

Advanced Cellular YNSN Printer Model

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Abstract

An advanced cellular YNSN (Yule-Nielsen modified spectral Neugebauer) model is proposed in this paper. This new model is modified from the YNSN model and the cellular Neugebauer model to get more accuracy. There are two important concepts in the advanced cellular YNSN model. First, the entire CMY (cyan, magenta, yellow) color space is partitioned into 27 small subcells to improve the correlation between output colors and input signal. Second, the YNSN equation is modified by using a wavelength dependent function $A_i(\lambda)$ instead of a wavelength independent function A_i used in the conventional YNSN model. In our experiments, 1134 patches were used to test the accuracy of our advanced cellular YNSN model and the conventional YNSN model, and we found that the average error of our advanced cellular YNSN model is $3.3 \Delta E_{ab}$, which is more accurate than that of conventional YNSN model, $4.98 \Delta E_{ab}$.

1. Introduction

Halftone technique is widely used in color printing. It develops colors by judiciously arranging three or more colors. To print color correctly, there must be an arithmetic model between the input primary colors and the reflectance of its output halftone colors. A well-known YNSN model [1-3] shows that the reflectance of a halftone color is a summation of that of primary colors weighted by their corresponding fraction area; that is:

$$R(\lambda)^m = \sum A_i R_i(\lambda)^m \quad (1)$$

where $R_i(\lambda)$: reflectance of primary colors.

A_i : fraction area of primary colors.

m : Yule-Nielsen correction factor.

The correction factor m is used to compensate the lateral scattering of light within paper substrate, but the scattering effect of different wavelength is not considered in this model.

Another model is cellular Neugebauer model [4] which partitions the CMY color space into rectangular subcell

and employs the Neugebauer equation within each subcell. The advantage is that partitioned subcell can improve the correlation between output colors and input signal. But the light scattering effect within paper substrate is not compensated in this model. So the accuracy of cellular Neugebauer model will be limited.

2. Advanced Cellular YNSN Model

The advanced cellular YNSN model corrects the defects discussed in the previous section to improve the accuracy of the printer model.

First, the axis of CMY color space are partitioned into three sections at 0, 85, 170 and 255 to produce $3 \times 3 \times 3 = 27$ subcells as shown in Figure (1).

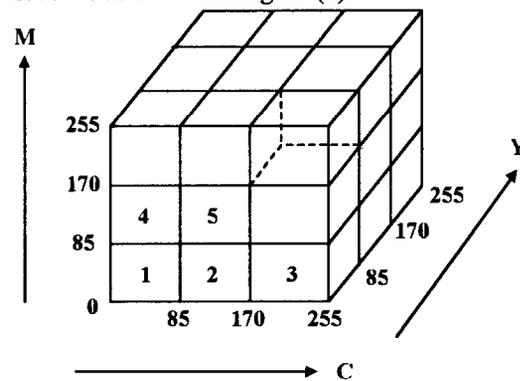


Figure (1). partitioned CMY color space

Then, the YNSN equation is modified to predict the reflectance of color in each subcell as shown in equation (2):

$$R(\lambda) = A_w(\lambda)R_w(\lambda) + A_c(\lambda)R_c(\lambda) + A_m(\lambda)R_m(\lambda) + \dots + A_{c+m+y}(\lambda)R_{c+m+y}(\lambda) \quad (2)$$

where $A_i(\lambda)$ is the fraction area of primary colors, $R_i(\lambda)$ is the reflectance of primary colors in each subcell. $\lambda = 400, 410, \dots, 700$ nm at 10 nm interval, $A_i(\lambda)$ is obtained by Demichel dot overlap equation:

$$A_w(\lambda) = (1 - a_c(\lambda)) \times (1 - a_m(\lambda)) \times (1 - a_y(\lambda))$$

$$A_c(\lambda) = a_c(\lambda) \times (1 - a_m(\lambda)) \times (1 - a_y(\lambda))$$

$$A_{c,m,y}(\lambda) = a_c(\lambda) \times a_m(\lambda) \times a_y(\lambda) \quad (3)$$

$$a_c(\lambda) = \frac{(1 - 10^{-D_c(\lambda)/yn(\lambda)})}{(1 - 10^{-D_{ic}(\lambda)/yn(\lambda)})}$$

$$a_m(\lambda) = \frac{(1 - 10^{-D_m(\lambda)/yn(\lambda)})}{(1 - 10^{-D_{im}(\lambda)/yn(\lambda)})}$$

$$a_y(\lambda) = \frac{(1 - 10^{-D_y(\lambda)/yn(\lambda)})}{(1 - 10^{-D_{iy}(\lambda)/yn(\lambda)})} \quad (4)$$

where $D_c(\lambda)$, $D_m(\lambda)$, and $D_y(\lambda)$ are the OD (optical density) values of the input colors at different wavelength. $D_{ic}(\lambda)$, $D_{im}(\lambda)$, and $D_{iy}(\lambda)$ are the OD values of solid colors of each subcell at different wavelength and dependent on the position of the subcell in the CMY color space. Since different wavelength of light in visual region has different scattering effect within the paper substrate, the Yule-Nielsen correction factor needs to be a wavelength dependent function $yn(\lambda)$ instead of a wavelength independent function yn used in the conventional YNSN model.

A series of methods are introduced in the following sections to get the reflectance of primary color in equation (2) and OD values and Yule-Nielsen correction factor in equation (4).

2.1 Method to get $D_{ic}(\lambda)$, $D_{im}(\lambda)$ and $D_{iy}(\lambda)$

Step 1. Print 33 patches with different gray levels for cyan, magenta and yellow respectively. The printed colors are as below:

(C, M, Y) = (0,0,0), (8,0,0), (16,0,0), ..., (255,0,0).

(C, M, Y) = (0,0,0), (0,8,0), (0,16,0), ..., (0,255,0).

(C, M, Y) = (0,0,0), (0,0,8), (0,0,16), ..., (0,0,255).

Step 2. Measure the reflectance of printed patches by color meter. Then use equation $D(\lambda) = -\log R(\lambda)$ to build a look up table as shown in Table 1:

Table 1: data structure of $D_{ic}(\lambda)$

gray	OD(λ) (optical density)			
0	$D_0(400)$	$D_0(410)$	...	$D_0(700)$
8	$D_8(400)$	$D_8(410)$	...	$D_8(700)$
16	$D_{16}(400)$	$D_{16}(410)$	...	$D_{16}(700)$
⋮	⋮	⋮	⋮	⋮
255	$D_{255}(400)$	$D_{255}(410)$	...	$D_{255}(700)$

$D_m(\lambda)$ and $D_y(\lambda)$ have the same data structure as $D_c(\lambda)$.

Step 3. Based on Table 1, we can get $D_{ic}(\lambda)$, $D_{im}(\lambda)$ and $D_{iy}(\lambda)$ of any CMY color levels at different wavelength of light using interpolation method. For example, the OD value of a cyan color located between 8 and 16, is

$$D_{ic}(\lambda) = \frac{16-C}{8} D_8(\lambda) + \frac{C-8}{8} D_{16}(\lambda)$$

2.2 method to get $D_{ic}(\lambda)$, $D_{im}(\lambda)$ and $D_{iy}(\lambda)$

Step 1. Find the CMY value at 8 vertexes of subcell. For example, the CMY value at 8 vertexes of subcell indicated by number 5 in Figure (1) are shown as follow:

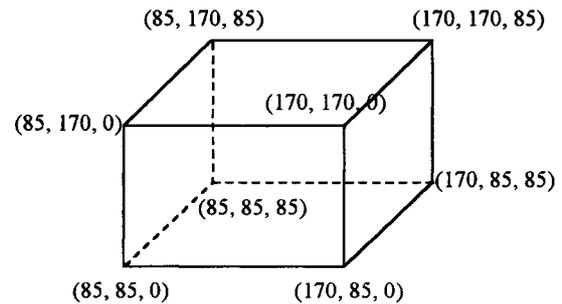


Figure (2). CMY value at 8 vertexes of subcell indicated by number 5 in Figure (1).

Print out these patches and measure their OD value.

Step 2. Compute the OD value of $D_{ic}(\lambda)$, $D_{im}(\lambda)$ and $D_{iy}(\lambda)$. For the same example in Step 1, $D_{ic}(\lambda)$ is the OD difference between (170,85,0) and (85,85,0), $D_{im}(\lambda)$ is the OD difference between (85,170,0) and (85,85,0), $D_{iy}(\lambda)$ is the OD difference between (85,85,85) and (85,85,0).

2.3 Method to get the reflectance of primary color

Step 1. Print color patches using the CMY value at 8 vertexes of each subcell. For example, the color patches printed from Figure (2) are: (85, 85, 0), (170, 85, 0), (170, 85, 85), (85, 85, 85), (85, 170, 0), (170, 170, 0), (170, 170, 85) and (85, 170, 85).

Step 2. Measure the reflectance of printed patches by color meter.

2.4 method to get $y_n(\lambda)$

Step 1. Design test patches uniformly distributed in each subcell. For example, the test patches of subcell indicated by number 5 in Figure (1), are marked by '#' as shown in Figure (3).

Step 2. Print test patches and measure the reflectance of each patches by color meter. Record these measured value in Table 2.

3. Experimental Result

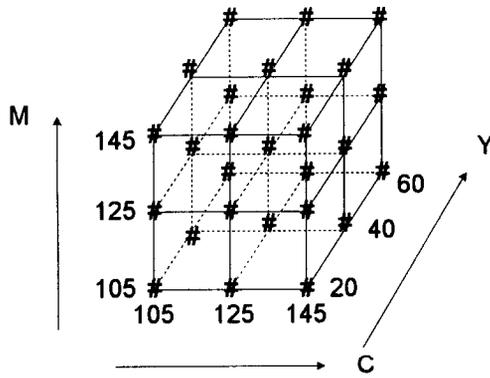


Figure (3). test patches of subcell indicated by number 5 in Figure(1) are marked by '#'

To compare the accuracy of our advanced YNSN model with that of conventional YNSN model, we use the Fargo PrimeraPro as experiment printer. 1134 patches are printed by this Fargo printer. The Lab value of these printed samples are measured by data color sensor at D_{65} light source and 10° view angle condition. The CMY value of these 1134 patches are inputted to our advanced YNSN model and the conventional YNSN model to predict the output Lab of these patches respectively. Then the error between the measured and predicted data of these two models are computed as shown in Table 3. From these experimental results, we found that the maximum error of the advanced YNSN model is $14 \Delta E_{ab}$ which is smaller than that of conventional YNSN model, $20 \Delta E_{ab}$. And, the average error of our advanced YNSN model is $3.3 \Delta E_{ab}$ which is smaller than that of conventional YNSN model, $4.98 \Delta E_{ab}$. Based on the above discussion, we can conclude that the advanced YNSN model is more accurate than the conventional YNSN model.

Step 3. Give an initial value $yn(\lambda)$ for the advanced YNSN model to compute reflectance. Then, choose the $yn(\lambda)$ which has the minimum average error between measured and computed reflectance to be the optimum $yn(\lambda)$.

Table 2: data for computing optimum $yn(\lambda)$

mea.			comp.			opti.
1	...	27	1	...	27	$yn(\lambda)$
$R(400)$	...	$R(400)$	$R(400)$	...	$R(400)$	$yn(400)$
$R(410)$	...	$R(410)$	$R(410)$	...	$R(410)$	$yn(410)$
:	...	:	:	...	:	:
$R(700)$	...	$R(700)$	$R(700)$	...	$R(700)$	$yn(700)$

Table 3: ΔE_{ab} of test patches

ΔE_{ab}	Advanced YNSN	YNSN
1	75	29
2	265	146
3	241	222
4	204	149
5	129	125
6	102	97
7	50	108
8	28	91
9	21	54
10	7	30
11	5	18
12	5	13
13	1	14
14	1	15
15	0	7
16	0	5
17	0	4
18	0	4
19	0	1
20	0	2

Step 4. Repeat Step 1 to Step 3 to find optimum $yn(\lambda)$ in all subcells.

These steps are summarized in Figure (4). Until now all the parameters in the advanced YNSN model are completed.

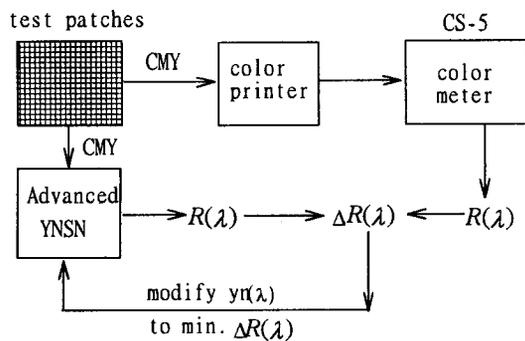


Figure (4). procedures for computing optimum $yn(\lambda)$

4. Conclusion

Color printer is widely used to reproduce color image from input device, for example scanner and digital camera. Because these input/output device have different gamut region, if we want to have the output image which look like the original image, there must be an arithmetic model of color printer to print color correctly.

In the halftone technology, we improve the accuracy of a printer model, but there is space to improve the accuracy of a printer model. For example, we can further partition the subcell which have larger error in computing optimum $yn(\lambda)$ into smaller subcell, but this will make us to pay more cost.

References

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