

Researches on Neugebauer equation correction

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Abstract

This article analyzes several correction methods of Neugebauer equation, and put forward a new correction method that is using exponential correction method with considering the impact of dot gain. Experiments and calculations show that this new correction method can improve the accuracy of calculation of Neugebauer equation. When using to creating output profile, It can significantly improve the accuracy of output profile, and the process of calculation is simple and convenient to actualize.

1. Summary

Neugebauer equation is about printing color and based on the model of printing dot and Grassmann Laws of Color Matching. In the color management software, Neugebauer equation is the important means to create an output profile. The merit of Neugebauer equation is the principle is clear, but we discovered that in the practical application, when we straight make use of Neugebauer equation to establish the output profile, the output profile precision is very low. Therefore, many people have researched into Neugebauer equation correction, and proposed respective correction method. There are three Neugebauer equation correction methods in common use, namely: The dot gain correction, the Yule-Nielsen exponential correction and the Cellular correction. This article will analyze them one by one in the second sect. they all are able to improve the computation accuracy in a certain extent.

Assumes on the mechanism of printing color, no matter what correction method we use, we all should first eliminate the influence of dot gain, next can try to reduce the error from the value computation, moreover this kind of thought can realize in theoretically. According to this thought, This article put forward a new correction method that is using exponential correction method with considering the impact of dot gain. Experiments and calculations show that this new correction method can improve the accuracy of calculation of Neugebauer equation, moreover certainly has not caused the process of calculation complicated.

2. Neugebauer equation correction

Because of the complexity of printing color, The computed result of Neugebauer equation is impossible to be very precise, it also needs to corrected. Hereinafter three kind of correction method in common use will be introduced simply, and induces the better correction method.

2.1 The dot gain correction^[1]

The factor that influences the printing effect greatest is the dot gain; therefore, firstly we should carry on the correction to the dot gain. The actual computation indicated that the computation error is smaller in lights and light tones, but in middle tones the error is big,

its rule is consistent with the rule of the dot gain, this shows the dot gain plays an important part in the computation.

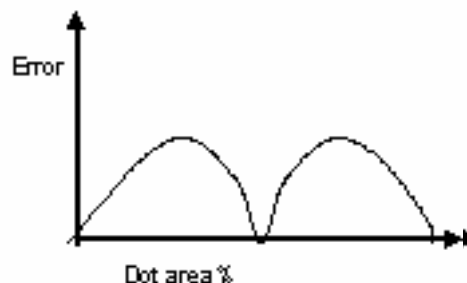


Figure1 the process of dot gain correction method

On the other hand, although the error is possibly composed by various reasons, but we can suppose Neugebauer equation is strictly tenable, other errors are caused by the dot gain. Measure each color value of the monochromatic wedges and use Neugebauer equation to compute the value of dot area coverage, and compute the difference between the measured value and predicted value, then obtains the curve of error like the chart. Take this curve of error as the value of correction.

When using Neugebauer equation to compute color, we should to correct the error according to the following method:

When computing the printing color with the known cmyk value of dot area coverage, the computed result does not contain the quantity of dot gain, when measure the printing color which are printed with the dot area coverage, the measured result contains the quantity of dot gain, therefore we should use the known cmyk value of dot area coverage plus the quantity of dot gain to compute the printing color.

When computing the cmyk value of dot area coverage with the measured value, because the measured value has already contained the quantity of dot gain, the actual value (on the plate) is equal to the result the quantity of dot gain subtracted from the computed value gives.

2.2 Yule-Nielsen exponential correction^[2]

Considering the light reflects many times in the paper interior, we increase a exponential $1/m$ in the Neugebauer equation, the equation is:

$$\begin{aligned} X^{1/m} &= \sum_{i=0}^{2^m-1} a_i \cdot X_i^{1/m} \\ Y^{1/m} &= \sum_{i=0}^{2^m-1} a_i \cdot Y_i^{1/m} \\ Z^{1/m} &= \sum_{i=0}^{2^m-1} a_i \cdot Z_i^{1/m} \end{aligned}$$

Because the value of m is related to printing material and the lines of screen and so on, generally between 1.2~3.0, moreover the value of m is usually not same in the three equations, it is actually very difficult to accurately determine, usually only can be determined through experiments or optimization methods.

2.3 Cellular correction method^[2]

This method divides the cmyk color space into certain smaller spaces, namely increases more Neugebauer primary color, for example: take the color of 50% dot area coverage as basal color. Regarding the three-color printing, when we take 50% dot as basal color, the total amount of basal colors becomes $3^3=27$, when four-color printing, the total amount of basal colors becomes $4^4=256$, the respective smaller space number is $(3-1)^3=8$ and $(3-1)^4=16$. If increases 25%, 50% and 75% three spots, then the basal color number becomes $5^3=125$ and $5^4=625$, the respective smaller space number is $(5-1)^3=64$ and $(5-1)^4=256$, the measured data increases greatly.

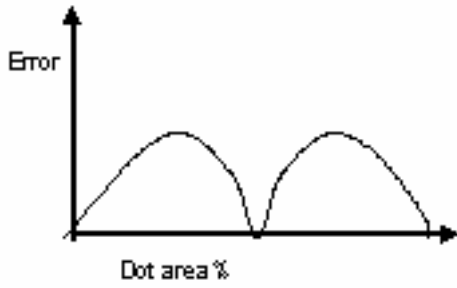


Figure 2 the process of Cellular correction method

The Cellular correction method may reduce the error in value.

3. New Neugebauer equation correction method^{[3][4]}

To explain simply, we write the correction Neugebauer equation as follows

$$\left. \begin{aligned} (X/X_0)^{1/n_x} &= \sum_{i=1}^{16} f_i U_i \\ (Y/Y_0)^{1/n_y} &= \sum_{i=1}^{16} f_i V_i \\ (Z/Z_0)^{1/n_z} &= \sum_{i=1}^{16} f_i W_i \end{aligned} \right\} \quad (1)$$

X_0, Y_0, Z_0 are the tristimulus values of printing paper under the D50 light. $U_i = (X_i/X_0)^{1/n_x}$, $V_i = (Y_i/Y_0)^{1/n_y}$, $W_i = (Z_i/Z_0)^{1/n_z}$.

New Neugebauer equation correction method is to correct the Neugebauer equation with exponential on the base of considering the quantity of dot gain, that is on the base of formula (1) to correct the CMYK with the curve of dot gain firstly, and then to match a certain number of tristimulus values of target colors with Least-square method to obtain the correction coefficient n_x, n_y, n_z and regression coefficient U_i, V_i, W_i ($i=1, 2 \dots 16$). The following is the specific process.

1) Obtain the dot gain curves

Measure the four colors printing wedges, and record the standard CMYK values and the measured CMYK values. And then obtain the dot gain cubic curves for CMYK four colors to correct the standard CMYK.

2) Obtain the regression coefficient

Assume the number of colors is N_0 , the tristimulus values of the number j color are X_j, Y_j, Z_j , and the value of dot area coverage is f_{ji} ($j=1, 2 \dots N_0, i=1, 2 \dots 16$), define the error function:

$$Q = \sum_j^{N_0} \left\{ [(X_j/X_0)^{1/n_x} - \sum_i^{16} f_{ji} U_i]^2 + [(Y_j/Y_0)^{1/n_y} - \sum_i^{16} f_{ji} V_i]^2 + [(Z_j/Z_0)^{1/n_z} - \sum_i^{16} f_{ji} W_i]^2 \right\} \quad (2)$$

In the equation, X_j, Y_j, Z_j, f_{ji} is known, so we can obtain the regression coefficient with the multiple linear regression algorithms.

3) Obtain the correction coefficient

To obtain the correction coefficient, firstly, we can scan them roughly in a certain range with certain interval $\Delta n_x, \Delta n_y, \Delta n_z$. Then n_x, n_y, n_z can have a series of values. Each group value of n_x, n_y, n_z can calculate the regression coefficient with the process 2). Then use the regression coefficient to calculate the tristimulus values with the formula (1), and calculate the error function

$$Q(n_x, n_y, n_z) = \sum_{j=1}^{N_0} [(X_j - X_j^c)^2 + (Y_j - Y_j^c)^2 + (Z_j - Z_j^c)^2]$$

X_j^c, Y_j^c, Z_j^c is the tristimulus values of colors calculated by formula (1). Then compare the error function calculated by each group value of n_x, n_y, n_z , make the n_x, n_y, n_z which can calculate the minimum Q as the first estimated value, recorded as $n_x^{(1)}, n_y^{(1)}, n_z^{(1)}$. Then we can reset the rang of n_x, n_y, n_z :

$$n_x = n_x^{(1)} - \Delta n_x^{(1)} \sim n_x^{(1)} - \Delta n_x^{(1)},$$

$$n_y = n_y^{(1)} - \Delta n_y^{(1)} \sim n_y^{(1)} - \Delta n_y^{(1)},$$

$$n_z = n_z^{(1)} - \Delta n_z^{(1)} \sim n_z^{(1)} - \Delta n_z^{(1)},$$

And scan again with smaller interval $\Delta n_x^{(2)}, \Delta n_y^{(2)}, \Delta n_z^{(2)}$. In this way, we can obtain the second estimated value of n_x, n_y, n_z , repeat the process to obtain the accurate value of n_x, n_y, n_z which can calculate the minimum Q .

the exponential correction coefficients obtained via this method is only used to correct optics error (when measure the output color bar, brought by printing ink and the scattering and absorption of light irradiated on the paper), and the mechanical error brought by the output process is considered separately, this article is to correct the mechanical error using the compensatory curve of dot gain. This method that consider the mechanical reasons and the optics reasons separately must be better than considering the two

reasons together theoretically, the experiment in this article has also confirmed this thought.

4. Experiments confirming New Neugebauer equation correction method^[3]

Because the purpose of researching on Neugebauer equation correction is to create the output profile with the corrected Neugebauer equation, the verification method is as follows

Experimental conditions: The experiment data is IT8.7/3 color bar printed by Epson4800, the measurement tool is spectroscan.

Firstly we use the general processing method and new Neugebauer correction method to obtain corresponding Neugebauer correction coefficients, and then complete the computation of transformation from CMY to $L^*a^*b^*$ color space with them separately. The purpose is to compare with the general correction method, and view with correction result can realize the color space conversion more accurately, and take this as the basis for evaluation.

Precision test method: Compute the chromatic aberration ΔE^*ab between measured $L^*a^*b^*$ and computed $L^*a^*b^*$, and count the biggest, the smallest chromatic aberration value and the quantity of them and the average chromatic aberration.

The specific steps are as follows

1) The precision test of general Neugebauer equation correcting processing method

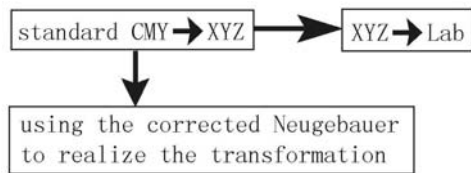


Figure3 the process of general method

The obtained correction coefficients are $n_x=2.936$, $n_y=2.100$, $n_z=1.412$. The chromatic aberration distributed situation see Table 1.

2) The experimental confirmation of New Neugebauer equation correction method

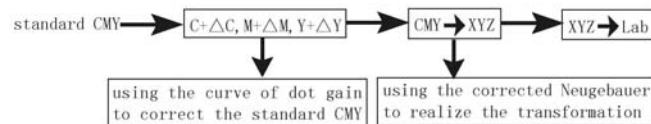


Figure 4 the process of new Neugebauer equation correction method

The obtained correction coefficients are $n_x=1.0$, $n_y=1.0$, $n_z=1.0$ ($n_x=n_y=n_z=1$ indicate the means "did not need to duplicate correction"). The chromatic aberration distributed situation see Table 1.

Table 1 chromatic aberration distributed situation

chromatic aberration distributed situation					
chromatic aberration n	0~1	1~2	2~3	3~4	Most chromatic aberration
Number (new)	27	59	39	18	14.88259
Number (general)	8	45	41	45	12.39229
chromatic aberration n	4~5	5~6	6~7	7~8	Least chromatic aberration
Number (new)	12	13	15	10	0.094591
Number (general)	37	16	11	3	0.463933
chromatic aberration n	8~9	9~10	10~11	11~12	Average chromatic aberration
Number (new)	11	6	2	0	3.627472
Number (general)	5	2	1	1	3.626982
chromatic aberration n	12~13	13~14	14~15		
Number (new)	2	1	1		
Number (general)	1	0	0		

If the x-coordinate express chromatic aberration sector, the y-coordinate express the quantity of chromatic aberration in each sector, and we may draw up the contrast situation between the general processing method and new Neugebauer correction method(to see graph 1).

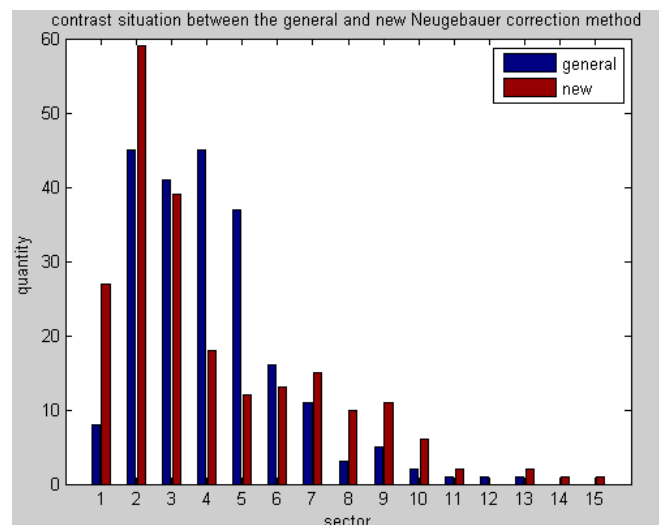


Figure 5 chromatic aberration distributed situation

See from the above graph, the result of new Neugebauer correction method is obviously more ideal than the general processing method, because the most chromatic aberrations concentrates in the 0~3 sector, moreover the bigger chromatic aberrations also are the same with the general processing method, through verifying, these corresponding color blocks of bigger chromatic aberrations is purple and coffee which are most difficult to duplicate in printing, This also certificate new Neugebauer correction method can obtain a high degree of precision in the color space transformation.

Reference:

- [1] The dot gain correction method on Neugebauer equation
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- [2] Color modelling method China printing periodical
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- [4] ICC specification Profile version 4.2.0.0