Study on Colorimetric Planar Properties included in the Colorimetric Data of Digital Proof and its Color Space Conversion Method

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Abstract

It is found in this paper that the colorimetric values of color patches are on the same plane by testing the digital proof of ECI2002 standard target and analyzing its experimental data. The conversion from CMYK to L*a*b* is built under different K values based on mathematic statistical method and numerical analyzing method. Then the precision of these equations is verified by using $\triangle E^*_{ab}$ color difference formula and the result shows it has high precision. Finally, it is concluded that a new efficient method of building the color space conversion between L*a*b* and CMYK in digital proof using such plane theory is effective and it can provide academic and substantial evidence for color space conversion' research in color management of digital proofing.

Foreword

While different manufacturers of multicolor image processing devices and systems have developed their own color management systems and different methods have been used to carry out color spaces conversation,it is hard to realize ideal color effect during whole image processing and transmission.In 1993 international color consortium was formed by eight industry vendors，Adobe Systems Inc., Agfa-Gevaert N.V., Apple Computer, Inc., Eastman Kodak Company, FOGRA (Honorary), Microsoft Corporation, Silicon Graphics, Inc., Sun Microsystems, Inc., and Taligent, Inc，in order to create a universal color management system . These companies committed to fully support the standard in their operating systems, platforms and applications. The consortium has since been expanded and now has over 60 members[1].

Therefore,researchers have made deep research on color space conversion.In this paper the colorimetric values of color patches in the digital proof of ECI 2002 standard target are analyzing and its included colorimetric planar properties are testified. The equations of these planes under the circumstances of different K values are set up and then transform from CMYK to L*a*b* directly could be achieved.The result shows the method is effective and it can provide academic and substantial evidence for color space conversion' research in color management of digital proofing .

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1 Plane Theory[2] Introduction

Plane theory was presented by a Japanese scholar-Mitsuo Kaji in 1998,Which is that, in CMYK four color printings where the dot values of one color(e.g.C) and K are settled while the others(e.g.M and Y) are variable,lie on a flat plane.The flat planes set by means of binary linear regression can be expressed by the simple equation as following equation(1), in which X represents either dot value of C、M or Y settled, while Q is correction factor being correlative to half-tone technology.Here Q is supposed to X×K,and coefficients values of plane equation R(X+K－Q)、S(X+K－Q)、T(X+K－Q) can be approximated by quadratic functions of variable-(X+K-X×K). Their relationship is fitted by means of least square fit method[6] in mathematic statistics.Its fitted curves are as equation（2）：

$$L^* = R(X + K - Q)a^* + S(X + K - Q)b^* + T(X + K - Q) \quad (1)$$

$$R = R_{ax}(X + K - X \times K)^2 + R_{bx}(X + K - X \times K) + R_{cx}$$
$$S = S_{ax}(X + K - X \times K)^2 + S_{bx}(X + K - X \times K) + S_{cx} \quad (2)$$
$$T = T_{ax}(X + K - X \times K)^2 + T_{bx}(X + K - X \times K) + T_{cx}$$

And based on equation(1) and (2),the transform from CMYK to L*a*b* under the circumstances of different settled K values are set up as following expressions(3)：

$$L^* = [R_{ac}(C + K - C \times K)^2 + R_{bc}(C + K - C \times K) + R_{cc}]a^*$$
$$+ [S_{ac}(C + K - C \times K)^2 + S_{bc}(C + K - C \times K) + S_{cc}]b^*$$
$$+ [T_{ac}(C + K - C \times K)^2 + T_{bc}(C + K - C \times K) + T_{cc}]$$

$$L^* = [R_{am}(M + K - M \times K)^2 + R_{bm}(M + K - M \times K) + R_{cm}]a^*$$
$$+ [S_{am}(M + K - M \times K)^2 + S_{bm}(M + K - M \times K) + S_{cm}]b^*$$
$$+ [T_{am}(M + K - M \times K)^2 + T_{bm}(M + K - M \times K) + T_{cm}]$$

$$L^* = [R_{ay}(Y + K - Y \times K)^2 + R_{by}(Y + K - Y \times K) + R_{cy}]a^*$$
$$+ [S_{ay}(Y + K - Y \times K)^2 + S_{by}(Y + K - Y \times K) + S_{cy}]b^* \quad (3)$$
$$+ [T_{ay}(Y + K - Y \times K)^2 + T_{by}(Y + K - Y \times K) + T_{cy}]$$

2 Experiment Condition and Data Analyzing

2.1 Experiment Condition

Using calibrated[4] digital proofer the ECI2002 standard target[5] is output to simulate offset printing effect. Then measure L*、a*、b* values of each patches and build up matching table of CMYK values and corresponding L*、a*、b* values.The experiment condition is in table 1.

Tab.1 The Condition of Digital Proofing Experiment

Digital Proofer	Ink	Paper	Color Measuring Device	Measuring Condition
EPSON STYLUS Pro9800	EPSON ULTRO CHROME K3 Max ink:240	"Easi Color" Half glossary coated proofpaper, 140g/m²	X-Rite DTP70	Illuminant:D50 2°standard observers

2.2 Data Analysis

In digital proof of ECI2002 standard target the patches of the different combinations of one settled C,M or Y under the circumstances of K=0%,K=20%,K=40%,K=60% or K=80% are selected to built up the plane equations.And available planes' number of K=0%,K=20%,K=40%,K=60% or K=80% and settled one color is 27,18,15,15 and 12.The classified data in ECI proof is in table 2.

K20C-plane is built up as equation 4.And the same way could be used to set up each KC,KM,KY-plane.

$$L^* = [0.220(C+K-C\times K)^2 - 0.097(C+K-C\times K) - 0.617]a^*$$
$$+ [-0.092(C+K-C\times K)^2 - 0.072(C+K-C\times K) - 0.084]b^* \quad (4)$$
$$+ [-4.839(C+K-C\times K)^2 - 69.696(C+K-C\times K) + 92.981]$$

Tab.2 The Classified Dot Value in ECI2002 Proof for Modeling and Verifying

Group Number	K Dot Percentage	C、M、Y Dot Percentage	Total Patch Amount	Verifying Patch Amount	Modeling Patch Amount
1	0%	0,10,20,30,40,55,70,85,100%	9×9×9=729	9×9=81	729-81=648
2	20%	0,10,20,40,70,100%	6×6×6=216	6×6=36	216-36=180
3	40%	0,20,40,70,100%	5×5×5=125	5×5=25	125-25=100
4	60%	0,20,40,70,100%	5×5×5=125	5×5=25	125-25=100
5	80%	0,40,70,100%	4×4×4=64	4×4=16	64-16=48

3 Establishment of Transform from CMYK to L*a*b*

3.1 Colorimetric Planar Properties included in the Colorimetric Data of Digital Proof

After classifying the dot samples of settled K value and one definite color and drawing them separately in L*a*b* space by using MATLAB software it shows that these classifying dots lie on one plane.And using binary linear regression method each plane (Equation 1)forming with the sampling dots of different combination of K and C，M or Y value settled could be fitted. Further study of multiple correlation coefficient-R verifying shows the variable L*,a* and b* values have remarkable linear relation, which means there is colorimetric planar properties included in the colorimetric data of digital proof. Take plane C10K0,M20K40, Y100K80 for example,its modeling sample dots and fitted plane are shown in Figure.1.

### 3.2 Foundation of Plane Equation of Settled K Value

Analyzing each coefficient of every regressive plane of settled K and one color,such as K20C0,K20C10,K20C20,K20C40, K20C70 and K20C100 plane,quadratic of coefficients (Equation 2)of plane equation could be fitted by means of least square method as shown in Figure 2，its coefficients R_{ac},R_{bc},R_{cc}, ect are expressed as in equation 2.In this way the equations of these planes of different settled K values are set up and its expression is shown as equation 3.The coefficients of fitted quadratic can be obtained by analyzing the relationship between coefficients R,S and T of KX-settled-plane and X dot percentage.For example
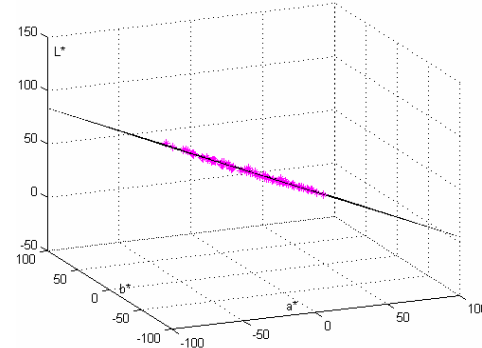
a The C10K0-plane and its Dot Samples
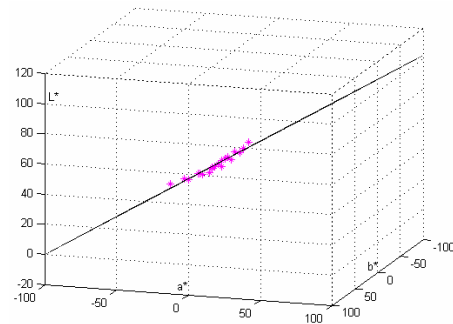
b The M20K40 and its Dot Samples
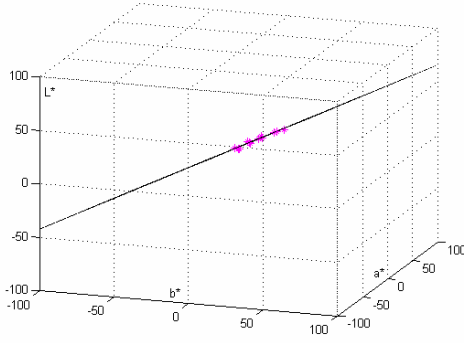
c The Y100K80 and its Dot Samples

Figure.1 *Colorimetric planar properties included in the colorimetric data of digital proof patches*
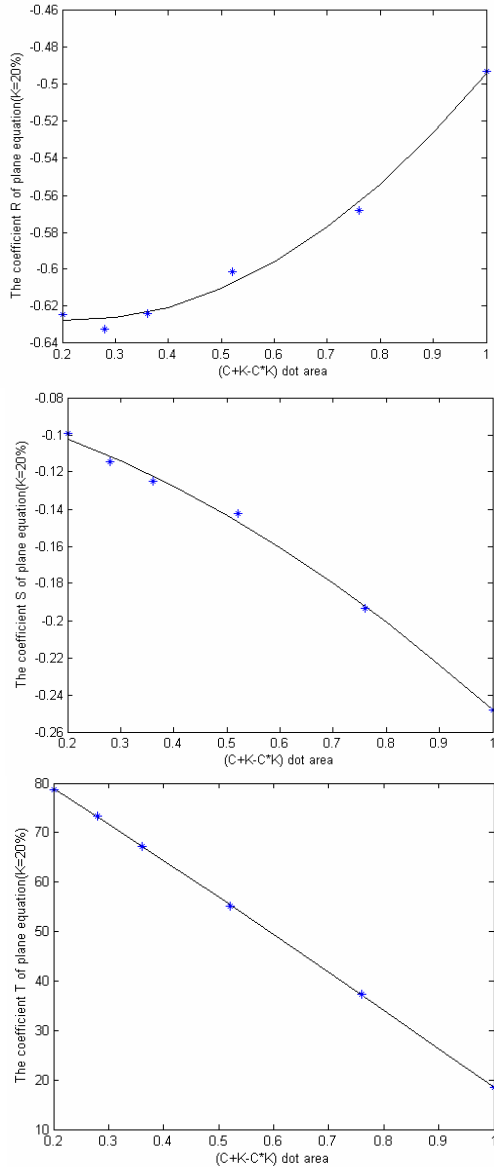

Figure.2 *Fitted quadratic curve of coefficients of plane equation*
3.3 Precision Analysis of Each K Settled Plane

Precision of the built transforms from CMYK to L*a*b* based on settled K=0%,K=20%,K=40%,K=60% and K=80% could be proofed by using verifying patch data in Tab.2 to calculate its L*', a*' and b*'.According to following $\Delta E_{ab}{}^*$ [6] deviation formula the transform precision could be analyzed and verifying result is shown in Tab.3.

$$\Delta E_{ab}{}^* = \sqrt{(L^* - L^{*'})^2 + (a^* - a^{*'})^2 + (b^* - b^{*'})^2} \qquad (5)$$

It is obvious that average chromatism of each plane equation of settled K value is less than $3\Delta E_{ab}{}^*$ unit,which means the plane equation set up has very high conversion precision.

Tab.3 The Deviation Result of Plane Equation of Settled K value

Plane Equation	least Deviation	Max Deviation	Average Deviation
K=0%	0.49	12.05	2.65
K=20%	0.47	6.90	2.75
K=40%	1.01	5.17	2.48
K=60%	0.67	3.8	1.93
K=80%	0.52	4.79	2.64

3.4 Study on Color Space Transform from CMYK to L*a*b*

Color space transform from CMYK to L*a*b* based on settled K0,K20,K40 ,K60 and K80 have been set up separately.But in practice K value in original is changed from 0% to 100%.Therefore conversion from CMYK to L*a*b* of variable K needs to build up.

By means of cubic spline interpolation method the relationship curves between each coefficient such as R_{ax}, R_{bx} ,R_{cx} ,S_{ax} ,S_{bx} ,S_{cx} , T_{ax} ,T_{bx} ,T_{bx} of corresponding transform from CMYK to L*a*b* based on K0,K20,K40, K60 and K80 and variable K are obtained . Here X represents C,M or Y color. With algorithm analysis in MATLAB software,the cubic spline curves of R_{ac}, R_{bc} ,R_{cc} , S_{ac} ,S_{bc} ,S_{cc} , T_{ac} ,T_{bc} ,T_{bc} are achieved shown in Fig.3 after running program.By the same way the relationship curves between each coefficient of corresponding KM,KY-plane and variavle K could also be got.Then establish needed KC, KM,KY-plane using the corresponding cubic spline interpolation curve expression according to the K value of each color patch to calculate its each coefficient R_{ax}, ect.For example,K10-plane equation could be list as equation 6.

$$L^* = [0.222(C + K - C \times K)^2 - 0.137(C + K - C \times K) - 0.595]a^*$$
$$+ [-0.141(C + K - C \times K)^2 + 0.009(C + K - C \times K) - 0.125]b^*$$
$$+ [-10.004(C + K - C \times K)^2 - 61.301(C + K - C \times K) + 90.783]$$
$$L^* = [0.016(M + K - M \times K)^2 - 0.446(M + K - M \times K) + 0.774]a^*$$
$$+ [0.084(M + K - M \times K)^2 - 0.045(M + K - M \times K) + 0.032]b^*$$
$$+ [28.159(M + K - M \times K)^2 - 102.512(M + K - M \times K) + 93.820]$$
$$L^* = [-0.249(Y + K - Y \times K)^2 + 0.836(Y + K - Y \times K) - 0.744]a^*$$
$$+ [0.850(Y + K - Y \times K)^2 - 2.016(Y + K - Y \times K) + 1.817]b^*$$
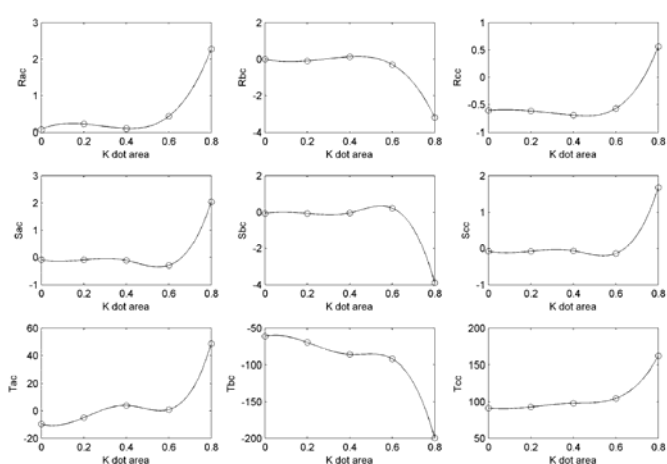$$+ [44.861(Y + K - Y \times K)^2 - 122.775(Y + K - Y \times K) + 102.213]$$

$$(6)$$

Figure.3 Cubic spline interpolation curve of K-dot area and each coefficient of KC-plane equation

So,put the C,M,Y,K value of verifying patch into calculated settled K-plane equation to work out corresponding L*,a*,b* value,then compare with measured L*,a*,b* value by usingΔE_{ab}^{*} deviation formula.And the precision of calculated settled K-plane equation can be verified.The calculated result indicates that in highlight and light area the color deviation is low,among which the least is 1.39ΔEab* unit,the max is 14.14ΔEab* unit and average color deviation is 4.37ΔEab* unit.But for the planes which settled K is more than 50%,the average color deviation are much larger than 6ΔEab* unit,which means these transform equations have low conversion precision and badly practicability.The reason mainly lies on uneven distributing of dot samples in ECI2002 target. Because of only fewer color patches of dark area are designed,there is not enough sampling numbers in dark area can be used to fit relevant cubic sline curves and these parts can hardly be accordant to practical situation.And furth research could be carried on based on more necessary sampling patches designed in digital proof.

4 Conclusion and Discussion

In this paper colorimetric planar properties included in the colorimetric data of digital proof have been testified.And based on the planar properties the color space transform from CMYK to L*a*b* has established and its precision has been verified by using 1976 CIEL*a*b* deviation formula.The research data indicate this method has academic and substantial significance for color space conversion' research in color management of digital proofing. And the further research should take GCR process and gray balance data into account or use genetic algorithm to build up converse transform from L*a*b* to CMYK.On the other hand the mechanism of colorimetric planar properties should be deeply explored.

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