

Development of “Toner Selection”

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Abstract

This report is about the development of the software “Toner Selection”, which can help accelerate the design of toners via simulation.

It has been 44 years since the first laser printer was invented in Xerox. In the laser printing, laser beam is projected onto the electrically charged rotating drum to rip off the charges. The charged toners are then transferred to the paper by the charged part of the drum to form the image. So the color properties of the toners are important factors to the image quality.

The design and development of toners is a lengthy procedure. The toner designers are often required to develop and prepare a series of candidate toners using chemical reactions and then mix these toners with other color toners for evaluation. One or several toners will be picked out from the candidates based on the color property of the overprint.

In this report, we demonstrate a software which can help the designers to accelerate the procedure. The color properties of overprint can be predicted in this software. The color gamut formed by the new toners can be shown in 3D or 2D. The designer can even have an optimized toner spectral curve for a given tristimulus value.

1 Introduction

Neugebauer model [1] is widely used to predict the spectral reflectance of the toner overprint. In order to improve the prediction accuracy, Yule-Nielsen modified Spectral Neugebauer (YNSN) model [2, 3], which models the dot gain effect with a factor n , is applied in this software to predict the spectra of toner overprint. For further improvement of the accuracy, the wavelength dependent Yule-Nielsen factor has been applied in YNSN [4, 5]. Another option to improve the accuracy is the cellular YNSN model, which divides the colorant spaces into small cells and applies YNSN in each small cell independently [6].

YNSN is based on the spectral information of the Neugebauer primaries [2]. There are two options to estimate the Neugebauer primaries of the overprint, Kubelka-Munk equation [7] or Bala’s regression [2, 3]. In Kubelka-Munk equation, the reflectance is related with the absorption ratio and scattering ratio and the reflectance of the overprint is based on the reflectance of all the toners. In Bala’s Spectral Regression, the weighted least square regression is used for the computation of Neugebauer primaries.

This software supports a combination of methods listed above. When the simulation is done, the color gamut can be shown in the UI, either in 3D mode or in 2D mode. The toner designers can zoom in to see the details or compare the color gamut with the color gamuts of other combinations for the difference.

2 Reflectance Spectra Estimation

2.1 Neugebauer Model

Neugebauer model estimates the reflectance of the overprint by the weighted full area coverage overprints. The full area coverage overprints, either single colorant or the overprints used in the Neugebauer model are called Neugebauer primaries. Equation (1) demonstrates the Neugebauer equation:

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$$\hat{R}_\lambda = \sum_i p_i R_{\lambda i} \quad (1)$$

where \hat{R}_λ is the predicted spectral reflectance of a halftone pattern, $R_{\lambda i}$ is the spectral reflectance of a Neugebauer primary, and p_i is a scalar weight representing the probability that a point/dot on a halftone pattern is covered by the i^{th} primary color. If the placement of each toner on a page is assumed to be random, the probabilities (p_i) can be determined by the Demichel equations. Equation (2) demonstrates an example of Demichel equations for a two ink system:

$$\begin{aligned} p_1 &= (1 - a_{ink1})(1 - a_{ink2}) \\ p_2 &= a_{ink1}(1 - a_{ink2}) \\ p_3 &= (1 - a_{ink1})a_{ink2} \\ p_4 &= a_{ink1}a_{ink2} \end{aligned} \quad (2)$$

where the p_i ($i = 1, \dots, 4$) are the weights by which a point/dot of a halftone pattern is covered by a subscripted Neugebauer primaries and the a_{ink1} and a_{ink2} are areas covered by two subscripted inks. Here, the area coverage that minimizes spectral errors in the Neugebauer model can be determined empirically for particular signals that are sent to the printer (e.g., digital count).

However, the Neugebauer model can't give good results in real practice. There are many factors to be considered in the Neugebauer model so that it can generate more accurate estimation. One of the most important facts is dot gain. There are two types of dot gain when printing halftone dots – optical and mechanical. Optical dot gain is caused by light scattering and absorption in the substrate, and absorption of light on the underside of a printed dot, thereby increasing the density in those areas. The printing system also experiences mechanical dot gain, which results from the physical spread of colorant on the paper. A combination of both optical dot gain and mechanical dot gain results in a nonlinear relationship between the input digital count to the halftone function and the dot area coverage used in the Neugebauer calculation.

2.2 YNSN Model

Yule and Nielsen proposed an empirically fit exponent (n) to raise each primary's spectral reflectance of the Neugebauer model and showed that the new YNSN model can better predict the spectral reflectance of overprints caused by the complex physical

and optical interaction between the toner and paper. YNSN equation is shown in equation (3).

$$\hat{R}_\lambda = \left(\sum_i p_i R_{\lambda i, \max}^{1/n} \right)^n \quad (3)$$

p_i is the weight by which a point/dot of a halftone pattern is covered by a subscripted Neugebauer primary and calculated as above. Each Neugebauer primary reflectance is raised to $1/n$, and whole linear combination is also raised to the power of n .

Neugebauer model is essentially applied to interpolate through the entire printer gamut from a few points on its surface. Given the nonlinearities imposed by light spreading in paper and many other effects, the interpolation over this space can sometimes cause large error. One approach is to reduce the space for interpolation by providing more “primaries” inside the printer gamut. For example, by measuring each colorant at 0%, 50%, and 100% coverage, the printer gamut is subdivided into 16 smaller cells for CMYK printing system. YNSN using this approach is called Cellular YNSN model [6].

2.3 Yule Nielsen Factor Optimization

If Yule Nielsen factor n is constant for all the wavelengths, all the possible factors can be enumerated to determine the optimized value. For each n , the estimated spectral reflectance is compared with the measured spectral reflectance, then the optimal n is determined which gives the smallest color difference between the estimated and measured reflectance. Equation (4) is used to acquire the optimal n which can minimize $f(n)$.

$$f(n) = \sum_{i=1}^k dE(pred(n), meas) \quad (4)$$

Here n is in the range of (1, 100). k is the number of the color patches. dE is the color difference equation and CIEDE76 is used here. $meas$ are the measured tristimuli and $pred$ are the predicted tristimuli based on n .

Berns proposed YNSN model with multi- n which is analogous to the single n -value form [4,5,6]. Here, the factor n varies with wavelength, as shown in equation (5).

$$\hat{R}_\lambda = \left(\sum_i p_i R_{\lambda i, \max}^{1/n(\lambda)} \right)^{n(\lambda)} \quad (5)$$

Here, $n(\lambda)$ is Yule-Nielsen factor for each wavelength. Equation (6) is used to acquire the optimal $n(\lambda)$ which can minimize $f(n(\lambda))$.

$$f(n(\lambda)) = \sum_{i=1}^k (pred(n(\lambda)) - meas)^2 \quad (6)$$

Here k is the number of the color patches. $pred(n(\lambda))$ is the predicted intensity at the wavelength of λ and $meas$ is the measured intensity at the wavelength of λ .

2.4 Kubelka-Munk Theory

Kubelka and Munk found that the spectral reflectance factor is a function of the ratio of absorption coefficient, K , and scattering coefficient, S [7]. There are two steps in the Kubelka-Munk application. First, the ratio (K/S) at each wavelength is computed for each toner and paper as shown in the equation (7):

$$\left(\frac{K}{S}\right)_{\lambda} = \frac{(1-R_{\lambda})^2}{2R_{\lambda}} \quad (7)$$

For the overprints, following equation is used to sum the $\frac{K}{S}$ values for paper and for the toners:

$$\begin{aligned} \left(\frac{K}{S}\right)_{\lambda, overprint} &= \left(\frac{K}{S}\right)_{\lambda, paper} + \left(\frac{K}{S}\right)_{\lambda, toner1} + \\ &\dots + \left(\frac{K}{S}\right)_{\lambda, tonern} \end{aligned} \quad (8)$$

Finally, the reflectance of overprints Neugebauer primaries is calculated using the equation (9):

$$R_{\lambda} = 1 + \left(\frac{K}{S}\right)_{\lambda} - \left[\left(\frac{K}{S}\right)_{\lambda}^2 + 2\left(\frac{K}{S}\right)_{\lambda} \right]^{1/2} \quad (9)$$

2.5 Bala Regression

Equation (3) can be expressed in the format of equation (10):

$$R = W \cdot R_p \quad (10)$$

Here W is the matrix of p_i for all the samples. R_p is the spectral reflectance of Neugebauer primaries raised to the power of $1/n$ which is to be determined. R is the matrix of the spectral reflectance of all samples raised to the power of $1/n$. R_p can be determined via the least square method.

3 Software Development

The software is developed in managed C++. Figure 1 shows the snapshot of the software. There are three computation modes: CMYK, CMYK replacement or CMYK plus RGB. The input data source can be from

measurement or from the estimation. From measurement, all Neugebauer primaries in target charts are used while from estimation, only a part of Neugebauer primaries in target charts is used. If it is from estimation, there are two options – Kubelka Munk or Bala's Regression. From both algorithms, the user can have better feeling of estimated gamut shapes.

The user can choose to use the pantone data, as shown in Figure 2. The default pantone colors are selected so that they can be out of Gauguin or Canon gamut's boundary. The pantone data can also be manually set in the UI as shown in Figure 3 by the button "Pantone+ Custom" is clicked.

In this software, two operations have been proposed for the data – comparison and combination. Enabling compared option allows the user to compare gamuts between the reference data and the estimated data. In the comparison between the reference data and the estimated data, the user needs provide the reference chart, the target Neugebauer primaries and the target ramp data. The ramp data can be from the color measurement or based on the given equations. By checking and unchecking combined option, the user can choose the format of the target charts. In combined chart, Neugebauer primaries and ramp data are put together in a single file. On the other hand, the user can alternatively choose to use separated two files for Neugebauer primaries and ramp data.

This software provides multiple algorithm options in the computation. For example, the user can use standard YNSN or cellular YNSN, single n or multiple n , Bala's least square or inverse Murray – Davis for the data fitting. TAC value can be provided to improve the accuracy of Neugebauer primaries of the dark colors further. After all the parameters are set, the computation will start when 'Run' button is clicked.

Figure 4 shows the UI of the 3D color gamut display. "Toner Selection" supports several types of data, including standard ICC profile, measurement data from Xrite II spectrometer, color gamut data and simple plotting data file. When the computation is done, the UI will show up. In this UI, the user can zoom in/out and rotate the color gamut. Three coordinates are supported – CIELAB, CIEYUV and Xxy. The software provides settings for the user to change the appearance of the gamut, such as color, surface and opacity for a better appearance. The user can also view the 2D slicer of the color gamut by setting the hue angle or lightness as constant value. Figure 5

shows the snapshot of 2D color gamut display. At the bottom of the UI, the statistical information such as the average and maximum color difference, ratio of the volume and volume coverage will be computed and displayed.

4 Experimental Results

With the software developed, we have done some experiments to verify the performance of these computation models. A Canon imagePROGRAF iPF5100 HIFI printer is used for the evaluation. This printer can support 12 color channels. Table 1 and Table 2 show the mean of the maximal color difference and the mean of the average color difference for CMYK plus Hifi channels. From the comparison, we can see that the performance of Kubelka Munk is similar to that of Bala's Regression. When multiple Yule Nielson factors are used, the maximal color difference and average color difference both dropped. In the simulation of ramp, it will be more accurate when reference chart is used. As the computation based on reference chart is based on YNSN, this again proves the effectiveness of YNSN model. It should be more accurate than a given function. Another thing can be noted is that the color accuracy might be lower when more hifi channels are used. The computation of color difference is in CIEDE2000 [9].

Figure 6 shows the slice area of a^*b^* at different lightness. We can see that the estimated area is very close to the targeted area in the whole lightness range.

Table 1 Comparison of Maximal Color Difference and Average Color Difference based on CMYK plus 3 HIFI channels

	Mean of Max DE	Mean of Avg DE
KM	15.53	4.03
Bala's	16.47	3.87
Single n	18.47	4.47
Multi n	13.53	3.43
Reference	15.10	3.64
Generic	16.52	4.08
Power	16.74	4.31

Table 2 Comparison of Maximal Color Difference and Average Color Difference based on CMYK plus 1 HIFI channel

	Mean of Max DE	Mean of Avg DE
KM	13.86	3.80
Bala's	15.18	3.83
Single n	15.33	4.31
Multi n	13.71	3.31
Reference	14.17	3.59
Generic	14.94	3.93
Power	14.38	4.01

5 Conclusion

This report discusses the design of "Toner Selection" – the software which aims to help the toner designers. The underlying theories have been listed and experiments have been done to test the performance. From the simulation results, we can see that the performance of Kubelka-Munk is similar to Bala's Regression. Multiple Yule-Nielson factors can lower the color difference. In the computation of ramp, reference chart (YNSN) can bring better accuracy than some generic equation and the power function. With more HIFI channels applied in the simulation, the color accuracy will drop. Furthermore, from the slice area of a^*b^* at different lightness, it could be noted that estimation approximates the target well.

6 References

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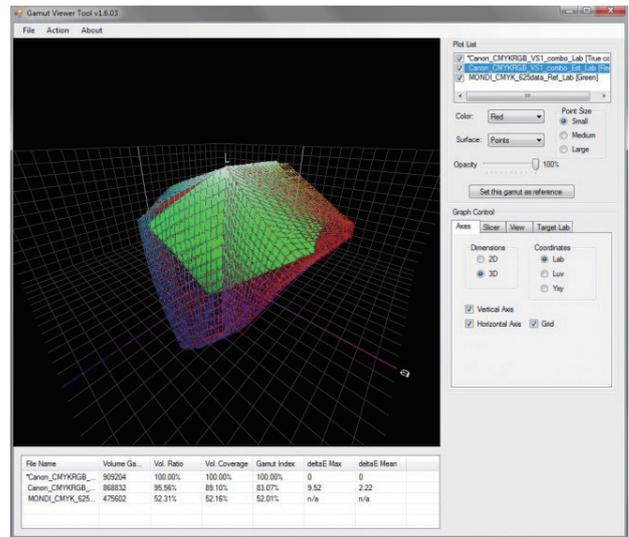


Fig. 4 Snapshot of 3D Color Gamut Display.

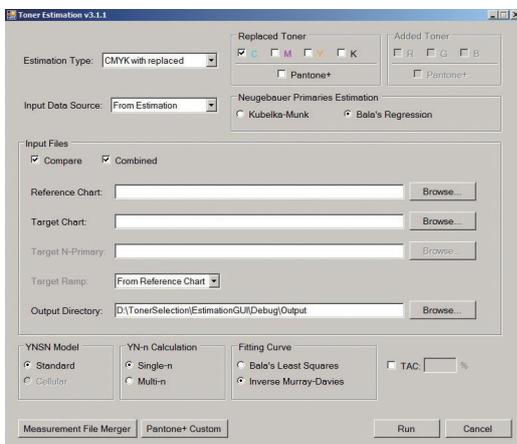


Fig. 1 Snapshot of the “Toner Selection”.

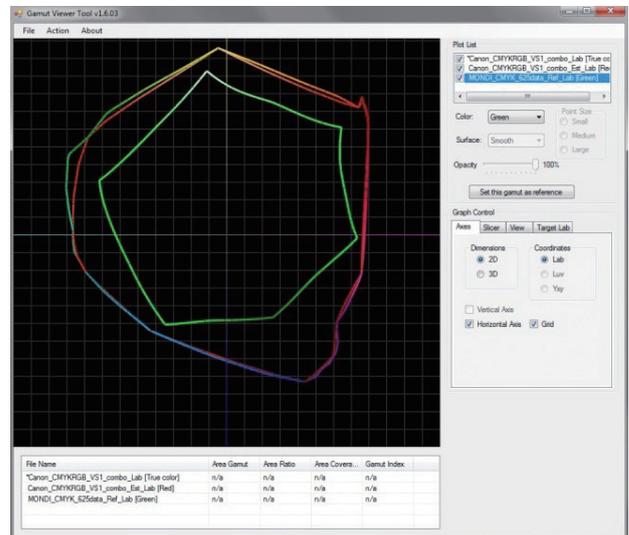


Fig. 5 Snapshot of 2D Color Gamut Display.



Fig. 2 Snapshot of the “Pantone Selection”.

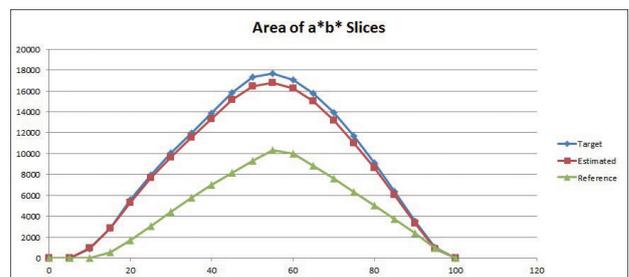


Fig. 6 Area of a*b* Slices.



Fig. 3 Snapshot of the “Pantone Color Setting”.