A New Model of Printer Characterization

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Abstract

In recent years, different methods were proposed for characterization of inkjet printers. The objective of this research is to produce output prints that are spectrally matched to original colors. The simplest model is the ideal ink or Block dye model. The physical model of the printer is generally based on the well known Yule-Nielson modified Neugebauer equation. The ink-paper interactions and the dot gain characteristics play very important roles in printer characterization and hence are studied thoroughly in this work. Moreover, the additivity characteristics of the inks are studied. In the present work, a spectral hue error correction factor has been introduced. The proposed model offers minimum color difference with input data. The correction factors for different primaries have been measured depending on the spectral characteristics of the inks and are incorporated in the equation. The output print quality has been assessed in three different printers with IT test target as well as other color patches. The suggested model with the correction factors offer better color matching with minimum ΔE_{00} in comparison with the existing Yule-Nielson modified Neugebauer equation.

Introduction

In recent years, many methods have been proposed for the characterization of inkjet printers. It involves physical description of the process to deal with mechanical and optical dot gains and the physical interaction among different inks and substrates.

In the traditional printers, the color gamut depends on the ink and substrate characteristics. The gamut can be enhanced by using high chroma inks, using a larger number of primaries or increasing the colorant density.[5]

The simplest printer model is the ideal ink or Block Dye model where the colorant amount required depends on the RGB values. But the spectral absorbance of the subtractive primaries do not correspond to this. The different models of printers are described thoroughly by Green.[5]

The physical printer models predict the relationship between reflectance and dot area. Among the models, Yule-Nielson modified Neugebauer equation predicts the reflectance of a colored halftone as a function of the fractional dot areas of the primary colorants.

The Neugebauer equation can be solved for optical densities rather than tristimulus values. The errors in the equation are smallest in solid prints of the colorant primaries and tend to be largest in neutrals.[5] The Neugebauer equation is not analytically invertible. Hence the inverse solution of the equation to predict the colorant amounts from colorimetric values is not trivial.[5] The original equations are modified to incorporate an exponential correction for light scattering using Yule-Nielson equation.

The vector corrected Neugebauer equation is basically a hybrid between modeling and a look-up table with proper interpolation. It requires a large number of measurements for prediction.

The spectral extension of the model is computationally more complex.

Imai and others[1] estimated the area coverage for CMYK inks using the transformation matrix, that was obtained by inverting the printer model. The printer model was based on the Yule-Nielson modified spectral Neugebauer equation for four color inks which is as follows:

$$R_s = \left[\sum_{I=1}^{16} f_i R_{i\,max}{}^{1/n} \right]^n \tag{1}$$

where R_s is the estimated printed spectral reflectance, n is the Yule-Nielson factor for dot gain, R_i is the spectral reflectance of the ith Neugebauer primary and f_i is the Demichel weighting of the ith Neugebauer primary which is defined by the product of the effective areas for each ink.[1] The dot area estimation in this way requires extensive measurement and complex algorithm.

Theory

The most widely used model is the ideal ink or Block dye model where the amount of cyan, magenta and yellow inks are calculated from R, G, B data:

$$C = 1\text{-}R \quad (2)$$

$$M = 1\text{-}G \quad (3)$$

$$Y = 1\text{-}B \quad (4)$$

where C, M, Y and R,G,B are normalized to unity.

These equations tell that the cyan dot area will depend only on red reflectance. Ideal cyan should absorb only red light and reflect blue and green light. But the spectral characteristics of the ink show that cyan absorbs green and blue lights as well. Similarly, magenta ink should ideally absorb only green and reflect the red and blue light. But its spectral curves show that it absorbs red and blue light. The unwanted absorption is minimum for yellow inks. It is also known that the unwanted absorptions of blue and green light are not same for cyan ink for which the colors appear to be bluish (most often) or greenish. Similarly, magenta appears reddish as its blue absorption is more than red absorption. This unwanted absorption has to be taken into account while modeling the printer. As the primary colorants are deviating from their ideal characteristics, the cyan appears bluish, magenta appears reddish and in effect all colors are deviated from the predicted colors. Considering these facts, the unwanted absorption and thus the relative color cast has to be estimated and incorporated in the model. A parameter known as spectral hue error is introduced to assess the unwanted relative absorption (or reflectance) of the inks as follows:

From the spectrophotometric curves, tristimulus values X, Y and Z, analogous to the R, G, B measurements are obtained. The trichromatatic coefficients or the CIE chromaticity coordinates may be calculated from tristimulus values.[3]

$$x = X/(X+Y+Z) \quad (5)$$

$$y = Y/(X+Y+Z) \quad (6)$$

$$z = Z/(X+Y+Z) \quad (7)$$

The advantage of the CIE is that the data correlate well with visual match.

The spectral hue error is defined as follows:

$$HR_c = \frac{y_c - x_c}{z_c - x_c} \quad (8)$$

$$HR_m = \frac{z_m - y_m}{x_m - y_m} \quad (9)$$

$$HR_y = \frac{x_y - z_y}{y_y - z_y} \quad (10)$$

The hue errors depend on the spectral characteristics of ink. Moreover, it varies with dot area also. As the dot area decreases from shadow to highlights, its spectral characteristics continues to change because of the effect of the spectral characteristics of the substrate. Hence the HR parameters in equations (8) – (10) are not constant but vary with dot areas.

The result of this hue error is the unwanted increase in the optical density of the output and reduction in the reflectance values of the output. Besides this, the physical and mechanical dot gain also increases the density and effectively reduces the reflectance. It results in images of lower brightness and chroma.

Hence it is necessary to reduce the print dot area so that it can increase the reflectance. The proposed model considers the unwanted absorption of the basic three subtractive primaries where the unwanted absorption is expressed in terms of the spectral hue error. According to the model,

$$C=1-(1+HR_c)*R \quad (11)$$

$$M=1-(1+HR_m)*G \quad (12)$$

$$Y=1-(1+HR_y)*B \quad (13)$$

Experiment

A CMYK test target IT 8.7/3 was printed to evaluate the printer characteristics. Some more neutral patches were taken beside the target for verifying the model in three different printers HP930C, Epson Color 640C and HP PSC500. The results are taken on plain paper as well as on photo quality paper. The dot gain characteristics have been studied for both papers and taken in account. The prints are taken with C, M, Y predicted from the equation disabling color management and enhancement.

The characterisation was started with the printing of the Neugebauer primaries by printing inks at full coverage and their overprints.

Prints are also taken with existing color management with perceptual rendering intent with no gray component replacement. Both the spectrophotometric and densitometric analysis have been done on the prints.

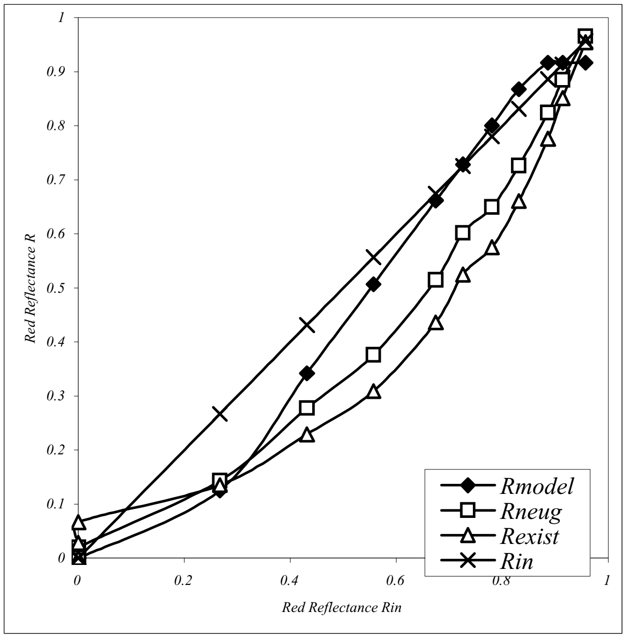

Figure 1. Reflectance of cyan ink

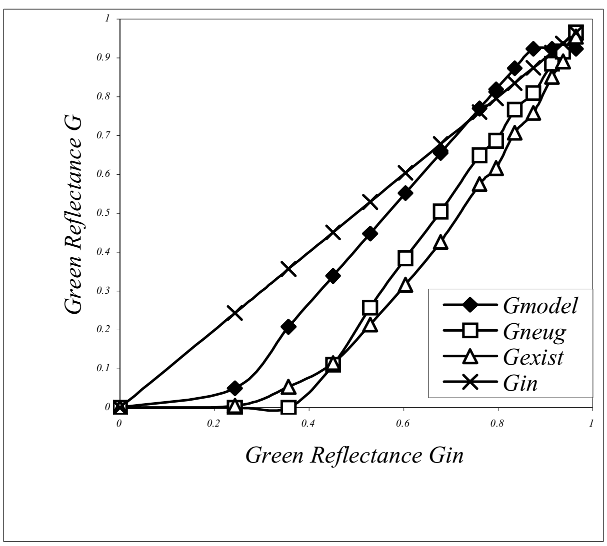

Figure 2. Reflectance of Magenta Ink

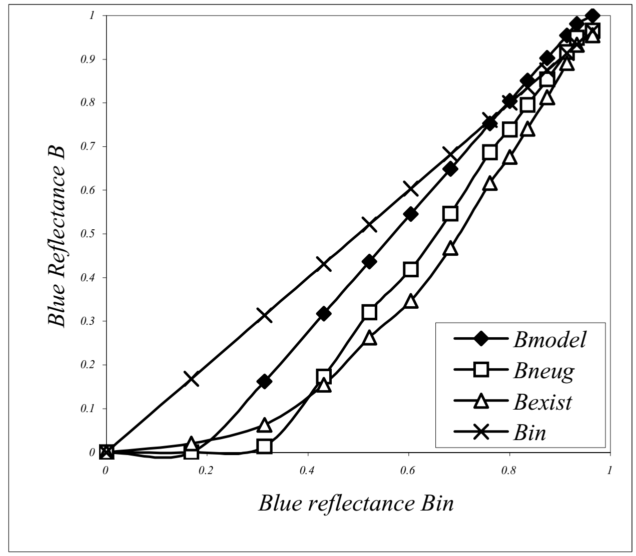

Figure 3. Reflectance of yellow ink

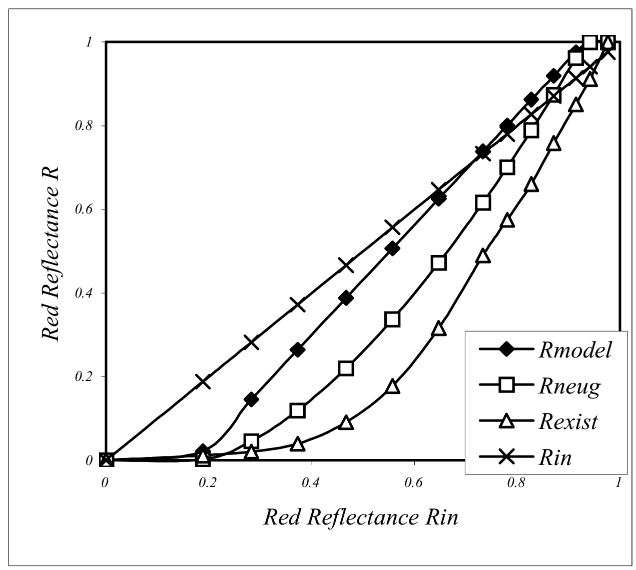

Figure 4. Red Reflectance of three-color overprints

GretagMacbeth Spectrolino Spectrophotometer and reflection densitometer were used for the measurements. The wavelengths of the spectra were taken throughout the visible range from 400 nm to 700 nm wavelength.

Results and Discussion

Figures 1, 2 and 3 show the red, green and blue reflectance of cyan, magenta and yellow inks. The RGB values of the prints as predicted by the suggested model are compared to the RGB values obtained using existing color management and Yule-Nielson modified Neugebauer equation.

The results show that the reflectance predicted by the proposed model comes closest to the input reflectance. The model deviates more in shadow region. In the midtones and highlights, the model predicts reflectance closer to the input values.

Figures 4, 5 and 6 show the red reflectance, green reflectance and blue reflectance of C, M, Y combinations against the RGB values of the input. It has been observed that the reflectance as per the predicted model offers better match with the input values. It coincides with the values obtained from Yule-Nielson modified Neugebauer equation in the highlights. The average color differences CIE ΔE_{00}

between the model and the input values is found as 1.41 for HP930C printer with photoquality paper. The ΔE_{00} value for Yule-Nielson modified Neugebauer equation is 1.5 and with available CMS is 2.16 with the same paper and printer. It has been found that the color difference is slightly better in the proposed model than Yule-Nielson modified Neugebauer equation.

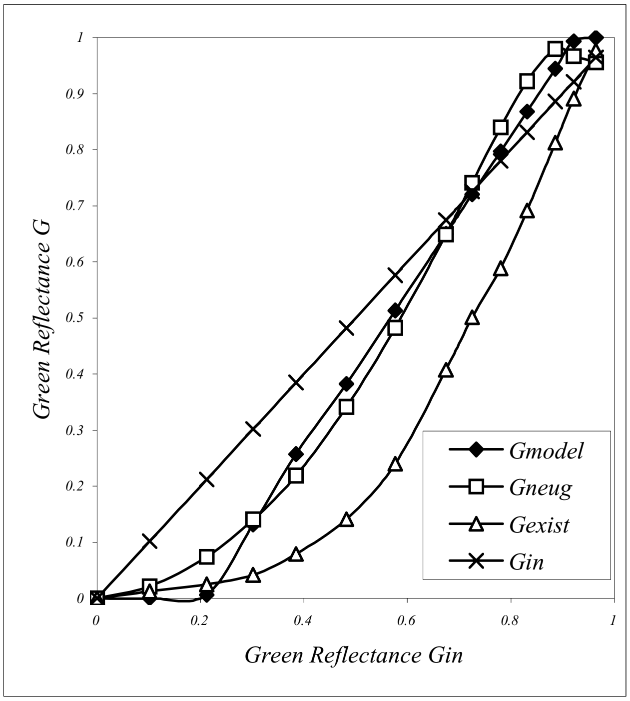

Figure 5. Green Reflectance of three-color overprints

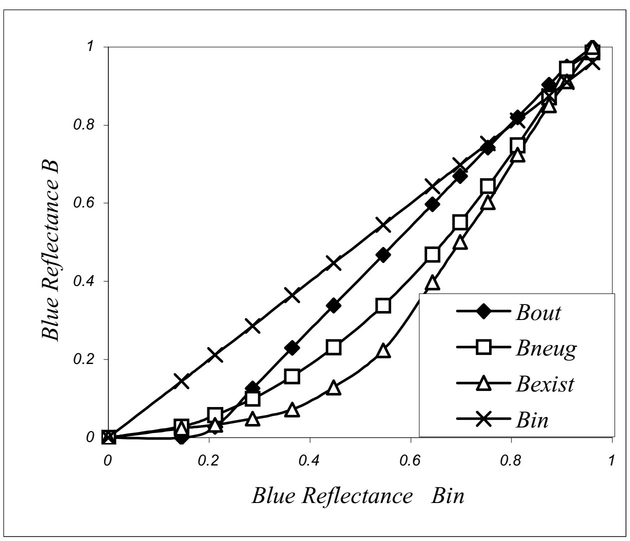

Figure 6. Blue Reflectance of three-color overprints

Conclusion

The objective of the work is to study the feasibility to suggest a simple model of printer characterization that are spectrally matched to original colors. The proposed model offers better match of the output print with the input. The effect of black printer may be studied further to reduce the color difference.

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Biography

Dr. Swati Bandyopadhyay received her B.E. degree in Chemical Engineering from Jadavpur University at Kolkata, India in 1987 and Ph. D. (Engg.) from the same University in 1995. Since 1990, she has worked as a lecturer of Printing Engineering Department in Jadavpur University. Now, she is working as Reader of the department. Her work is primarily focused on image quality of ink jet printer and color theories. She is a member of IS&T and IIChE.