Colour Aspects in Photo-quality Ink-jet Printing

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Abstract

The topic of photo-equality in hardcopy technologies has been widely discussed from the beginning of digital printing until today. Photographic quality prints can be made on desk-top printers with little compromises in permanence and performance. The paper compares the status of ink-jet prints in professional and desktop systems with commercial photography.

The gamut of typical ink-jet dye and pigment-based prints and the influence of using more than four colour channels was investigated. In a 6-channel system, the addition of green and orange leads to a similar increase in gamut as the addition of diluted cyan and magenta. However, multi-level printing allows more continuous tone type tone reproduction and better image quality. Diluted colorants provide the gamut gain in high lightness areas. As light colours are prevalent in pictorial images and natural scenes, diluted colours are more beneficial to colour and tone reproduction for a photo-quality printing system than hexachrome colours. Colorant stability considerations limit the ink dilutions as very diluted colour dots may suffer from permanence defects.

Photographic images may be displayed in areas with natural daylight, tungsten light or fluorescent light. They are expected to exhibit a neutral tone scale under all conditions. Very brilliant colorants and certain pigments are shown to have appreciable colour metamerism which leads to unacceptable colour shifts under mixed illumination.

The reproduction of certain important colours is another factor in colorant selection and printer design for photographic reproduction. The paper tint of many ink-jet systems is very bright compared to typical photographic prints and their limitations in minimum density.

Introduction

Ink-jet printing has made appreciable inroads into the commercial display, professional photography and home photo market. For all these applications, silver halide images are the target to reach in permanence and image quality. Continuous tone silver halide images excel by their low grain, smooth tone reproduction, neutral gray scale, and low colour metamerism. A drawback of traditional photography is the limited set of imaging dyes and the resulting limited colour gamut as well as grayish paper whites. Ink-jet printing with its versatility is the most successful among the photo successors. Depending on the layer system used, polymer or porous, the inks, pigment or dye-based, aqueous or solvent, the printer, 4 colour or more, the image quality can vary from low screen printing quality to high end photographic quality. Permanence may vary over orders of magnitude. Today, photo permanence can be surpassed, but only with some compromise in photo image quality or gamut.[1] A previously described gamut program[2] was used to characterize dye and pigment-based ink-jet prints and the influence of using more than four colour channels on gamut.

The paper elucidates some of the colour characteristics of traditional photography compared to dye- and pigment based ink-jet printing.

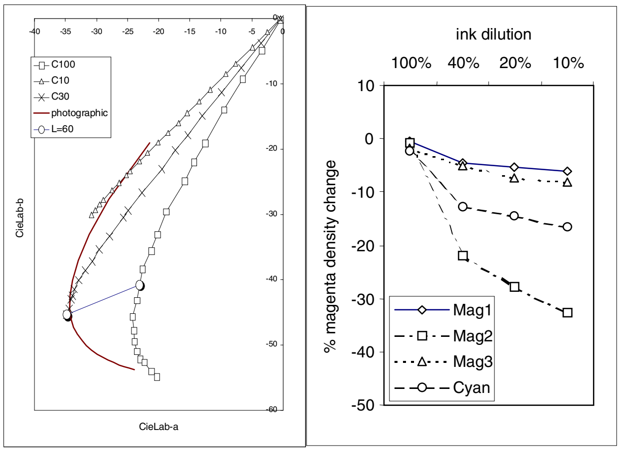

Figure 1. CIELab a, b plot for different ink concentrations and Density change after 10 Mluxh exposure as a function of ink dilution.

Results

Continuous vs. Half-Tone Printing

It is often assumed that by reducing the dot size, a half-toned print will finally resemble continuous tone prints. Although this may be true for extreme reductions this is not true on a scale below 1000 dpi. While graininess and other image quality attributes benefit from the dot size reduction, the colorimetric appearance does little. 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 even at high resolution. This has been known from comparisons of offset printing to photography before the digital age.

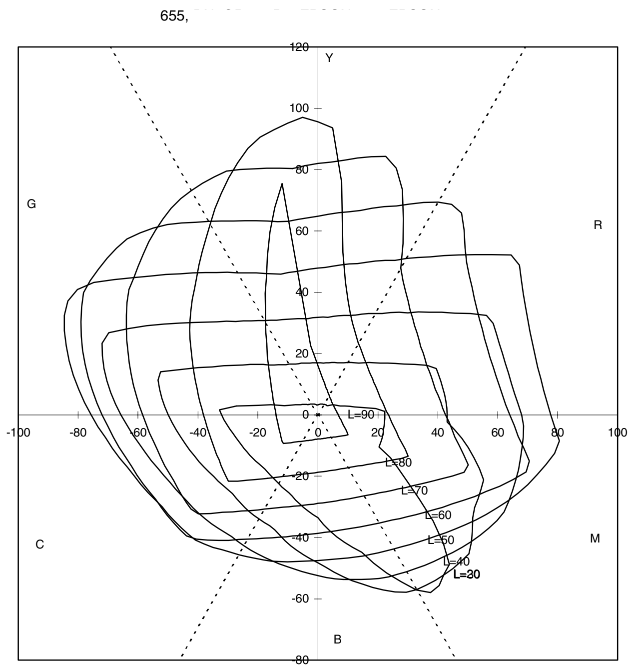

Figure 2a. Dye based ink jet

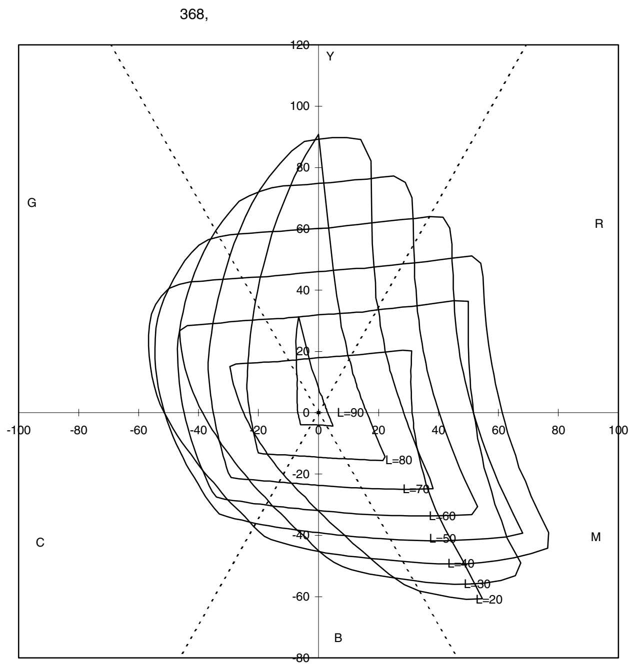

Figure 2b. Full gamut photo

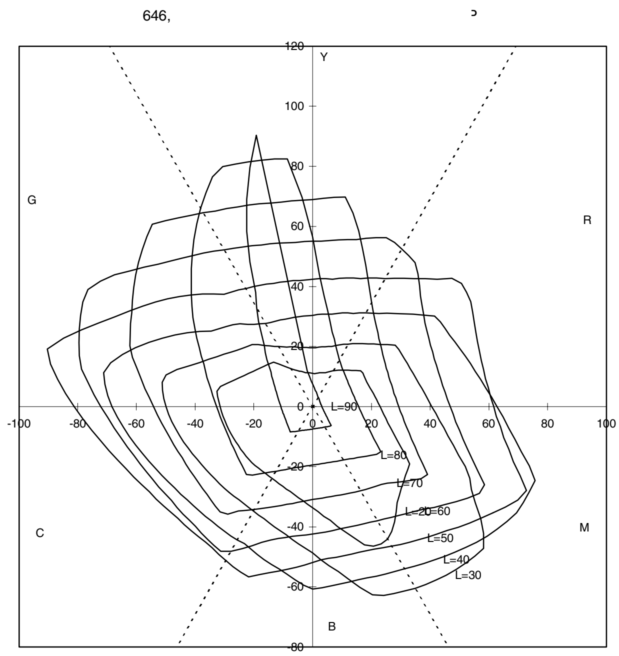

Figure 2c. Full gamut plot of pigment based ink-jet

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.[3] This relationship also holds true for dot size modulated printing.

The better approach to achieve continuous tone printing is by creating intermediate colour shades through multi-level inks. Some printers offer variable concentrations (typical 10%, and/or 30% ink concentration) in addition to the 100% ink. The hue curves shown in fig. 1 (left side) are plots from cyan wedges printed with 100% ink, 30% ink, and 10% ink concentration respectively. The steps of equal lightness were compared. For the lightness level of L=60 shown in the graph as a straight line, the saturation difference between the 30% ink and the 100% ink is 10 CIELab units in favour of the diluted ink. The combining curve 'photographic' is the true continuous tone curve for a cyan wedge made up of the same colorant.

The colorimetrically favoured very diluted colorants at below 30% ink concentrations often show much lower permanence especially in light exposure. Figure 1 (right side) shows the density loss of colour patches after accelerated light exposure of 10 Mluxh, which corresponds to 5 years display in a typical home at 450 lux. Three different magenta colorants and one cyan were investigated at 4 ink dilutions, 100%, 40%, 20% and 10%. Depending on the colorant, ink dilution may degrade the light stability by a factor 5-7. This makes it necessary to select the best compromise between gamut/image quality and image permanence.

Colour Gamut and Colorants

The very important contribution of the colorants on gamut is well known. Two typical ink-jet ink gamuts are shown as equiluminance plane diagrams in fig. 2a (Epson 750 dye), 2c (Epson 2000 pigment) and a typical photographic gamut as a reference in 2b. The ink-jet prints are made on the same microporous photo glossy paper.

Table 1

Gamut volume	Dye ink Fig. 2a	Photo Fig. 2b	Pigment ink Fig. 2c	Ink set 2 media 1	Ink set 2 media 2
Gloss 20°	27	76	27	60	40
Gloss 85°	81	93	81	84	79
Tint L	94.8	93	94.8	96	92.4
Tint a	-0.8	-0.8	-0.8	0.2	3.8
Tint b	-2.5	-0.5	-2.5	-0.6	-8
Y	6048	6178	4361	9966	9165
R	4908	3897	3184	7780	6945
M	5437	5390	5352	7180	6932
B	3267	2461	3790	5832	5271
C	4764	2550	4798	6001	5878
G	7391	4458	6527	8501	7906
Total	31814	24934	28012	45260	42097
Metam. Index	5.4	2.5	11.7		

The colour gamut volumes of photo and the ink sets per sector and in total are listed in table 1. The photo gamut is appreciably inferior to a typical dye ink-jet gamut fig 2a, which surpasses it in every sector. The pigment ink-jet gamut is only slightly large than photo, but very differently distributed in colour space. While photo is superior in Y and R, the pigment set is superior in G and C.

Colour Gamut and Additional Colour Channels

The main advantage of ink dilution is lower grain and better tone reproduction, but there is also a gain in gamut.

For the study of the benefit of ink dilution for colour gamut, we arbitrarily fixed three levels d = 15%, 25% and 40% of full-strength ink. Different combinations of these dilutions were investigated.[4] The addition of 25% ink to full strength ink leads to an overall gamut growth of 12%. The addition of a 15% ink dilution provides 14.8% more gamut The addition of a 15% ink dilution in addition to the 25% ink leads to a 17.6% growth.

Instead of adding ink dilutions, additional color channels may be added (hexachrome ink). Considerable gamut gains of 18% can be achieved, that surpass the gamut gains made with ink dilutions (table 2.). The gamut gains by ink dilution are more even over the colour space and thus preferable for a photographic system.

In addition, diluted inks add gamut in light areas that are important for pictorial images. Fig 3 shows the gamut gain achieved by adding a 60% ink in magenta and cyan to the full strength inks Y,M,C,K for the equiluminance level of L=70 and L= 80 on the same photo glossy media.

Influence of Gloss and Tint on Gamut

The receiving media used is another important factor in gamut even if we only compare the class of photo glossy products. Paper colour has a strong influence on the gamut of light colours.

An ink-jet dye set was printed on two different commercially available photo papers that vary in paper colour (tint) and gloss. The gamut volumes are shown in table 1, last two columns.

Table 2. Gamut gains by a) adding orange and green ink at full-strength to Y,M,C full strength ink and b) magenta and cyan 15% ink dilution to full-strength ink

Sector	a)	b)
Yellow	+35.3%	+6.6%
Red	+24.3%	+6.5%
Magenta	+0.6%	+26.1%
Blue	+0.0%	+20.0%
Cyan	+7.5%	+22.1%
Green	+28.7%	+19.4%
Total	+18.9%	+14.8%

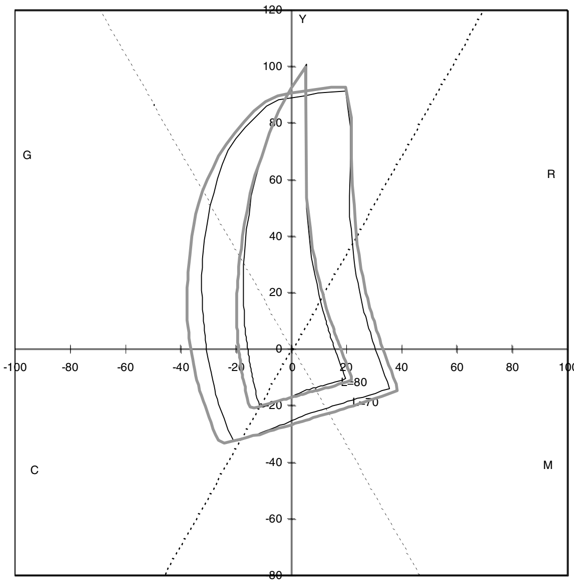

Figure 3. Equiluminance planes L = 70 and 80 for full strength ink (thin line) and additional diluted inks (thick line)

Compared to the photo glossy media 1, the second media shows a moderate loss in gamut of 7 percent. However, most of this loss occurs in the light colour areas and thus becomes more objectionable. The strong influence of tint on the gamut size especially in light colours is also visible when comparing fig. 2a and b. The L=90 equiluminance plane is very much smaller for the photo media than for the ink jet prints due to the inferior whites of photo.

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.[5] Its effect on colour saturation and on surface finish is shown in fig. 5, for the case of a RC glossy paper a) and a fine arts print b). 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.

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.

Other Factors Important in Colour Reproduction in Photographic Systems

Brilliant colours are often obtained from colorants with very narrow absorption curves, but such absorption curves can lead to metamerism. Illuminant metamerism[6] 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 in table 1.

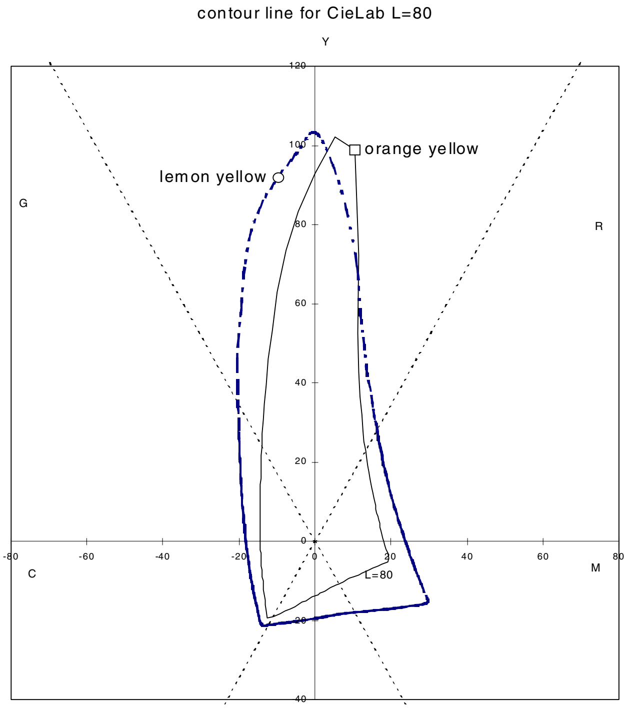

Figure 4. Enlarged yellow/red sector

The pigment ink set exhibits the highest index. It 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. Difficulties may already arise between indoor daylight and fluorescent light, a combination often encountered in actual image display.

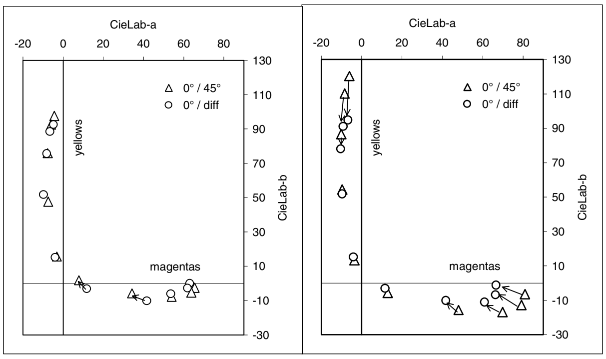

Figure 5. Geometry effect on glossy prints and fine art prints

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 two typical ink-jet inks fig. 4. Both ink sets have a comparable yellow gamut volume. The yellow hue angle of one ink set is greener and opens a void in orange. Whereas the yellow of the second ink reproduces the very saturated yellows of a lemon, the yellow/magenta combination of this set is less suitable to produce a brilliant orange or good skin tone.

Conclusion

Photographic colour reproduction cannot be characterised by the size of the gamut alone. Many digital hardcopy technologies surpass the photo gamut, but are still inferior in colour reproduction. Photographic prints are biased towards yellow/red reproduction and quite weak in green/cyan and white. With the freedom to add additional ink channels, there is the choice between hexachrome (addition of orange and green) and diluted colours (diluted magenta and cyan). It should not based on maxium overall gamut but on low grain of the image and smooth tone scale. The lower the density of ink used for printing the more it approaches continuous tone printing. However, very low ink concentrations do not provide the required photographic permanence.

Today's desk-top dye-based ink-jet systems encompass the photo gamut fully, commercial desk-top pigment systems only in certain sectors. Both exhibit more colour metamerism than photography, which is a disadvantage for any display media that may encounter mixed or varying illumination sources.

The orientation of the colour gamut needs to be taken into consideration when designing photographic hardcopy systems.

References

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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 she joined ILFORD in 1985 she has been involved in research and applications for digital photography, photographic colour science, image evaluation of hardcopy technologies and the development of tests methods for ink-jet media. She is currently head of R&D for the ILFORD Group.