Practical Ink Selection for Multispectral Printing in the Graphic Arts Industry

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Abstract

This paper shows how to optimally select aqueous inkjet inks in order to reproduce objects typical for graphic arts use. Using a modified 7-channel inkjet printer various inks are printed on a proofing paper exhibiting no optical brighteners. First different methods for linearization and ink limitation are examined and discussed. This is followed by an analysis of the colour- and spectral gamuts, namely the spectral gamut index, resulting from the chosen primaries. A spectral reference dataset has been created representing the spectral variability of offset and gravure printing processes. A modified spectral Neugebauer model is used for the prediction of the spectra from driving code values while linear regression iteration was used for the backward model. Finally the resulting spectral matching accuracy is evaluated.

Introduction

Digital contract proofing, using metameric reproduction, has nowadays reached a high level of colour accuracy. The digital proofing forum [1], to be held this year for the fifth time has clearly indicated this trend. Beside the wrong usage of the system and problems for unambiguous interpretation (Ripping) of PDF-files comprising new PDF features like layers, transparencies and overprinting, there are two predominant issues. On the one hand digital proofs exhibit a certain amount of colour inconstancy which becomes evident when inspecting a proof under different light sources. Such a degree of metamerism (illuminant and observer) between the proof and the original today's customer will hardly accept [2]. Both issues could be dealt with using spectral reproduction, in this context considered as Multispectral Printing. With a proofing system that incorporates a high degree of spectral variety one can choose the most colour constant spectra [3]. A closer spectral match between the original and the proof will result in less illuminant and observer metamerism. It should be noted that multispectral imaging is capable of solving many more purposes beside these [4,5].

Beyond academic use, Multispectral Printing, considered here as multichannel (n >4) reproduction of object colours using a digital printing process and having a lower degree of metamerism, is getting increasingly interesting for practical implementations in the graphic arts. More and more desktop inkjet printers are capable of printing 7, 8 or even 12 inks. Generally the additional ink cartridges are filled with diluted cyan, magenta or black inks in order to achieve a smooth gradation of vignettes and transitions. Using today's out-of-the-box refilling products greatly facilitates the ink supply. Having an inkjet-printer capable of printing dye- and pigment based inks one has an enormous degree of flexibility for setting up a printing system with primaries designed for Multispectral Printing.

How to set up a multispectral printing system

Generally speaking a multispectral printing system is based on a conventional digital printing system comprising a printer, appropriate software for driving and controlling the printer and suitable combinations of substrates and inks. Compared to conventional inkjet printing a greater number of channels is required. Though a multispectral printing system has more than four channels, disregarding the diluted primaries.

Printer

The colour difference, due to lacking homogeneity as well as short- and long-term repeatability must be as small as possible, see Table 1 for the figures of the printer used in this paper. Here an Epson Stylus Pro 7600 has been chosen because of its ability to both print dye-based and pigmented inks. Further selection reasons have been the printing resolution, the excellent registration, the availability to add refillable ink cartridges and a good print head cleaning routine.

Table 1: Colour difference across the sheet and over time (24h)

Parameter	
Mean ΔE	0,5
Maximum ΔE	2
95 % quantile	1,2
Mean RMS	0,015

Software

Usually printing systems come with a software driver for Windows and sometimes Macintosh OS. This piece of software mostly includes sophisticated transformation from RGB-data to the printer channels, known as RGB drivers, for different papers of interest. Some models additionally have a CMYK-version in order to bypass the before-mentioned transformation. Nevertheless there is no direct control of the ink limit, the gradation or the halftone model used; let alone the amount of the diluted inks.

Here proofing RIPs come into play. They offer different means for limiting inks and adjusting the gradation in order to achieve a high quality colour transform (e.g. an ICC-printer profile) between the driving values and the resulting tristimulus values. The printers rarely give separate access to the individual printing channels because they mostly use the halftone model provided by the printing vendor. Therefore special software is used in this project to control each of the printing channels individually.

Paper

The next player in Multispectral Printing is the substrate. In order to exclude the extra complexity introduced by optical brighteners a Schoeller proofing paper (H74261) with no optical brighteners in the ink receiving layer is used. It is a semi-gloss paper having a TAPPI gloss of 60 % and an ISO-brightness value of 92,3%. The light fastness is excellent, it was measured according to ISO 12647-7 [6]; the digital proofing standard. Further quality aspects such sas colour bleed, coalescence and ozone fastness are all perfect.

Inks

Nowadays there are several CMYK ink sets to choose from. In this study the Epson Ultrachrome inkset is complemented with the red, green and blue inks intended for use with the Epson Stylus Photo R800. These inks are filled into separate cartridges. Patches of each ink were printed as solids and measured to produce the reflectance spectra shown in Figure 1. By inspection, it is clear that the green and reddish inks cannot be reproduced spectrally by combinations of cyan, magenta yellow and black.

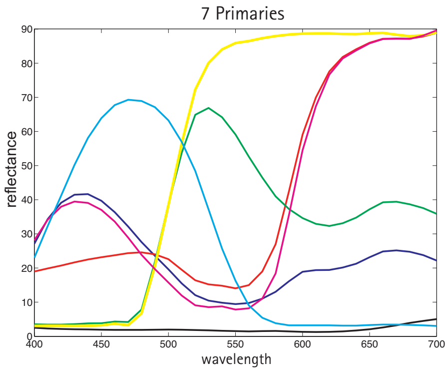

Figure 1. *Spectral reflectance of the 7 primaries used in this study*

For reliable results it is indispensable to operate the inkjet system in a controlled environment. This was done by the means of a controlled temperature (23 °C) and humidity (50 % r. h.) in the fogra lab.

Multi-linear Ink-limitation

Once a printing system has been set up the very first thing to do is the scrutiny of the solid tones. They are many good reasons for not printing 100% of each channel in order to achieve the outer limit of the colour space. The main reason is the prevention of "hooking", meaning that the more ink jets on paper line in the CIE a*b* plane get curved; like a hook. If excessive amounts of ink are deposited the colour locus tends to hook in CIELAB space. This is shown in Figure 2 for the "HP vivera" inkset printed on the semi gloss HP paper.

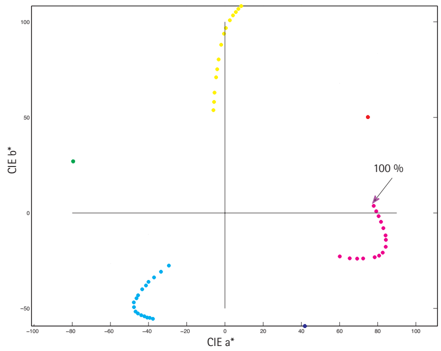

Figure 2. *Primary ramps for the HP vivera illustrating hooking*

Depending on the optimization criteria there a several ink limits of interest. For digital proofing one wants to achieve the closest value to a well-known aim to be simulated, e.g. the primaries of the ISO offset printing standard [7]. Photo printing on the other hand is looking for the biggest colour gamut. In this paper empirical ink-limits are chosen and finally judged by both the colour difference to the ISO aims and the spectral matching accuracy to be described later. A last point to consider in this aspect is the tone value sum (TVS) defined by the maximum amount of inks being printable without any printing problems like cockling. When printing solid inks on top of each other, the ability to print the later wet ink on top of formerly printed wet ink is call ink trapping. Inkjet inks printed on inkjet substrates usually have a TVS between 200 and 300 % depending on the physical and chemical design of the ink materials. In this paper a novel multi-linear ink-limitation [8] method has been used. Here all 2^m ramps, where m represents the number of inks, going from paper white to the pertinent Neugebauer primaries, are limited individually and stored in a m-dimensional array.

Linearization and halftoning

The next step is the so-called linearization process. The main reason for this is to improve the final colour characterisation of the system. Strictly speaking there are many ways to linearise a process. While in conventional printing broadband densities were used to setup a baseline for the printing process, nowadays different methods are utilised [8]. Depending on the pertinent colour a linearization with respect to CIE L*, CIE C* or CIE Y* is used in modern proofing solutions. For Multispectral Printing the linearization is strongly connected with the forward and backward model to be described later. Based on an evaluation of typical linearization methods for multispectral printing [8], the CIEL* linearization has been used in this study. The differences among the linearization methods turned out to be not very significant. This could be due to both the accuracy of the spectral model and the transformation from effective tone value (area coverage) to the driving tone values. It should be noted that the majority of tests has been conducted on colour patches rather than multispectral images.

Beside the colour accuracy the smooth rendition of vignettes or gradients is of major interest; sometimes even more important that colour. In order to achieve that goal the dot placement, often called halftoning, plays a predominant role. Again most printing systems offer a limited range of halftone screens, mostly modifications of a dispersed like screening. In this paper a Floyd-Steinberg error diffusion like halftone model has been used. The printing modes on the other hand range from single pass print at a low printing resolution (360 dpi) up to a 8 pass multi-weaving print at 1440 dpi having the choice of 5 different drop sizes each. This leads to an enumerable amount of possible combinations that has been visually evaluated with the test target shown in Figure 3 for a reasonable amount of combinations.

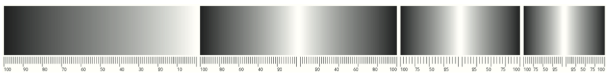

Figure 3. *Test target for checking the smooth rendition*

The spectral fingerprint of a printing system therefore depends on a variety of system parameters that needs to be documented.

Spectral Dataset

In the graphic arts industry at least two different groups of originals have to be addressed. On the one hand originals such as artwork, textile, wood or plastic while on the other hand production prints serve as the colour reference that are to be reproduced. Concentrating on the essentials for ink selection for multispectral printing, two typical datasets have been used for spectral evaluation. Both are based on spectral measurements of 1485 patches of the ECI2002 test target; a subset of ISO 12642-2. The first set is derived by statistical evaluation of a print run using offset while the second set originates from a gravure print run. These spectral reflectance curves used represent practical offset and gravure samples in daily catalogue and publishing work. A more comprehensive and substantial dataset including other printing processes such as flexography or screen-printing is currently under development.

Spectral Model

In this study a Yule-Nielson-modified spectral Neugebauer model (YNSN) is used for the forward model, as described by Wyble [9]. The effective tone values are calculated using least square analysis, described in the same paper.

Since an analytical inversion of Neugebauer equation is impossible to accomplish, it must be approximated by a numerical, iterative approach [10, 11, 12]. As already indicated in the spectral gamut discussion, an exact reproduction of requested spectra is often not possible. Therefore one candidate out of the multitude of available spectra must be selected, based on a reasonable error metric. A good overview of spectral and colorimetrical metrics is given by Imai, Rosen and Berns [13]; complemented by the SCI method by Viggiano [14]. The spectral accuracy is measured by the means of 24 observers [17]. It was found by the group centered around Prof. Hill, Aachen, that the average colour difference is poor indicator of the overall colour reproduction quality. Hence the maximum colour difference of the worst-case observer should be considered alongside the colour difference formulae like CIELAB 1976 and CIEDE2000.

The spectral based separation is done by the means of linear regression iteration as suggested by Urban [15]. This method inverts the YNSN-model, utilizing it's affine multi-linearity in the 1/n space. By means of linear regression, a sequence of colorant combinations is constructed converging to a colorant combination, which approximates the desired reflectance spectrum in the sense of the smallest RMS error. The performance of the current implementation slightly depends on the starting values chosen for the iteration. Therefore different starting values have been tested for each spectrum of the spectral dataset separately by means of the smallest RMS.

Spectral Gamut Index

As discussed up to now the spectral fingerprint of a printing system depends on a variety of system parameters that need to be addressed when dealing with spectral characterisation. The ability of an imaging system to synthesise a specific amount of spectral variability is often called Spectral Gamut even if there is no clear, agreed upon, definition, as for grey balance. In this context an interim connection space has been introduced by Rosen in [16], which complements CIELAB with three additional coordinates called "PQR".

Focussing on practical ink selection this study defines a spectral gamut index as follows:

a) Determine the spectral dataset to be reproduced (e.g. a multispectral image, a graphic arts dataset, etc.)
b) Determine the spectral noise level of the printing system characterized by shortcomings due to short and long term repeatability and measurement issues.
c) Setup the pertinent printer-model (forward and backward).
d) Establish the tone values for each spectrum (separation)
e) Print and measure the estimated spectra using the tone values (d).
f) Conduct the spectral comparison using the noise-level as a tolerance sleeve.
g) Compare the spectra within the tolerance to the entire dataset and calculate the percentage of spectra that fulfilled the condition.

Though the spectral gamut index only depends on three major parameters: the printing system including the measurement setup, the spectral model for prediction and separation and the spectral dataset of interest. It therefore serves as an additional objective function for selecting the optimal ink within a multispectral printing system.

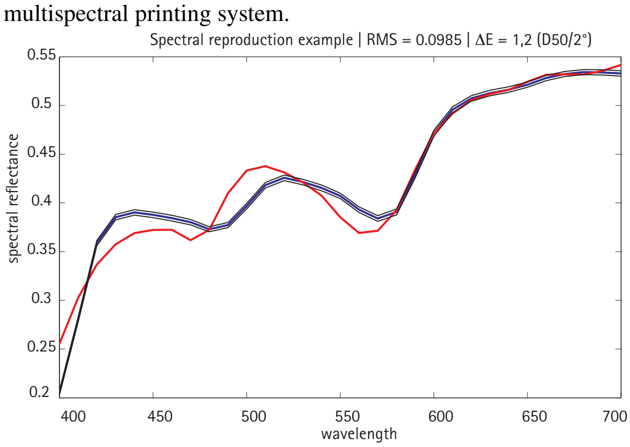

Figure 4. *Reference (blue) and printer noise (black) vs. printed spectra (red)*

A showcase offset reference and reproduction can be seen in figure 5. The blue spectrum illustrates the reference to be reproduced while the surrounded black line denotes the printer's noise level. The latter is determined by the means of the standard deviation of 471 reference samples printed across the sheet and over 3 days, see Table 1. In this example the multispectral reproduction (red line) is not considered being within the spectral gamut of the multispectral printing system and therefore doesn't contribute to the spectral gamut index. Note that, from a colorimetrical point of view, this multispectral reproduction is almost ideal.

Table 2: Spectral Gamut Indices in percent

Coverage factor	Dataset "Offset"	Dataset "Gravure"
1	1	1
2	4	5
3	6	9
4	10	15
5	13	20
6	18	26
7	22	33
8	25	41

Based on the two datasets used in this study, comprising 1485 spectra each, the corresponding spectral gamut indices are given in Table 2. Considering the selection of out-of-the-box inks, rather special designed ones the results are encouraging. In order to obtain a concept of the overall spectral matching performance the printer's noise level has been expanded by the means of a scalar, called coverage factor. It can be seen that the set up used in this study works spectrally better for gravure than for offset samples. A slightly different trend can be seen when examining the colorimetrical performance, given in Table 3.

Table 3: Colorimetrical analysis (D50/2°)

		Dataset "Offset"	Dataset "Gravure"
ΔE^*_{ab}	mean	1.9	5.9
	std	0.9	3.2
	max	9.3	25
ΔE^*_{00}	mean	1.2	3.9
	std	0.7	11.5
	max	6.9	1.9
ΔE^*_{00} among 24 observers	mean	6.9	11.2
	std	0.3	0.2
	max	7.5	11.6

Discussion

At this early stage of the project only one set of inks and only colour patches have been used. Nevertheless the procedure for setting up a multispectral printing system could already be applied to selecting other materials such as paper.

The measures for multi-linear ink limitation, at the very beginning of the setting up procedure, seems to be essential. This is due to the possibility that high amounts of inks are deposited by up to 7 channels on the same spot of the paper, leading to very dark colours. This turns out to be a roadblock for iteration algorithms, which would then have to start or iterate in a "dark hole".

The linearization method does not significantly affect the spectral accuracy evaluated so far. This could be due to the compensational effect in the transformation from effective tone values to the driving code values. Focusing on images and smooth transitions, the linearization may need more attention.

Modeling issues seem to have the greatest effect on the overall system performance. Here a systematical evaluation is planned, where different Yule-Nielsen n-values, various methods to compute the effective tone values (area coverage), different starting values and the multi-linear weighting concerning the tone value sum (TVS) are to be analyzed.

A final aspect is the measurement device used for the spectral readings. It is very convenient to use chart readers in order to measure many patches spectrally in a short period of time. Great care has to be taken when handling the samples because it is very easy to damage the patches by the internal transport mechanisms.

Conclusion

In this paper the roadblocks for practical ink selection in the graphic arts industry have been discussed. Using the set up procedure incorporating multi-linear ink limitation, linearization including a smoothness control and the YNSN and LRI spectral separation method respectively one can test different ink sets or variations thereof. Focusing on the spectral gamut index, a major property of a multispectral printing system, one can chose the ink or ink set that produces the system with the highest spectral gamut index.

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