Colorimetry vs. Densitometry in the Selection of Ink-jet Colorants

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Abstract

The gamut performance of different ink-jet ink sets on photo glossy media was investigated using spectrophotometry. The influence of media gloss, paper colour and printing pattern is compared to the gamut variation due to the different colorants in the ink. Gamut size is not the only factor that is important for high quality photo-realistic ink-jet printing. Metameric properties of the ink sets as well as the reproduction of specific important colours are considered.

The current state of photo-like ink-jet printing is approaching but not achieving true continuous tone colour reproduction. The reduction of dot size from 300 dpi to 600 dpi does not change the colorimetric properties of the print. However, using multi-level inks brings more colour saturation thus approaching continuous tone colour reproduction.

Introduction

As ink-jet printing is becoming the technology of choice for photo-realistic digital prints, there is a rising expectation as to their quality and permanence. This puts a high demand on the components used. The selection of the colorants is an important part of a photo-realistic ink-jet system. Ink-jet colorants have to exhibit a range of properties, the most important of which are:

- Excellent solubility, non-reactive, stable in solution (for printing and head reliability)
- Good light stability (for final print permanence)
- Low toxicity
- Excellent colour gamut and colorimetric properties (for brilliant image quality)

This paper looks at certain aspects in colour reproduction and gamut and their relevance for the selection of ink-jet colorants. It further investigates some characteristics that distinguish high quality ink-jet prints from true continuous tone colour reproduction.

Method and Experimental Set-up

The experimental basis of the colorimetric comparison are colour wedges made with different ink-jet dye sets on photo glossy papers. The wedges were printed with the test ink-set from a digital Y,M,C,K file onto selected substrates. Pure colours (100% Y,M,C, R,G,B) were printed to white and black in steps of 5% dot percentage. Black was mixed in as composite black. The images to be compared were printed on the same printer, with the same fixed colour profile (45° curve) and specified half-tone algorithm. Photo prints were corrected for neutrality and printed on a Lightjet 5000 from an equivalent R,G,B file.

The wedges were measured in a proprietary spectrometer with automatic sample feed. The spectrometer is based on the commercial Bruins Omega 20, with Czerny-Turner monochromator, holographic grazing and photo multiplier. The equipment works as a pseudo- two beam instrument. It measures in 45°/0° geometry against a white backing and with a tungsten halogen light source (about 0.6 Mlux). The aperture size is 4 mm. Each sample is referenced to ideal white and measured in the range of 380-750 nm in steps of 1.0 nm which are averaged to steps of 5 nm for further data processing.

The spectra measured can be converted into a number of different units for example status A densities or CIEL*a*b* colour co-ordinates. Colour densitometry is popular in photography to investigate contrast curves. The status A filters are quite well adapted to typical photographic colorants (1). Ink-jet colorants vary more in their spectral properties among brands and make densitometry less suitable, see Fig 1.

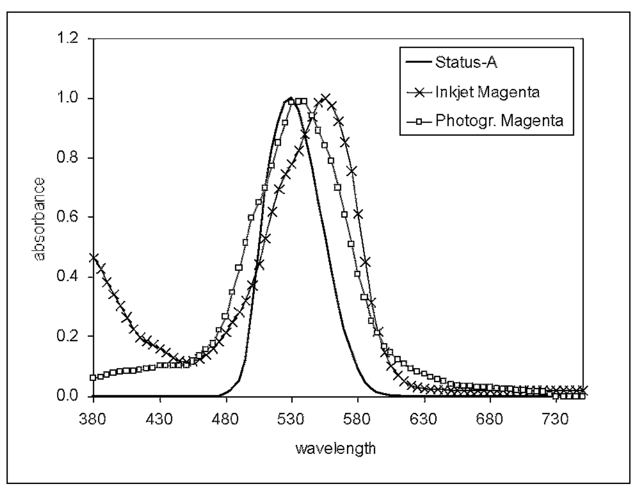

Figure 1. Status A green filter spectrum on a typical colour negative photo magenta and an ink-jet magenta

In addition, ink-jet inks in a set can be changed and mixed with a lot more ease than was possible in a photographic system where changing one colorant was a major technical effort. More than 3 or 4 colours in an ink-set are possible. To select the right colorants for an ink set, status A densitometry was no longer regarded sufficient and colorimetric criteria needed to be taken into consideration.

CIEL*a*b* colour co-ordinates are frequently used to make colour comparisons in photography. Although found to be deficient in describing colour appearance (2) in general, they are well adapted for colour comparisons of reflective prints viewed under standard illumination conditions. We used CIEL*a*b* coordinates (2° observer D65 illuminant for our comparisons.

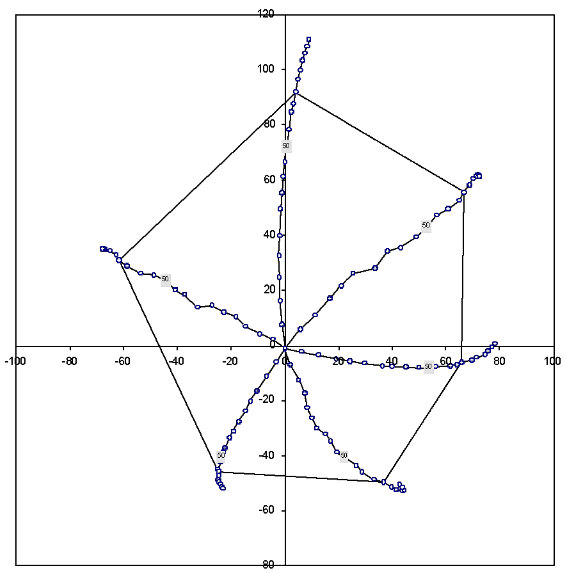

Figure 2a. Hexagon plot at 70% dot

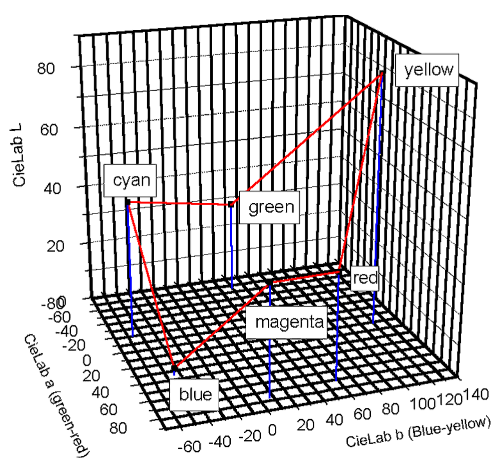

Figure 2b. Hexagon position in colour space

Gamut investigations are frequently done on hexagon plots which represent a projection through colour space on the points of maximum saturation, maximum density or a specified dot percentage. Figure 2a shows such a hexagon plot for a slice at 70 % dot in two-dimensional projection. Figure 2b shows its actual position in colour space. The hexagon approach is a very rough approximation of the actual colours space and does not allow the investigation of fine detail.

For our investigation, we used slices through the colour gamut at every 10 L* units interpolated from the printed colour wedges. The evaluation is based on 504 original data points measured on the 24 printed colour wedges each with 21 steps as described above. Intermediate lightness steps and the corresponding saturation along the axes of the wedges were linearly interpolated in CIEL*a*b* units as the step size is quite small (2-5 L* units). For the curves connecting the six main hue axis linear interpolation in CIEL*a*b* seemed no longer justified because the step size is much larger. For these curves, the original density spectra were linearly interpolated and the corresponding CIELab coordinates calculated. Experimental prints of intermediate hue curves have shown this method to be closer to the real gamut contours than the linear L*a*b* interpolation.

The resulting full gamut plot for the ink/media system in figure 2a is shown in figure 3b.

Results

The Influence of Ink and Media on Gamut

The very important contribution of the inks and colorants on gamut is well known. Three typical ink-jet ink sets gamuts are shown as a slice diagram in fig 3a-c. The inks are all printed on the same photo glossy paper.

Table 1

Gamut volume	**Ink set 1 (fig. 3a) media 1**	**Ink set 2 (fig. 3b) media 1**	**Ink set 3 (fig. 3c) media 1**	**Ink set 2 media 2**	**Ink set 2 media 2**
Y	8795	9966	8894	9165	8829
R	7529	7780	8045	6945	7299
M	5889	7180	8748	6932	7361
B	5151	5832	6479	5271	5951
C	5432	6001	5941	5878	5739
G	6788	8501	7423	7906	7952
Total	39585	45260	45531	42097	43130
Metam. volume	6	6	9		

The colour gamut volumes of the three ink sets on photo glossy media 1 per sector and in total are listed in table 1. The highest gamut has 13% more volume than the lowest gamut.

The media used is another very important factor even if we only compare the class of photo glossy products. Dot size, paper colour and paper gloss have an influence on the gamut.

The ink set 2 was printed on two other commercially available photo glossy papers that vary in colour and gloss from the first photo glossy. The gamut volumes are shown in the last two columns of table 1.

Table 2

	Media 1	Media 3	Media 2
		Paper colour	
L	96	95.5	92.4
A	0.2	-0.4	3.8
B	-1.6	1.0	-8
		Gloss	
20°	60	40	40
60°	91	76	78
85°	84	77	79

Compared to the photo glossy media 1, the two other media show a loss in gamut. The lowest gamut is 7 percent less than the total gamut volume on media 1. The main difference between the three media is their pre-print gloss and their paper colour as shown in table 2.

Whereas gloss, dot size and paper colour have a measurable effect, it is small compared to the contribution of the colorants. If the investigation is extended to other than photo glossy media, much larger media effects can be encountered. In a typical example we found a gamut reduction of 50% for the same ink printed on fine arts paper instead of photo glossy.

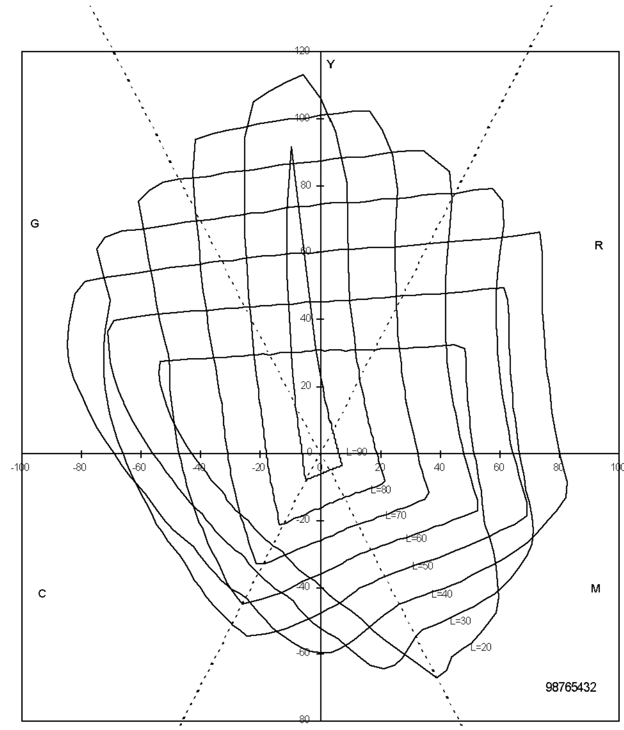

Figure 3b. Full gamut plot of ink set 2 on media 1

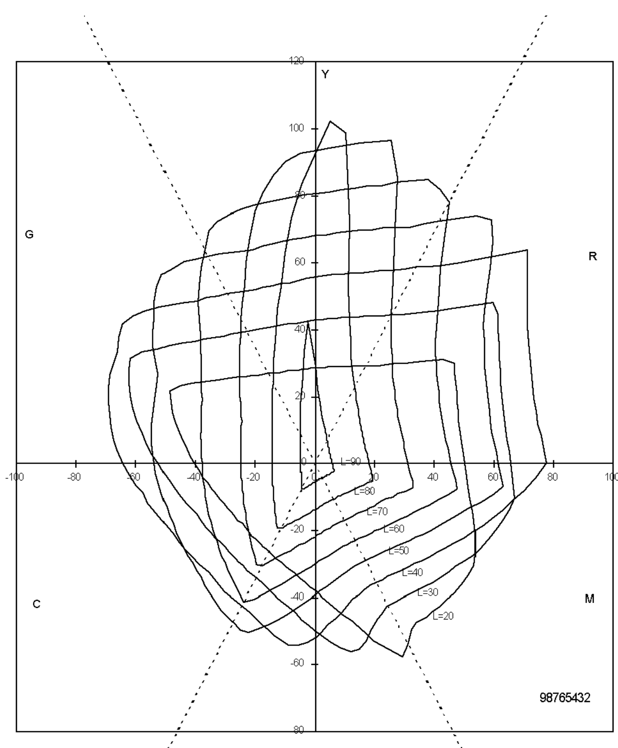

Figure 3a. Full gamut plot of ink set 1 on media 1

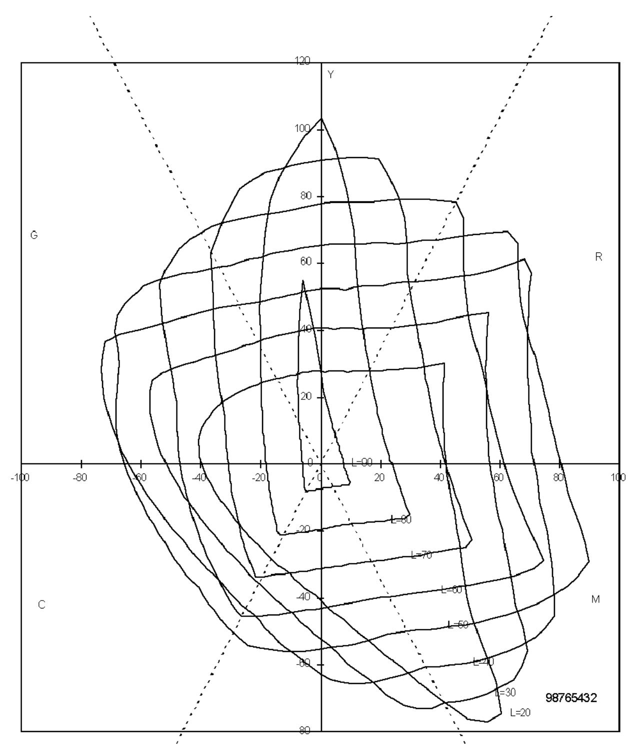

Figure 3c. Full gamut plot of ink set 3 on media 1

The Influence of Dot Size and Half-Tone Pattern on Gamut

Apart from components and inks, the printing mechanism is an additional factor to be regarded for its influence of colour gamut.

Table 3 summarises the gamut variations that resulted from printing the same ink/photo glossy media combination on the same printer (same print heads) with different halftone patterns. Care was taken to leave the curves and the maximum density unchanged.

The first halftone pattern is clearly inferior in gamut to the other 4 which are quite similar. A gamut loss of up to 6 percent can be accounted for by changing the halftone pattern.

Continuous vs. Half-tone Printing

It is often assumed that by reducing the dot size, the ink-jet print will finally resemble continuous tone prints. Although this may be true for extreme reductions this is not true on the current scale below 1000 dpi. While graininess and other image quality attributes benefit from the dot size reduction, the colorimetric appearance does not. Continuous tone images generally have an advantage in the reproduction of saturated pastel colours. Colormetrically, the additive mixing of full colour dots and white background leads to desaturation especially in light colours. This has been known from comparisons of offset printing to photography before the digital age.

For an ideal hard dot, the size of the dot should not have an influence on the colour gamut, as long as the coloured and the total white area stay the same. To verify this in a practical case, the same ink and media was printed with a 300 dpi and a 600 dpi print head and steps of same lightness were compared. In most areas of the colour gamut, the theoretical prediction that both should show the same colour gamut was well confirmed. The strongest variation was found on the green wedge shown here in figure 4 with a slight saturation gain for the 600 dpi system.

Table 3. Halftone-pattern

Gamut Volume	Screen	Ordered dither	FDRP line	FDRP Diffus	Stochastic
Y	8662	8763	8804	8795	8805
R	7152	7340	7283	7377	7407
M	4983	5398	5519	5450	5488
B	4919	5038	5118	5062	5042
C	5348	5688	5772	5726	5769
G	6903	7425	7578	7515	7569
Total	37968	39653	40174	39923	40079

This gain is probably due to the fact that dots do not have perfectly vertical slopes, but borders which tend to create a continuous tone step. However, this is only a very small approach to real continuous tone colour reproduction.

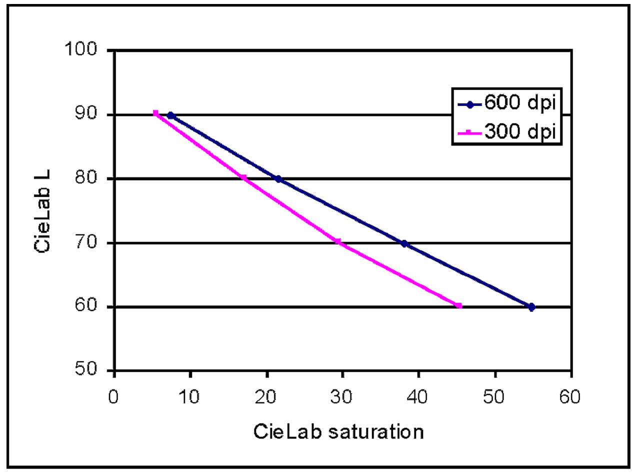

Figure 4. Colour saturation for 300 dpi vs. 600 dpi print

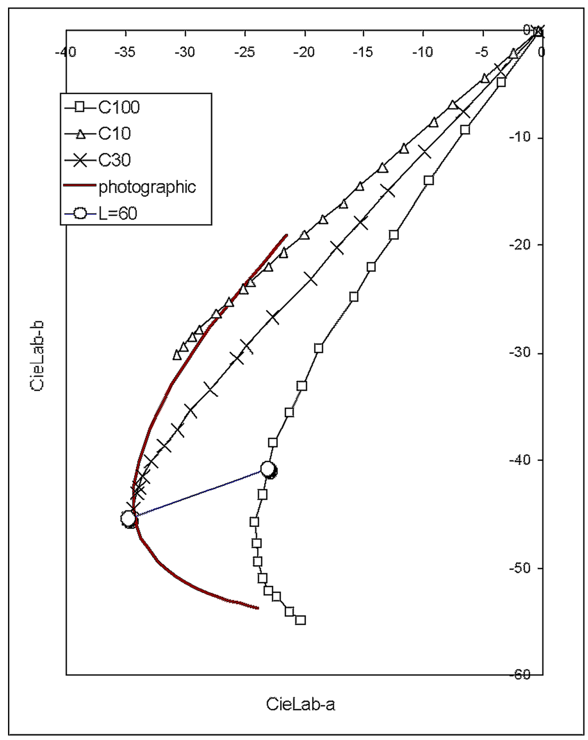

Figure 5. CIELab a, b plot for different ink concentrations

The better approach to achieve continuous tone printing is by creating intermediate colour shades through multi-level inks. Some printers now offer variable concentrations (typical 10%, and/or 30% ink concentration) next to the 100% ink. This allows better colour rendition and extends gamut in light areas. The efficiency of this second approach to continuous tone printing is shown in fig. 5, where the saturation for a

30% ink wedge is compared to the saturation of a wedge printed with the 100% concentration. The hue curves shown in fig. 5 are plots from cyan wedges printed with 100% ink, 30% ink, 10% ink respectively. The plots were measured on wedges printed with the specified ink concentration. The steps of equal lightness were compared. For the same lightness of 60 shown in the graph, the saturation difference between the 30% ink and the 100% ink is 10 CIELab units in favour of the diluted ink.

With even more different concentrations of ink, ink jet prints will approach continuous tone images. The combining curve 'photographic' is the true continuous tone curve for a cyan wedge made up of the same colorant.

Other Factors Important in Colour Reproduction for Dye Selection

Gamut is not the only factor important for photo- realistic colour rendition. On the contrary, if an ink set is very brilliant it will have to be de-saturated to render important colours as skin tones and many natural colours. This is done by adding black in finite steps. Often, at least in 300 dpi systems, the smallest step size is not fine enough to allow a balanced print and it creates a very grainy appearance. Colour sets with less saturated colours may end up with the better colour reproduction.

Brilliant colours are often obtained with very narrow absorption curves, but such narrow dye absorption curves can lead to metamerism. Illuminant metamerism (1) is created by the interaction of colour spectra with different light sources. A metameric index was calculated for the three ink sets of table 1 and is listed in the last row of table-1. For the metameric index a neutral grey wedge of the three ink sets is calculated from the dye spectra under illuminant A. The illuminant is changed to C while leaving the spectra unchanged. The resulting colours under illuminant C are compared to the original neutral grey. The step with the highest deviation from grey is chosen and its Delta E from neutral is given as the metameric index.

The ink set with the highest index is set 3, which has a magenta dye with a very narrow absorption peak. A high metameric number points to difficulties in balancing prints for different display conditions or changing illumination, as good neutrality will not be possible for tungsten as well as for daylight at the same time.

By the size of the gamut in a certain sector it is not possible to infer that all the important colours can be reproduced. The position of the sectors or the hue of the colorants is also critical. This can be demonstrated in the yellow sectors of ink set 1 and ink set 3, fig. 6. Both sets have a comparable yellow gamut volume. The yellow hue angle of ink set 3 is greener and opens a void in orange. Whereas the yellow of ink set 3 reproduces the very saturated yellows of a lemon, the yellow/magenta combination of this set is not suitable to produce a brilliant orange.

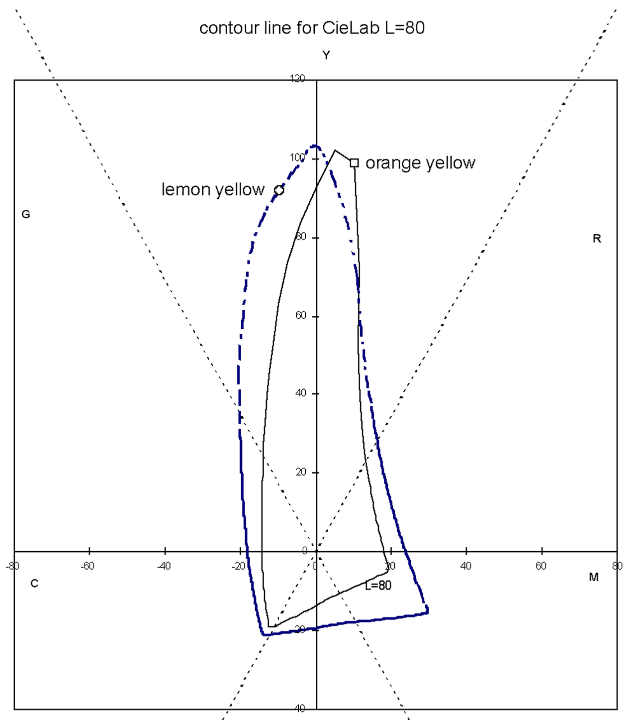

Figure 6. Enlarged yellow/red sector of ink set 1 and ink set 3

Conclusions

Colorimetry is necessary to elucidate the performance of different ink-jet ink sets. The choice of the colorant is the most important factor for the overall gamut on photo glossy papers, the gloss of the media, the type of layer as well as the printing pattern have a minor but noticeable contribution. Reducing the dot size from 300 dpi to 600 dpi does not have a major colorimetric influence and does not close the gap between halftone printing and continuous tone colour reproduction. Apart from gamut size alone, other colorimetric properties of dyes should be considered, namely its metamerism in the ink set as well as the hue angle that may preclude the reproduction of certain important colours.

Acknowledgement

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