Optimizing Ink Jet Dyes and Dye Dilutions for Color Gamut

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Abstract

Modern ink-jet printers often provide more than 4 print heads. The additional channels can be used for faster printing, diluted process colours or additional dyes (green, orange). A proprietary gamut evaluation program is used to investigate the benefits of diluted inks vs. the addition of colours. The experiments are made using a four- ink printer. The eight-ink system has to be simulated by specially designed colour wedges that are printed with 4 inks each and are later assembled into colour space ribs. The colour gamut is calculated as the colour space volume sustained by the ribs using a spectral interpolation technique. The evaluation includes colour gamut size, tone reproduction and image quality criteria as well as permanence considerations.

Introduction

Photo-like ink-jet output on the desk top is a reality today. Two methods have been used to reach such impressive imaging performance, reduction of the dot size and multi-level printing[1]. Multi-level ink-jet printing is recognized as a very strong tool to approaches continuous tone output in digital printing techniques. In addition to the gamut gain, image quality aspects as grain can be much improved using diluted inks. As an ink supplier we have to address the question of how far the colour reproduction of digital images can be enhanced and how the other aspects of image quality benefit from offering more than one ink concentration per channel. The permanence of diluted inks is known to often be inferior to the full-strength inks[2]. This is a second parameter to be optimised in the selection of the right ink dilution.

Method

To avoid writing a dedicated printer driver for every ink combination, we simulated various different ink combinations on a 4-ink printer. If the emphasis is put on the maximum saturation for each brightness and each hue, the approximation to print with 4-inks simultaneously and to later assembly the color wedges is justified. Thus, the limits of the gamut can relatively easily be traced.

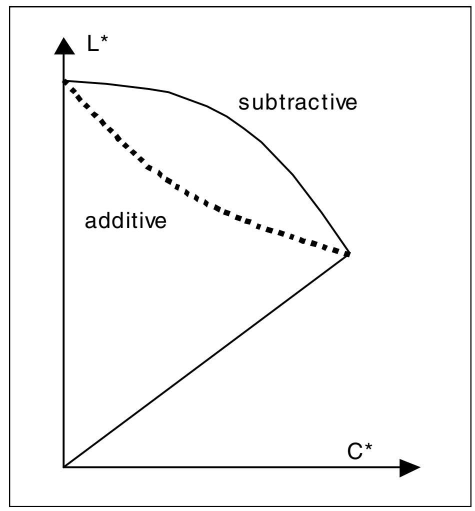

Figure 1. Diluted colours (sub) versus offset colours (add)

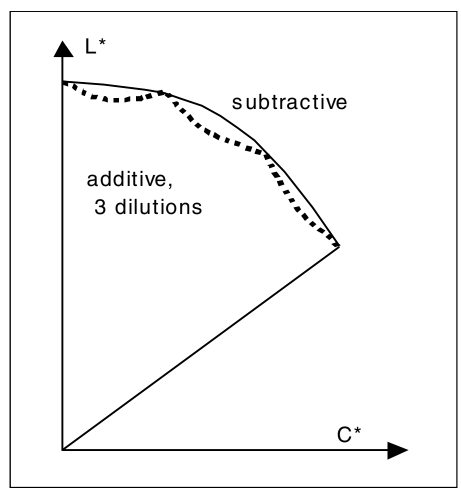

Figure 2. Gamut gain through dilutions

A sufficient condition for the gamut borders is that one of the three inks Y, M and C must be missing or must be present in maximum concentration.

Typical ink-jet inks for 4-ink printers contain 3-5% of colorant in solution to provide a maximum density of 2-2.5. This ink is referred to as full strength or 100% ink. For a 6-ink printer the 100% ink is often diluted to 40% or less by the addition of ink carrier. The study assumes the presence of 100% Y, M, C ink and one or two dilutions of M and C in addition to the full-strength inks.

The general character of gamut gains with the introduction of diluted inks is shown in figure 1 and 2. Figure 1 is a vertical cut of the CIE L*a*b* space with the hue direction of cyan. By applying the cyan ink on white paper in either subtractive (modulation by dilution) or additive mode (modulation by covered area) one obtains colors of very different saturation for a given brightness. The subtractive mode is superior in gamut size. The introduction of diluted inks in additive mode enhances the gamut as shown in figure 2.

An interesting point is that the differences in saturations shown in figure 1 are getting smaller if the spectrum of the cyan has less spectral side absorptions and a steeper green flank. In the case of a block dye, a hypothetical perfect colorant with no spectral side absorptions and a vertical green flank the differences vanish.

In most printers the multiple ink dilutions of a single channel are driven as shown in figure 3.

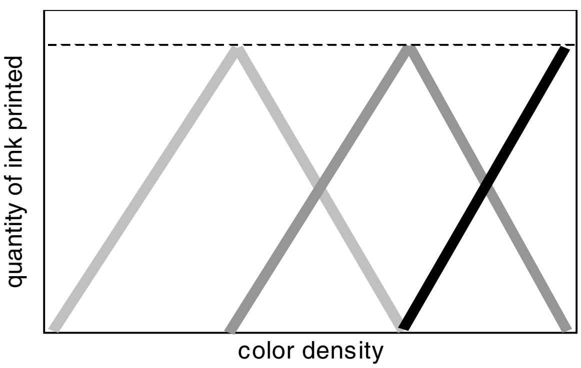

Figure 3. Mixing scheme of two dilutions and full-strength ink

In the first third of a wedge of increasing cyan density only the most diluted ink is used. In the higher densities of the wedge the increase of the more concentrated ink is compensated by a corresponding decrease of the more diluted ink in order to avoid ink loads exceeding 100% per channel. The full strength ink and the least concentrated ink are not simultaneously present. When simulating such wedges on a 4 ink printer it is necessary to mount ink combinations such as C'' (most diluted cyan), C' (diluted cyan) and C (normal cyan) simultaneously on the printer at the place of Y, M, C and K. In the case of one dilution of ink only the mixing scheme of the first two thirds in figure 3 must be applied.

The gamut limits are traced by six ribs. These ribs are made of six assembled wedges each from white to colour and six assembled wedges from colour to black using the six hues yellow, red, magenta, blue, cyan und green. All 12 wedges are split up in three parts following the mixing scheme of figure 3. For each part, the type of ink, the placement of the ink (Y, M, C or K station) and the mode increasing or decreasing must be noted.

In the case of two dilutions for cyan and magenta and only full-strength ink for yellow 24 different designs for the partial wedges and 10 different ink combinations are sufficient. Only in two of the 36 = 12 x 3 partial wedges, i.e. in the last two parts of wedge from yellow to black, it was necessary to have 5 inks simultaneously present. This case was avoided by a compromise as shown in figure 4. One of the 36 partial wedges is shown as an example.

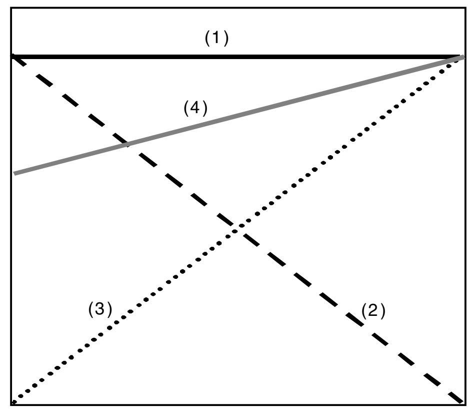

Figure 4. Last portion of the wedge magenta to black, (1) magenta at maximum, (2) removal of the dark dilution of cyan, (3) addition of the full strength cyan, (4) variation of yellow in the last third

Once all partial wedges are printed which necessitates 10 ink changes, their 20 steps each are measured at 75 wavelengths. The spectral data are grouped in 12 virtual wedges and are evaluated by a proprietary programme for estimating gamut[3] using 6 ribs. The procedure comprises two different interpolations. In the first part, the interpolation is done in spectral density and not in L*,a*,b* space. The spectra of corresponding steps in neighbouring ribs are linearly mixed. In a second part, the lightness is interpolated in L*,a*,b* space inside these newly created intermediate ribs to generate the final contour map and the equiluminance planes of the gamut.

In assembling the virtual wedges, the non-linear relationship between degree of dilution d and covered area A has to be considered. The overlaps between the partial wedges have to be chosen such that the area A partially covered with full strength ink of density D yields the same apparent density as the diluted ink with d*D density covering 100% of the paper.

$$A = \frac{10^{-D \cdot d} - 1}{10^{-D} - 1} \qquad (1)$$

A covered area (0 to 1)
D density of full strength ink
d dilution (0 to 1)

Results

To investigate the benefits of ink dilutions, the media (a photo glossy RC paper), the printer and the RIP were kept unchanged in the experiments.

For the study the degree of dilution was arbitrarily fixed to the three levels d = 15%, 25% and 40% of full-strength ink. Different combinations of these dilutions were investigated.

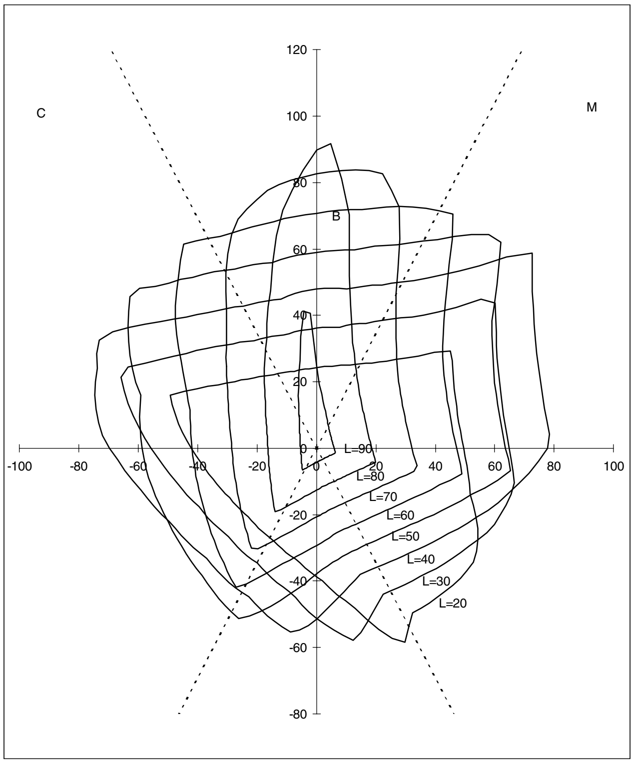

Figure 5. Reference gamut without diluted inks

Following equation (1) the corresponding covered area of 50%, 68% and 84% were chosen as overlaps for the partial wedges.

As a starting point, the gamut growth resulting from the introduction of 25% dilutions in magenta and cyan was looked at. The gamut of full-strength ink alone is shown in figure 5, the gamut including 25% ink dilutions in figure 6.

The gamut gains resulting from the addition of either 25% ink dilutions or 15% and 25% ink dilutions are listed for 6 different colour sectors in table 1. The overall gain by adding one 25% dilution is 12.1%, the overall gain adding 15% and 25% dilutions is 17.6%. As expected, doubling the number of additional dilutions does not double the percentage gamut gains. Overall, the second additional dilution adds only 6% to the 12% gain of the first dilution.

We compared an ink-set with only one additional dilution at a medium level of 25% to an ink set with two additional dilutions. The combination of a 15% and a 25% dilution, i.e. adding light dilution, is more powerful (+17.6%) than the combination of 15% and 40% ink dilutions (+14.3%), i.e. replacing the starting dilution by two neighbouring ones.

Table 1. Gamut gains by adding magenta and cyan at a) 25% and b) 15% ink dilution to full-strength ink

sector	a)	b)
Yellow	+4.5%	+9.0%
Red	+6.7%	+7.6%
Magenta	+24.6%	+30.7%
Blue	+14.5%	+21.4%
Cyan	+18.6%	+24.6%
Green	+14.0%	+24.5%
Total	+12.1%	+17.6%

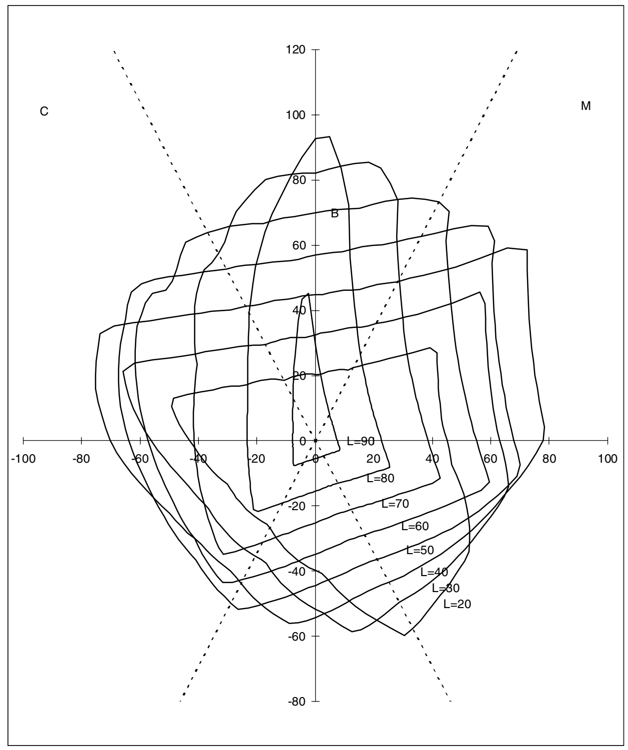

Figure 6. Sample gamut of full- strength ink and additional 25% dilutions in magenta and cyan

Table 2. Gamut gains by adding magenta and cyan at a) either 40% dilution or b) 15% dilution

sector	a)	b)
Yellow	+1.0%	+6.6%
Red	+6.1%	+6.5%
Magenta	+26.3%	+26.1%
Blue	+14.8%	+20.0%
Cyan	+18.0%	+22.1%
Green	+13.7%	+19.4%
Total	+11.3%	+14.8%

We wanted to know which of the three available degrees of dilution provides the best gamut gain in a system with only one additional dilution for magenta and cyan. Table 2 list the results. As is to be expected, the darkest dilution 40% yields the smallest gamut gain and the lightest dilution of 15% the highest.

Instead of adding ink dilutions to existing channels, additional color channels may be added (hexachrome ink). The results for such a system are listed in table 3. Considerable gamut gains of 18% can be achieved, that surpass the gamut gains due to ink dilution.

Table 3. Gamut gains by adding orange and green ink at full-strength to Y,M,C full strength ink

sector	gamut
Yellow	+35.3%
Red	+24.3%
Magenta	+0.6%
Blue	+0.0%
Cyan	+7.5%
Green	+28.7%
Total	+18.9%

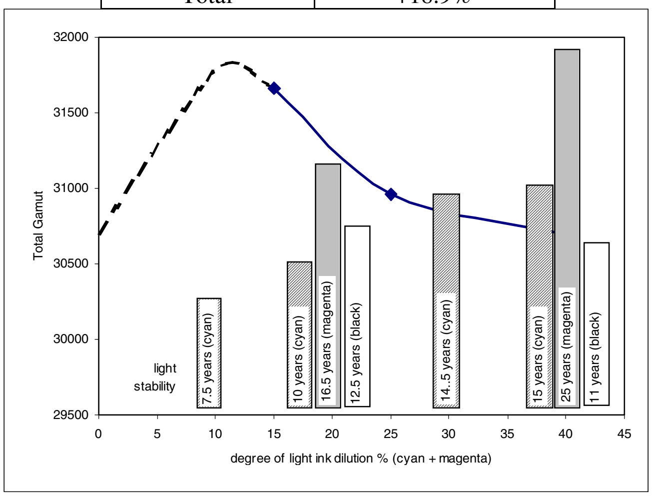

Figure 7. Total gamut depending on the degree of dilution of additional ink and permanence of diluted inks.

The three investigated cases of additional ink dilution and their contribution to gamut allow some general conclusion. The full-strength gamut is assumed as a baseline. Taking into consideration that an additional ink of 0% dilution means no additional ink at all we can establish a relationship between the degree of ink dilution and the total gamut as depicted in figure 7.

A known disadvantage of diluted inks is their often lower light permanence[2]. A trade-off has to be made between image quality and gamut advantages versus permanence. Figure 7 shows the decline in light permanence for the ink dilutions treated in the gamut study. Life expectancies are given in years at a display condition of 450 lux for 12h. Because the light cyan ink (15% dilution) is especially prone to permanence problems[2], we investigated the loss of gamut for a system with light cyan at 25% dilution and light magenta at 15%. We found a non-negligible gamut loss of about 4% compared to the case of twice 15%.

Gamut gains are not the only benefit of diluted inks. Advantages in tone reproduction are achieved as well. If the additional channels are used for dilutions in black instead of a third dilution of cyan and magenta superior grey balance may result. The measured colour differences between prints of uncorrected black ink dilutions reached 5 DE. Individually grey balancing each black ink solution may reduce this colour shift.

But the main advantage of more than one ink dilution is less grain. One aspect of image quality in ink jet printing is the conspicuousness of the least printable densities of an ink in another (sometimes referred to as peppering). It is evident that the use of dilutions and the smaller density difference of print dot and background reduce this conspicuousness. The reduction of grain and the smoothness of tone reproduction surpass the visual impact of the gamut gain and make diluted ink systems preferable to hexachrome inks for photographic output.

Conclusion

With frequent ink changes on a 4-ink printer, a 6- or 8- ink system can be simulated by assembling colour wedges.. The gamut gains expected from introducing a second ink dilution in the magenta and cyan channel could be estimated by such a simulation and could be compared to the benefits of a hexachrome system.

It could be demonstrated that the doubling of the number of ink dilutions does not double the gamut gains. The introduction of the second ink dilution has only half the power of the introduction of the first ink dilution. A general relationship of gamut versus ink dilution is proposed. Adding light green and orange in full-strength produces similar gains in gamut as adding two diluted inks. However, hexachrome inks do not offer the advantages in tone reproduction and in graininess.

References

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Biography

E. Baumann studied physics at Fribourg University. Since 1968 he has worked with Ilford in the area of photographic sensitometry, color science and image quality and has published several papers in this field. Since 1985 he has been active in digital imaging, first for digital photography later in ink-jet.