Spectral printing with a CMYKRGB printer: a closer look

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Abstract

With the advent of multi-channel technologies, printers offer more and more possibilities for spectral reproduction. In order to print a specific color sensation, there are now more degrees of freedom when it comes to combining inks (i.e. more metamerism). In this paper, we take the example of a CMYKRGB printer and propose to visualize the extent of its spectral variability (or degree of metamerism) through the analysis of so-called paramer-mismatch gamuts. We then evaluate the suitability of the recently proposed LabAB interim connection space in the design of look-up tables for spectral color management. We demonstrate in particular that the spectral variability of this printer is small enough to drastically reduce the number of necessary grid points needed to sample the connection space without loss of perceived quality.

Introduction

In the traditional color management workflows, colorimetric accuracy is evaluated with respect to one specified set of viewing conditions: one light source, one standard observer model. They do not allow to predict/control the appearance of the output (e.g. a printout) for other illuminants or for observers with a color vision that differs from the CIE standard observer. Only a *spectral* workflow allows the control of the printed reflectance. In this paper, we focus on multi-channel printing. If all printable spectra are known (the spectral gamut), one can then decide which combination of inks will engender the most accurate rendering under any given light. Although the state-of-art inkjet printers do not have a very large spectral variability[1], recent studies [1] have shown that it is possible to achieve very convincing metameric effects with 7-channel printers. Unfortunately, the underlying pixel-wise direct computation is numerically expensive and requires much processing time for megapixel images making it unattractive for the industry. In addition, it is impractical to encode these transformations in lookup tables for faster processing because the high dimensionality of spectral space requires enormous storage space for the tables. Approaches were proposed to reduce the dimensionality of the problem by transforming the spectral data to a so-called *interim connection space* [2, 3, 4]. Even though corresponding lookup table encodings are inferior with respect to spectral accuracy, they were free of banding artifacts [5], a problem observed in direct computation [6].

Among the proposed interim connection spaces, the recently proposed LabAB [4] was claimed to offer the best compromise with respect to memory requirements, reflectance reconstruction accuracy and perceptual uniformity. In this paper, we first propose to visualize the so-called paramer-mismatch gamuts of a CMYKRGB printer in order to evaluate its spectral variability. Additionally, we investigate the suitability of LabAB in the design of small-sized look-up tables for a multi-channel printer. We show in particular that the number of grid points needed to sample the space can be drastically reduced without loss of perceived quality.

The LabAB interim connection space

The LabAB space [4] consists of the concatenation of two perceptually-uniform LAB2000HL[2] color spaces [8], each one based on a different illuminant. The lightness channels of these two spaces being highly correlated [9], one is discarded, which results in a five-dimensional space. The two illuminants I_1 and I_2 are to be chosen with respect to a specific application, although they should be as different as possible in order to minimize redundancy within the space. In this paper, we propose to use CIED50 for I_1, as it is the standard illuminant used in ICC profiles. As for I_2, we used the same approach as in [4]: we made a selection θ of spectral power distributions that we decorrelated from CIED50 by Orthogonal Subspace Projection before extracting a so-called *representative* illuminant by principal component analysis. We considered a total of 74 illuminants for θ: four CIE daylights (D50, D65, D80 and D100), the CIE A and Fluorescent Series as well as the full collection made available by the National Gallery of London [10]. We divided this group into four categories: daylights, Light-Emitting Diodes (LED), fluorescent and tungsten-based lights. Figure 1 shows the CIE 1931 xy coordinates of the representative illuminants (white points) for each category. Figure 2 illustrates the composition of LabAB.

Paramer-mismatch gamuts

Definition

Let us consider a set of parameric printable spectra that render almost the same color under light I_1 ($\Delta E_{00} < 1$) but different colors under I_2. This set of colors under

[1] We define the *spectral variability* of a printer as its degree of metamerism, i.e. the size of the gamut of reflectances creating the same color sensation under a given light.

[2] LAB2000HL is a hue-linear version of the LAB2000 color space [7], designed so that the Euclidean distance within the space agrees with the CIEDE2000 color difference equation.

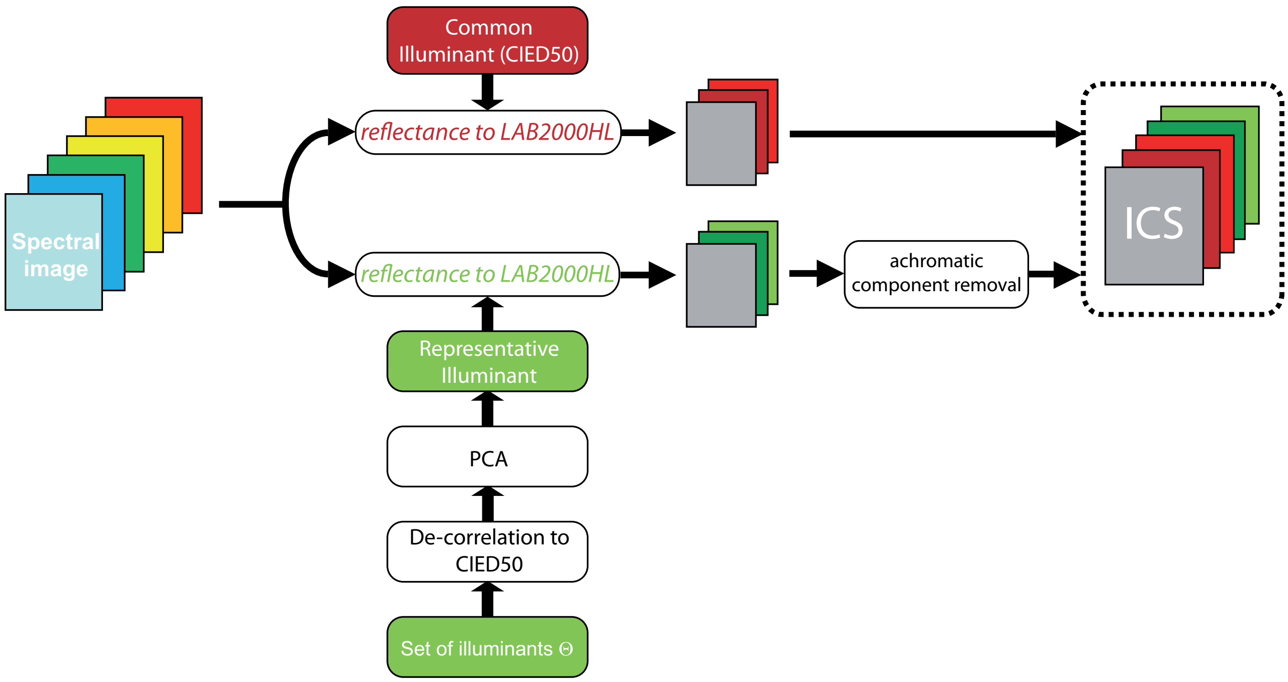

Figure 2. Conversion of a spectral image to the LabAB interim connection space (figure taken from [4]).

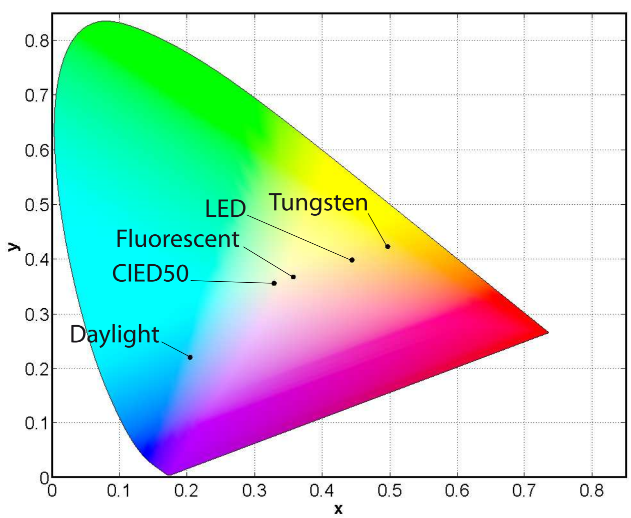

Figure 1. CIE 1931 xy chromaticiy diagram and coordinates of the white points of the representative illuminants for each category. Note that they are all de-correlated from D50, which explains for example why the representative daylight is so far away from D50. See Figure 4 for the spectral power distributions of these illuminants.

I_2 is referred to as a *paramer-mismatch gamut* [1]. There exist such gamut for each printable color under I_1, but they obviously vary in size.

Visualization

We propose to visualize these gamuts to evaluate the spectral variability of a 7-channel CMYKRGB Canon iPF5000 printer with a Felix Schoeller H74291 270 g/m^2 paper (without optical brightener to avoid any effects caused by fluorescence). Only 4-ink combinations were considered (e.g. CMYK, CKRG or MYKB) as proposed in [1] since we observed that 5-, 6- or 7-ink combinations do not contribute much to the spectral variability of the printouts and are therefore of limited interest in the present study (i.e. most of the spectral gamut can be described with 4-ink combinations only).

In [1], Urban *et al.* introduced a spectral gamut mapping strategy, based on a sequence of colorimetric mappings within paramer-mismatch gamuts. We used this approach in order to compute the paramer-mismatch gamuts of a set of color patches uniformly sampled in the LAB2000HL color space. The gamut mapping strategy takes as an input two images, corresponding to the desired rendering of the output under two different illuminants I_1 and I_2. By creating a patch with color $(L, a, b)_1$ for I_1 and the full (a^*, b^*) plane for I_2 the paramer-mismatch gamut corresponding to $(L, a, b,)_1$ can simply be isolated by identifying those pixels whose colors were not affected by the mapping, as shown in Figure 3. In order to reduce the computation time, we use a rough quantization of the (a^*, b^*) plane (a pixel covers an area of $2.121\ \Delta E_{ab} \times 2.121\ \Delta E_{ab}$). For this reason, we counted a pixel to be within the paramer-mismatch gamut if its color is not changed by more than 3 ΔE_{00HL} units (more perceptually meaningful than ΔE_{ab}) by the gamut mapping transformation.

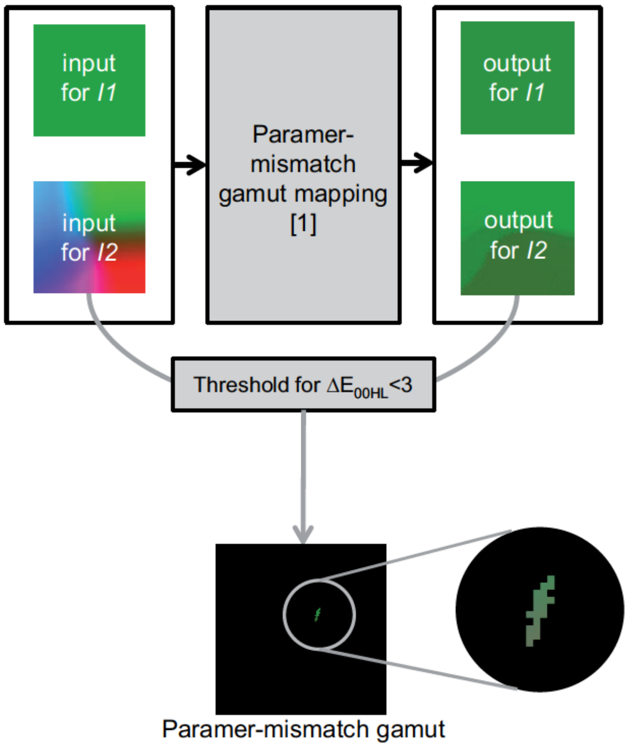

Figure 3. *Example of paramer-mismatch gamut. The desired rendering for I_1 consists of a patch with a single color $(L, a, b)_1 = (50, -27, 21)$. On this image, one pixel is 2.121 ΔE_{ab} units wide. Also, note that $1\Delta E_{00HL} \approx 1\Delta E_{00}$ [8].*

We measured the area covered by the paramer-mismatch gamuts for each sampled color in CIELAB, and depicted their sizes on the contour graphs in Figure 4, averaged for $L^* = (30, 40, 50, 60, 70)$, and for each representative light source. The outside boundary on each contour graph is nearly the actual printer's gamut boundary for the CIED50 illuminant. Table 1 gives the average paramer-mismatch gamut sizes measured. We also computed these sizes in the case where only CMYK inks are used, in order to demonstrate the extent to which the RGB inks can increase the spectral variability of this printer.

We observe that the average size and position of the largest paramer-mismatch gamuts depend on the second illuminant I_2. We also note a counter-intuitive fact: the largest paramer-mismatch gamuts are not found around the grey axis, but instead mostly in the blue and green hues, for all I_2. Even though the total number of ink combinations reproducing grays under I_1 is larger for our printer,

Table 1: Average paramer-mismatch gamut sizes (in square ΔE_{ab} units, averaged for $L^* = (30, 40, 50, 60, 70)$), for 7 channels (CMYKRGB) and 4 channels only (CMYK). Note that the whole (a^*, b^*) plane represents $256^2 = 65536$ square ΔE_{ab} units.

	Tungsten	LED	Fluo	Day
CMYKRGB	141	136	121	151
CMYK only	93	98	91	104

corresponding reflectances seem to have a smaller variability than spectra yielding blues and greens under I_1. Note that other choices for I_2 may engender different trends: as one can see on the last row in Figure 3, choosing daylight yields a slight shift of one of the regions of larger spectral variability towards purple hues. Nevertheless, we assumed that the five selected categories of illuminants are fairly representative for most applications in printing.

Grid points

In order to speed up processing, most color management systems use look-up tables to convert colors from a space such as CIELAB to control values (ink combination). To manipulate spectral data, we propose to use the LabAB interim connection space instead of considering high-dimensional pixels which would create extremely large tables. For example sampling each dimension with 33 grid points (this grid point number is used by accurate ICC profiles) would yield more than 10^{47} entries in the table for 31 dimensions, whereas in 5 dimensions, it would create only $39,135,393$. Furthermore, we argue that the last 2 dimensions of LabAB do not require as many grid points as the first three ones, due to the relatively small sizes of the paramer-mismatch gamuts of this printer (see previous section). Indeed, the larger the color differences that can be achieved under I_2 without perceived change under I_1, the larger the spectral variability of the printer under consideration and therefore, the more grid points are necessary to sample the last two components of LabAB.

Additionally, we propose to convert the AB coordinates of LabAB to relative coordinates as follows: $\delta A = A - a$ and $\delta B = B - b$ (where a and b are the a^* and b^* coordinates for I_1). This allows to shift the paramer-mismatch gamuts towards the origin where they can be accurately sampled by regular look-up tables.

Table 2 gives the maximal width spanned by all the paramer-mismatch gamuts together in the (a^*, b^*) plane as well as number of grid points needed to sample the last two components of LabAB in the case of different illuminants. Note finally that we constrained the number of grid points to be an odd number, in order to always have one in the origin.

We conclude that we can achieve the same precision as in ICC profiles for I_2, with less than half of the standard number of grid points (15 instead of 31). Intuitively, the ranges of δA and δB get larger as the chromatic difference between I_1 and I_2 increase, which is why we also observe

Table 2: Maximum width in the (a^*, b^*) plane and number of grid points necessary to sample the last two components (A/B) of LabAB with a step of 7.76 $\triangle E_{ab}$ units (as used by many ICC profiles).

Tungsten	LED	Fluo	Day
92.22 / 72.61	82.10 / 61.72	80.20 / 56.71	112.03 / 92.67
13 / 11	11 / 9	11 / 9	15 / 13

a correlation between the number of grid points and the distance of the white point of I_1 and I_2 in xyY coordinates.

Conclusion

We took the example of a CMYKRGB printer and visualized the extent of its spectral variability through the analysis of so-called paramer-mismatch gamuts in the case of several illuminants. We then evaluated the suitability of the recently proposed LabAB interim connection space in the design of look-up tables for spectral color management. We demonstrated in particular that the spectral variability of this printer is small enough to halve the number of grid point used in ICC profiles in the last two components of LabAB, without loss of colorimetric accuracy.

Acknowledgments

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Author Biography

__Steven Le Moan__ received his PhD degree in 2012 from the University of Burgundy, France. He is currently enrolled at the Technische Universität Darmstadt, as an Experienced Researcher in the Marie Curie-funded CP7.0 project (Colour Printing 7.0: Next Generation Multi-Channel Printing). His research is mainly focused on spectral imaging, image quality and visualization.

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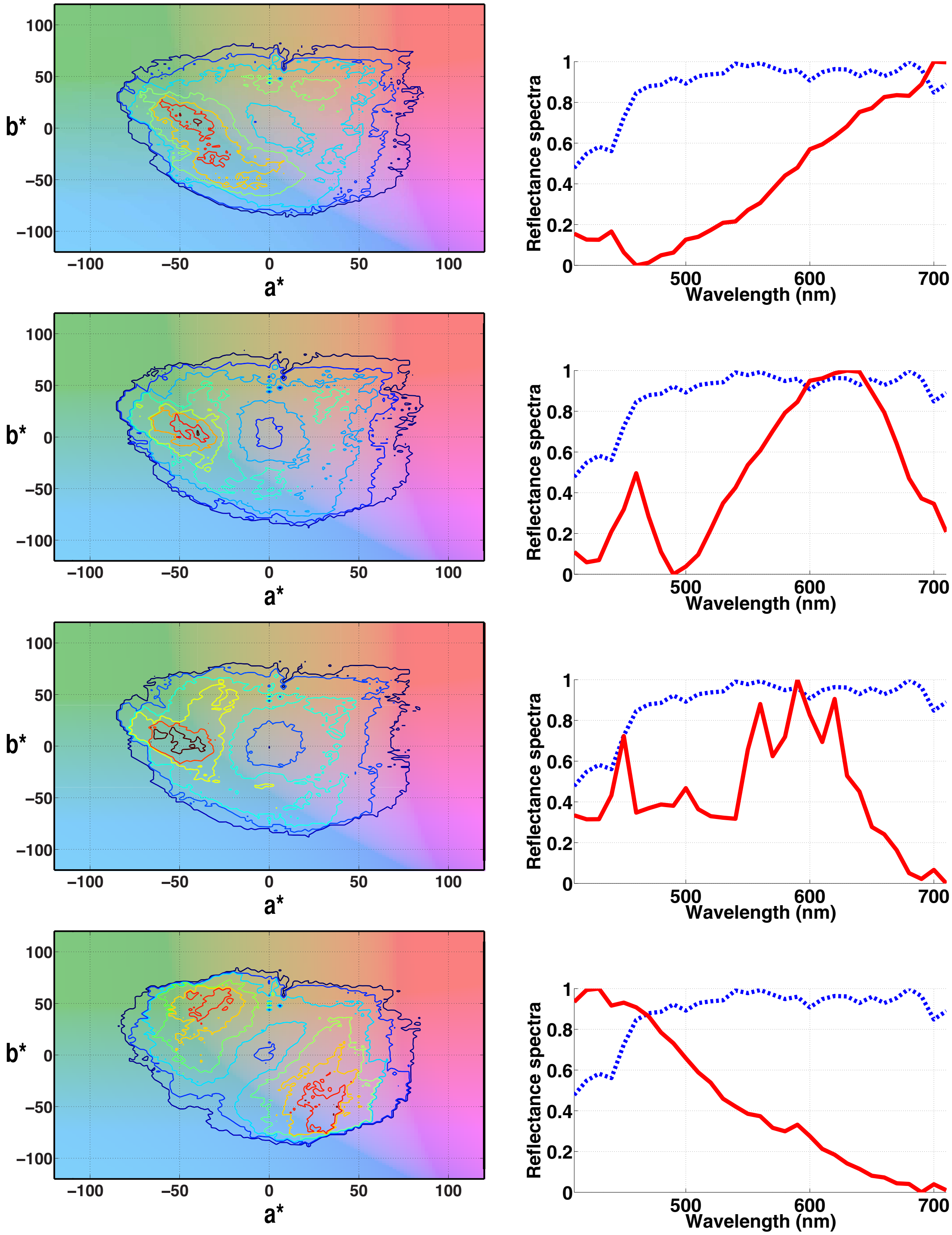

Figure 4. *Paramer-mismatch gamut sizes for I_2 visualized as contour plots within the gamut for I_1 and, Tungsten, LED, Fluorescent and Daylight de-correlated representative illuminants for I_2. The red contour are the boundaries of the areas where the largest gamuts are encountered. The right column depicts the spectra of I_1 (blue, dashed) and I_2 (red).*