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Color prediction based on individual characterizations of ink layers and print support

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Abstract

The rendering of a same printed image can change drastically considering the large number of different types of print support (paper, metallic panel, textile, plastic, etc.) and different types of inks (dye based, pigment based, etc.). Predicting the visual rendering of inks printed on any support by characterizing separately the spectral properties of the inks and those of the print support has been for a while an objective for the printing community.

In this paper, we propose a multiscale solution to this issue which combines optical models and measurements. On the one side, we predict the reflectance and transmittance of ink layers alone (without support) by using a radiative transfer four-flux model based on the microscopic characteristics of the inks. On the other side, the reflectance and transmittance of the print support are obtained directly through macroscopic measurements. Finally, through the four-flux matrix model, we compute the joint reflectance and transmittance of the superposition of the stack of inks on the support. Initial results show that the proposed approach is suitable for the prediction of image rendering on different combinations of ink and print support.

Introduction

With the growth of digital imaging and 3D printing, color management is becoming the cornerstone of a satisfying visual rendering. In general, the wide range of potential interactions between ink, print support, printing technology and light environment makes color management a complex and non-stable task in printing applications [1].

In 2.5D or relief printing [2], we are able to stack layers of UV curable ink. The use of UV curable inks that do not get absorbed by the support allows us to print on any media and also to create objects only made of ink. By taking advantage of the translucency of the inks, special effects can be obtained by printing on a specular support [3] or by observing a double-side print by one face in reflection mode or through both faces in transmission mode [4].

Methods based on physical models for spectral reproduction have been developed in the recent decades. In particular, improvements have been made to flux transfer matrix models [5] that can predict the spectral reflectance and transmittance of stacks of scattering and absorbing layers. Two-flux models including the well-known Kubelka-Munk method [6] are often favored because of their efficiency and simplicity. The absorption and scattering coefficients, the main parameters of the generalized two-flux model, usually become those of an “effective medium”. For printed materials, such effective medium is typically associated with a macroscopic component made of a strongly scattering substrate (paper) coated with absorbing, weakly scattering materials (inks).

Undoubtedly, color prediction models (CPMs) make use of a low number of measurements to calibrate a printing process [7]. Yet, the predictions performed using the macroscopic approach (i.e. Kubelka-Munk approach) cannot be generalized, as they are constrained by that particular ink and support configuration. In other words, current models are unable to predict the color of the superposition of inks on a support knowing the reflectances of the individual solid inks and the unprinted support. To use a macroscopic approach, one would have to print at least a single layer on a given support and measure its reflectance and transmittance in order to make further predictions. In that case, each time that either the inks or the support change, the process has to be repeated.

Our objective in this study is to be able to predict the colors obtained with fulltone (100% surface coverage) primary colors printed on different supports by merging the separate characterizations of the inks and the support.

To disconnect the ink from the support, the macroscopic approach of the two-flux model is no longer beneficial as we want to treat the ink and the support as two distinctive units. Moreover, the applicability of the two-flux approach [8] is limited to strongly scattering layers illuminated by a Lambertian flux or stack of similar non-scattering components illuminated by collimated light (for example a stack of colored films [9]). It is the scattering of light occurring inside the material that complicates the optical characterization of translucent material such as inks.

With previous CPMs, the inks are characterized with Kubelka-Munk or Beer law. This is possible because in classical printing inks are assumed to be non-scattering. Yet, from the highly scattering opaque white ink to the non-scattering transparent clear varnish, inks have various levels of translucency and scattering.

In this paper, we choose to use a four-flux matrix model (similar to the one presented by [10]) which is suited for a wider range of scenarios, especially translucent layers. We use a radiative transfer version of the model [11] which computes the multiple scattering by considering stacks of layers made of scattering and absorbing particles. In other words, we characterize the inks at the pigment scale. To do that, we use the optical indices of both the pigment and the binder forming the ink determined in a previous work [12]. By treating inks and support independently from each other, our method requires measuring only once the reflectance and transmittance of the unprinted support from which we compute its complex refractive index. Finally, by considering the print support as another layer of the stack, we can predict the reflectance and transmittance of the superposition of ink layers stacked on the support.

The matrices that describe the four-flux model are briefly presented in the first part of this paper. Then we explain how the print support is accounted for in the model. In the second part, we test the method by making predictions of the superposition of inks on top of various supports, more or less absorbing/scattering. Results show that the method works best for weakly scattering print supports, either transparent or very reflective.

Radiative transfer multilayer four-flux matrix model

We use here a radiative transfer four-flux matrix model capable of predicting spectral properties of a stack of layers. The use of the four-flux model allows accurate predictions of translucent materials such as ink layers while the radiative transfer theory describes scattering within the material at a very small scale [13]. This model has shown accurate results (with $\Delta E_{94} < 2$) in our previous work for the predictions of ink layers printed without any support [12, 14-15].

We consider that printed materials are made of a succession of interfaces and scattering and/or absorbing media. In the four-flux model, light is decomposed into four fluxes, two collimated fluxes traveling in the forward F_c^+ and backward F_c^- directions perpendicular to the multilayer material and two diffuse fluxes traveling in the forward F_d^+ and backward F_d^- directions.

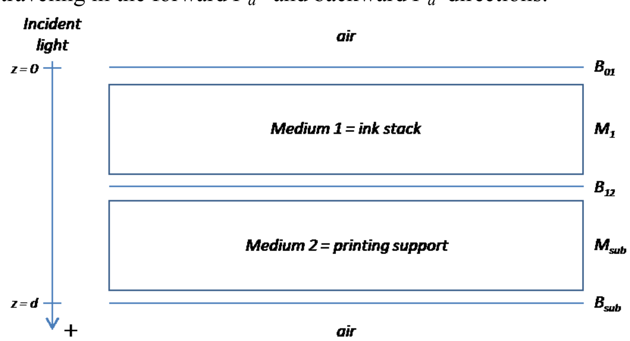

Figure 1. *Case of one stack of ink (medium 1, with matrix M_1) printed on a support (medium 2, with matrix M_{sub}) with three interfaces (i.e. air-ink, ink-support, support-air, with matrices B_{01}, B_{12} and B_{sub}).*

Figure 1 describes our printed material for a stack of thickness d made of ink printed on a support, the whole being surrounded by air when observed. In our case, the stack is made of two media and three interfaces. The four-flux matrix model assigns a matrix to each layer and each interface. Each matrix expresses the fluxes outgoing of one component as a function of the fluxes incoming from the adjacent components. B_{01}, B_{12} and B_{sub} are the interface matrices. M_1 and M_{sub} are the passage matrices. In the following sections, we explain how we compute the elements of the matrices of the model for the ink and print support.

Interface matrix

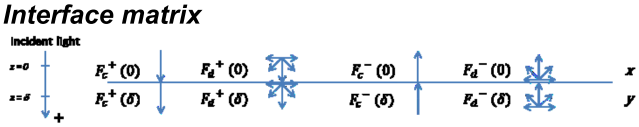

Figure 2. *Representation of the outgoing and incoming fluxes at an interface between layers x and y.*

Figure 2 presents the flux transfer at an interface between a layer x and a layer y. The interface matrix B_{xy} expresses the fluxes at the back ($z=\delta$) as a function of the fluxes at the front ($z=0$) where δ is an infinitesimal interface thickness (equation (1)).

$$\begin{pmatrix} F_c^+(\delta) \\ F_c^-(\delta) \\ F_d^+(\delta) \\ F_d^-(\delta) \end{pmatrix} = B_{xy} \begin{pmatrix} F_c^+(0) \\ F_c^-(0) \\ F_d^+(0) \\ F_d^-(0) \end{pmatrix} \tag{1}$$

B_{xy} can be expressed as a 2-by-2 matrix by expressing its elements as 2-by-2 matrices, similar to the form presented in [12]. Then, (1) can be written as:

$$\begin{pmatrix} F_c^\pm(\delta) \\ F_d^\pm(\delta) \end{pmatrix} = \begin{pmatrix} B_{cc} & 0_{2*2} \\ B_{cd} & B_{dd} \end{pmatrix} \begin{pmatrix} F_c^\pm(0) \\ F_d^\pm(0) \end{pmatrix} \tag{2}$$

where $F_c^\pm$ and $F_d^\pm$ are 2-by-1 vectors and B_{cc}, B_{cd} and B_{dd} are 2-by-2 matrices that describe the transfers between the fluxes. The nature of these flux transfer are collimated-to-collimated (*cc*), collimated-to-diffuse (*cd*) and diffuse-to-diffuse (*dd*).

The elements of the interface matrix are expressed as a function of the reflection and transmission coefficients.

To obtain the elements of the interface matrix in terms of the reflection and transmission coefficients, we solve equation (1) for the outgoing fluxes as a function of the incoming fluxes. To compute the elements of the interface matrix, we require only the refractive index of each layer. It allows the computation of the polarization-averaged, angular dependent Fresnel coefficients (Fresnel's formulae) from which we can compute the *cc* reflection and transmission coefficients. The *dd* coefficients can be deduced by integrating the *cc* coefficients over the hemisphere [16] . In case of rough interfaces, the *cd* coefficients can also be computed from the *cc* coefficients using Kirchhoff theory [17].

Passage matrix for the ink layer

One layer of ink is modeled as a diffusing medium of thickness d containing a volume fraction C of pigments (of radius r) dispersed inside a binder.

By solving the radiative transfer equation with the four-flux model (as done by [18]), we can express the fluxes inside the diffusing medium as a function of the absorption and scattering coefficients of the pigment particles and binder forming the medium as well as integration constants determined by boundary conditions.

With the same approach as for the interface matrix, we can express the fluxes at the back of the medium ($z=d$) as a function of the fluxes at the front ($z=0$) of the medium with the passage matrix (equation (3)).

$$\begin{pmatrix} F_c^\pm(d) \\ F_d^\pm(d) \end{pmatrix} = \begin{pmatrix} M_{cc} & 0_{2*2} \\ M_{cd} & M_{dd} \end{pmatrix} \begin{pmatrix} F_c^\pm(0) \\ F_d^\pm(0) \end{pmatrix} \tag{3}$$

To compute the elements of the passage matrix for the ink, we require four intrinsic characteristics of the ink. The inputs of our model are the wavelength-dependent optical indices of the pigment n_p and binder n_b forming the ink as well as the pigment size r and the volume fraction of pigment C in the ink. Before making any predictions with support, we determined the values of these four inputs in our previous work for each ink [12]. In other words, the inks have been characterized spectrally at the microscopic scale (pigment scale).

Our model has been validated with predictions of ink layers made of primary and secondary colorants [14] with no print support (stacks made of ink only). The model shows an accuracy regarding color differences of less than 2 units of CIELAB ΔE_{00}.

Passage matrix for the print support

Contrary to the ink, we do not characterize physically the print support. By considering the print support as an absorbing medium containing no scattering particles, we can assign a simple matrix to the print support. In that case, the passage matrix M_{sub} is:

$$M_{sub} = \begin{pmatrix} e^{\frac{4\pi k_S Z_S}{\lambda}} & 0 & 0 & 0 \\ 0 & e^{\frac{-4\pi k_S Z_S}{\lambda}} & 0 & 0 \\ 0 & 0 & e^{\frac{4\pi k_S Z_S}{\lambda}} & 0 \\ 0 & 0 & 0 & e^{\frac{-4\pi k_S Z_S}{\lambda}} \end{pmatrix} \quad (4)$$

where k_s and Z_s are respectively the absorption coefficient and the thickness of the support. Therefore, we only need to determine the refractive index and the absorption coefficient of the print support to compute the elements of both the passage matrix M_{sub} and the surrounding interface matrices B_{12} and B_{sub}. These characteristics can be deduced from the measurement of the transmittance T_s and the reflectance R_s of the unprinted support. The support refractive index n_s and absorption coefficient k_s are given by the following formulas (from [19]). For supports that have translucency, (5) gives the refractive index. For opaque support, t_s is zero and (6) gives the refractive index.

$$n_s = \frac{1}{T_s A}\left[\left(1 - R_s - T_s\sqrt{A^2+1}\right) - \sqrt{2T_s}\sqrt{A + T_s - (1 - R_s)\sqrt{A^2+1}}\right] \quad (5)$$

$$n_s = \frac{1 + R + 2\sqrt{R}}{1 - R} \quad (6)$$

$$k_s = -\frac{\lambda \ln(t_s)}{4\pi Z_s} \quad (7)$$

$$A = \frac{(1 - R_s)^2 - T_s^2}{2T_s} \quad (8)$$

$$t_s = \sqrt{A^2 + 1} - A \quad (9)$$

In theory, these formulas are valid for transparent, non-scattering and weakly absorbing substrate. However the purpose is not to compute the exact complex refractive indices of the print supports. The idea here is to account for the effect of the substrate by computing the reflections at the ink/substrate and substrate/air interfaces (through the interface matrices) as well as the absorption of the medium (through the passage matrix).

Computation of the reflectance and transmittance of ink layers + print support

The objective is to relate the fluxes to measurable physical quantities (the reflectance and the transmittance).

For the system made of one medium (ink), one print support, and three interfaces, as shown in Fig. 1, (10) describes the flux transfer in the case of an incident light coming exclusively from the *z=0* side with $F_c^+(0)$ being the ratio of collimated illumination (*coll*) and $F_d^+(0)$ being the ratio of diffuse illumination (*diff*). In this case, fluxes $F_c^-(d)$ and $F_d^-(d)$ are zero.

$$\begin{matrix} T_{cc} = \\ 0 = \\ T_{td} = \\ 0 = \end{matrix} \begin{pmatrix} F_c^+(d) \\ F_c^-(d) \\ F_d^+(d) \\ F_d^-(d) \end{pmatrix} = \underbrace{B_{23} M_2 B_{12} M_1 B_{01}}_{Q} \begin{pmatrix} F_c^+(0) \\ F_c^-(0) \\ F_d^+(0) \\ F_d^-(0) \end{pmatrix} \begin{matrix} = coll \\ = R_{cc} \\ = diff \\ = R_{td} \end{matrix} \quad (10)$$

Equations (11-14) give the reflectance and transmittance solutions of the stack. Here R_{cc} and T_{cc} are the collimated reflectance and transmittance which can be measured with an integrating sphere spectrophotometer by subtracting the specular excluded (SPE) measurement from the specular included measurement (SPI). R_{td} and T_{td} are the total diffuse reflectance and transmittance equal to the sum of the *cd* and *dd* components. It corresponds to the SPE measurement. The sum of the *cc* and *td* components corresponds to the SPI measurement.

$$R_{cc} = -Q_{10} * coll / Q_{11} \quad (11)$$

$$R_{td} = -(Q_{30} * coll + Q_{31} R_{cc} + Q_{32} * diff)/Q_{33} \quad (12)$$

$$T_{cc} = Q_{00}\mathrm{coll} + Q_{01} R_{cc} \quad (13)$$

$$T_{td} = Q_{20}\mathrm{coll} + Q_{21} R_{cc} + Q_{22} diff + Q_{23} R_{td} \quad (14)$$

Methodology summary

We can generalize the prediction for any combination of ink + support, without having to print when one of the elements (ink or support) changes. In other words, our workflow is based on the separate characterization of the inks and the unprinted support (see fig. 3).

On one hand, the inks are characterized at the microscopic scale through radiative transfer and Lorenz-Mie theory. With these intrinsic characteristics, the four-flux model allows to make predictions of ink layers alone printed without print support. On the other hand, we simply make macroscopic spectroscopic measurements of the print support without trying to understand what it is made of. Finally, using the four-flux matrix model, we can make predictions of the joint ink/support configuration. This method is therefore tested in the next section on a variety of print supports. Results are analyzed and discussions determine for what kind of support the method works better.

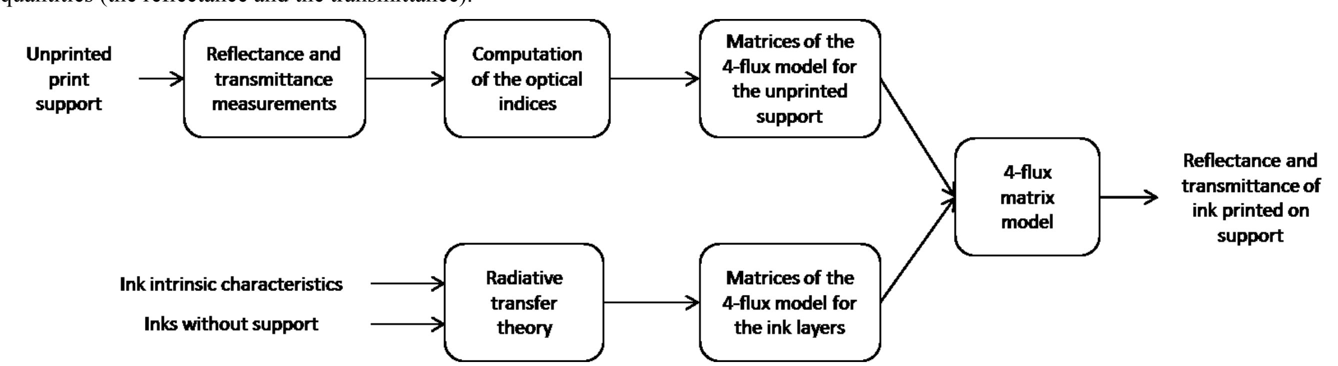

Figure 3. *Workflow of our method to compute the reflectance and transmittance of ink printed on a support by characterizing separately the ink and print support.*

Evaluation of the effectiveness of the method

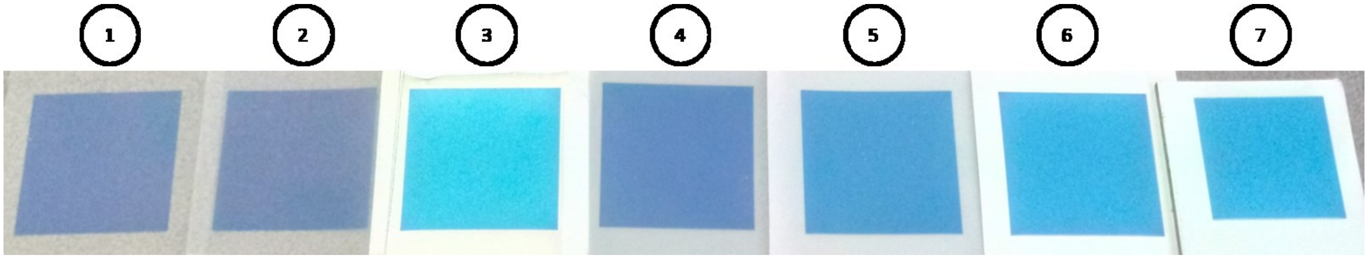

Figure 4. *Photograph of seven print supports. In this picture, each support is printed with a stack made of two layers of cyan (thickness of the stack = 20 µm).*

Using the workflow described in the previous section, we can make predictions of patches of ink printed on the different supports. As mentioned, we use the characterization of the inks made in [12] and the measured reflectance and transmittance spectra of the unprinted support.

In this section, we first present the print supports of the experiment. Then we simulate the total reflectance and total transmittance of fulltone layers of cyan (C), magenta (M), yellow (Y) and black (K) inks at different thicknesses (one to five layers with one layer having a thickness of 10 µm) on seven print supports. Samples were printed using 2.5D printing technology. Figure 4 shows a photograph of the different supports printed with two layers of cyan (20 µm). The total transmittance and the total reflectance of each sample were measured with a CARY 5000 Agilent spectrophotometer equipped with an integrating sphere (SPI measurement). The incident light is 100% collimated (*coll=1* and *diff=0* in equations *11-14*). Hence, the last part of this section presents the color and spectral differences between the measured and predicted spectra.

Description of the print supports

We printed on supports consisting of different scattering/diffusing levels. To determine the level of scattering of a material, one can look at its translucency. A transparent material let light through without deviating it meaning that there are no particles or asperities (scatterers) scattering photons out of the specular direction. Transparent materials are non-scattering. On the contrary, a white opaque material is a highly diffusing material as it backscatters photons towards the incident direction inducing high (diffuse) reflectance and low transmittance.

Figure 5 shows the absorbance, transmittance and reflectance spectra of these unprinted supports. The first two supports are transparent films which are not scattering and very weakly absorbing. They are 70 and 200 µm thick. The thicker film has also a rough side. The third support is a glossy, mirror-like film. It is almost non-scattering but has a high specular reflectance (around 80%) as well as some translucency. The fourth support is a tracing paper which is moderately scattering, mostly transparent with a reflectance of around 30%. The fifth support is also reasonably scattering; however it is more translucent with an almost even part of transmittance and reflectance. The sixth and the seventh supports are diffusing white print supports. The sixth is a white coated paper, while the seventh is an opaque white aluminum composite panel. Referring to the absorbance spectra, none of the supports is highly absorbing.

The print supports used here can be arranged into three groups according to their scattering power: weakly scattering (transparent and reflective supports), mid-scattering (tracing paper and translucent film) and very scattering (white aluminum panel and white paper).

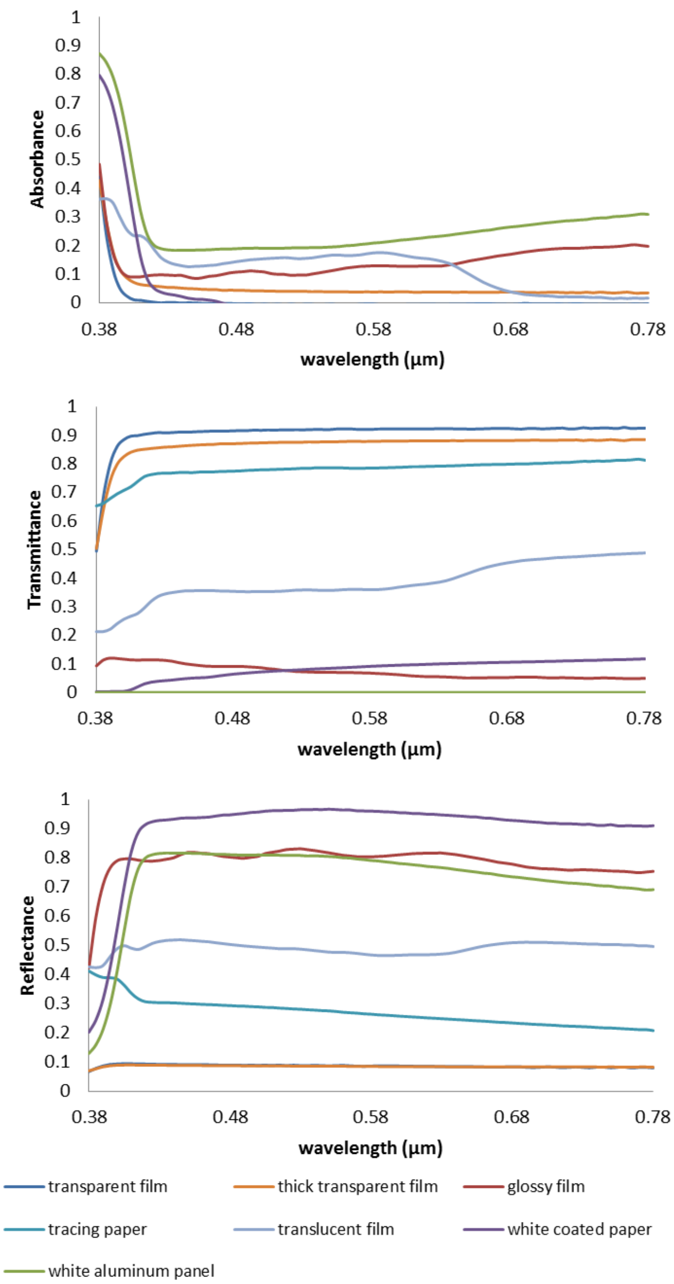

Figure 5. *From top to bottom: absorbance, total transmittance and total reflectance spectra of the seven unprinted supports.*

Assessment of the model predictions

To assess the deviation between the measured and predicted spectra, we compute the color deviations (visual metric CIELAB ΔE_{00} computed from CIELAB color coordinates of the spectra using the standard illuminant D65) and spectral deviations (unweighted root mean square deviation RMSD). Table 1 shows the median and the 95th percentile for both the ΔE_{00} and the RMSD for each group of printed stacks.

For inks layers only (without support) our previous work [12] show an accuracy regarding color differences of less than 2 units of CIELAB ΔE_{00} for the primaries (C, M, Y, K). The results of this previous study are reminded in Table 1 (in the "ink only" column). This allows checking the impact of the supports on the predictions and the effectiveness of our method.

In general, we consider that the prediction is acceptable when the color deviation is below 2 ΔE_{00} units (which represents an almost unnoticeable difference to the human eye). On the contrary, we consider here that the prediction is unsatisfactory when the color deviation is above 5 ΔE_{00} units (which is a common threshold in the industry) or the spectral difference is above 5%.

First of all, we compute the reflectance and transmittance of only the print support (without ink jetted on it). These predictions are very precise both in terms of color and spectral differences except for the transmittance of the white paper.

The predictions are accurate for inks printed on transparent films. Considering the predictions were already fairly accurate without any support, this was to be expected since transparent films are the supports which have the lesser impact on the spectral properties of the printed layers of ink. Moreover, the formulas used to compute the optical indices of the support are well-suited for transparent films.

When comparing to the predictions made for ink layers only, the color difference may slightly increase when the support is added. For example the median color difference for the reflectance of cyan only is 0.47 and it is 1.82 with transparent film 1 and 1.02 with transparent film 2. However in this example, the spectral difference is lower with the supports (median RMSD is 0.005 with transparent film 1 and 0.006 with transparent film 2 while it is 0.014 for cyan only). It must be said that the reflectance of cyan is close to 10% over the whole visible waveband; therefore small spectral differences can yield to high color difference. The impact of the measurement must not be neglected here. Overall, it seems adding transparent supports to the model doesn't yield worse predictions.

The predicted spectra are also acceptable for the glossy film, with the exception of the transmittance for the yellow ink. However, these transmittance values are low, which explained the small spectral deviations. Even if the formulas are not theoretically appropriate to compute the indices of the glossy film, this support is practically not scattering. Thus, the two main physical events, reflection (mainly specular) and absorption, are well accounted for by the model. The method is well adapted to the first three supports which are all weakly scattering.

For the two translucent supports, the tracing paper and the translucent film, predictions are not always accurate enough. However, in terms of spectral differences, they are acceptable, except for the transmittance of the yellow and magenta inks. Predictions are worse for support 5 (translucent film), which is more translucent than support 4 (tracing paper) for which predictions are acceptable except for cyan in reflectance.

The predictions are not satisfying for the two other print supports, the white aluminum panel and the white coated paper, which are very diffusing. Predictions are particularly poor for cyan, the less scattering ink, in reflectance. For support 6, the white paper, predictions in transmittance are not precise enough either. There are no predictions in transmittance for support 7, as the white aluminum panel is opaque. The fact that the predictions are worse for the diffusing/scattering supports can be explained by the way our method works, as the computation of the passage matrix does not account for the scattering happening in the support. Yet, with these supports, predictions are acceptable in reflectance and transmittance for yellow and black inks. Yellow ink is the most scattering ink. The model is therefore appropriate for highly scattering ink printed on highly scattering support. Predictions for black ink are good whatever the print support. This is because the ink is so absorbing that beyond two layers (20 µm) it becomes completely opaque and the print support becomes spectrally meaningless.

Our method is considerably accurate for weakly scattering supports, whether they are transparent or very reflective, both in terms of color and spectral differences. Overall, the less scattering the support is, the better the predictions are. The method is not adapted to mid-scattering inks (cyan especially) printed on mid or highly scattering support.

Table 1. Color and spectral deviations between predicted and measured spectra in both transmittance and reflectance.

Print support type			Ink only		transparent film 1		transparent film 2		glossy film		tracing paper		translucent film		white paper		white alu panel	
Support thickness (µm)					70		200		70		100		250		200		3000	
			T	R	T	R	T	R	T	R	T	R	T	R	T	R	T	R
Support only	DE00		-	-	0.44	0.99	0.16	0.89	0.60	0.66	1.83	1.13	0.28	1.03	3.34	1.70	-	0.62
	RMSD		-	-	0.004	0.005	0.005	0.005	0.004	0.015	0.050	0.010	0.005	0.019	0.013	0.063	-	0.020
C	median	DE00	0.81	0.47	0.84	1.82	1.58	1.02	2.62	2.42	1.50	3.09	3.97	3.91	3.47	9.33	-	7.80
		RMSD	0.022	0.014	0.012	0.005	0.014	0.006	0.003	0.014	0.023	0.013	0.035	0.021	0.011	0.086	-	0.065
	95th percentile	DE00	2.07	0.90	1.64	2.66	1.92	2.80	2.72	2.67	2.37	5.89	4.93	5.90	3.86	11.33	-	10.06
		RMSD	0.027	0.016	0.018	0.008	0.028	0.010	0.003	0.018	0.035	0.015	0.042	0.024	0.016	0.094	-	0.072
M	median	DE00	0.75	1.34	0.50	1.79	1.35	2.41	1.54	1.83	3.40	1.14	4.38	1.92	3.59	4.45	-	3.48
		RMSD	0.019	0.008	0.005	0.009	0.010	0.008	0.003	0.022	0.032	0.006	0.035	0.016	0.021	0.050	-	0.035
	95th percentile	DE00	1.52	1.46	0.80	2.27	1.67	2.73	2.22	2.00	7.00	2.79	7.61	4.36	3.91	6.43	-	5.39
		RMSD	0.024	0.009	0.009	0.011	0.012	0.010	0.004	0.027	0.053	0.019	0.047	0.031	0.022	0.071	-	0.053
Y	median	DE00	0.56	1.30	0.87	1.57	0.24	1.43	5.77	0.92	1.86	1.72	8.53	8.09	4.11	1.52	-	1.13
		RMSD	0.016	0.012	0.019	0.007	0.015	0.009	0.010	0.020	0.020	0.010	0.050	0.086	0.026	0.051	-	0.017
	95th percentile	DE00	1.12	1.62	1.70	2.32	0.70	1.78	8.66	1.27	3.11	2.46	12.99	8.75	5.02	1.89	-	1.19
		RMSD	0.025	0.014	0.033	0.008	0.016	0.014	0.013	0.023	0.030	0.020	0.070	0.099	0.031	0.055	-	0.020
K	median	DE00	0.04	0.56	0.13	1.14	0.50	0.96	0.01	1.27	0.28	0.77	0.06	0.75	0.06	1.22	-	1.19
		RMSD	0.000	0.002	0.000	0.003	0.001	0.002	0.000	0.003	0.000	0.000	0.000	0.002	0.000	0.002	-	0.003
	95th percentile	DE00	0.63	1.35	0.71	1.27	2.02	1.35	0.38	1.88	3.14	0.83	3.35	1.00	2.42	1.51	-	1.47
		RMSD	0.002	0.005	0.002	0.004	0.010	0.005	0.000	0.009	0.013	0.002	0.011	0.004	0.004	0.004	-	0.004

Conclusion

Optical models are slowly making their way into the industry mainly through CPMs based on the two-flux approach. With these CPMs, the macroscopic measurement of the reflectance and transmittance of only one component can be enough to predict the reflectance and transmittance of any number of similar components. But these methods have limited applications and do not work well with translucent layers. More importantly, they are unable to predict the color of the superposition of inks on a support knowing the individual contributions of each element, even though some methods have been implemented without enough accuracy [20-21].

Here we present a method to predict the color of the superposition of inks on a support knowing the spectral characteristics of the individual solid inks and the unprinted support. This method is based on the four-flux model.

Results show that this method is suitable for weakly scattering print supports. It is also accurate for diffusing supports in case we print very scattering or very absorbing inks but it is not appropriate for moderately scattering inks (such as cyan). This hinders the use of the proposed model as diffusing supports are essential in the printing industry to have large color gamut.

Yet, the main contribution rests on the characterization of the inks and the support. Once the inks intrinsic characteristics are determined, only the measurement of the spectral properties (reflectance and transmittance) of the unprinted support is required. Hence, no calibration is required. With the proposed model, we can generate color by superposing fulltone/contone layers of ink inside the printed volume and get predictions for certain types of support. This could be a useful CPM for color contoning workflow [22]. However, halftoning techniques remain the main methods to create color. Thus, future work will focus on extending our method to halftone layers.

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