Some Colorimetric Properties included in the Color Characterization Data of Process Prints

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Keyword: Color reproduction, Characterization, Color cubic, Gamut mapping, L*a*b*- CMY(K) conversion

Abstract

In the ISO/TC 130 committee, various efforts have been undertaken to make common the color characterization data for the offset printing using the ISO 12642 Output Target. The authors participated in printing test project in Japan produced test proofs and obtained various color characterization data for some combinations of papers, inks and screens.

In this paper, the qualitative properties of measured colorimetric data of the process prints and the relationship between values of CMYK and color coordinates expressed by CIELAB values are explained on the basis of the results of our investigation. First, we studied the colorimetric characteristics of proofs certified as meeting the requirements of JAPAN COLOR Conditions.

The measurements had been performed by using printed color patches on the proofs where dot values were specified in ISO 12642 "Graphic technology-Prepress digital data exchange-Input data for characterization of 4-colour process printing". The results of our studies of the characterization data can be summarized as follows;

1) Regarding the color patches of 3-color process prints for which the dot values of C,M, and Y are specified by ISO 12642, all CIELAB values of patches where the dot values of the one color(e.g. C) are the same and others (e.g. M and Y) are variable, lie on a flat plane.
2) These phenomena can be observed for other combinations.
3) The flat planes can be expressed by the simple equations

$$L^* = \alpha(C) + \beta(C)a^* + \gamma(C)b^* \qquad \text{for each C value}$$
$$L^* = \alpha(M) + \beta(M)a^* + \gamma(M)b^* \qquad \text{for each M value}$$
$$L^* = \alpha(Y) + \beta(Y)a^* + \gamma(Y)b^* \qquad \text{for each Y value}$$

and the coefficients values of α, β, γ can be approximated by quadratic functions of C, M or Y dot values. [5]

By using these equations, the trials of the conversion between CIELAB values and C, M, and Y dot values are performed and their results are evaluated by calculating

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ΔE between predicted CIELAB values from specified CMY dot values and measured CI ELAB values. The comparison shows the ΔE is less than 5.0 for the offset prints on the Type I paper.
For color patches including black inks, the relationship between K values and coefficients values is investigated and it is made clear that the CIELAB values of the patches where C and K values are the same and M and Y values are variable lie on a flat plane as well as in the 3-color prints.
Moreover, the plane is the same as the plane of C = constant where C (value of 3-color print) = C* (value of 4-color print) + K − Q, and Q is related to the halftoning technologies (e.g. dot gain). The Q value is analyzed in detail in this paper and has been confirmed by test prints.
Also a subjective comparison of color patches one of which has the specified C M Y dot values and the other has the CMY dot values calculated from the same CIE LAB values for the specified CMY dot values has been performed with prints produced by using the Pictrography.
Consequently, we can make clear the colorimetric characteristics of process prints and the results will contribute to the color reproduction technique.

1. Introduction

The introduction of electronics into the graphic arts has forced printing to change to a much more open process. This has led to an increased dependence on more analytically-based processes including digital proofing and imaging technologies.
Such processes impose increasingly stringent requirements for consistency and predictability in the printing process. In order to meet these requirements, the relationship between the printed color and the associated input CMY(K) data has to be characterized.
These efforts have been continued in ISO/TC130 (Graphic Technology) six years long. Subsequently, printing tests to specify either the reflection density or the tristimulus values of a solid printed ink film and to specify tolerances of colorimetric values at which various halftone dot values should be reproduced have been per-formed in USA, Japan and Europe by using the specifications of the ISO 12642"Graphic technology- Prepress digital data exchange- Input data for characterization of 4-colour process printing" standard. [1]
As the specifications for the process control elements, SWOP in the USA and FIPP in Europe are widely recognized standards.
In 1990, the Japan National Committee for TC130 (JNC) had specified a similar standard "JAPAN COLOR Conditions", in which Standard Ink SF- 90, Standard Paper, Standard Color values and Standard Color Samples are included.
The JNC experts group, working in conjunction with industrial groups, undertook the development of the standardization of printing conditions and the creation of characterization data for material printed in accordance with the JAPAN COLOR Conditions . [2],[3]
This paper shows first the colorimetric properties included in the characterization data for 3-color prints prepared by our laboratory when participating in the JNC

project, and next studies about the relationship between CMY dot values and L*a* b* values and how to obtain the mutual conversion formulas for both values.
For confirming the accuracy of the conversion formulas, the CIELAB color difference ΔE between measured values and values predicted by conversion formulas are compared for every patches. The results are shown in figures.
Moreover, a subjective comparison of both prints having the specified C M Y dot values and prints having the CMY dot values predicted from the measured L*a*b* values for the specified CMY dot values were performed to confirm the conversion accuracy.
Finally we confirmed that the colorimetric values of the color patches including K are located on the flat plane in the CIELAB coordinates and the same coefficients of the plane equation for 3- color prints are available for 4-color prints. The achromatic processing where the minimum of the CMY dot values is fully replaced by the K value according to our studies, are tried and the prints are produced and compared with 3-color prints.

2. Measurement Protocol

2.1 Prepress Model

If constructing the color reproduction systems, three conversion processes should be needed as shown in Fig. 1.
At Conversion 1, RGB color separation values should be converted to the device independent data like as XYZ, CIELAB or CIELUV to make possible the exchange of data. The function of Conversion 2 is to convert the color gamut of the original data to the gamut of the reproduction systems on the uniform color space.
The color prints must use the C M Y (K) color materials by all means and then the conversion from the uniform color space to the CMY(K) color space is performed in Conversion 3.
The research described in this paper focuses on this Conversion 3 process. The Conversion 3 processes are usually implemented by using the lookup tables (LUT) combined with interpolation techniques in the reproduction devices. If a conversion by using transformation formulas is possible, the conversion algorithm will become easier than with LUT techniques.

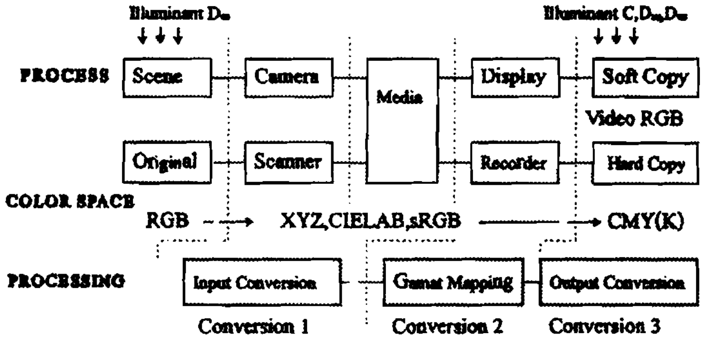


Fig. 1 Process model of color reproduction system

2.2 JAPAN COLOR Conditions

The suggested values of process parameters required for halftone offset prints are specified in the International Standard ISO 12647/1,2, and the Japan Color Conditions are specified on the basis of this standard as follows;

1. Color Separation Film
   - Transmission density of dot ・・・・・ at least 2.5
   - Film base plus fog ・・・・・・・・・ less than 0.06
2. Screen ruling
   - 70 cm-1 for commercial/specialty printing
3. Screen angle

   Normal screen separation for cyan, magenta and black shall be 30° with the Yellow separated by 15 ° from another color.
4. Substrate

   Type 1 (gloss-coated 115g/m2) for proof prints

L*	a*	b*	gloss	brightness
93±2	0±2	-3±2	40±2 %	85±2 %

   JNC designates 2 brands "Tokubishi-Art" and "OK-Art" as the standard paper Corresponding to the specifications of ISO 12647/2.
5. Ink set colors as printed

   Recommended data are shown in Table-1.

Table-1 *CIELAB coordinate of colors for the color sequence cyan-magenta-yellow; black backing, illuminant D50. (1993)*

	L*	a*	b*	(1)	density	(2)	(3)
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	–	–	–

(1): ΔE allowable in JAPAN COLOR Condition, (2): Deviation tolerance, (3): Variation tolerance, Both (2) and (3) are defined in ISO 12647/2 standard.

2.3 Samples and Measurement Procedure

Prior to producing the test prints, the following activities were done in our laboratory.

(1) The separation films which layout is shown in Fig. 2, screen ruling is 70 cm-1 and dot shape is square are prepared.

(2) Dot gain values of square dots are measured. (Fig.3)

(3) By using these films, plates to be used were produced with adequate exposing time which was controlled so as to remain 8 μm lines in Bruner Chart.

(4) A proof printing machine was used to make samples.
The aim density of solid portion defined by JNC were measured for every print. (Refer to Table 1.)

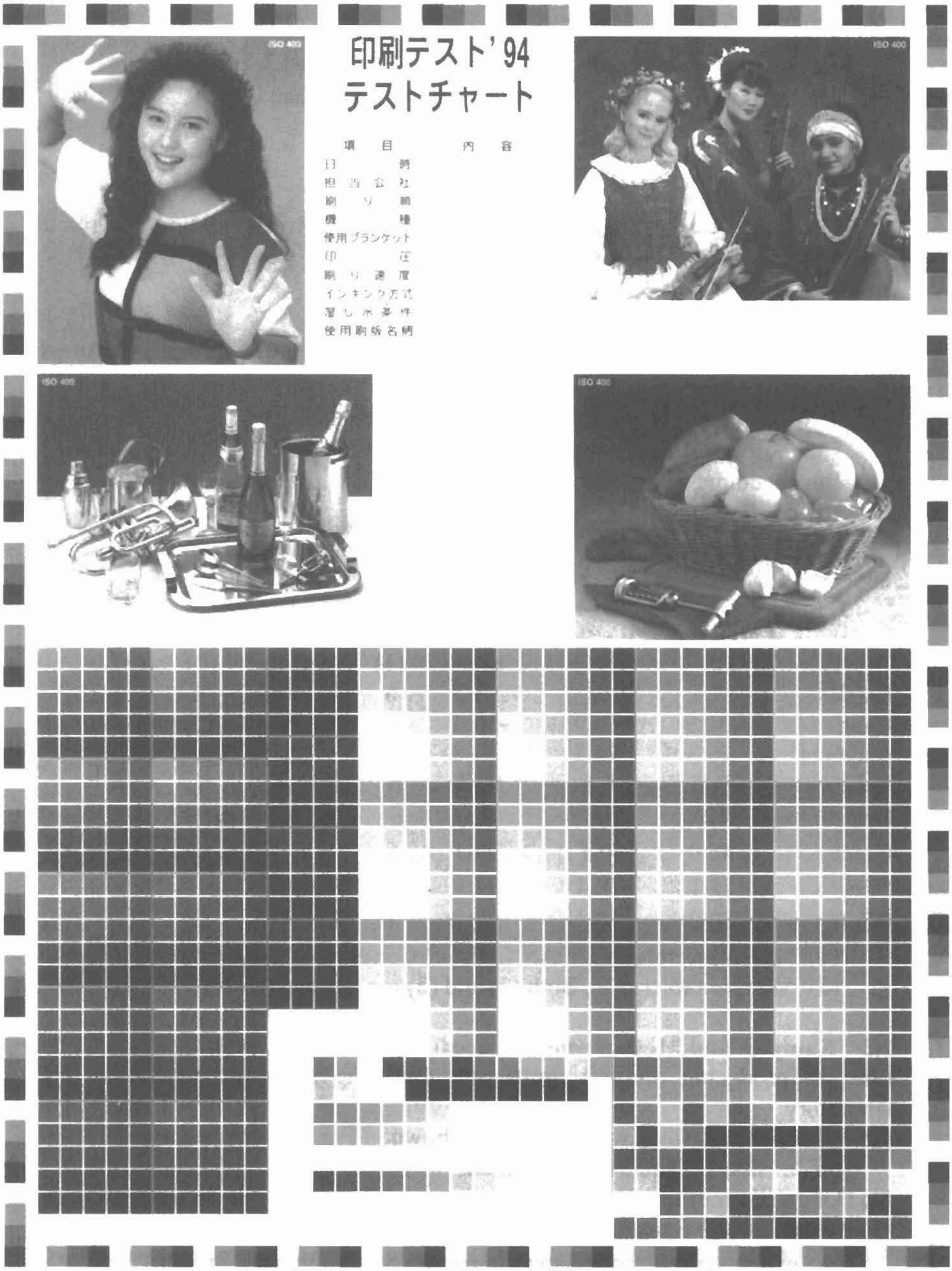


Fig.2 The form assembled by JNC for test print

The following materials were used to produce samples.

- Paper: Tokubishi-Art 128g/m2
- Ink : Japan Color SF-90
- Proofing Machine: KF-123-GL (Dainippon Screen)
- Blanket: Barcan New 278
- Plate: FPP-J (Fuji Film)
- Color sequence: Cyan → Magenta → Yellow → Black

(5) All measurements were implemented in accordance with the procedures of ISO 12647-1. That is, 2° observer, illuminant D50, $45^{\circ}/0^{\circ}$ or $0^{\circ}/45^{\circ}$ geometry and black backing was used The actual operations were performed by using the X-Rite 938 spectrodensitometer. [4]

Color patches specified in ISO 12640 (SCID) or 12642 (Output Targets) are constructed from 928 patches for which combinations of dot percent values are defined.

Around 928 patches were measured colorimetrically, and the primary Ink value combinations of 216 patches excluding black values have been selected for the purpose of modeling the transformation formulas from CMY to $L^*a^*b^*$ or vice versa. The primary group includes all combinations of the following ink values.

Cyan :	0,	10,	20,	40,	70,	100	%
Magenta:	0,	10,	20,	40,	70,	100	%
Yellow :	0,	10,	20,	40,	70,	100	%

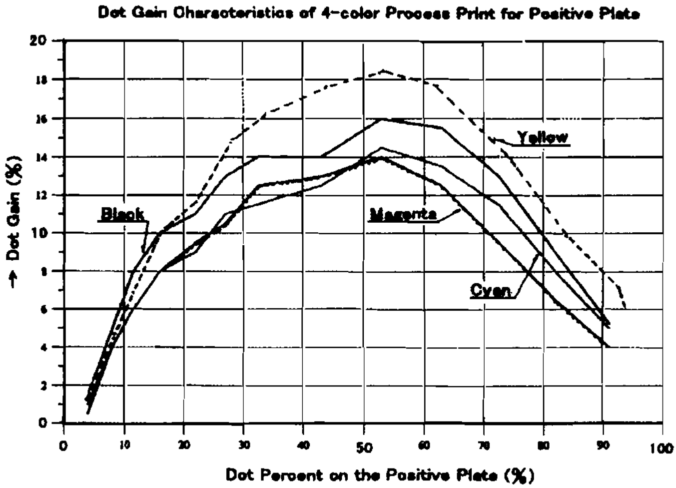


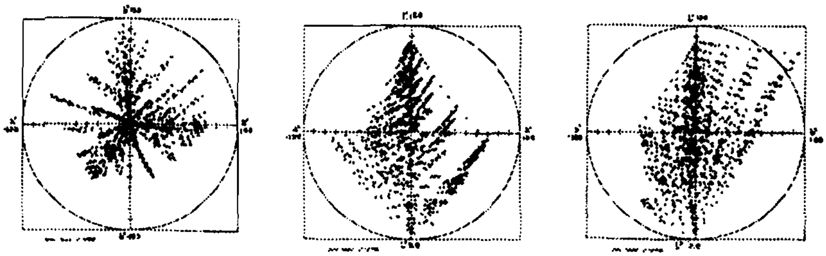
Fig.3 Relation between dot value on positive film and dot gain on print.

3. Results

3.1 Gamut of Process Print

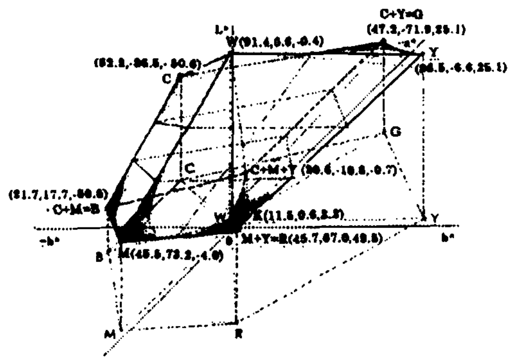
Fig.4-(a), Fig.4-(b) and Fig.4-(c) depict gamut of proof prints having screen ruling of 70 cm-1. The range of reproduced colorimetric values are L* : 2.9~92.7, a*: -72.6~+70.6, b*: -51.2~93.9.

Unless the dot shape is square or stochastic, the ranges of L*a*b* values of prints are almost same. Fig. 4-(d) is the color cubic expression of gamut for square dot.



(a) a* b* plane (b) L* a* plane (c) L* b* plane

Fig. 4 Gamut reproduced by using the Japan Color conditions (70 cm-1)



(d) Color cubic

Fig. 4 Gamut reproduced by using the Japan Color conditions

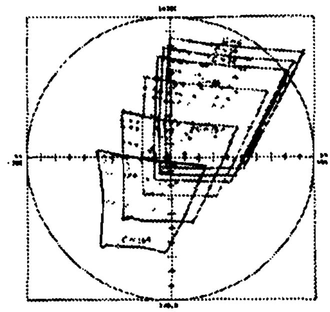


Fig. 5 Gamut reproduced by using 3 process color inks. All of data for C= constant is locates almost on a flat plane.

3.2 Colorimetric Properties of Three Color Print

When observing the distribution of measured colorimetric values of patches printed with three colors, we can find out that the measured data for C = constant value and M,Y = arbitrary values are almost on a flat plane in the L*a*b* coordinates. For M and Y, the same phenomena can be observed from Fig. 4 and Fig. 5.

The plane on which the data group of same color value are located is represented by Equation (1).

$$L^* = \alpha(C) + \beta(C)\,a^* + \gamma(C)\,b^*$$
$$L^* = \alpha(M) + \beta(M)\,a^* + \gamma(M)\,b^* \quad \cdots (1)$$
$$L^* = \alpha(Y) + \beta(Y)\,a^* + \gamma(Y)\,b^*$$

Fig. 6 shows coefficients of $\alpha(\ )$, $\beta(\ )$ and $\gamma(\ )$ for C,M and Y as the function of dot values.

These curves shown in Fig.6 (a), (b) and (c) can be approximated satisfactorily by quadratic equation of Equation (2). Coefficients a, b and c are expressed on Fig.6 (a), (b) and (c) respectively.

$$y = a\,x2 + b\,x + c \quad \cdots\cdot \quad (2)$$

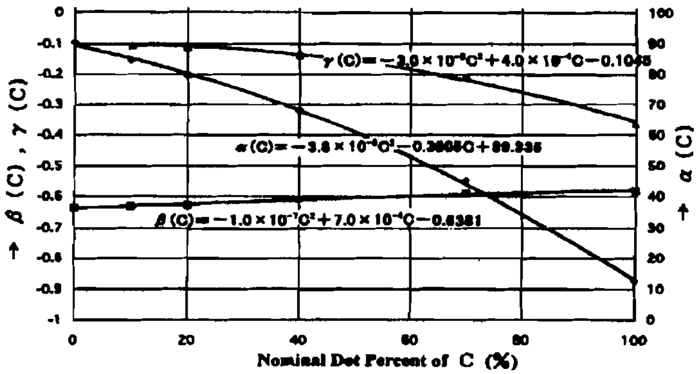
where y represents coefficient of $\alpha(\ )$, $\beta(\ )$ or $\gamma(\ )$ and x corresponds to dot values of C, M or Y.

If $\alpha(C)$, $\beta(C)$ and $\gamma(C)$ are expressed as a function of C values, then C values are related to L*a*b* values from Equation (1). The relationship for M = constant and Y = constant can be obtained as well as the case of C. For the case of proof print using the Type 1 paper, the ink percentage values of C,M and Y can be calculate from Equation (1) and Equation (3) is obtained.

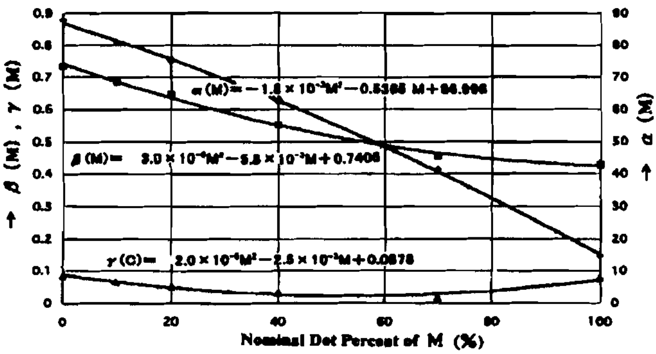
$$C= (-380500+700a^*+400b^*)+\{(-380500+700a^*+400b^*)^2-4(3800+a^*+30b^*)\times (-8.9335\times 10^7+638100a^*+104500b^*+10^6L^*)\}^{1/2}/2(3800+a^*+30b^*)$$

$$M= (53650+580a^*+250b^*)-\{(-53650-580a^*-250b^*)^2-4(-180+3a^*+2b^*)\times (8.6998\times 10^6+74080a+8780b^*-10^5 L^*)\}^{1/2}/2(-180+3a^*+2b^*)$$

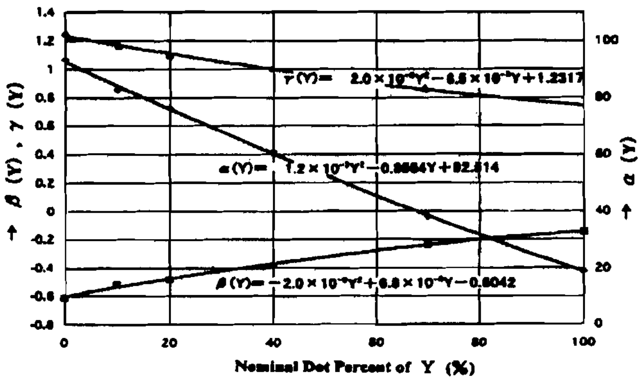
$$Y= (85840-680a^*+650+b^*)-\{(8540-680a^*+650b^*)^2-4(120-2a^*+2b^*)\times (9.2514\times 10^5-60420a^*+123170b^*+10^{5L^*})\}^{1/2}/2(120-2a+2b^*)$$



(a) Characteristics of coefficients for Cyan ink



(b) Characteristics of coefficients for Magenta ink



(c) Characteristics of coefficients for Yellow ink

Fig.6 Relationship between coefficients and nominal values of dot percent

3.3 Evaluation for Approximation

A degree of approximation of Equation (1) and (3) is investigated as follows;

(1) Color difference

By using Equation (1) the value set of (L*', a*', b*') can be predicted from coefficient values of α, β, γ for specified dot value set (C,M,Y).
The predicted value set of (L*', a*', b*') is compared with measured value set of (L*, a*, b*) and the color difference $\Delta E=[(L^*-L^{*\prime})^2+(a^*-a^{*\prime})^2+(b^*-b^{*\prime})^2]^{1/2}$ for each patch is calculated..
ΔE values for every color patches are shown in Fig.7 and the mean value of the ΔEs is less than 3.0.

(2) Approximation of dot percent values

By using Equation (3), the predicted dot values for measured values of (L*,a*, b*) corresponding to the specified CMY dot values can be obtained..
Comparison of predicted values of CMY and specified values is illustrated in Fig. 8.

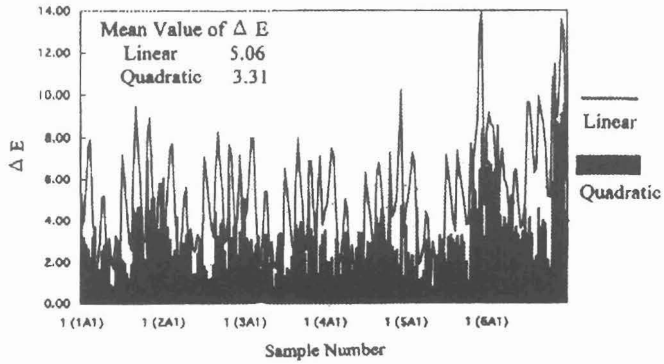


Fig.7 ΔE characteristics of print which screen ruling is 70 cm-1

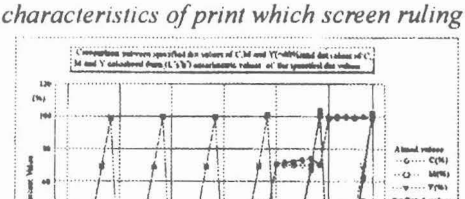


Fig.8 Comparison between specified dot percent values of C,M and Y(=40%) and values of C,M and Y calculated from (L, a*, b*) values corresponding to*

the C,M and Y(=40%) by using Equation (3).

(3) Gray balance

By assuming $a^*=0$, and $b^*=0$, then the condition of gray balance can be calculated by Equation (1) or (3) as shown in Fig. 9. In midtone, C value is 5 or 10 % larger than M or Y values as well as our experience.

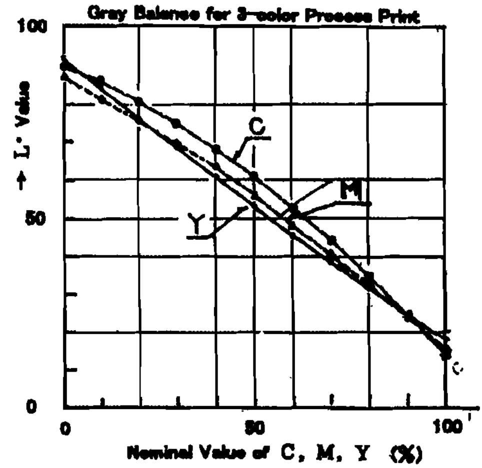


Fig.9 Relationship between dot percent values for gray balance condition

3.4 Colorimetric Properties of Four Process Color Print

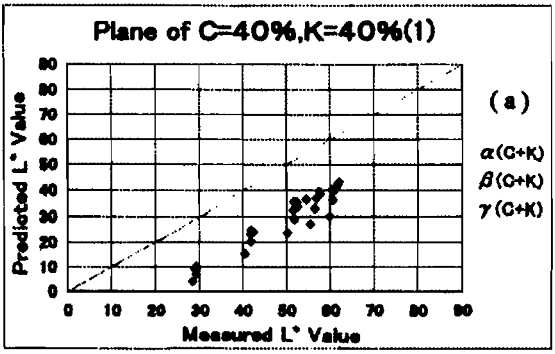
The measured colorimetric values of patches printed with four colors are located on the flat plane as same as those of three color prints. We found out that the equation of that flat plane are
approximated by Equation (4) below for C.

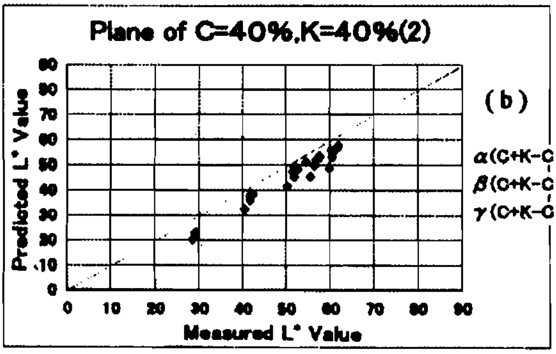
$$L^* = \alpha(C+K-Q) + \beta(C+K-Q)a^* + \gamma(C+K-Q)b^* \qquad (4)$$

where α, β and γ are same as those of Fig. 6 (a), (b) and (c), Q is correction term .
Also, the same type formula can be applied for M or Y.
As the result of observing in details, we arrive at a conclusion that the assumption of $Q=K+\delta$ is suitable to predict L^* value of patches including K.
The coefficients are converted as follows;

$$\begin{aligned} \alpha(W) &\rightarrow \alpha(W+K-W\cdot K-\delta) \\ \beta(W) &\rightarrow \beta(W+K-W\cdot K-\delta) \\ \gamma(W) &\rightarrow \gamma(W+K-W\cdot K-\delta) \end{aligned} \qquad (5)$$

where W Indicates dot values of C,M or Y.
Fig. 10 shows the approximation become better when additional value of δ is adopted. In this paper the value of dot percent means nominal value and excludes dot gain.





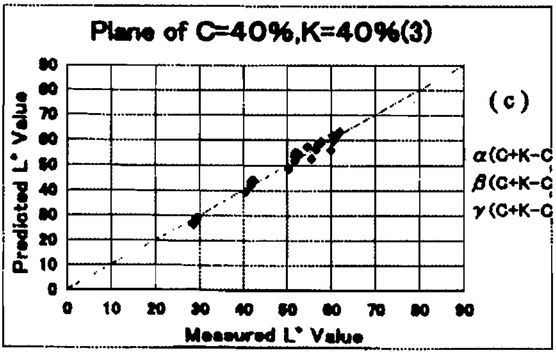


Fig. 10 Relationship between measured L value and predicted L* value calculated by Equation (4) in the case of C=40% and K=40%.*

(a) Coefficients are $\alpha(C+K)$, $\beta(C+K)$ *and* $\gamma(C+K)$

(b) Coefficients are $\alpha(C+K-C\cdot K)$, $\beta(C+K-C\cdot K)$ *and* $\gamma(C+K-C\cdot K)$

(c) Coefficients are $\alpha(C+K-C\cdot K-\delta)$, $\beta(C+K-C\cdot K-\delta)$, $\gamma(C+K-C\cdot K-\delta)$

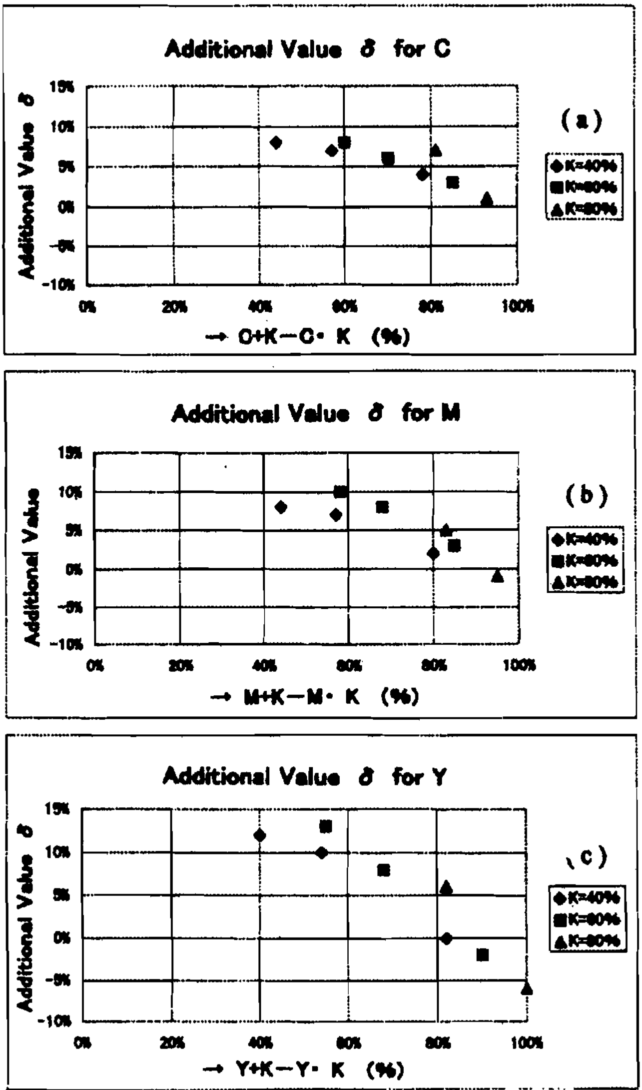


Fig. 11 Characteristics of additional value δ

(a) *Relationship between values of (C+K) and additional value of δ*

(b) *Relationship between values of (C+K —C · K) and additional value of δ*

(c) *Relationship between values of (C+K —C ·K — δ) and additional value of δ*

However, the value of δ seems to relate to the gray balance or the value of dot gain deeply.
The additional values of δ for various values of C,M,Y and K are more or less 7.0~10.0 % at the range of practical use. The value of δ seems like a value almost equal to the product of dot gain ΔK at black dot percent K and dot percent value of C,M or Y. δ values are shown in Fig. 11 (a),(b),(c) as the functions of $(C+K-C \cdot K)$, $(M+K-M \cdot K)$ and $(Y+K-Y \cdot K)$.
By using these results, a part of color components can be replaced by black ink and the influence for the color reproduction can be evaluated in advance. If a part of the color ink of W % is replaced with the black ink of K %, then the remained color ink of W' % is calculated approximately by the equation (6).

$$W' = (W - K)/(1 - K - \Delta K) \qquad (W', W: \text{ Dot value of C,M or Y}) \qquad (6)$$

where W' and W are dot values of C,M or Y, and ΔK is the dot gain of the black ink at K %.

4. Conclusion

A approximation algorithm between dot values of CMY and their CIELAB values is studied and the results have been explained. The average color difference value ΔE between measured colorimetric values and the predicted colorimetric values for various specified dot values is less than 5.0 and this value indicates that the accuracy is satisfactory.

To confirm the approximation accuracy, we produced the color output of specified dot values of CMY and that of predicted dot values of CMY with the Pictrography 3000 and compared.

As for the 4-color prints, after confirming the colorimetric values of color patches which dot values of one color and K are constant are on a flat plane, we investigated the properties of that plane. As a result, we found out the coefficients of plane of 4-color prints were equal to α(W+K-Q), β(W+K-Q) and γ(W+K-Q) where W means dot value of C,M or Y and Q means the correction factor. By using this relationship, it is possible to calculate dot values of 4-color prints when achromatic processing is performed. Test prints in which the color patches produced by 3-color process prints and 4-color process prints are aligned side by side are produced and compared subjectively. The achromatic processing is applied for the 4-color prints.

The results of subjective comparison of the prints were almost indistinguishable.

As the consequence of our studies, a lot of properties included in the characterization data could be explicated and the result would provide the basic understanding of color reproduction systems in DTP field.

The projective transformation method to covert the device independent data to CMYK values we proposed, will prepare easier way of conversion method rather than lookup table method.

Acknowledgments

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