the derived rules are shown as follows;

1. Regarding the color patches of 3-color process prints, three-dimensional sample coordinates for which ink values of one color are fixed and others are arbitrary, lie on the flat plan in L* a* b* color space.

Colorimetric coordinates of 4-color patches where the ink value of both one color and K added are fixed, are located on the flat plane as well as for 3-color prints

3. A set of coefficients of the plane equation for 3-color process prints is available for 4-color prints.

Thus, on these results we were interested in exploring several research goals relating for color management systems.

The first goal was to declare the gray balance conditions that became possible to show by using the flat plane equations.

The second goal was to develop the simple expression of the output device profile that could be expressed with equations and/or smaller CLUT. The third was to apply the rule declared in characterization data to achromatic process.

In Chapter 3, we describe tests using our equations and smaller CLUT to derive the put device profile.

Finally we make prints and proofs where color patches were aligned side by side for evaluation of our predictions. Half of the color patches were 3-color prints, and the others were achromatic. Color difference values ΔEs between color patches are measured to confirm the efficacy of our method. The results are depicted as a figure.

2.Experimental

2.1 Samples

The test prints and proofs are produced under the following conditions;

(a) Test images (same for process prints and proofs)
- Color patches specified in the ISO 12640 (SCID) and ISO 12642 (Output target)[1]
- Attached natural image used : two images included in ISO 12640 SCID

(b) Color Separation Film (same for prints and proofs)[2,3]
- Transmission density..............at least 2.5
- Film base plus fog..................less than 0.06
- Dot shape..............................square

(c) Screen ruling (same for prints and proofs)
- 70 line / cm

(d) Screen angle (same for prints and proofs)
Screen separation for cyan, magenta and black is 30 degrees with the yellow separated by 15 degree from another color.

Table 1. CIELAB coordinates of colors for conditions of color sequence cyan → magenta → yellow → black, black backing and illuminant D50. (1993)[3]

	L*	a*	b*	Allowance	Density	Deviation Tolerance	Variation tolerance
Black	12.5	0.7	1.2	6	1.83	4	2
Cyan	53.9	-35.9	-50.4	6	1.48	5	2.5
Magenta	46.3	74.4	-4.8	6	1.53	8	4
Yellow	86.5	-6.6	91.1	6	1.04	6	3
Red	48.0	65.5	48.0	6	—	—	—
Green	48.9	-70.1	27.1	6	—	—	—
Blue	23.1	20.4	-52.1	6	—	—	—
White	93.0	0.5	0.4	6	—	—	—

Tolerance values are specified in the ISO 12647/2 standard.

(e) Substrate (process prints)
Type 1(gloss-coated 115 g/m^2)
(f) Ink set colors as printed (process prints)
Recommended data are tabulated in Table 1
(g) Proofs
"COLORART" (Fuji Film) laminate type proof is used.

2.2 Measurement[4]

We used color patches based on the 928 patches in the ink value data set as specified in the ISO 12640 (SCID) and ISO 12642 standards. Patches of basic data set were consist of the following alignments;

1) Neugebauer equations (1-26),
2) Four color vignette (27-78),
3) Combinations of 0, 20, 40, 70 100 % of respective C,M,Y inks (79-121) and
4) Combination to get efficacy of adding black and to ensure the good reproduction of neutral gray.

Patches of extended data set consist of following three parts.

1) Combinations of 0, 10, 20, 40, 70 and 100 % ink values in cyan magenta and yellow with 0 and 20 % black (183-614),
2) Combinations of 0, 20, 40, 70 and 100 % ink values in cyan, magenta and yellow with 40 and 60 % black (615-864), and
3) Combinations of 0, 40, 70 and 100 % ink values in cyan, magenta and yellow with 80 % black (865-926).

All measurements were implemented in accordance with the procedures of ISO 12647-1. That is, the condition of 2° observer, illuminant D_{50}, 45°/0° or 0°/45° geometry and black backing was used. The X-rite 938 spectrodensitometer was used for actual measurement.

3.Results[5,6,7]

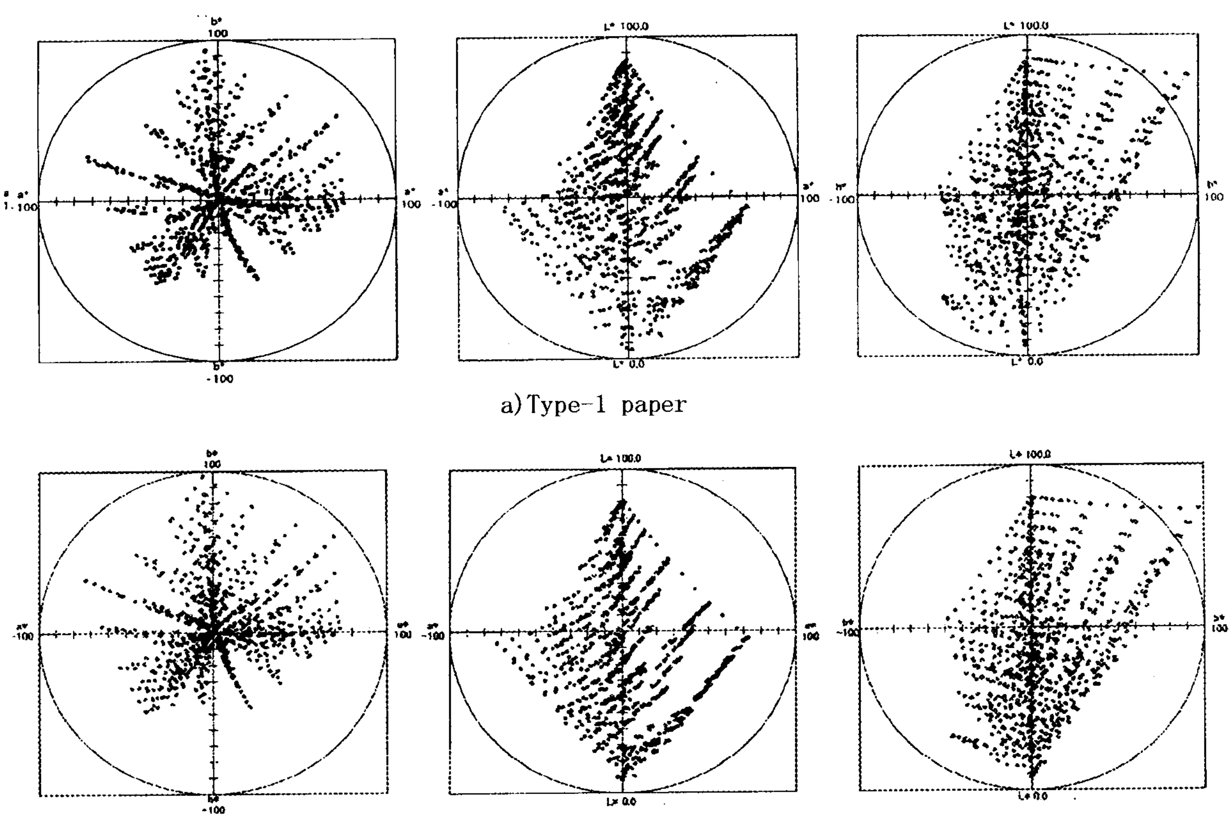
3.1 Color Gamut of Reproduced Images

Fig.1 (a) and (b) depict color gamut of process print and proof reproduced.

The range of reproduced colorimetric values is L*: 2.9~92.7, a*:-72.6 ~+70.6, b*:-51.2 ~+93.9 for process print and L*: 14.5~91.3, a*:-68.0~+72.3, b*: -47.3~+90.8 for COLORART proof.

3.2 Colorimetric Properties of 3-Color Images

3.2.1 Planar Relationship. When observing the distribution of measured colorimetric values of color patches printed with three inks, we discovered and confirmed that the coordinates of measured colorimetric values for color patches of C (ink value of cyan) = fixed value and M,Y (ink values of magenta and yellow) = arbitrary values are almost on a flat plane in the L*a*b* color space. For M or Y = fixed, the same results



(b)COLORART proof

Figure 3-1 Color gamut of reproduced images

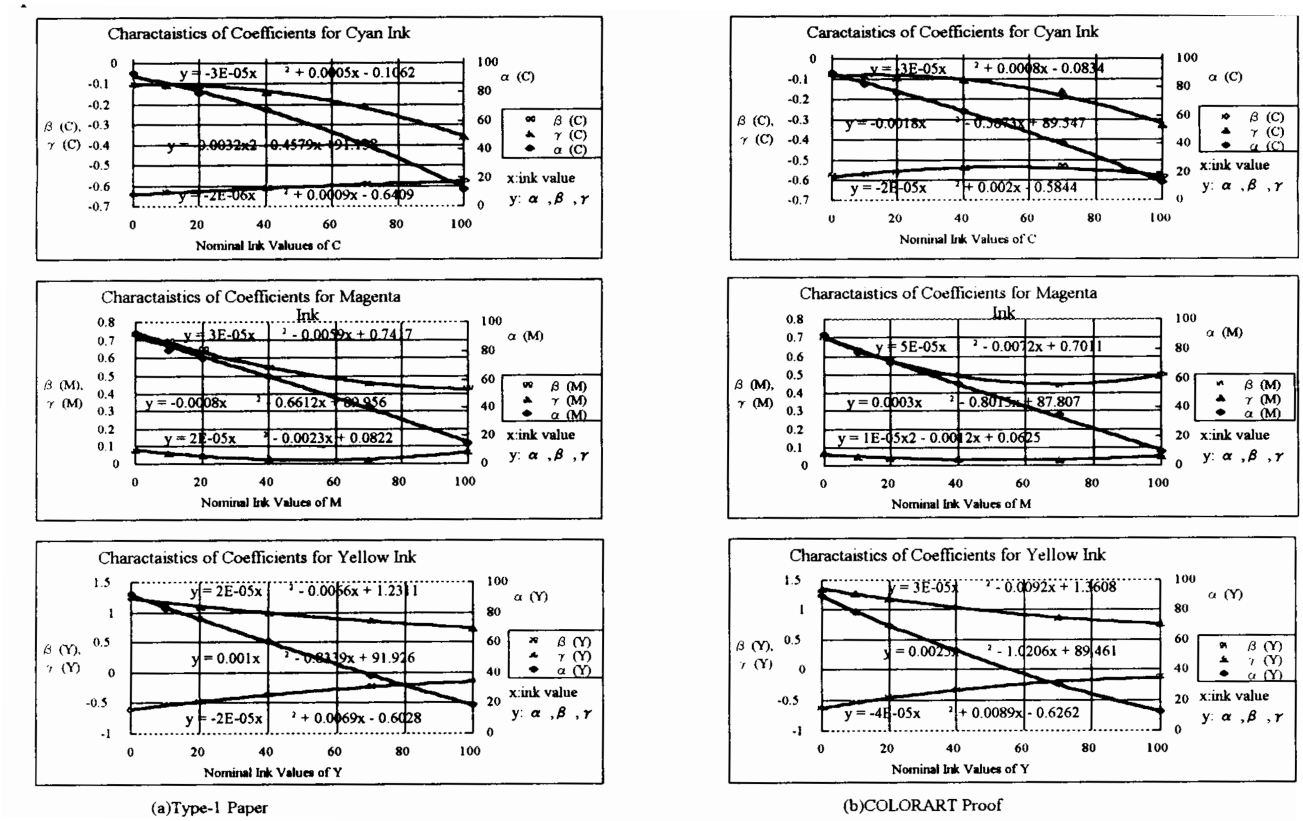


Fig.3-2 The relationship between coefficients of Equation (3-1) and ink values.

could be observed from the colorimetric values plotted on the CIELAB diagram.

The plane in L*a*b* color space can be represented by the following equations.

$$
\begin{aligned}
L^* &= \alpha(C) + \beta(C)a^* + \gamma(C)\, b^* \\
L^* &= \alpha(M) + \beta(M)a^* + \gamma(M)b^* \\
L^* &= \alpha(Y) + \beta(Y)a^* + \gamma(Y)b^*
\end{aligned}
\qquad (3\text{-}1)
$$

where $\alpha(F)$, $\beta(F)$ and $\gamma(F)$ are function of ink values and F represents ink value of C, M or Y.

After investigating characterization data of various prints including data performed by ANSI/CGATS and BVD/FOGRA and various proofs we could observe that the relationship shown by Equation (3-1) exists for various output devices.

Fig.3-2 shows the relationship between coefficients $\alpha(\,)$, $\beta(\,)$ and $\gamma(\,)$ of Equation (3-1) and ink values. Although the precise shapes of the curves are specific to each ink, the curves can be approximated satisfactorily by quadratic equations shown in Fig. 3-2.

Also, we can observe the declinations of curves have same trends for various type of hardcopy systems.

By using Equation (3-1), we can evaluate (1) gray balance condition from highlight to shadow and (2) simple expression of output device profile (conversion between ink values and colorimetric values).

3.2.2 Gray Balance. By assuming a*=0 and b*=0 in Equation (3-1), then the gray balance for any L* values can be calculated.

Fig. 3-3 (a) and (b) show the gray balance for the print and the COLORART proof. In midtone, the tone value of C is 5-10 % larger than that of M or Y for the process print and 5-8% larger than for the COLORART proof. This is consistent with our experiences.

3.2.3 L*a*b* ⇔ CMY Conversion. By using the Equation (3-1), the color space conversion can be performed with Equations (3-2).

$$
L^* = \frac{\begin{vmatrix} \alpha(C) & -\beta(C) & -\gamma(C) \\ \alpha(M) & -\beta(M) & -\gamma(M) \\ \alpha(Y) & -\beta(Y) & -\gamma(Y) \end{vmatrix}}{\Delta}
$$

$$
a^* = \frac{\begin{vmatrix} 1 & \alpha(C) & -\gamma(C) \\ 1 & \alpha(M) & -\gamma(M) \\ 1 & \alpha(Y) & -\gamma(Y) \end{vmatrix}}{\Delta}
\qquad
b^* = \frac{\begin{vmatrix} 1 & -\beta(C) & \alpha(C) \\ 1 & -\beta(M) & \alpha(M) \\ 1 & -\beta(Y) & \alpha(Y) \end{vmatrix}}{\Delta}
\qquad (3\text{-}2)
$$

$$
\text{where } \Delta = \begin{vmatrix} 1 & -\beta(C) & -\gamma(C) \\ 1 & -\beta(M) & -\gamma(M) \\ 1 & -\beta(Y) & -\gamma(Y) \end{vmatrix}
$$

Because the coefficients $\alpha(F)$, $\beta(F)$, and $\gamma(F)$ are quadratic functions of the ink values as in Formula (3-3).

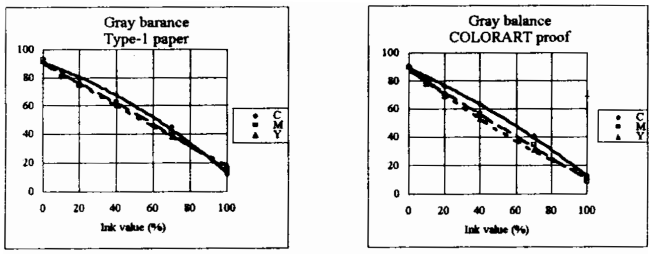


Figure 3-3. The relationship between ink values for gray balance.

As shown in Fig. 3.2, coefficients α(F), β(F) and γ(F) are approximated by quadratic functions of ink values as in Formula (3-3).

$$y(\text{Values of coefficients}) = p\,F^2 + q\,F + r \qquad (3\text{-}3)$$

Where F indicates ink values of C, M or Y and p, q and r are constants and their values are written in Fig.3-2. So ink values for C, M or Y corresponding the three-dimensional coordinates (L* a* b*) are calculated by Equation (3-1).

Calculated values of C, M and Y for both the process print and the COLORART proof produced by our laboratory can be written as Equation (3-4) and Equation (3-5).

1) Process Print

$$C = [-228950+450a^*+250b^*+ \{(228950-450a^*-250b^*)^2 -4(1600+a^*+15b^*)\times (-4.5569\times107+320450a^*+53100b^*+5\times105L^*)\}^{1/2}]/ \{2(1600+a^*+15b^*)\}$$

$$M = [66120+590a^*+230b^*]- (-66120-590a^*-230b^*)^2 -4(-80+3a^*+2b^*)\times (8.9956\times106+74170a^*+8220b^*-105L^*)\}^{1/2}]/ \{2(-80+3a^*+2b^*)\} \qquad (3\text{-}4)$$

$$Y = (-83390+690a^*-660b^*)+ \{(83390-690a^*+660b^*)^2 -4(-100+5a^*-2b^*)\times (-91926\times106-60280a^*-123110b^*+105L^*)\}^{1/2}]/ \{2(-100+5a^*-2b^*)\ \}$$

2) COLORART Proof

$$C = [-53600+200a^*+80b^*+ \{(53600-200a^*-80b^*)^2 -4(220+2a^*+3b^*)\times (-8.8339\times10^6+58440a^*+8340b^*+10^5L^*)\}^{1/2}]/ \{2(220+2a^*+3b^*)\}$$

$$M = [70150+720a^*+120b^*- \{(-70150-720a^*-120b^*)^2 -4(-50+5a^*+b^*)\times (8.5451\times10^6+70110a^*+6250b^*-10^5L^*)\}^{1/2}]/ \{2(-50+5a^*+b^*)\} \qquad (3\text{-}5)$$

$$Y = [-104840+890a^*-920b^*+ \{(104840-890a^*+920b^*)^2 -4\ (-280+4a^*-3b^*)\times (-9.0117\times10^6+62620a^*-136080b^*+10^5L^*)\}^{1/2}]/ \{2(-280+4a^*-3b^*)\}$$

The accuracy of these approximations has been reported already in reference paper.[5]

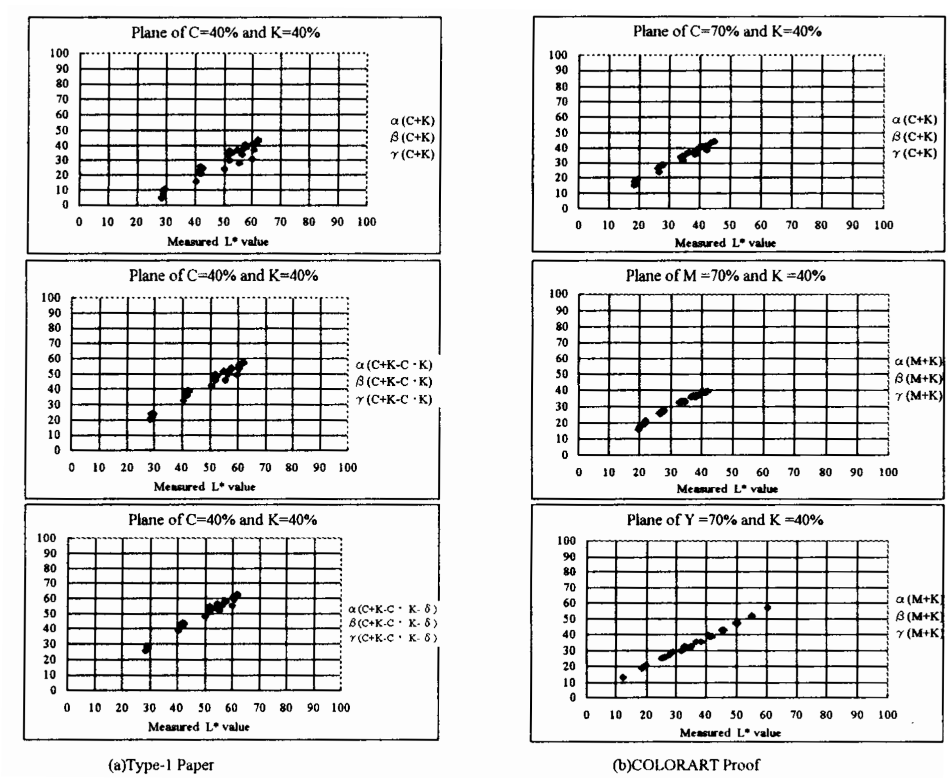


Figure 3-4. Comparison between measured L value and predicted L* value calculated with equation (3-5).*

When comparing the L* values measured and L* values predicted from measured values of a* and b* with Equation (3-1), the color difference values of $\Delta E[=(\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2}]$ are;

Process prints: less than 6.0 and average value of 3.3
COLORART proof: less than 6.0 and average value of 2.8

3.2.4 Three-Dimensional Colorimetric Values of 4-Color Images. When observing the measured colorimetric values of patches printed with 4-color process inks, we worked out the following empirical rules;

(1) Three-dimensional coordinates (L* a* b*) of patches with 4-color inks are approximately on the flat plane.
(2) The equation can be formulated as (3-5) by using the same coefficients as for 3-color prints.

$$L^*=\alpha(F+K-Q)+\beta(F+K-Q)a^*+\gamma(F+K-Q)b^* \qquad (3\text{-}5)$$

Where F is the ink value (for cyan, magenta or yellow) and Q is correction term.

(3) Correction term Q can be expressed by the following Formula (3-6).

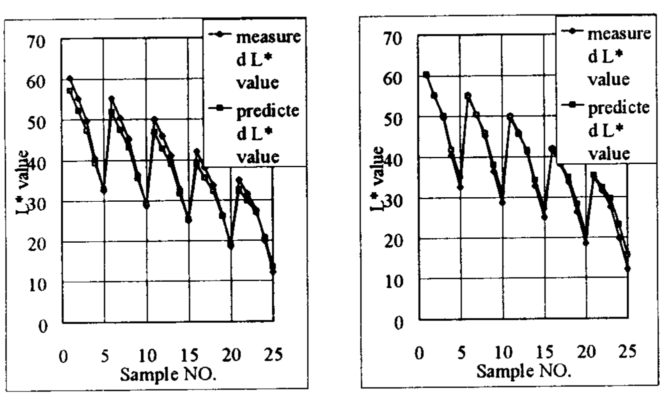
$$Q=F\times K+\delta \qquad (3\text{-}6)$$

Where δ is a part of the correction term related to inks and ink values.

By investigation for various imaging systems including inkjet printers and color copying machine, we followed the Q is almost approximated by F×K. At the same time, we recognized the fine correction is needed in process prints and COLORART proof which require the precise color matching. For this purpose, we adopted "Additional factor δ".

Fig. 3-4 shows how to search the δ value of both the process print and the proof.

Our Results indicated that the additional factor δ is small and less than 7 % in the range of normal usage and seems to have a relationship to the dot gain. Because the nominal value of F is used in our analysis, δ should be recognized as the correction factor for dot gain phenomena in respective imaging systems.



(a) δ=0 (b) δ=4

Figure 3-5. Comparison of the measured L values and the predicted L* values when Y=70%, K=40% and δ=4%*

Table 3-1 shows the precise values of δ for process prints and COLORART proof.

The result of accurate correction for an example Y=70%, K=40% δ=4% is shown inl Fig.3-5.

From our investigation, δ values of ink jet recording systems are almost zero. In order to improve the accuracy of our approximations, we are continuing to investigate the characteristics of the additional factor δ.

Table 3-1 Relationship between inks, ink values and additional factor δ

C	K	δ	M	K	δ	Y	K	δ
0	20	-3	0	20	2	0	20	6
0	40	-3	0	40	2	0	40	9
0	60	-1	0	60	4	0	60	11
0	80	1	0	80	3	0	80	5
10	20	-1	10	20	3	10	20	5
100	20	-1	20	20	3	20	20	5
100	40	-3	20	40	3	20	40	8
100	60	-5	20	60	5	20	60	9
100	80	-7	40	20	3	40	20	5
20	20	0	40	40	4	40	40	8
20	40	0	40	60	5	40	60	7
20	60	1	40	80	1	40	80	-1
40	20	1	70	20	2	70	20	3
40	40	1	70	40	1	70	40	4
40	60	2	70	60	1	70	60	2
40	80	0	70	80	-3	70	80	-6
70	20	1	100	20	-1	100	20	-1
70	40	0	100	40	-3	100	40	-3
70	60	0	100	60	-6	100	60	-6
70	80	-2	100	80	-9	100	80	-13

3.2.5 Application of Correction Term Q to UCR. As the next step, we can apply the results described above to UCR (Under Color Removal).

If a part of the color ink of F % is replaced by the black ink of K%, then the remained ink value of F' should satisfy the Formula

$$F= F' + K - F'\times K-\delta.$$

Then remained ink value F' is calculated as

$$F' =(F-K+\delta)/(1-K) \qquad (3\text{-}7)$$

The counterintuitive meaning of Equation (3-7) is that the more K is increased, replacing another color, then the lower the replaced percentage required for the remaining color inks. The replaced ink value of another ink is never same as K.

For confirmation of our results, we produced the test prints and proofs in which color patches having C, M and Y ink values and patches having values of two colors and black calculated from Equation (3-7) (achromatic processing) are aligned side by side.

[Example]

	3color	UCR	Achromatic
1. (C,M,Y,K)	(40,40,40,0)→	(26,29,31,20)→	(0,5,8,40)
(δc,δm,δy,-)		(1, 3, 5,-)	(-, 3, 5,-)
2. (C,M,Y,K)	(70,40,40,0)→	(64,28,29,20)→	(49,0,7, 41)
(δc,δm,δy,-)		(1, 2, 3,-)	(0,1,4,-)

The comparison of colorimetric values of both patches is shown in Fig. 3-6.

The approximation accuracy shown by ΔE were less than 7% for process print and less than 6% for COLORART proof.

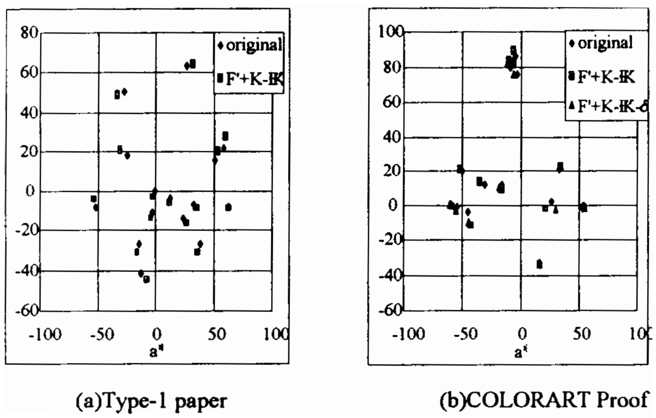


Figure 3-6. Comparison of three-dimensional values of both patches of 3-color inks and those applied the UCR operation.

4. Conclusion

A new approximation algorithm for output device profile is proposed. The conversion between ink values of cyan magenta, yellow and black and colorimetric values is made clear and the results can apply to UCR calculation. As discussed in ICC profile, the output device profile is one of the larger issues in graphic technology. The usual method for color space conversion is to prepare a large LUT based on the measured values and interpolation protocol. Because the proposed conversion method is based on the equations and a small LUT, then the expression of device profile becomes much easier.

As the consequence of our studies, a lot of properties included in the characterization data could be explained and the result would provide the basic understanding of color reproduction for a new output device profile.

Also, the discussion about UCR on the basis of colorimetric analysis will provide the theoretical background of how to calculate the remaining ink values.

Acknowledgments

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