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Kubelka-Munk theory for efficient spectral printer modeling

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ABSTRACT

In the context of spectral color image reproduction by multi-channel inkjet printing a key challenge is to accurately model the colorimetric and spectral behavior of the printer. A common approach for this modeling is to assume that the resulting spectral reflectance of a certain ink combination can be modeled as a convex combination of the so-called Neugebauer Primaries (NPs); this is known as the Neugebauer Model. Several extensions of this model exist, such as the Yule-Nielsen Modified Spectral Neugebauer (YNSN) model. However, as the number of primaries increases, the number of NPs increases exponentially; this poses a practical problem for multi-channel spectral reproduction.

In this work, the well known Kubelka-Munk theory is used to estimate the spectral reflectances of the Neugebauer Primaries instead of printing and measuring them, and subsequently we use these estimated NPs as the basis of our printer modeling. We have evaluated this approach experimentally on several different paper types and on the HP Deskjet 1220C CMYK inkjet printer and the Xerox Phaser 7760 CMYK laser printer, using both the conventional spectral Neugebauer model and the YNSN model. We have also investigated a hybrid model with mixed NPs, half measured and half estimated.

Using this approach we find that we achieve not only cheap and less time consuming model establishment, but also, somewhat unexpectedly, improved model precision over the models using the real measurements of the NPs.

Keywords: Spectral color reproduction, Spectral printer modeling, Kubelka-Munk theory, reflectance estimation.

1. INTRODUCTION

High-fidelity color image reproduction is one of the key issues for different industries these days. For this purpose, spectral color image reproduction is considerably effective [3, 4, 9, 16, 19]. It enables to obtain the spectral reflectance, to greatly improve the colorimetric accuracy, and to reproduce colors faithfully under different illuminations.

It is well known that printing devices with three chromatic colorants are able to reproduce colors which are spectrally different but appear identical to the original one, within the limitations of the device color gamut. This is due to the phenomenon called metamerism, in which two objects having different spectral power distribution match in color under a given illumination. Unfortunately, such conventional printers have some serious limitations. These include the fact that the metamerism generally breaks down when the viewing illuminant changes, resulting in objectionable color mismatches. Spectral color reproduction will be a good remedy for this problem. In it we aim to reproduce a color as defined by its spectral reflectance instead of by trichromatic values. This will increase the color fidelity quality of the reproduction under different illumination conditions and gives higher color accuracy.

Spectral color image reproduction is very wide and complicated problem [3]. In this paper we only consider the problem of spectral printer modeling, particularly, on the use of the Kubelka-Munk model [2, 6, 8, 10, 11] for estimating the Neugebauer Primaries and using these with Spectral Neugebauer (SN) model [1, 3, 7, 12, 15, 18, 21] and the Yule-Nielsen modified Spectral Neugebauer (YNSN) model [13, 22, 23, 24] for spectral printer modeling.

For the sake of establishing the SN and YNSN models we need to print and measure patches of Neugebauer Primaries (NPs). One of the problems with this approach is that the number of patches we need to print increases exponentially with the number of colorants of the printer. This is because of the number of possible combination of n colorants is given by 2^n. For a spectral printer with more than 4 or 5 colorants, printing all those NPs and measuring them will consume a large amount of time and materials. The process of finding and printing NPs for such spectral printers also is not an easy job. There might be some charts which include all NPs of CMYK printers. What if we want to model printer with higher number of channels, for example for a spectral printer with 12 colorants? There are no charts which actually incorporates

NPs of such spectral printers. In this case we are forced to have the SDK of the printer and find out some way to be able to control the printer to print any ink combination desired. We find this process as very burdensome and tedious work.

In this paper we present our solutions for the above problems. We print only the primary colorants and estimate the rest of the reflectances of the NPs using the simple Kubelka-Munk theory. We have also investigated a hybrid model with mixed NPs, half measured and half estimated. We have experimentally tested our approach on different types of papers and for two types of printers. We finally present the types of papers and the process of measurements which will lead us to a good and accurate estimation of NPs for high-quality spectral printer modeling.

First, in Section 2, we describe the well known spectral printer models and the proposed printer models, while our experimental set up followed by our experimental results are presented in Section 4.. Finally in (Section 5), our conclusion and directions for further researches will be given.

2. SPECTRAL PRINTER MODELS

2.1 Murray Davies Model

The Murray Davies equation is used to predict the reflectance of a given colorant with a given area coverage and it is given as follows.

$$r(\lambda) = (1 - c)r_{paper}(\lambda) + cr_{maxcol}(\lambda), \tag{1}$$

where $r_{paper}(\lambda)$, $r_{maxcol}(\lambda)$, c, and $r(\lambda)$ are the paper measured spectral reflectance, the measured spectral reflectance of the paper covered by the colorant at maximum coverage(100%), given colorant coverage and the predicted spectral reflectance, respectively.

The Murray Davies model, which predicts the reflectance of a single colorant coverage, will not be enough for printer characterization of more than one ink because of the overlapping of different colorant droplets by the time of printing process. It will be very important to estimate all the different colorant overlaps in addition to estimating each colorants independently. For a good estimation of colorant combination, it should include all NPs (the Neugebauer primaries) which are reflectances of all colorants of the printer, all possible combinations of them and reflectance of the paper.

2.2 Spectral Neugebauer Model (SN)

The Neugebauer model is the extension of Murray-Davis model which could handle all the above mentioned issues. In this model the estimated reflectance r can be written as the convex combination of n *measured* reflectances of NPs r_i; i=1 . . . n:

$$r(\lambda) = \sum_{t=0}^{2^m-1} w_t r_{imax}(\lambda) \tag{2}$$

while

$$w_t \epsilon [0,1] \; and \; \sum_{t=0}^{2^m-1} w_t = 1$$

where w_i is the area coverage of the i^{th} primaries.

2.3 The Yule-Nielsen Modified Spectral Neugebauer Model (YNSN)

This model incorporates everything which is in Spectral Neugebauer model but this model also tries to incorporate the optical dot gain effect. This is done by adding Yules-Nielsen n factor to the previous Neugebauer model as follows:

$$r^{1/n}(\lambda) = \sum_{t=0}^{2^m-1} w_t r_{tmax}^{1/n}(\lambda) \tag{3}$$

To find the n factor, we can use methods with an iterative process which estimates the spectral reflectances for various n factor values. Then by comparing the estimated spectral reflectances with the measured spectral reflectances, we can choose the *n* value which gives the smallest colorimetric differences or smallest spectral difference.

2.4 Kubelka-Munk theory and K/S

The Kubelka-Munk equation [6,26] defines a relationship between spectral reflectances of the sample and its absorption and scattering characteristics of the samples with Opacities greater than 75% using the equation:

$$\frac{K(\lambda)}{S(\lambda)} = \frac{(1 - 0.01R(\lambda))^2}{2(0.01R(\lambda))} \tag{4}$$

where R is the reflectance given in percent (%) and K and S are the absorption and scattering coefficients of the colorant.

These ratios for individual colorants are then stored and can be used for computing the K/S ratio of the mixture in which these colorants are used. This can be done just by extending the above Kubelka-Munk theory. K/S of the mixture is given by the sum of the K/S values of the individual colorants.

$$\left(\frac{K(\lambda)}{S(\lambda)}\right)_{mixture} = a\left(\frac{K(\lambda)}{S(\lambda)}\right)_{colorant1} + b\left(\frac{K(\lambda)}{S(\lambda)}\right)_{colorant2} + \ldots + \left(\frac{K(\lambda)}{S(\lambda)}\right)_{paper} \tag{5}$$

where *a,b,c,* ... are the concentration of the colorants in the mixture.

Ones one has *K/S* for all colorants and their combinations, he/she can compute the reflectance of the primaries and their combinations as follows.

$$R_\infty(\lambda) = 1 + \frac{K(\lambda)}{S(\lambda)} - \sqrt{\left(\frac{K(\lambda)}{S(\lambda)}\right)^2 + 2\frac{K(\lambda)}{S(\lambda)}} \tag{6}$$

And, for its simplicity and its ease of use, we prefer to use this method as our main algorithm for predicting NPs for spectral printer modeling.

2.5 KM plus Spectral Neugebauer Model (KM-SN)

This model is the same as Spectral Neugebauer model in which the estimated reflectance r can be written as the convex combination of n reflectances of NPs r_i; i=1 . . . n. (Equation 2). The only difference between them is that in place of measured reflectances of NPs here we used KM estimated reflectances (section 2.1.4) of NPs.

2.6 KM plus Yule-Nielsen Modified Spectral Neugebauer Model (KM-YNSN)

This model is also the same as YNSN model which includes everything in Spectral Neugebauer model and Yules-Nielsen n factor for taking care of optical dot gain effect (Equation 3). The only difference between them is that in place of measured reflectances of NPs here we used KM estimated reflectances (section 2.1.4) of NPs.

2.7 Hybrid SN and YNSN models

We also tried a hybrid SN and YNSN model which uses mixed (half measured and half estimated) reflectances of NPs. In this model the reflectances of the first 8 NPs were measured reflectances and the next 8 reflectances were estimated using the KM theory (section 2.1.4). We used these hybrid reflectances for SN and YNSN spectral modeling of our printers (equation 2 and 3 respectively).

Since we have only 16 NPs (4 primaries), we choose to test only half measured and half estimated reflectances. We expected that this way of mixing the NPs will give us results with higher variation from the results of the models in section 2.1.5 and 2.1.6. The number of the NPs is too few to try another way of mixing. Therefore, using measured reflectances for more than half of the NPs will not be different enough from using measured reflectances of all NPs. Also using estimated reflectances of more than half of the NPs will not be more different from using all measured NPs.

2.8 Opacity

Opacity is the measure of impenetrability to the illuminant in to the specimen and is given by the following formula.

$$OS = \left(\frac{Y_b}{Y_w}\right)100 \tag{7}$$

where OS is opacity under 0/45 geometry, D50 illuminant and two degree observer. Yb is the Y tristimulus value computed from measurements made using black backing. Yw is the Y tristimulus value computed from measurement made using white backing.

3. EXPERIMENTAL SETUP AND RESULTS

3.1 Experimental setup

For our experiment we have used two CMYK printers for spectral modeling, a Xerox Phaser 7760 color laser printer connected to Apple Mac. and an HP 1220C DeskJet printer connected to a PC running Windows XP. Both printers are 4 channel (CMYK) printers.

The colorant combinations have been printed on three types of papers (Table 1) all in A4 size. The characteristics of papers that we should use for different printers differ a lot. Because of the high heat and toner formulation during leaser printing, we could obviously not use HP photo paper for a print using our Xerox Phaser color laser printer.

Table 1: The three papers we used for our experiment

Papers	Grammage	Opacity
Staple copy paper	80 g/m^2	94.1126
Color Copy paper	250 g/m^2	99.5077
HP advanced Photo paper	250 g/m^2	96.2078

The ECI2002 CMYK iCColor chart is used as a main source for CMYK primaries and NPs. It is a very large chart which includes the four primaries (CMYK) and all possible combinations of them. For visualizing and printing the chart we used Adobe Photoshop CS4. We also used MATLAB for modeling the printers.

We chose GretagMacbeth Eye-One Pro UV cut spectrophotometer, among the available spectrophotometers in our lab, for our measurement because it has more close measurement with the more accurate HySpex Hyper-Spectral camera and it has UV filter for removing effects of optical brightness of the papers. We used this spectrophotometer with measure tool software of Profile Maker pro 5.0.9 for measuring the NPs (Figure 1) and the test charts (Figure 2). 108 patches are extracted from ECI2002 CMYK chart to be used as a test chart. We divide the large ECI2002 CMYK iCColor chart in to 6 equal parts in order to print it on our A4 size papers. Each part has 14 columns of the large color chart. Our test chart includes all the patches at the end column of each part.

Figure 1: CMYK NPs from the ECI2002 CMYK iCColor chart

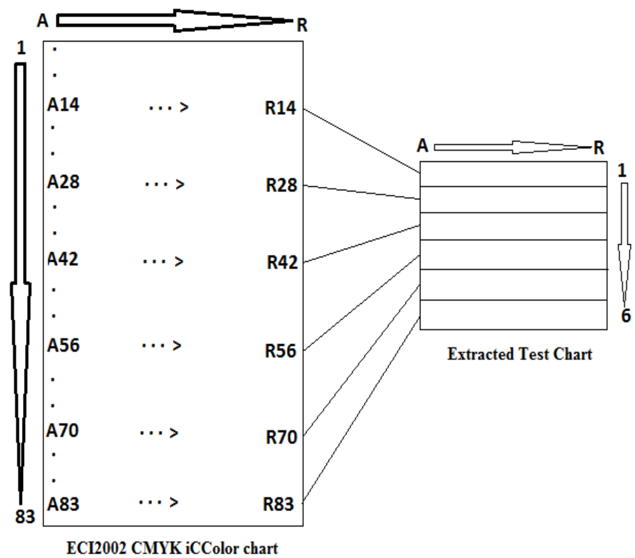

Figure 2: Test chart extracted from the ECI2002 CMYK iCColor chart

3.2 NP Estimation

In order to estimate the reflectances of NPs we use the KM theory mentioned in section 2.1.4. We used the measured reflectances of the primary colorants (CMYK) of the printers as a starting point for the estimation of the reflectance of the rest of the NPs. First, we calculate the K/S ratios for these primaries (equation 4). Then we use these ratios in order to compute the K/S ratios for the possible combinations of these primaries (equation 5). Finally, we computed the reflectance of each NPs from their resulted K/S ratios (equation 6).

For the comparison purpose we also printed out the 16 NPs (2^4) of each printer from ECI2002 CMYK chart on the mentioned three types of papers. We use Adobe Photoshop CS4 software. The chart was opened in CMYK mode. Since it is a CMYK TIFF file and since we have CMYK printers, we were able to find pure and independent primary prints by putting off both monitor and printer color management. We set the color management policies RGB, CMYK and Gray options to be off and we set the color handling option to no color management. For example, Cyan patch of the chart contains only Cyan ink after a print out using both of our printers. We were also able to print Magenta, Yellow and Black patches independently like Cyan. These verify for us that the primaries of our printers are independent of each other and there will not be any unnecessary mixing of colorants.

During the measurement of the patches we used the self backing. We measured the patches by placing them on the 20 similar but blank papers. We measured the reflectance of printed NPs and compare them with the estimated once. We used both Spectral and colorimetric distance metrics [14, 25] so that we can notice how much diverse they can be both spectrally and perceptually.

3.3 Spectral Modeling

The main question that we are trying to answer here is whether is it possible to use KM theory to estimate the NPs for spectral printer modeling, and how much more advantage or disadvantages does this have over using the measured NPs? We model both of our printers using both the spectral Neugebauer (NG) printer model and the Yule-Nielsen modified spectral Neugebauer (YNSN) model.

For the sake of dot gain effects [5, 16, 17] we need to compute effective colorant coverage of each primary. For computing LUTs of colorant coverage for our printers, we prepare, print and measure pure ramp reflectances for each colorant on mentioned three papers. They are a series of patches with equally spaced colorant coverage values range from 0% to 100% in 5% interval (Figure 3). We then use these reflectance measurements and Murray Davies equation (section 2.1.1) for computing effective colorant coverage for the patches of the ramp and to build LUTs [20]. Figure 4 explains the necessary steps for such effective colorant computation. Once we had these LUTs we were able to compute effective colorant coverage of our test chart by interpolation.

Having the LUTs and reflectances of NPs, one can model the printers spectrally. We model both of our printers three times, once using measured NPs, once using estimated NPs and once using the hybrid NPs (Section 2.1). Once we have the model we can compute or estimate reflectances of any colorant combinations of the primaries by inverting the models.

We measured the reflectances of each patch of the test chart and we estimate the reflectances of the same patches using our printer models, both NG model and YNSN model. First, we estimate the reflectance of our test chart by the spectral model which is built by estimated NPs (section 2.1.5 and 2.1.6). Again we estimated the same chart using the spectral model built by measured NPs (Section 2.1.2 and 2.1.3) and hybrid NPs (Section 2.1.7). We used the effective colorant coverage for all estimation of reflectances. Finally, we computed the difference between the three estimated and combined spectral reflectance values of our test chart and the measured reflectances of the test chart both spectrally and perceptually.

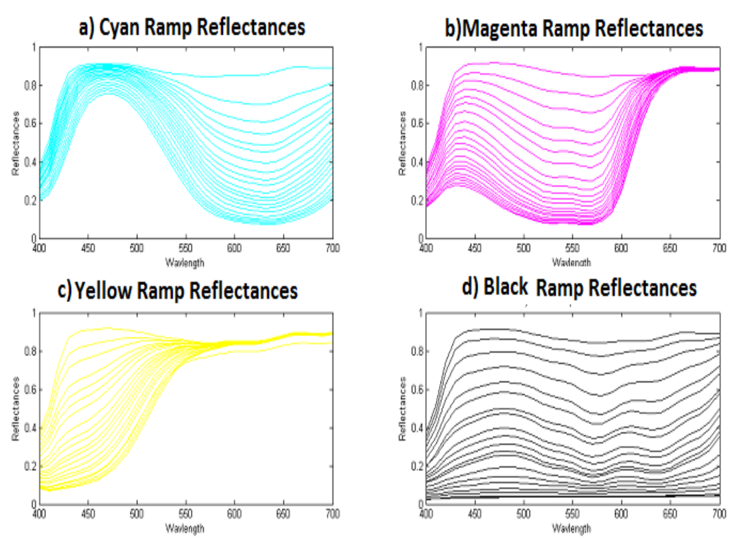

Figure 3: Measured spectral reflectances of equally spaced ramps of our InkJet printer primaries on color copy paper.

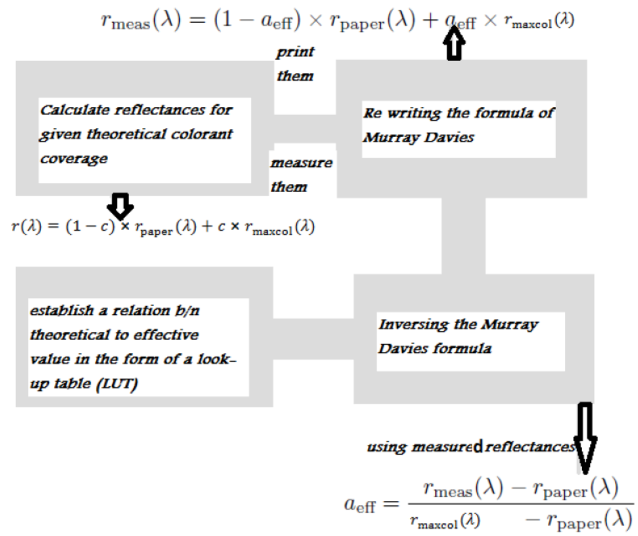

Figure 4: Process of Forming Look up Table for effective colorant coverage

3.4 Results and discussion

We computed repeatability of our measurements in two months interval. Within these two months there might be different changes including the fading of the colors of our prints. In contrary, we find the color difference between the two measurements acceptable. Average $\Delta E94 < 2$ is a good value and tolerable for long term repeatability and our results for both ΔEab and $\Delta E94$ are below 0.5 for Laser printer and less than 1 for inkjet printer. From this we can conclude that our first measurement was correct and reliable and it helps us to develop much stronger confidence in our overall results.

Mostly the difference between the estimated and measured reflectances of the NPs for both printers and three types of papers are in scale. Their perceptual and spectral differences for all types of papers and printers are given below (Table 2-4). We also plot the estimated and measured NPs in order to analyze their differences more in detail. We plot them in different ways to see their difference more clearly (Figure 5,6 and 7). In all cases the estimated reflectances are a bit darker than measured reflectances.

Table 2: Average spectral and colorimetric difference between measured and estimated NPs on Staple Copy Paper

	Staple Copy Paper ($80g/m^2$)			
Laser Printer	RMSE	GFC	ΔE	ΔE_{94}
Mean	0.0153	0.9876	6.4653	4.9102
Std.	0.0131	0.0133	5.5108	3.9201
InkJet Printer				
Mean	0.0190	0.9845	4.7043	4.1043
Std.	0.0329	0.0325	5.2501	4.3531

Table 3: Average spectral and colorimetric difference between measured and estimated NPs on Color Copy Paper

	Color Copy Paper (80g/m^2)			
Laser Printer	RMSE	GFC	ΔE	ΔE_{94}
Mean	0.0194	0.9838	8.0119	6.3770
Std.	0.0160	0.0207	6.2939	5.1163
InkJet Printer				
Mean	0.0192	0.9845	5.1893	4.5134
Std.	0.0311	0.0315	5.1741	4.1921

Table 4: Average spectral and colorimetric difference between measured and estimated NPs on HP Photo Paper

InkJet Printer	HP Photo Paper (80g/m^2)			
	RMSE	GFC	ΔE	ΔE_{94}
Mean	0.0241	0.8946	6.1282	4.1370
Std.	0.0454	0.1486	10.9297	7.2655

The LUTs for both printers and three types of papers are all almost linear except some little spikes in the yellow channel. Since we didn't set the printer's dot-gain correction to be off during the printing process the LUTs should all be linear. Some of the spikes must be from ink spreading on the paper and measurement errors. We can also see that (Figure 8) the prints from Laser printer and inkjet printer were both linear. Since there is less ink-spreading in laser printers than the inkjet ones, Laser printer's LUTs were more linear.

After modeling the two printers by SN and YNSN spectral printer models (using the measured, estimated and hybrid NPs), we also estimated the reflectances of the test chart patches. We also print out the test chart, on the three papers using both printers, and measured their spectral reflectances. Finally, we compared the estimated and measured reflectances of our test chart spectrally and colorimetrically.

Spectral NG printer model for the inkjet printer resulted higher spectral and colorimetric difference than the laser printer (Table 5 and 6). Using estimated NPs or mixed NPs for NG modeling of the laser printer resulted less than 4% of spectral error which is almost half of the 8% spectral error resulted for the inkjet printer. The same is true for their colorimetric differences. This shows that Spectral NG printer modeling works better and it is more accurate for the laser printer than inkjet printer.

We also find that using estimated and mixed NPs for Spectral NG modeling of laser printer gives smaller spectral and colorimetric differences than using the measured reflectances of the NPs. That means using estimated NPs by this less complicated Kubelka-Munk theory for laser printer modeling improves print estimation than using measured NPs.

Spectral NG model have less accurate performance on inkjet printer than laser printer and also using estimated NPs has not much effect on the modeling of the inkjet printer. It doesn't improve it nor make it worse. Mixing the estimated NPs and measured NPs for NG modeling improves a little the result of spectral NG model of the inkjet printer.

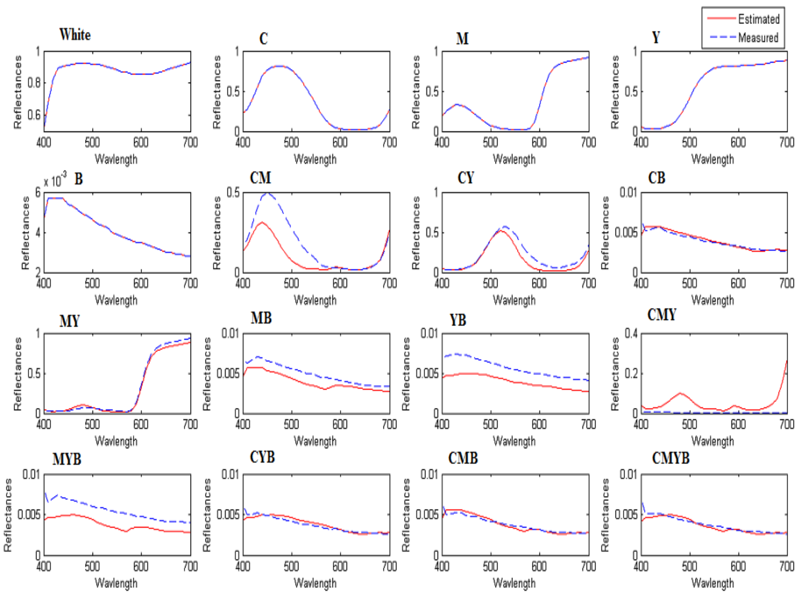

Figure 5: KM Estimated and Measured reflectances of NPs for the photo paper and DeskJet Printer. (Note: scales in the y-axis are different for some of the plots)

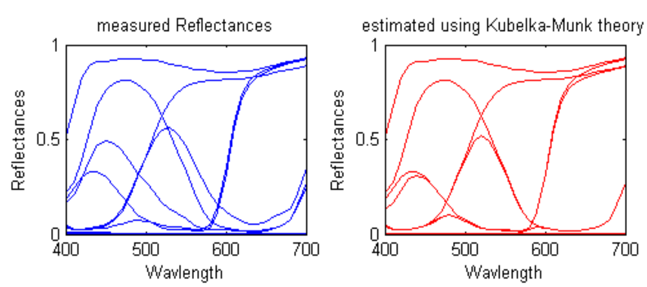

Figure 6: KM Estimated and Measured reflectances of NPs for the photo paper and DeskJet Printer separately and with the same scale.

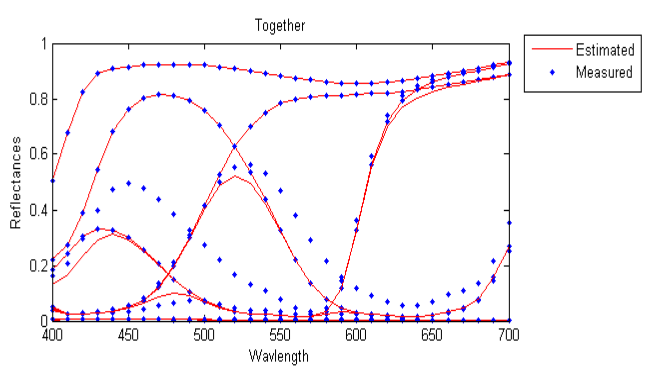

Figure 7: KM Estimated and Measured reflectances of NPs for the photo paper and DeskJet Printer all together and with the same scale.

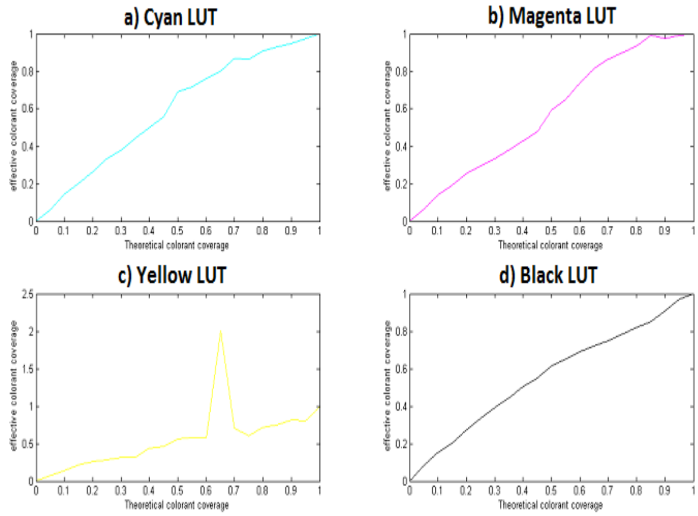

Figure 8: Computed LUTs for Xerox Laser printer and color copy paper using simple NG model averaged by wavelength.

The performance of the Spectral NG model for the inkjet printer with HP photo paper was very poor. These errors were almost double of the errors which have been found using the other two papers on the same printer. This might be because of some noisy waves resulted on some of the patches during our printing process. Actually, the opacity of this photo paper was not different from other papers we used (Section 2.1.8 and Table 1).

We also examine the results of the spectral and perceptual differences between the measured and estimated reflectance of our test chart using YNSN model for various *n* values. For the case of laser printer and staple copy paper using the estimated and mixed NPs gives better perceptual results than using measured NPs for n equals to 1-1.4 both spectrally and colorimetrically. When it comes to the color copy paper, using mixed NPs for spectral modeling gives improved spectral results than using estimated NPs only. Their color difference also shows the improved result from mixed NPs for a number of different n values.

Table 5: Average Spectral and colorimetric model prediction error for our Laser Printer NG model with color copy paper

	NG With Estimated NPs			
Laser Printer	RMSE	GFC	ΔE	ΔE94
Mean	0.0358	0.9930	7.3620	5.0476
Std.	0.0233	0.0096	4.1586	2.7372
	NG With Measured NPs			
Mean	0.0390	0.9942	7.8647	5.3988
Std.	0.0252	0.0073	4.9943	2.8342
	NG With Mixed NPs			
Mean	0.0361	0.9947	6.9254	4.7810
Std.	0.0251	0.0065	4.1005	2.6841

Table 6: Average Spectral and colorimetric model prediction error for our InkJet Printer NG model with color copy paper

	NG With Estimated NPs			
InkJet Printer	RMSE	GFC	ΔE	ΔE94
Mean	0.0749	0.9718	16.0265	9.9521
Std.	0.0394	0.0291	9.0443	4.9305
	NG With Measured NPs			
Mean	0.0708	0.9777	14.7690	9.0236
Std.	0.0404	0.0233	8.9696	4.9683
	NG With Mixed NPs			
Mean	0.0735	0.9736	15.8245	9.7646
Std.	0.0393	0.0294	9.2825	5.1346

The same as SN model, YNSN model also performs worse on the inkjet printer than its performance on laser printer with all papers. For the staple copy paper using measured or mixed NPs doesn't have any influence on the performance. For HP photo paper the performance become even worse. Using estimated or mixed NPs also doesn't improve the performance or it doesn't make it worse for all types of papers. Using mixed NPs or only estimated NPS has almost similar effect for overall performance of the spectral printer model.

We also see that using the YNSN model improves the performance of NG model (Figure 9-11). The improvement is a lot more visible for laser printer than inkjet printer. From the overall results, we are able to see that it is difficult to choose one specific *n* value for a good improvement of the model.

It varies from paper to paper and printer to printer but all improvements over NG model are found for n values in the range [1,1.4], particularly around n=1.3. In order to see these improvements more clearly we re-run the YNSN model for the n value with a finer step [1:0.1:2]. See Figure 9-11.

Here our results differ from results found by Gerhardt [4]. We just test a number of n-values without any optimization. It means that we didn't iterate the YNSN spectral modeling process in the loop for choosing the best n value. We also didn't make the dot-gain correction to be off during our printing process. That is why the look up tables (Figure 6) are somewhat linear and that is why our result for n value is closer to 1 than Gerhardt's result (n=2). The LUTs in Gerhardt's work were not linear and that is because there was no dot gain correction during his printing process. He also used the optimization process in order to choose the best n for each NP.

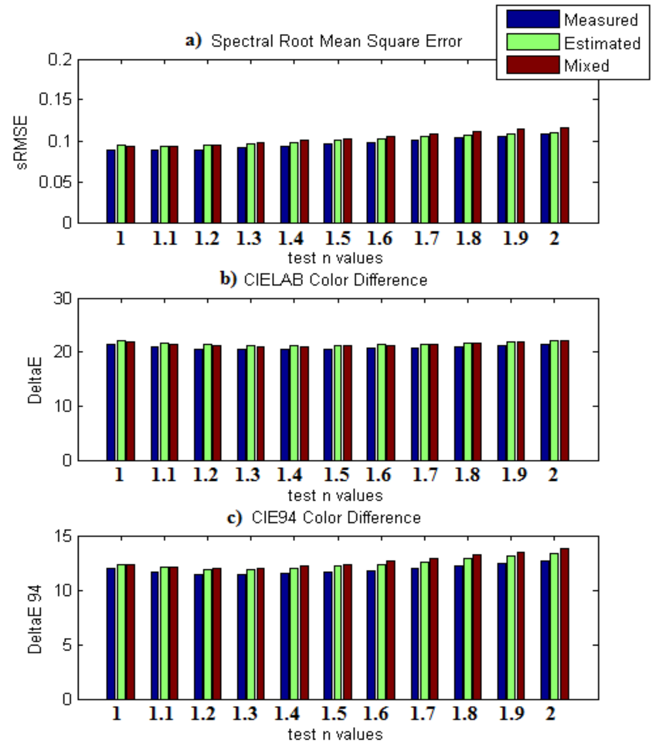

Figure 9: Average spectral and color differences for the Inkjet printer and HP photo paper A) Spectral root mean square error B) CIELAB color difference C) CIE94 color difference

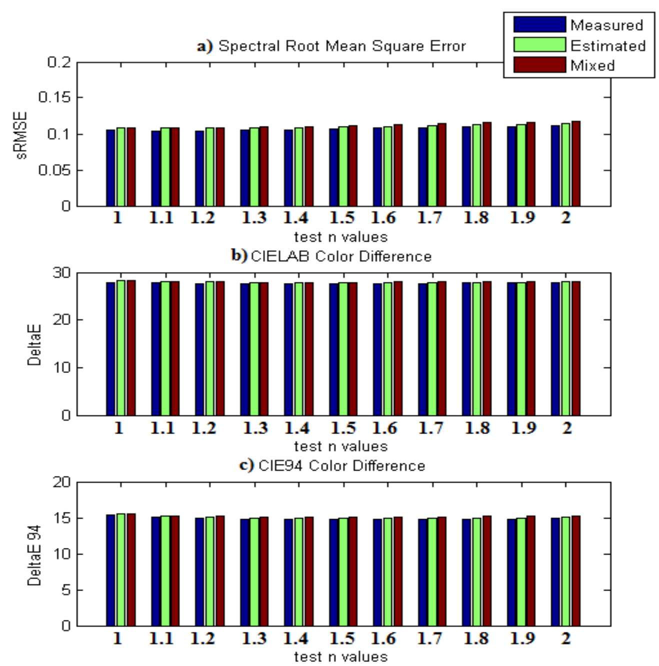

Figure 10: Average spectral and color differences for the Inkjet printer and color copy paper A)spectral root mean square error B) CIELAB color difference C) CIE94 color difference

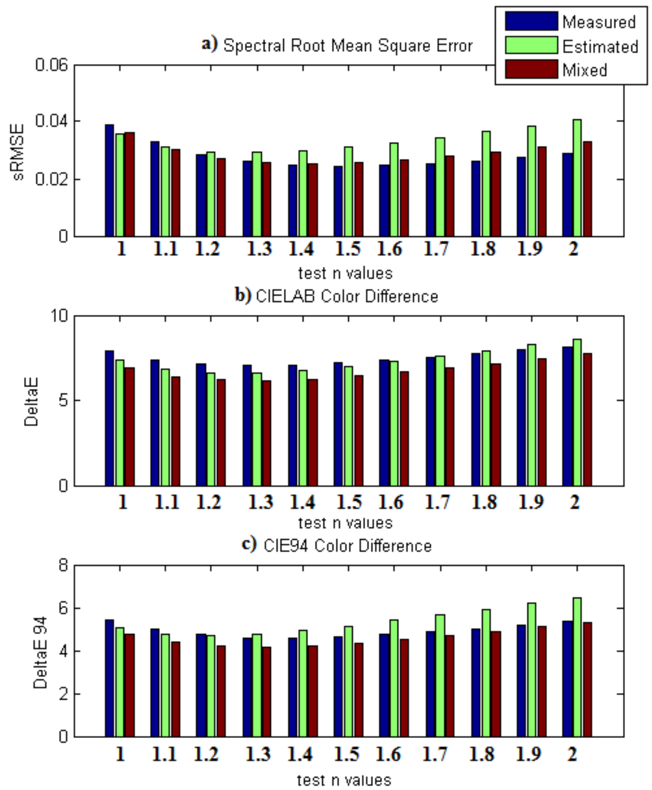

Figure 11: Average spectral and color differences for the Laser printer and color copy paper A) Spectral root mean square error B) CIELAB color difference C) CIE94 color difference

4. SUMMARY, CONCLUSION, AND PERSPECTIVES

Our experimental comparisons between the measured reflectances of the patches of the test chart and the SN and YNSN estimated reflectances of the patches of the test chart using the three types of NPs (measured, estimated and mixed) shows us the reasonability of the way we used kubelka-munk theory for spectral printer modeling. The estimated and hybrid NPs creates more accurate SN and YNSN models than the measured NPs. Sometimes the spectral printer model gives very poor estimation but it is for all types of NPs. The model performance differs from printer to printer and from paper to paper and the criteria to choose a good paper for spectral printer modeling using KM theory should be the Opacity of the paper.

Here, given a printer with n-colorants, we suggest some important points related with spectral printer modeling including, which Neugebauer Primaries should be printed and which one of them should be estimated, types of paper to be used, and things to be done during printing and measurement process.

- Print and measure primary colorants of the printer
- Estimate the rest of the NPs
- If possible making half of the NPs to be measured and half of the NPs to be estimated will give a little bit better results sometimes. We need to make sure that the cost of printing and measuring half of the NPs should not be greater than the improvements we get with only estimated NPs.
- During printing colorants, make sure there is no mixing of color from the other channels. This can be done by having direct access to the printer driver or by using Adobe photo shop software with all types of color managements being off.

- Kubelka-Munk gives an accurate prediction for more opaque papers. While choosing a paper, no matter how cheap it is just focus on the opacity of the paper. The higher the opacity of the paper the more accurate will be the KM model.
- Optical brightness of the paper might affect the overall result of the model. Using UV filter during measurement will solve this problem.
- During measuring spectral reflectances of the patches always make sure that you are using white backing. Using more than 20 blank paper of the same type, as the one we are measuring, as a background will be enough.
- Incorporating mechanical dot gain effect and optical dot gain effect through effective colorant coverage LUTs and YN n factor will increase the performance of the spectral printer model.
- Treating each channels of the printer independently for computing the best YN n factor will be recommended since different inks has different mechanical and optical properties.
- By the time of calculating effective colorant coverage, considering effective colorant coverage in every superposition condition might help enhancing the model accuracy.

There are lots of things in this area to be explored and studied in the future. For example, we have to find some other way of improving our Spectral printer models for more accurate results. One can test KM estimated NPs with cellular NG model, and by taking care of the effective dot sizes of NPs and with EYNSN. The kubelka-Munk theory we used for this paper should also be evaluated so that we could get better performance. Adding more paper, ink and light interaction properties to this simple KM theory will help a lot. Applying and testing the KM theory for estimating NPs for printers with higher number of channels (12 channel printer), and using their spectral printer models for colorant selection is also a good direction for future work.

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