Print Performance Evaluation of Ink-jet Media: Gamut, Drying, Permanence

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Abstract

A method to quantify gamut on various ink-jet media and ink sets is described. The robustness of the interpolation to the reduction of data points in the hue direction is demonstrated. The influence of the spectral measurement geometry on the gamut has to be taken into account when colour appearance is compared on samples with different surface finish.

A known effect of humidity on ink-jet prints is lateral dye diffusion, bleeding of coloured lines into white or other full colour areas and a darkening of the print. A quantitative description of this effect must be based on a carefully chosen test pattern.

Introduction

Ink-jet printing freed creative printing from the many restrictions proper to closed systems as photography or thermal dye transfer. It offers great flexibility in the number and types of colours, as for example process colours, hexachrome colour, spot colours and special effect colours. It allows even more choices for the media from plain to RC glossy papers, clear to metallic films and canvas to leather. With such a variety of very different products it is difficult to define ubiquitous image quality criteria and provide predictions about print performance. The paper addresses two areas of print evaluation namely colour gamut and humidity sensitivity of prints.

Part I: Gamut Investigation of Ink-jet Prints

Experimental Set-Up and Numerical Calculation

The experimental basis of the colour metric investigation are printed colour wedges from a digital data set. Pure colours (100% Y,M,C,R,G,B) are printed to white in steps of 5% ink load and to black, whereby black was mixed in as composite black. The wedges were printed on the same printer, with the same fixed colour profile (45° curve) and constant raster algorithms.

The prints are left to fully dry for at least 24h at ambient conditions (45-55% r.h.). They are measured with a proprietary spectrophotometer as described in [1]. It uses 45°/0° geometry (according to ISO 5/4). Each sample is measured in the range 380-750 nm in steps of 1.0 nm which are then averaged to steps of 5 nm for further processing. The spectra are converted into CIEL*a*b* co-ordinates based on the 2° observer and D65 illuminant.

To look into details of colour gamut and colour reproduction, a fine scan of the colour space is necessary. The gamut evaluation is based on 252 original data points measured on 12 printed colour wedges with each 21 density steps. The experimental points are interpolated to obtain a finer mesh of 10 units in L* and 2°-5° steps in hue. The resulting gamut wire plot is shown in fig.1

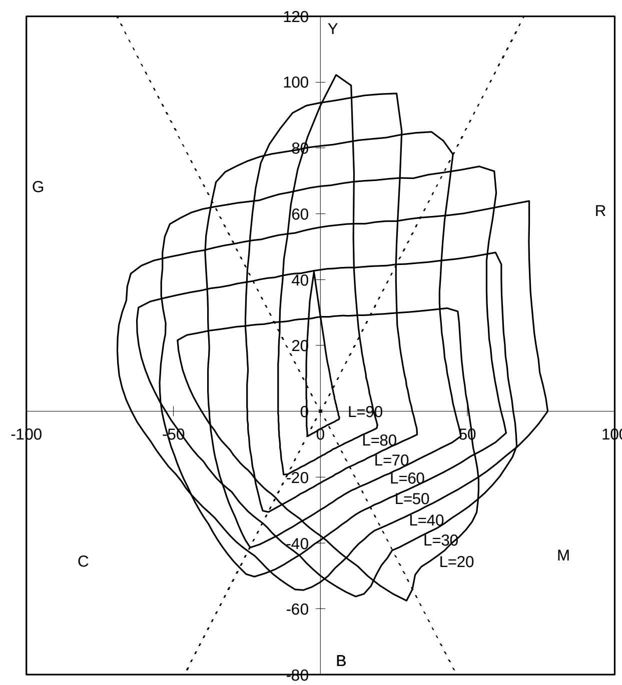

Figure 1: Full gamut wire plot

The interpolation from the measured data points to the finer wire mesh is done in two steps graphically represented in fig. 2a and fig. 2b. The graph shows a segment of the colour space between two experimental wedges (ribs). In a first step, 9 intermediate spectra are interpolated between point p1 and p2; both original colour patches on two adjacent ribs. Only three of the nine intermediate states are shown in the graph for simplicity. Although only sketched for one wavelength (550 nm), the interpolation is actually done in 75 wavelengths between 380 to 750 nm for the spectral absorbance of each of the nine intermediate states according to

$$S_p = (1-m)S_{p1} + mS_{p2}$$
$$0 < m < 1$$

The corresponding CIEL*a*b* values are calculated. The hue mesh is constructed out of 170100 interpolations. The second step of the interpolation relates to the L values along a rib between point p3 and p4. To find the correct CIEL*a*b* values for the equiluminance planes of the gamut, a linear interpolation in CIEL*a*b* is done as shown in fig 2b. As an example, the calculation for L=70 would be:

$$m = \frac{L_{p3} - 70}{L_{p3} - L_{p4}}$$
$$a_p = (1-m)a_{p3} + ma_{p4}$$
$$b_p = (1-m)b_{p3} + mb_{p4}$$

In a final step, equal distant hue angles are calculated and the gamut volume is obtained by adding the squares of the saturation for every point. This is strictly proportional to the areas of the equiluminance planes. The last step provides arbitrary units (divided by 70 for matching a previous database) not CIEL*a*b* volume units. The conversion is possible by using a factor of 70 π /6.

To test the quality of the interpolation, some experimental colour wedges were suppressed and the program was forced to spectrally interpolate over a much wider range. When omitting the red rib, the total gamut would only change by –2%, the Y and R sector by –3% and by - 6 % respectively. Omitting the blue rib reduced the B sector gamut by 5% and grew the M gamut by 9%. The suppression of the green rib had the largest effect as total gamut was reduced by 7%, and Y,C and G by 5%, 5% and 25% respectively.

The calculation replaces the missing experimental ribs red and blue very well and proves that the interpolation does predict the actual shape of the colour space satisfactorily in most sectors. The suppression of the green rib is not recommended. A further reduction in the number of interpolation steps could also be envisaged but needs further investigation.

Application

The gamut plots, total and sector gamut volumes have been used to characterise gamut in media and ink design.[1] The size of the mesh is fine enough to resolve differences in raster algorithm, print gloss and media tint. For gamut studies dealing with the comparison of different dye sets, such a fine mesh may not be needed.

The method attempts to describe the colour gamut of prints viewed under the same illumination conditions to characterise media, dyes and ink. It does not claim to provide an appearance based rating or colour matching.[2] The great variety of surfaces available for ink-jet makes colour matching very challenging.

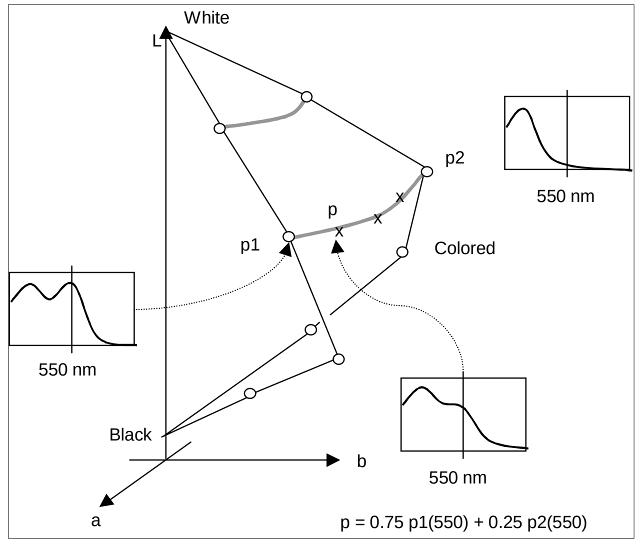

Figure 2a: Interpolation step 1

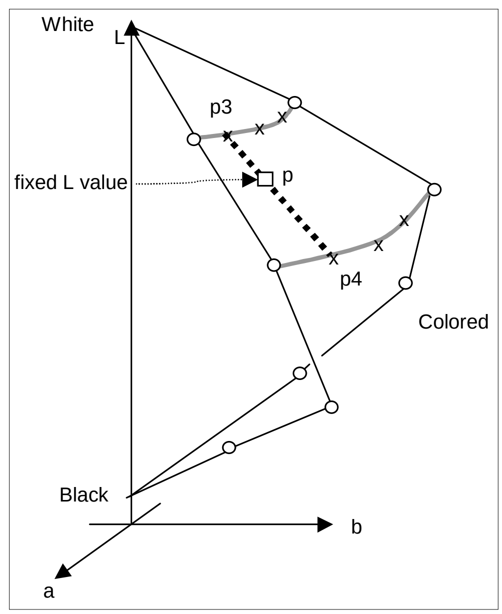

Figure 2b: Interpolation step 2

The influence of the spectral measurement geometry (0°/45° vs. 0°/diffuse) and on the CIEL*a*b* values has been reported in the literature.[3] Its effect on colour saturation and on surface finish is shown in fig. 3, for the case of a RC glossy paper a) and a fine arts print b), and NCS colour patches c).[4] The prints were spectrally measured both with 0°/45° geometry and with an integrating sphere. The CIEL*a*b* yellow and magenta sector are shown for the two measurements.

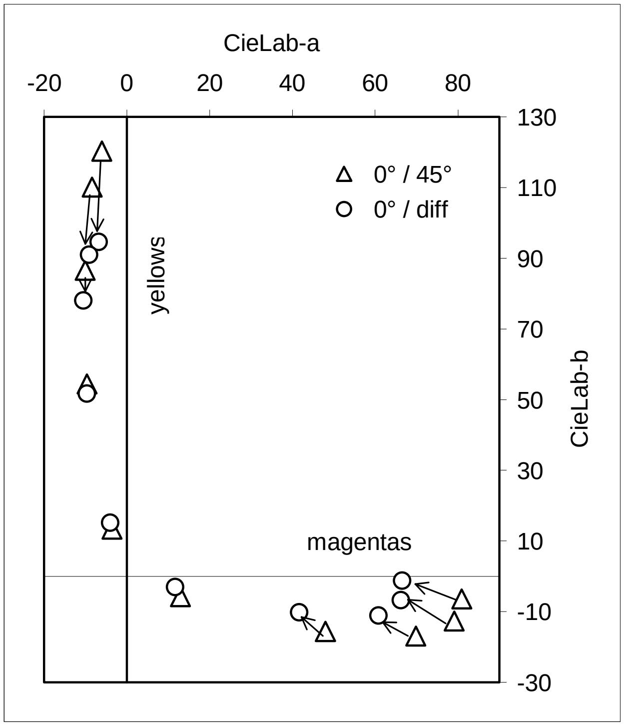

Figure 3a: Geometry effect on glossy prints

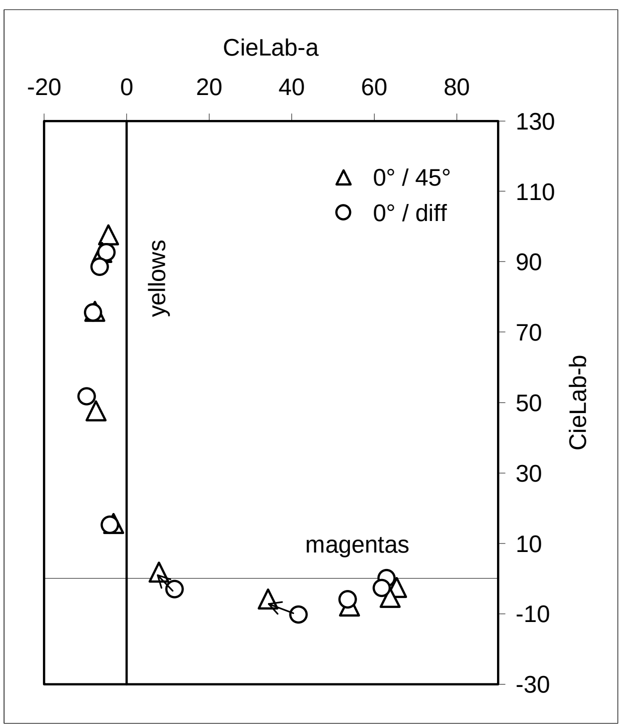

Figure 3b: Geometry effect on fine art prints

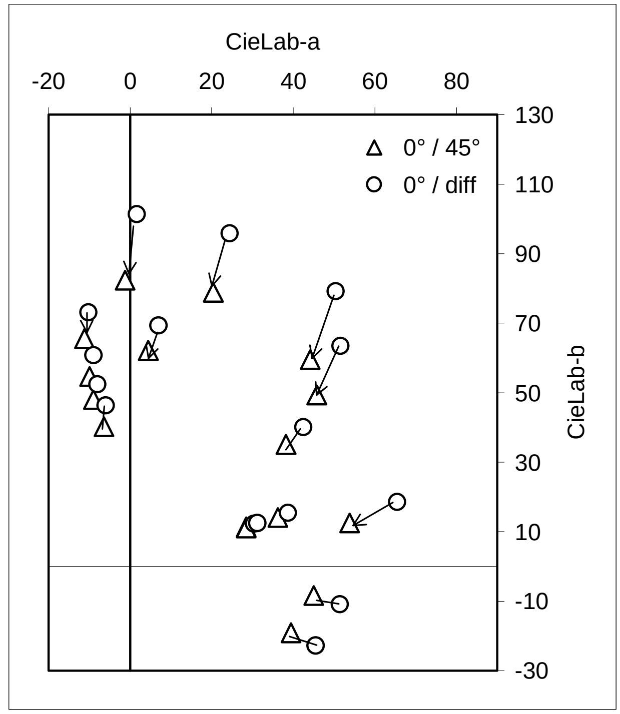

Figure 3c: Geometry effect on NCS samples

Whereas the measurement geometry has only a minor influence on the fine arts paper print(-1.5% for 45° to diffuse), it has a remarkable influence on glossy paper (-14 % for 45° to diffuse). Introducing an asymptote of 1.2 in the 0°/45° data approximates the 0°/diffuse data and seems to represent the visual appearance of the prints better.

Part II: Dye Diffusion in Ink-jet Prints

In a humid environment, an often observed change in ink-jet prints is the diffusion of colorants into neighbouring areas visible as colour bleeding into white or colour, unsharp text, colour shifts, density and contrast changes. The aim was to find a test target and quantitative evaluation procedure that gives reproducible results, is most critical and is able to discriminate between different ink and media properties. In low dot percent areas, the individual dot gain can be observed, but such dot gain turns out to be much less discriminating and does not well predict the bleeding of small text inside full colour areas. A much larger amount of humectants and water is available in a full colour square fueling diffusion.

Experimental Method

A set of samples consisting of different ratios of white lines to colour lines, of different colour densities and colour composition (monochromes and bichromes) was printed with two ink sets on several media to find the most sensitive and reproducible colour test pattern. The samples were submitted to climatic tests at 40°, 50% r.h. and 40° 80% r.h for 7, 14 and 21 days and the density changes for the different patterns were recorded.

Results

The diffusion data at 50% r.h show a very minor effect on all ink/media combinations. The 80% r.h samples generate a significant change over the period of 21 days. Dye diffusion creates a contrast increase (and colour shift) that is strongest in the intermediate density range of 0.5-1.5. This should be borne in mind when working on colour profiles, colour calibrations and colour studies. Reference samples need to be measured quickly after full drying and should be stored at below 55% r.h

The most discriminating test pattern for strong and weak dye diffusion is a square of full colour intersected by a grid of white lines which are 2-4 pixel wide (2w-4w) and spaced 4-8 pixels apart (4c-8c). Fig. 4 shows the yellow density change for the case of a very diffusion-fast (left) and a very strongly diffusing ink/media combination (right). The other inks showed a very similar behaviour.

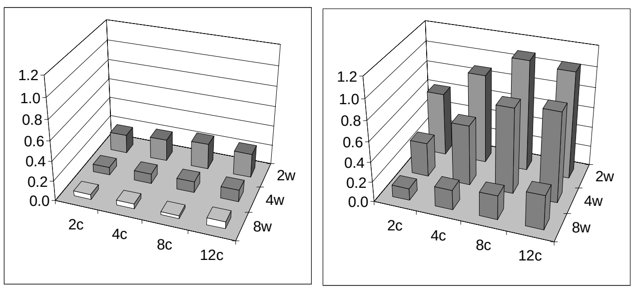

Figure 4: yellow density change depending on line width (2w-8w) and line spacing (2c-12c) for two different inks

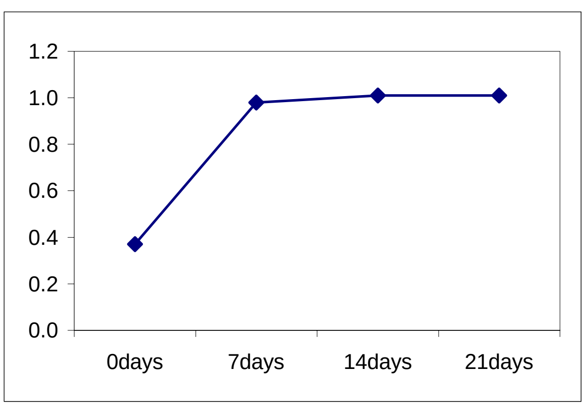

Figure 5: densities of test pattern after 80% r.h test.

At 40°, 80% r.h. the major changes in density appear in the first 7 days, although in most cases the plateau is not reached even after 21 days, see fig. 5.

Ink-jet prints are often laminated quickly after printing to protect them. Lateral dye diffusion occurred on such freshly laminated samples underneath the laminate. At least 8h of drying in 50% r.h conditions were needed to stop the diffusion.

Conclusions

Using spectral and CIEL*a*b* interpolation gamut can be quantitatively characterised for ink-jet media. The sensitivity of colour appearance to the measurement geometry, known from graphic arts, is even more important with ink jet prints which may have widely varying surface texture and surface finish.

A small grid test pattern is suitable to quantify dye diffusion under high humidity conditions. The target pattern provides a sensitive and reproducible response. Storage of print reference samples in controlled low humidity is recommended for any colorimetric work.

References

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2. T. Newman, CIE Divison 8: New Directions and Dimensions in Colour Standard, *Proc. Internatl..Colour Management Forum*, pg. 7. (1999).
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Biography

R. Hofmann has a degree in physical chemistry from the University of Goettingen. After postdoctoral studies in atmospheric sciences at the University of Colorado, she joined Ciba for research in the field of analytical chemistry and laser applications. Since 1985, she has been involved in research and applications for digital photography, photographic colour science and image evaluation of hardcopy technologies.