A New Method for Characterizing Output Devices and its Fit into ICC and HIFI Color Workflows

Jean Pierre Van De Capelle and Baldewin Meireson
Barco Graphics, Gent, Belgium

Abstract

A method is presented to characterize output devices, such as printers and presses by means of spectral measurements of single inks. This leads to a very small number of measurements to be made for characterizing output devices using a larger number of inks, as for instance in so called "HIFI color" applications.

The method is based on the derivation of substrate color independent spectral characteristic parameters of the different inks. Using these parameters the method is capable of predicting the spectral reflectance of printed samples using these inks with some form of screening or dithering.

Introduction

A main issue within the color management arena and the ICC standard group is the characterization of output devices. Nowadays this is usually being done by printing a kind of sheet, usually containing many color patches and also overprints of different inks. For instance an IT 8 7.3 chart contains nearly a thousand patches for a four color output device.

This is a major problem if these methods have to be used in an environment where many different kinds of inks are being used, i.e. inks different from cyan, magenta, yellow and black. For some applications the inks can be selected out of a set of for example a thousand possible inks. In this case the number of possible ink combinations is so large that it is just impossible to make prints with all possible ink combinations. In case of a combination of four inks that can be selected out of a thousand different inks, this would mean about a trillion (10^{12}) possible combinations and hence near to a thousand trillions (10^{15}) measurements should be taken. This is a little too much for mankind.

Even if we look at Hexachrome, with only six colors, the number of possible combinations of four colors out of six is twelve (if we assume printing order is not relevant), and doing around a thousand measurements per combination still adds up to a large number of measurements.

Also, looking at the ICC-workflow, a number of severe problems arise for applications like HIFI color. The ICC standard uses look up tables and interpolation to predict the CIELAB values of a particular output device. The number of nodes in these lookup tables increases exponentially with the number of inks, and the amount of computer resources becomes too high to be feasible.

Given these observations the aim of this paper is to describe a method of characterizing individual inks when printed on a certain output device, rather than combinations of overprints of these inks, and from these characterizations predict the appearance (e.g., the color renditions) of screened, dithered or non screened overprints. The goal is to develop a method that is neither limited by the number of measurements to be done, nor by the amount of computer resources needed to do the color management.

Setting up models for characterizing output devices has been done in the past by a number of people, with varying levels of success. Investigations of all these models showed that a high enough accuracy could not be achieved with any of the known methods, at least for the applications we had in mind.

We investigated the Neugebauer[1] type models and their derivative based on Yule-Nielsen[2] and spectral Neugebauer[3] equations. However, the Neugebauer-like models still need the knowledge of the color of the overprints of the primary inks. The Kubelka Munk[4,5] theory has been investigated for the predictions of the overprints of the primary colors, e.g. to determine the spectral reflectance of the red, green and blue overprints for a CMYK output device.

So we looked at the Neugebauer like models with the assumption we would be able to predict the overprints of the primary colorants by means of another model. Therefore, we initially measured the overprints and applied various Neugebauer like models though without achieving very good results.

In the mean time we looked at the Kubelka Munk model for the prediction of the overprints of the primary colorants. As a major disadvantage of this model we found that the parameters K&S from the "Two Constant Kubelka Munk" model heavily depend on the substrate color on which these parameters were determined, which indicates that they cannot be seen as real colorant parameters.

Hence we abandoned the Neugebauer type models and the Kubelka Munk based models. We developed a new method that fulfils the pre-set requirements: no overprints of colorants needed and accurate prediction of the color rendition of the output device.

The accuracy criterion we used was the following: a maximum deviation between predicted color and calculated color of around 5 CIELAB Delta E, and an average of around 2 CIELAB Delta E). We achieved this goal for our main output devices in mind, being analogue proofing devices such as Dupont's Cromalin and 3M's Matchprint.

Methodology

Consider a colorant for which we will determine the colorant parameters for a certain printing technique on a certain substrate. This is the method we will follow to derive the spectral parameters for the colorant:

- Prepare three different background colors on the substrate:
  1. The naked substrate (will be further referenced as the white substrate)
  2. The naked substrate with 50% black printed on it (will be further referenced as the gray substrate)
  3. The naked substrate with 100% black printed on it (will be further referenced as the black substrate)
- Print on each of the three substrate colors a raster with densities going from 100% to 0% in steps of 10% using the colorant you want to characterize and the printing technique concerned.(See Fig 1).
- Measure each of the 33 colors with a spectrophotometer.
- Each print of the raster percentages is considered to produce a colorant layer of which we ignore the microscopic look. We have thus 11 colorant layers and for each we have six measurements :

  $R_{piw}(\lambda)$: Reflection of p% layer on white
  $R_{pig}(\lambda)$: Reflection of p% layer on gray
  $R_{pik}(\lambda)$: Reflection of p% layer on black
  $R_w(\lambda)$: Reflection of white
  $R_g(\lambda)$: Reflection of gray
  $R_k(\lambda)$: Reflection of black

  We calculate 3 colorant parameters as follows:

$$S_p(\lambda) = R_{pik}(\lambda) - R_k(\lambda) \tag{1}$$

  p = 0%,10%, ... , 100%

$$\alpha_p(\lambda) = 1 - \frac{R'_{piw}(\lambda)}{R_w^{\mu_p(\lambda)}(\lambda)} \tag{2}$$

and

$$\mu_p(\lambda) = \frac{\log\left(R'_{piw}(\lambda) \big/ R'_{pig}(\lambda) \right)}{\log\left(R_w(\lambda) \big/ R_g(\lambda) \right)} \tag{3}$$

with

$$R'_{piw}(\lambda) = R_{piw}(\lambda) - S_p(\lambda)$$

$$R'_{pig}(\lambda) = R_{pig}(\lambda) - S_p(\lambda)$$

- For the percentages that we didn't measure we derive the reflection spectra for the prints on white, gray and black by interpolating between the reflection spectra of the raster percentages that we did measure. Out of the calculated reflection spectra we calculate the colorant parameters as described above in (1), (2), (3).
- For the colorant we wanted to characterize we end up with 3 spectral parameters :

$$\alpha(p, \lambda), \ \mu(p, \lambda) \text{ and } S(p, \lambda)$$

These colorant parameters are independent of the substrate color which means we can calculate the color resulting from printing the colorant with raster percentage p on the substrate being considered, with the printing technique being considered and for the substrate having color $R_{bg}(\lambda)$ as:

$$R_p(\lambda) = (1 - \alpha(p,\lambda)) * R_{bg}(\lambda)^{\mu_{(p,\lambda)}} + S(p,\lambda) \tag{4}$$

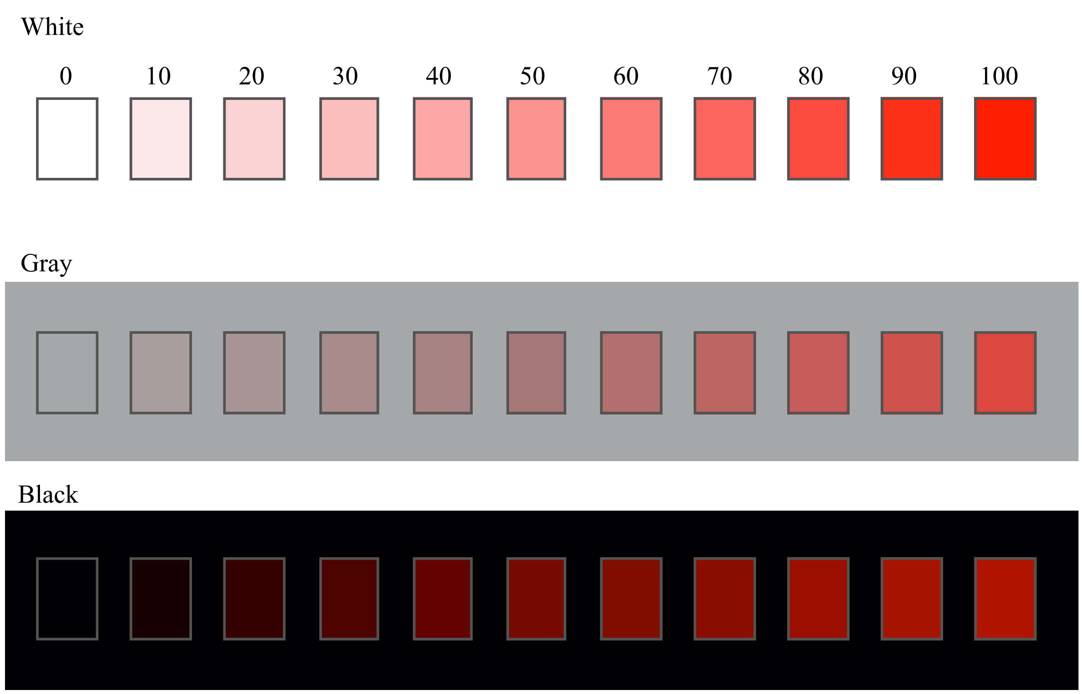

Figure 1. Testchart for characterizing an individual ink

By using formula (4) recursively we can predict the color resulting from printing multiple inks consecutively at a certain raster percentage on top of each other.

Experimental Results

Table 1. Comparison between measured and calculated overprints.

	# patches	#overprints	average ΔE	maxΔE
1) Matchprint (CMYK)	25	2	2.5	4.1
2) Cromalin (CMYK)	50	2	1.8	3.9
3) Cromalin PrB/Gr/PantY/PantK	1331	3	3.0	5.3
4) Cromalin (CMYK)	1331	3	2.9	5.1

- For various colorants, both scattering and non-scattering, the colorant parameters were calculated on different substrate colors. It was clearly seen that the colorant parameters are independent of the substrate color. In Fig.2 and 3 the colorant parameters α(λ) and μ(λ) are shown for a 100% Yellow on different substrate colors.

$$\alpha(\lambda) = 1 - \frac{R_{ys}(\lambda)}{R_y^{\mu(\lambda)}(\lambda)}$$

$$\mu(\lambda) = \frac{\log\left(R_{yw}(\lambda) \big/ R_{ys}(\lambda) \right)}{\log\left(R_w(\lambda) \big/ R_s(\lambda) \right)}$$

with :
$R_{ys}(\lambda)$: Reflection of 100% Y on substrate color
$R_{yw}(\lambda)$: Reflection of 100% Y on white
$R_s(\lambda)$: Reflection of substrate color
$R_w(\lambda)$: Reflection of white

The printing technique we used was MatchPrint®

- In our experiments we printed the test charts of Figure1 for each ink together with a classical test chart that consists of a set of overprints of various raster densities of the inks. Table 1 shows the comparison between the calculated colors of the overprints using the model here proposed and the measured colors of the overprints. Given the limited reproducibility of the Cromalin® and Matchprint® process, the results are quite good.

Conclusion

With this new approach we made it possible to characterize print processes with an unlimited number of inks without the need to measure overprints. This is an enormous advantage over the workflow that ICC follows and it allows changing inks with very little effort. Printing with non-CMYK inks and HIFI-printing becomes feasible now.

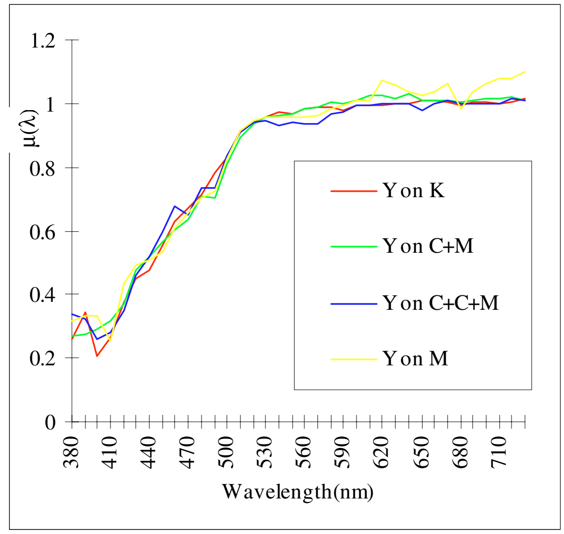

Figure 2. Colorant parameter μ(λ) of Matchprint Yellow, derived from prints on various substrate colors

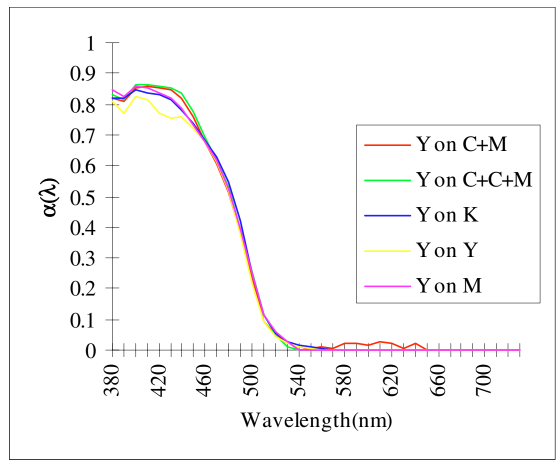

Figure 3. Colorant parameter α(λ) of Matchprint Yellow, derived from prints on various substrate colors

References

1. "Die theoretischen Grundlagen des Mehrfarbenbuchdrucks", H. E. J. Neugebauer, Zeitschrift fur wissenschaftliche Photographie, *Photophysik und Photochemie*, Band **36**, Heft 4, April 1937
2. Modeling the Yule-Nielsen Halftone effect, J.S. Arney, C.D. Arney, *Journal of Imaging Science and Technology*, vol. **40**, No. 3, pp. 233-238, June 1996.
3. "Accuracy of Various Types of Neugebauer Model", R. Rolleston, R. Balasubramanian, *IS&T and SID's Color Imaging Conference: Transforms and Transportability of Color*, pp. 32-37, 1993.
4. "Kubelka-Munk Theory and the Prediction of Reflectance", James H. Nobbs, *Rev. Prog. Coloration*, **15**, pp. 66–75, 1985.
5. "Comparison of Color Mixing Theories for Use in Electronic Printing", Henry R. Kang, *IS&T and SID's Color Imaging Conference*, pp. 78-82, 1993.

✰ This paper was previously published in *IS&T/SID 5th Color Imaging Conference Proc.*, p. 66 (1997).