Color Profile: methodology and influence on the performance of ink-jet color reproduction

Lionel Chagas*, Anne Blayo*, Patrice Giraud**
*** EFPG, French Engineering School of Paper making and Printing, Grenoble, France**
****ESISAR, Valence, France**

Abstract

The objective of this work was to quantify the influence of (i) ink-jet printer calibration and (ii) ink-jet printer profile creation, on the quality of color reproduction, in the context of fine art printing. The first step involved a fine setting of the output device, in order to stabilize the results. The second step is a complete characterization of the printers, with color profile determinations. During the profile creation, different input parameters were adjusted: total ink coverage, black ink limit coverage, black-printer strategy. The performance of the color profiles (output data) was analyzed by color differences (ΔE), the volume of color gamut, and spectral characteristics of the printed colors. Moreover, a visual appreciation of the printed samples was conducted.

From these results, the profiles were edited and optimized in order to reduce the color differences.

Introduction

Color management allows conservation of color information throughout the printing process. The only RGB or CMYK information is not sufficient. ICC profiles contain tables with correspondences between RGB (or CMYK) and L*a*b* values.

With a good knowledge of color meaning, it is possible (i) to simulate industrial printing - offset, flexography etc. – or (ii) to print more accurately a digital document on an ink jet printer.

(i) The first item is possible because an ink jet generally enables a larger color gamut than the other industrial printing processes.

(ii) The second item, as illustrated by this study, may be to reproduce art documents.

Two steps are necessary to make color more predictable within the limitations of the devices in use: calibration and characterization.

The objective of this study was to set up a methodology to obtain a good printing quality on fine art papers with an ink jet printer. The first step was the calibration of the printer according to the paper. The second step consisted in the characterization of this paper through an ICC profile creation.

After a short overview concerning the different ways of calibration and characterization the methodology is described. Then the results obtained on fine art paper at each stage are compared with those obtained on a coated paper chosen as a reference.

Method

1. Calibration (or linearization)

The tone increase value for ink jet printing is generally larger than for the other printing processes because ink jet uses stochastic screening. Without correction the increase of dot area may reach 50 to 60% which means that on the printed material there is no difference between a 70% and a 100% (solid) patch. Consequently the details in the ¾ tones of pictures are lost.

The aim of the printer calibration is often to obtain linear relationship between the digital reference dot area input for each channel CMYK and an output value which can be a variation of color (delta E) or a luminance (L)[1]. This calibration tends to minimize the dot gain for each primary ink. After this step the dot areas are often similar to those obtained by offset printing. The typical offset values are recorded in the standard documents ISO 12647-1, 2, 3. For example, the dot gain on a coated paper at 50% is 17%.

Figure 1(a) represents the variations of the dot area after printing without calibration. Between 70% and 100% the reference variation is 30%, whereas on a printed paper this variation is less than 2%.

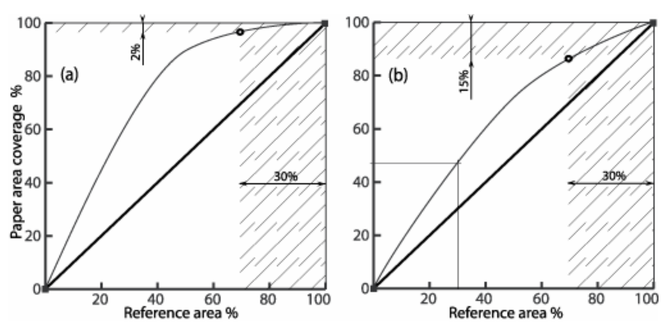

Figure 1. (a) Classical area coverage on paper vs digital area coverage before calibration
(b) Classical area coverage on paper vs digital area coverage after calibration

Figure 1(b) represents the variations of the dot area after printing with calibration. This linearization increases significantly the details in the ¾ tones range: a difference of 30% (between 70% and 100%) corresponds to 15% on the paper. Besides, a difference of 30% in the ¼ tone corresponds to 40 to 50% on the paper. This operation does not provide a linear curve (50% on a paper for 50% digital).

The dot gain can be determined by two methods: Murray-Davis or Yule-Nielsen models[2]. Most printing devices are only binary which means that they cannot produce intermediate ink densities. In such devices the visual impression of intermediate gray or color is usually obtained by means of the halftoning technique. The Murray-Davis model (see equation 1) assumes a linear behavior between reflectance values R(λ) and dot area. This model can be applied to transparent substrates, but for papers the relation is nonlinear. To take into account this nonlinearity, Yule and Nielsen proposed a correction with an empirical factor n (see equation 2).

$$R(\lambda) = (1-a)R_P(\lambda)+aR_S(\lambda) \quad (1)$$

$$R(\lambda)^{1/n} = (1-a)R_P(\lambda)^{1/n} +aR_S(\lambda)^{1/n} \quad (2)$$

2. TAC (Total Area Coverage) determination

The Total Area Coverage corresponds to the addition of the maximum ink coverages. For example, in four-color process four layers of ink can be printed; if the maximum of each ink (CMYK) is 100% the TAC is 400%. In practical, the superimposition of 4 inks leads to TAC of 150 to 380%.

The determination of the limit TAC accepted by a paper is crucial in order to avoid problems such as poor ink drying and smudges. Table 1 presents typical values of TAC for different printing processes. Generally these values are high in offset compared with ink jet: 350% on a coated paper for offset, 250% on a coated paper for ink jet.

To determine a limit TAC it is possible to use a test chart such as that available on the Web site of Don Hutcheson[3]. This type of form is composed of several gray or black patches having variable values of superimpositions. Generally the optical density or the luminance do not evolve after a given value of superimposition. In this work the IT8 7/3 or TC 3.5 chart was used to obtain the limit TAC. In addition the white separation between each patch allows appreciating the migration of the ink.

Table 1. TAC limit for different printing processes

Printing process	*TAC*	*Dot gain at 50%*	*Printing process*	*TAC*	*Dot gain at 50%*
Laser printing	260%		*US Web Coated (SWOP-offset)**	300%	21%
Ink jet printing	250%		*US Web Uncoated (offset)**	260%	18%
*Euroscale coated (offset)**	350%	19%	*US Sheetfed Coated (175 lpi-offset)**	350%	19%
*Euroscale uncoated (offset)**	260%	25%	*US Sheetfed Uncoated (offset)**	260%	18%

3. Gray balance

The human eyes are very sensitive to gray differences. A neutral gray is obtained when a*, b* are equal to 0 at any value of L*. The knowledge of theoretical proportion of Cyan, Magenta and Yellow needed to reproduce a neutral gray is important. In offset, gray balance is influenced by many materials and press parameters: quality and color of paper surface, ink film thickness, ink trapping, printing sequence, dot gain etc.

In ink jet printing there are less parameters: type of inks, paper, type of screening, dot gain.

To determine exactly the neutral patches test image proposed by GATF or Hutcheson[3,4] can be used. In this study a gray balance chart was developed to obtain the proportion of CMY for a black equivalence at 15%, 25%, 50%, 75% and 80%. The values obtained are more accurate than the values determined by the software of creation of ICC profiles because there are more gray patches.

4. Characterization of the output system

The characterization consists in determining the output of a system to a known input. Characterization provides the knowledge of the color gamut and reproduction characteristics of a device. At this step an ICC profile can be created. Making a CMYK output profile (ICC) involves printing a color target which contains hundreds to thousands color patches. A measure of each patch is made by a spectrophotometer.

This stage allows modeling (i) relations between the device colors (CMYK) and the colors described in an independent space (XYZ or L*a*b *) or (ii) direct links between two devices (RVB-CMYK or CMYK1-CMYK2). There are many techniques to convert a color from one space to another: modeling resulting from a physical approach of the interaction light - substrate (model of Neugebauer for example), or modeling resulting from empirical techniques (polynomial modeling or interpolation methods starting from a large series of values)[1,5].

Mesurements

Instruments

In this study an Epson ink jet printer pro 5000 was used with solvent inks. Its maximum resolution was 1440 dpi with stochastic screening and the dot size was approximately 70 µm. Printing was controlled by a Bestcolor RIP (Raster Image Processor). In this sort of RIP two profiles can be introduced: one for the paper to be printed and the second to simulate an other printing process (offset for example).

Densitometric and colorimetric measurements of TC 3.5 chart were conducted on a densitometer D19C, and the Spectroscan table of GretagMacbeth, respectively. The densitometer was equipped with a light source A and a set of filters corresponding to the standard Status E. The connected Spectrolino used the 45/0° geometry. The reflectance values from 380 nm to 720 nm by 10 nm steps were registered. The colorimetric values calculation was made with D50 standard illuminant.

The application of the profiles or the transfer functions was done indifferently through the RIP BestColor or Photoshop.

Substrates

Two papers were used: one coated paper 180g/m² and one fine art paper 280 g/m² with a cloudy texture. Typically made from 100% cotton fibers, fine art papers are acid free and buffered against atmospheric acids. The hot pressed papers, with their smooth surface, are the most suitable for detailed works that require clean and crisp edges. Hot pressed papers do not suffer the increased feathering of the ink, or dot gain, whereas cold pressed and rough papers do. The cold pressed papers have a pleasing texture and are considered suitable for most printing applications as they are a compromise between hot pressed and rough papers, both in texture, feel and ink feathering. Rough papers are heavily textured, and this pronounced texture gives a more grainy look to images because of ink spreading (See also reference 6).

Results and discussion

1. Step by step characterization

a) Printing without correction

Figure 2 represents the CMYK chart initially printed without correction. This operation is necessary to determine the dot gains. The calculation was made with the model of Murray-Davis.

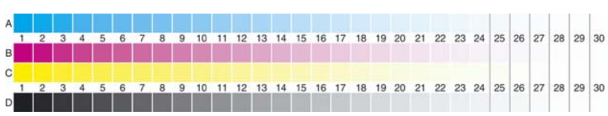

Figure 2. CMYK chart for the first step of calibration. The dot area increases from 2% to100%.

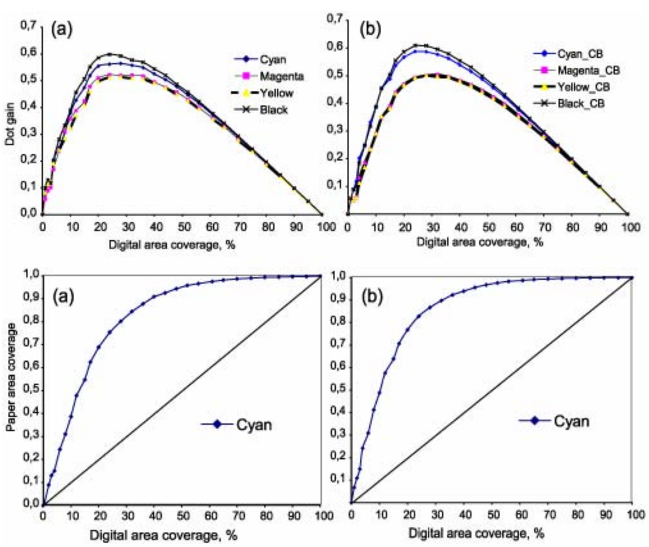

Figure 3. Dot gains on Fine Art (a) and glossy coated paper (b) calculated by Murray-Davis model

The results obtained are presented on figure 3. The maximum value is obtained for digital reference values varying between 25% and 40%. The dot gain can reach 60% for the black. This is explained by the high optical dot gain of stochastic screens. There is no significant difference between the printing on coated and fine art papers. The dot gains for yellow and magenta inks are slightly lower in the case of the coated paper.

The dots of stochastic screens were also observed under an optical microscope. No significant difference was noticed between the two types of paper regarding the shape of the dots. Moreover for high coverages the printing on fine art paper reveals some irregularities.

Table 2. Comparison of area values between microscope determination and Murray-Davis calculation

Reference dot area %	4	10	15	20	40	70	90
Glossy coated paper							
Microscope values of area %	17	36	47	61	81	99	100
Values of area calculated by MD %	22	49	65	79	95	99	100
Fine Art paper							
Microscope values of area %	16	35	48	63	84	98	100
Values of area calculated by MD model %	24	49	66	79	94	99	100

From the microscope observation the percentages of coverage resulting from the printing of the following patches: 4, 10, 15, 20, 40, 70 and 90% (digitals values) were determined. These results are compared with those obtained by calculation via the Murray-Davis model (see tables 2, 3).

Table 3. Determination of the factor n of the Yule-Nielsen model for the black ink

Fine Art paper (before linearization)								
Optical density	2,31	2,19	1,94	1,22	0,66	0,46	0,29	0,12
Reference area %	100	90	70	40	20	15	10	4
Microscope area %	100	100	98	84	63	48	35	16
Calculated area MD %	100	100	99	94	79	66	49	24
Factor n (Yule-Nielsen model)	1	-	1,43	1,74	1,64	1,72	1,6	1,6

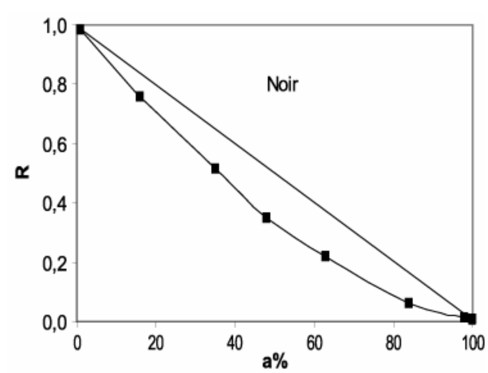

Figure 4. Reflectance values (R calculated with densities values) vs microscope area for the black ink on Fine Art paper.

From 4 to 40%, the parameter n is nearly constant. For these patches the average for n is equal to 1.66.

b) Printing after RIP correction

The BestColor RIP was used to correct the dot gains. The results are presented on figure 5. The dot areas were calculated from the Murray-Davis equation (n = 1 in Yule-Nielsen model). In addition, it would be possible to characterize the ink/paper interactions by means of this parameter n.

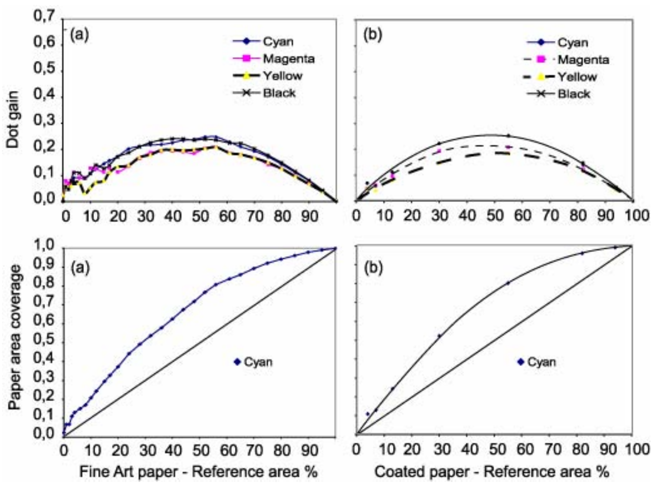

Figure 5. Dot gains on fine art and glossy coated paper calculated by Murray-Davis model after RIP calibration

c) TAC determination

After linearization of the printer, it is necessary to determine the maximum TAC accepted by the paper. This value was determined from the test form TC 3.5. The chart was printed with different TACs from 280% to 160%. Figure 6 presents the two versions of printing. For a limit of 280% there is a problem of ink migration towards the adjacent patches. The white lines between the patches can disappear completely. At 160% the form does not present any problem. This value will be retained to limit inking. There is a strong difference with the coated paper which accepts higher ink superimpositions.

Figure 6. Two versions of test form TC 3.5 (TAC 280% and 160%)

This limit (160%) can involve variations of color in the dark zones. To appreciate these variations the two printed forms were compared at 280% and 160%. The average color variation (ΔE_{av}) is 1.1. The maximum color variation (ΔE_{max}) is 8.7. On figure 7 squares surrounded by yellow present the greatest variations of color. For these patches the ΔE varies from 3 to 8.

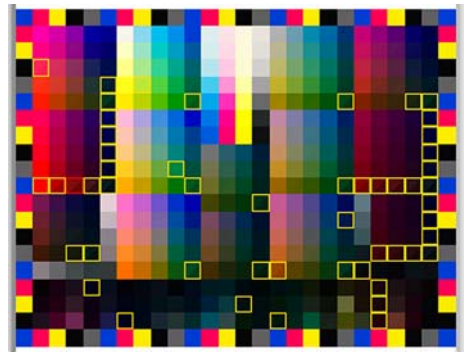

Figure 7. Colour difference (delta E) between the two printed test form with limitation on the Total Area Coverage at 280% and 160%

The luminance value (L*) is the most influent parameter in the delta E variation. The luminance variation delta L* is lower (from 2 to 8.2) for a TAC of 160% compared to 280%. In most cases, the saturation parameter is lower at 160% (C* from 0 to 6.5). On the other hand the variations of the hue angle (delta H*) are not very pronounced (variations from 0.1 to 1.6).

d) Gray balance

After the determination of the TAC value it is necessary to know the exact proportions of CMY inks which give a neutral gray (L* unspecified, a*=b*=0). A specific test form was printed in order to determine the neutral gray corresponding to 15%, 25%, 50%, 75% and 80% black equivalence. For each grid the percentage of coverage of the cyan was fixed (15, 25, 50, 75, 80%). The yellow varied by step of 2% on the vertical axis while the magenta varied on the horizontal axis.

Table 4 gives the CMY values obtained for the neutral gray. For the ink jet printing the values were quite different from those obtained in offset. In addition, results significantly depend on the paper especially for the small percentages.

Table 4. CMY values to obtain a neutral gray in ink jet and offset processes for two papers.

Black equivalence	15%	25%	50%	75%	80%
C/M/Y (Fine Art) %	15/11/13	25/23/23	50/50/50	75/80/80	80/88/90
C/M/Y (Coated) %	15/11/19	25/20/27	50/48/50	75/82/82	80/94/92
C/M/Y (Offset) %	15/09/09	25/19/19	50/41/41	75/64/64	-

e) Characterization of papers and ICC profiles creation

The TC 3.5 test form was printed on a calibrated printer and the reflectance values of the set of color patches were measured between 380 nm and 720 nm. These measurements allow to determine the gamut of the paper and to know the signification of the colors. Contrary to fine art paper, a coated paper can accept a TAC of 400%, which makes it possible to reproduce more colors particularly in the dark areas. These results are presented on figure 8.

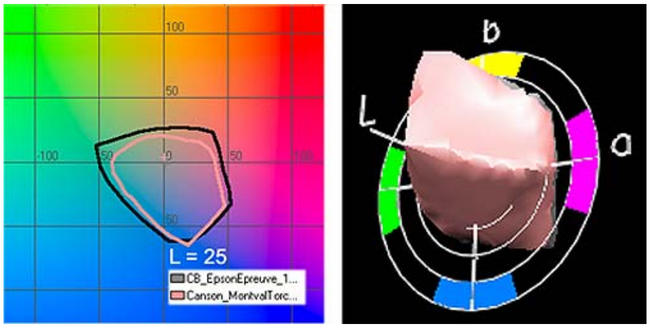

Figure 8. Reproducible colors for the two papers: coated (dark line) and fine art (clear line)

Conclusion

The aim of this study was to set up a methodology to obtain a good quality ink jet printing on fine art papers.

This work led to the following conclusions:

a. Printing without correction does not give large differences between the fine art and coated papers. The values of dot gains are about the same in the two cases. The n factor of Yule-Nielsen model can be calculated from 0 to 40% of reference coverage. This factor is not very different in both cases. The values of optical density are higher for the coated paper. It is the only significant difference.

b. The linearization of the printing gives almost the same values of dot gain for the two papers. Only the yellow ink gives a slight difference: for the coated paper the dot gains are smaller in the range of 10 to 40%.

c. On the other hand there are great differences between the two papers regarding their capacity to accept a high Total Area Coverage of ink. Coated paper can accept 400% of ink whereas fine art paper gives correct results from 160%. The reproduction of the dark zones is less accurate for the fine art paper. The variations of colors (ΔE) can reach values from 8 to 9.

d. The printing of neutral gray gives different results from those obtained in offset printing. The proportion of yellow and magenta becomes large in the high percentages range. It can be necessary to refine calibration through the adjustment of the gray balance.

e. Finally, the ICC profile creation after calibration underlines a smaller gamut in the dark areas for fine art paper compared to coated paper. This result can be sensitive for the reproduction of dark paintings.

References

1. Raja Bala, *Device characterization, Chap. V in Digital Color Imaging Handbook*, *ed. Gaurav Sharma CRCPress* (2003), p269-379.
2. Emmel Patrick, *Physical models for color prediction, Chap. III in Digital Color Imaging Handbook*, *ed. Gaurav Sharma CRCPress* (2003), p220-224.
3. http://www.hutchcolor.com
4. Richard M. Adams II, Joshua B. Weisberg, *The GATF practical guide to color management*, *GATFPress* (1998).
5. Johnson Tony, *Colour management in graphic arts and publishing*, *Pira International* (1996).
6. Blayo Anne et al., *Influence of media and ink characteristics on the quality of color ink jet reproduction of fine art pictures, NIP20 Salt Lake City*, (2004).

Biography

Lionel Chagas graduated from the French Engineering School of Papermaking and Printing in 1989 and received his Ph. D. at the National Polytechnique Institute Of Grenoble in 1997. Since then he has been working in the French Engineering School of Papermaking and Printing as a teacher and searcher. His work is focused on prepress and particularly on color management.