Towards an Optimal Design of Digital Ink Jet Proofing Systems

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Abstract

Today, conventional proofing systems are more and more replaced by flexible and cheaper systems based on ink jet technology. The advantages of conventional proofing devices such as color stability, inks that mimic accurately the printing process to be simulated and a relatively high printer resolution to reproduce screened images are more and more taken over by digital ink jet systems. Moreover, due to the combination of ink jet systems and digital workflows, a printing system can be designed containing a plethora of functionalities fulfilling the needs of proofing solutions for several printing applications.

Proofing is one of the most demanding printing applications in the field as the ultimate proof should be an exact copy of the print. The proof is expected to correspond closely to the look and feel of the print.

The control over the color reproduction behavior of a printing system is in reality one of the key elements for the design of a proper proofing system. In general, it is not sufficient to optimize the printing device and the digital workflow; the whole system has to be optimized and integrated properly. As a minimal requirement, the color management, the calibration, the screening and the inks of the proofing device have to be tuned properly. However, it is as essential to take into account the characteristics of the printing process to be simulated and the viewing environment of the visual print-proof comparison. Too often there is a difference between a visual match and a match based on measurements.

Introduction

Conventional proofing systems were in most cases designed to simulate an offset printing system with a fixed set of inks that resemble as closely as possible the printing inks. At the time computer to film systems were used to develop printing plates, the same film was used to make the proof and the plates. As a result, conventional proofs were screened proofs, mimicking the screening of the press exactly under the condition that the overlaps of the different screens were the same.

With the introduction of ink jet devices, several proofing providers have made a big effort to design a proofing system based on ink jet technology. This technology is rather promising as it is significantly cheaper than the conventional systems and has a larger flexibility in media and ink sets to be used.

However, at the beginning the main disadvantages of ink jet were the rather low resolution of the heads and the rather unstable color reproduction due to a bad medium ink interaction resulting in fading over time, bleeding and coalescence.

From the very beginning, the resolution was improved by making use of multi-density inks. A light ink version of cyan and magenta was provided to reduce the visible noise of the corresponding heavy inks resulting in an apparent lower resolution of the printing device.

For a long time, the black ink was provided only in a heavy version, but nowadays several solutions are present making use of two or three multi-density blacks for several application areas.

Nowadays, the main disadvantages have been addressed by a better medium ink interaction by improving both the media and the inks and by reducing the ink drop sizes so that higher printing resolutions can be obtained. Instead of making use of multi-density inks, there has also been a tendency to provide several drop sizes or to put several ink drops on the same location with the smallest drop size. Nowadays, there are a large number of dot sizes, multi-density inks and printing resolutions available to tune the printing system for a number of application requirements such as accuracy, noise level and printing speed to name a few.

In this publication we will mainly focus on tuning an ink jet device to obtain a good proofing system. This includes the design of a digital workflow, the creation of resources and the optimization of the ink set of the printing device.

Digital Color Workflow

The main problem to be solved in an ink jet system is how to use the different multi-density inks and drop sizes to get a good color reproduction that is optimized for a given ink paper combination and a given printing mode.[1] With printing mode it is meant printer parameters such as printer resolution, unidirectional or bidirectional printing, and head height.

As multiple drop sizes and multi-density inks are mainly used to increase the apparent resolution of the printing device, the easiest approach to characterize the device is to consider the multi-density inks for the same printing color and the different drop sizes of an ink as one global ink value. This means that the multi-density inks and drop sizes have to be combined in a way to create a global ink value (GIV). In this approach, it is assumed that the different multi-density inks and drop sizes contribute independently to the global ink value; i.e. the contribution of the multi-density inks an different drop sizes to the global ink values can be set by curves between which no restrictions have to be taken into account.

The different multi-density inks and drop sizes are referred to as partial inks and a colorant value that addresses an amount of the partial ink is called the partial ink value (PIV). The relation between the global ink value and the partial ink values is referred to as the ink mixing curves; i.e. partial ink values in function of global ink values.

In reality, there is a small gamut limitation involved in decomposing the global ink values into partial ink values. This limitation is mainly due to the fixed relation between the multi-density inks, not so much due to the partial inks only differing in drop size. As the multi-density inks in general rotate differently in the a*b* plane of the CIELAB space (see Figure 1), a fixed relation between the multi-density inks will limit the gamut in reality.

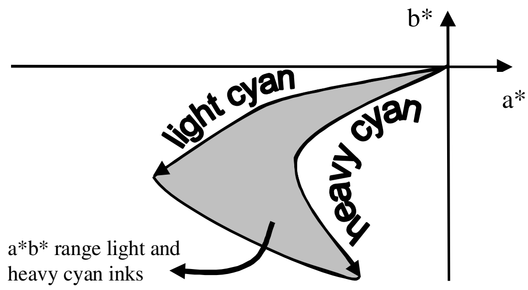

*Figure 1. a*b* range of CIELAB space of two multi-density cyan inks*

Per partial ink, error diffusion is applied before the color signals are coded for a given printer driver. Before the ink mixing, calibration and color management is applied on the global ink values.

The general digital color workflow for a proofing system is represented in Figure 2. In this workflow, also a controlling mechanism is implemented for the different processing blocks; i.e. for the characterization, calibration and ink mixing.

Ink Mixing and Calibration

As mentioned before, the ink mixing and calibration are the most important blocks to process the different multi-density inks and drop sizes.

Ink Mixing for Multi-Density Inks

Assume there are two multi-density inks for a given global ink value and each multi-density ink has one dot size. The inks are referred to as the light and heavy ink.

In general an ink split will be made as represented in Figure 3: for the lower global ink values only light ink values are used whereas at the global ink value the light ink reaches its maximum, the heavy ink starts.

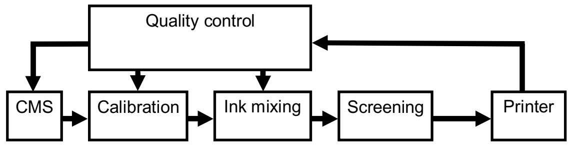

Figure 2. Digital workflow proofing

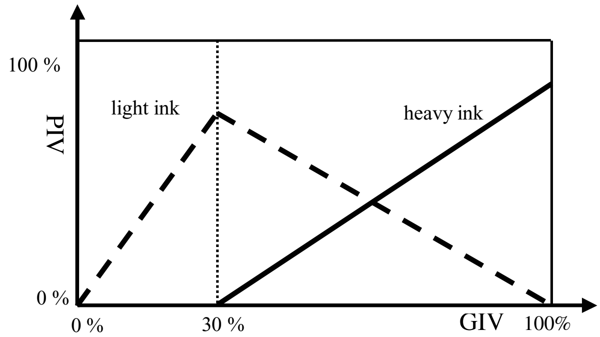

Figure 3. Ink splits in case of multi-density inks

A global ink value at which a partial ink changes with a sharp edge is called a switch point. In our example we have switch points at 0 %, 30 % and 100 %. In general, at the global ink value of 30 %, the corresponding color behaves differently before and after the fixed switch point so that the printer has to be modeled accurately at this point. By preference, the partial ink value at this point is defined by its color value and not by its partial ink value. Such a point is called a fixed switch point as its position should be maintained by the calibration curve (see later).

Ink Mixing for an Ink with Multiple Drop Sizes

It is assumed that we have an ink with 3 drop sizes. The ink splits in this case are typically made as represented in Figure 4.

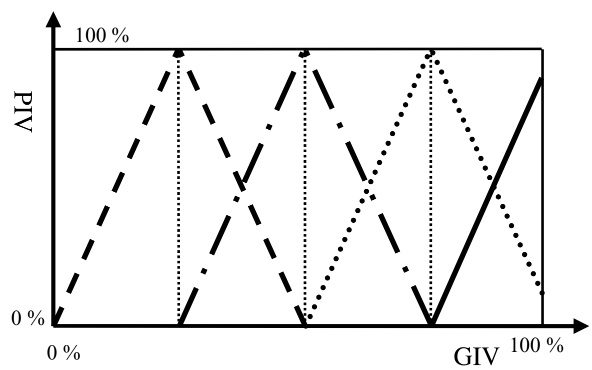

Figure 4. Ink splits in case of multiple drop sizes

Here all edge points are not fixed except at the 0 % and 100 % global ink values where fixed switch points are preferred. All other points can be remapped by the calibration curve and hence they are called floating switch points.

Calibration

After having designed the ink splits, the calibration approach will be defined. During the calibration process, the global ink values are remapped such that the whole digital flow from the calibration step till the screener behaves as defined by the calibration aim curve. The calibration aim curve gives the relation of a given 1-dimensional measurement unit in function of the global ink value. This behavior of the global ink process is defined the first time the printer is installed.

For fixed switch points, the global ink value may not by changed by the calibration process. For floating switch points, no limitation is specified. As a result, the calibration curve is a strictly monotonic increasing curve without remapping the ink values of the fixed switch points (see Figure 5).

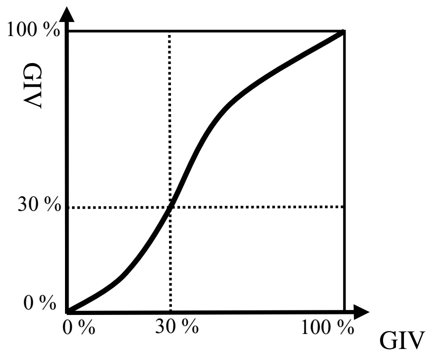

Figure 5. Calibration curve for a fixed switch point at 30 %

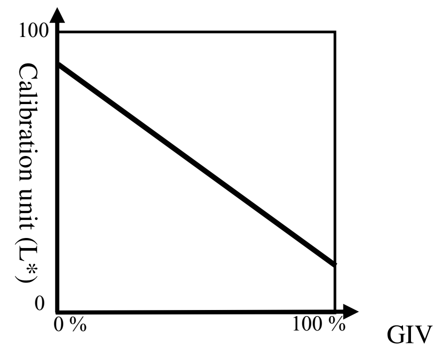

Figure 6. Calibration aim curve for multiple drop sizes

The calibration aim curve is in general different for the combination of multiple drop sizes and the multi-density inks. For the combination of multiple drop sizes this relation is linear (see figure 7). For multi-density inks however, the behavior is often piecewise linear. This is due to the fact that a proper choice of the partial ink value at the switch point of 30 % is in most cases a trade off between a minimum ink usage and minimum noise level at this global ink value. The corresponding calibration aim curve for the case of different drop sizes and multi-density inks are represented in Figure 6 and 7 respectively. As calibration any unit can be used but by preference visual units are selected. Colors at fixed switch points are preferably defined by colorimetric values. Typically, lightness is used to calibrate cyan, magenta and black whereas chroma is used for yellow.

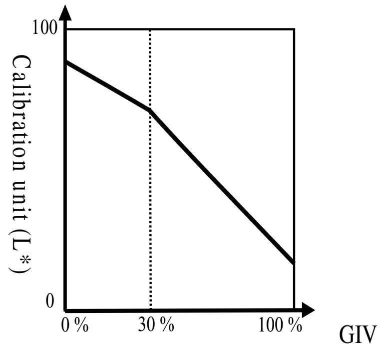

Figure 7. Calibration aim curve for multi-density inks

The main reason to select chroma for yellow is that there is a larger range in chroma compared to lightness if yellow goes from 0% to 100%. For cyan, magenta and black, lightness results in sufficient accuracy to calibrate these inks.

To specify fixed switch points, by preference CIELAB values are used. The reason to use multi-dimensional values is that in some cases for some inks such as magenta, the lightness value almost does not change any more if the global ink value is about its maximal value whereas the a* and b* values still might change significantly. By preference, the calibration unit can be deduced from the color specification for fixed switch points.

For floating switch points, only partial ink values are specified.

Color Management System

To convert colors in an open environment from one color reproduction system to another, a color management system (CMS) has to be applied. The industrial standard to convert colors has been developed by the International Color Consortium (ICC), and is nowadays widely adopted in the field.[2]

The basic idea of the ICC approach is that each device has to be characterized separately and if a transform is needed from one system to another, the characterization data of both devices have to be combined in a color transform from the first device to the second one.

To characterize an output device, a printer target has to be printed and measured. In a next step a printer model is created that predicts color values in function of colorant values. Based on the printer model, both forward (from colorant space to color space) and inverse (from color space to colorant space) color tables are made and stored into a file, the profile for the given output device.[3]

Linking Accuracy

For proofing applications nowadays, there is a tendency to have a deltaE of zero for the colorimetric conversion from the press to the proofing device. In practice there will be some errors due to printer and measurement variations, colors of the press out of gamut for the proofer and effects in the digital workflow such as interpolation errors and bit accuracy.

A typical test to check the accuracy of the profiles for a conversion from the press to proofer is the conversion of the color patches of the IS12642 printer target, formerly known as the IT8.7/3 target, from the press profile to the proofer profile and converting the resulting CMYK values to CIELAB space with the proofer profile. These values are compared to the CIELAB values obtained by converting the original CMYK values of the patches of the printer target to CIELAB with the press profile.

For a conversion between the StandardEuro profile and an ink jet device with the absolute colorimetric rendering intent, the results are represented in the column “Conventional linking” of Table 1.

In making a link, techniques can be applied to eliminate interpolation errors. The results of this approach are represented in the column “Improved linking” of Table 1. Here we see that in gamut colors can be reproduced quite accurately; i.e. an average deltaE of 0.04 and a maximum deltaE of 0.05. Out gamut colors are also improved but not significantly.

The maximum improvement for in gamut colors is 5.1 deltaE and 2.1 deltaE for out gamut colors.

Table 1. DeltaE values for a conversion of the color patches of an IS12642 printer target from StandardEuro to an ink jet system

	Conventional linking	Improved linking
Average deltaE	0.67	0.26
Average deltaE in gamut colors	0.44	0.04
Average deltaE out gamut colors	1.90	1.39
Max deltaE in gamut colors	5.12	0.05
Max deltaE out gamut colors	5.46	5.43

Viewing Conditions

After having achieved the required accuracy of the linking mechanism, the next concern is how good is the match from a visual point of view.

The first problem to be solved is that the viewing conditions used in an ICC framework are D50 as illuminant and a 2 degree observer. In reality, proofs are often evaluated with the print in viewing booths with D50 simulators. D50 simulators are fluorescent lamps for which the perfect reflector corresponds closely to the white point of D50. However, as the power spectrum is often quite different from the power spectrum of D50, there might be a significant color difference between both illuminants for saturated color patches.

Experiments indicate that for color patches of an IS12642 target the difference between lab values based on D50 and a D50 simulator is 1.3 deltaE on average with a maximum of 4.7. The maximal differences occur for the most saturated colors. In our example a pure cyan has a deltaE of 4.7, pure magenta a deltaE of 3.3 and pure yellow a deltaE of 2.5.

Hence, the lab values as defined by the Profile Connection Space (PCS) do not correspond to the viewing conditions used in most proofing environments.

This problem is solved by assuming that the viewing conditions at the device, i.e. the device viewing conditions, and the PCS can be different. If we do so, the color transformation tables in the profile also have to take into account the transformation from the viewing conditions corresponding to the proofing device and the PCS. For this extra transform, an appearance model has to be used as this transform has to preserve the color from a visual point of view. Or in other words, the lab values of the color seen under the device viewing conditions have to be mapped to lab values that result in the same color perception for an observer completely adapted to the viewing conditions defined by the PCS.

As the print and proof are evaluated simultaneously, the viewing conditions of the press profile and proofer profile have to be the same.

The problem that will be encountered often is that the appearance transform of the press profile and the proofer profile might be different, and hence a color on the press that is in gamut for the proofer will be simulated with a color difference.

At the moment there are two ICC profile versions on the market; i.e. v2 and v4 profiles. The advantage of v4 profiles for proofing applications is that

1. a clear definition is given of the PCS for the different rendering intents
2. a dedicated tag is provided describing the chromatic adaptation transform (CAT) used.

Hence, v4 profiles take into account a dedicated transform to map differences in viewing conditions, however, this is not an appearance transform as a CAT only

1. accounts for a difference between the colors of the illuminants by a 3X3 matrix
2. assumes that the observer completely adapts to the color of the illuminant; i.e. the observer will perceive the color of the illuminant as white.

What makes it even more difficult is that different CAT’s are being used in the literature. Hence, due to the usage of different CAT's, also a mismatch can occur. Therefore, it is possible to undo the CAT of the first profile and apply the same CAT of the second profile. If the viewing conditions, i.e. the color of the device illuminant, are different form the PCS, the applied CAT tag has to be supplied. As the specification of the CAT tag is only defined for v4 profiles, this can only be applied to make a link between v4 profiles.

For proofing, the CAT's of the press and proofer profile have to be the same to avoid color mismatches. For proofing the colorimetric rendering intent is used and for this rendering intent the PCS values are defined as measurement values possibly corrected by a CAT to transform colors from the device illuminant to corresponding colors for D50. Hence, if different CAT's are used, the CAT of the press profile has to be replaced by the CAT of the proofer profile (or vice versa). This is indeed what is expected in the field as when both profiles are made for the same viewing conditions, undoing the CAT will be similar as a using a PCS that is based on these viewing conditions.

Calibration Unit and PCS

Finally, if we look at a color table used in profiles, such a table is a regular grid, either in the device dependent color space in case of the forward table or in XYZ or CIELAB for the inverse table. As the spaces we are working with are multi-dimensional, also the grids are multi-dimensional. A grid is defined by a number of sampling points per axis. Since we usually work with 3- or 4-dimensional color spaces, the number of sampling points has to be limited, definitely for the 4-dimensional tables, to reduce the size of the profiles. Hence, it is advantageous to use the same space or subspace in the calibration step as the PCS, as the calibration guarantees that the interpolation used to apply the tables is correct, at least for the specified calibration unit and the 1-ink processes Cyan, Magenta, Yellow and Black.

Ink Selection for a Proofing Device

After having optimized the whole digital workflow, the next step will be to tune the printing device to obtain a proofing system to simulate a given output device properly.

It is assumed that during the calibration and characterization step the interaction between the ink and media is optimized, and the best printer settings such as resolution, head height, unidirectional or bidirectional printing are selected for a given task with the required image quality and printing speed.

In this section, we will discuss an optimal set of inks from a color management point of view. We will restrict ourselves to four global inks; i.e. cyan, magenta, yellow and black. The main criteria to be used are the gamut so that typical CMYK output systems can be simulated properly; and to reduce noise as much as possible. The main press processes to be reproduced are SWOP, EURO, flexo, gravure and newspaper printing.

If we would like to have a gamut large enough to simulate the before mentioned press processes, we could measure these processes and take the union of these gamut as the target gamut. Another criterion could be to build a gamut as large as possible.

Conventional CMYK inks with hues and lightness values that are about the same as for the press but with a significantly larger chroma do not seem easy to make. When the CMYK inks of most ink jet systems are evaluated, they all appear to be rather similar to press inks, perhaps slightly larger in chroma and darker but in general not that much.

If we cannot make inks that are significantly larger in chroma, it is important that the CMYK inks are about similar to the press inks in hue and lightness as the shape of a CMYK gamut is mainly defined by the positions of the primary and secondary colors and the darkest color we can obtain by the overlap of the CMYK inks.

In general this can be done easily with the exception of the yellow ink. As the gamut in the yellow region is quite sharp, the hue and lightness of the yellow ink should map the corresponding values of the process to be simulated as closely as possible and the chroma should be as large as possible to account for possible mismatches; e.g. due to changes of the press paper.

If we look at low ink percentages, for most ink jet systems the drop sizes of the inks are too large and the corresponding resolution of the printing device is too low to have the impression of a continuous color printer. To reduce the visual artifacts introduced by the real printing resolution, a proper error diffuser and multi-density inks should be used.

The selection of the multi-density inks can be based on the contrast sensitivity function (CSF) of the human visual system. As the CSF of the luminance channel is much more sensitive to image variations than the red-green and yellow-blue CSF's, mainly ranges in luminance can be used to define how many multi-density inks have to be used.

If we look at the different colors, the lightness difference between 0 % yellow and 100 % values are about 50 lightness values for cyan, 50 lightness values for magenta, 10 lightness values for yellow, and 80 values for black. This indicates that about the same number of multi-density inks are required for cyan and magenta. For black at least one extra multi-density ink is required.

Hence a well balanced ink jet system with multi-density inks consists of two multi-density cyan inks, two multi-density magenta inks, one yellow ink and two or three black inks. In practice, two black inks are sufficient as black can also be made by the overlap of cyan, magenta and yellow. If the dynamic range of the images to be reproduced is larger than 90 lightness units, by preference a third black ink should be used.

For a long time, ink jet systems only had two multi-density cyan inks, two multi-density magenta inks, one yellow ink and one black ink. To make neutrals on such a system, black can not be used as it would result in too noisy images. Hence, neutrals have to be created by the overlap of cyan, magenta and yellow in the lighter areas, whereas for the darker neutrals black should be used to reduce the amount of ink. The main problem is that it is much harder to calculate separations for neutrals with CMY than with K. In reality making a neutral with CMY overlaps is much more unstable than making a neutral with a maximum of K. Stability is defined as the change of the resulting color for a unit change of the CMYK inks. It can be shown that the stability for a maximum K solution (neutrals made with as much black in as possible) is significantly larger than for a minimum K solution.

So the second reason to switch to an ink jet system with multi-density blacks, is to be able to make neutrals in the most stable way by using the maximum amount of K. An extra advantage that is also important for ink jet printing is that the maximum K solution results in the minimum ink consumption. However, making separations for a maximum amount of black requires sometimes an adjusted printer target as the IS12642 target often results in less accurate separations as there are not enough color patches with different black values.

Conclusion

By optimizing both the digital workflow and ink set of the ink jet system, a proofing system can be designed with which proofs can be made in an accurate way. In this publication we limited ourselves to the main processing blocks of the digital workflow including characterization, calibration and ink split, and the optimization of the ink set of the printer to obtain a gamut that is large enough and a smooth reproduction of color gradations.

References

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Biographies

Stefan Livens received a M.S. degree in physics at the University of Antwerp (Belgium) in 1992 and a Ph.D. in sciences at the same university in 1998 for a color analysis study on microscopic images of silver halide crystals. After working at Barco Graphics, he joined Agfa-Gevaert N.V. in 1999. He has since worked on the development of color imaging technologies such as ink jet proofer calibration and halftone proofing.

Marc Mahy received a M.S. degree in physics at the Katholieke Universiteit Leuven (Belgium) in 1986 and a Ph.D. in sciences at the same university in 1994 for his study on color spaces for visual and physical image processing. Since 1995, he was employed as Color Scientist at Agfa-Gevaert N.V. where he was responsible for the development of color management for several products. Since 2001 he is working with a dedicated team on the development of color imaging technologies for graphic arts applications.

Koen Vande Velde received a Ph.D. degree in sciences at the Katholieke Universiteit Leuven in 1995. He then worked on image enhancing techniques at the Medical Image Processing lab of Katholieke Universiteit Leuven. In 2000 he joined Agfa, where he is working in the area of color management and halftoning.

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