

Investigation of Workflows for High Quality, Fine Art Black & White, Digital Publishing

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Abstract

Despite the advent of color printing, for many artists and photographers, a high quality black and white image is still the preferred output medium for their fine art work. Classically, the highest quality black and white photography books are printed using offset presses equipped with multiple gray inks for rich, smooth and detailed prints. Similar quality is difficult to achieve on modern digital presses, where the output production is typically limited to a standard 4-color (CMYK) ink set. HP Indigo digital presses have the ability to print with up to 7 different inks. While the typical use of the additional 3 channels is for custom colorants deployed in spot color applications, they also have the potential to be deployed for fine art black and white printing using multiple gray inks similar to those deployed in conventional offset presses. Such custom, black and white ink based workflows, deployed on digital presses, have the added advantage of being able to print short-run productions which are very desirable in limited-edition, fine art reproduction applications.

This paper summarizes some general results of experiments performed at HP Labs, along with work-in-progress in attempting to produce high-quality reproductions of a silver halide portfolio on an HP Indigo digital press at RIT using 2 different workflows – one using standard 4 color (CMYK) inks and the other using custom mixed gray inks (3 grays and black – hence referred to as GGGK). While acceptable results were achieved using the CMYK method, it was found that the GGGK method produced noticeably better results. However, the transfer curves and separations could benefit from some additional mathematical rigor. There was some unacceptable posterization in areas of density transition in some images. The workflow is being refined to fix this problem and new results will be reported later.

Introduction

The advent of color digital printers - such as the HP Indigo press - has not supplanted the need for fine art black-and-white prints. In fact, the availability of such presses encourages more artists to want to publish their work using short run lengths. A digital press is an almost perfect press for the so called *limited edition books* artists like to produce. HP recently launched MagCloud, an online magazine publishing service that utilizes HP Indigo digital presses. A survey of MagCloud publishers conducted in October 2008, revealed that 47% of respondents publish or plan to publish an art or photography magazine, which is by far the most popular category selected.

For black and white reproductions printed using colored inks, it is a challenge to obtain a smoothness of the tones (lack of graininess and plenty of gray levels), a pleasing neutrality, a high

maximum density and a similar tone reproduction curve as silver halide photographic prints. Simply using black ink only is not adequate because of limited contrast and graininess obtained due to the halftone screening. Using process color (CMYK), one can assure the stability of neutrality by using mostly black ink and adding small amounts of CMY to add more halftone dots which in effect results in a less visible and finer halftone pattern. Another method consists of using gray inks to form the low density tone values. In 2006, Golodetz et al demonstrated how adding a gray ink can reduce the graininess of black and white images [1] while in 2007, Koh and Chatow, published results showing the improvement in gray neutrality and illumination sensitivity [2].

Glossiness

Gloss is an important aspect of image quality. The gloss of an original silver print might range from matt to very glossy, and newer inkjet printers utilize both a matte and gloss black ink in order to reproduce a wide range of output. Glossy black ink on matt paper results in the largest printable contrast. One advantage of liquid electrophotography technology over dry toner electrophotography is the use of a much smaller particle size (1 μm vs $>5 \mu\text{m}$). **Figure 1** below shows a cross section of a piece of paper printed using these two technologies. Because of the small particle size, liquid electrophotography prints can follow the topography and replicate the gloss of the underlying substrate (**Figure 2**). Therefore, the chosen paper has a big influence on the obtainable gloss and contrast. The printing paper itself can be matt, semi-matt or glossy.

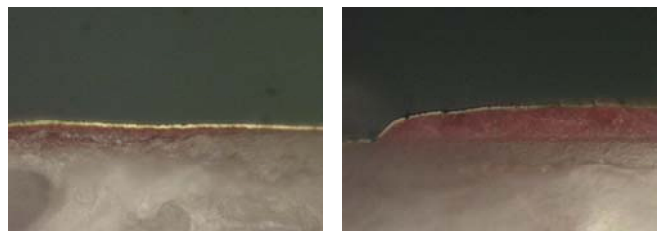


Figure 1. Cross-section image showing the ink thickness of liquid electrophotography (left) and dry toner electrophotography (right).

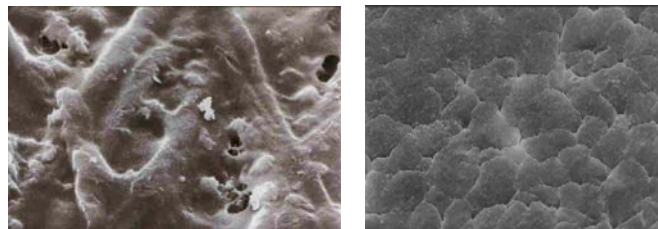


Figure 2. SEM capture of surface texture of uncoated plain paper printed using liquid electrophotography (left) and dry toner electrophotography (right).

Screening

Silver halide originals are inherently continuous tone. However, the printed reproduction requires a halftone to create the tone values. Often there is more than one screening method available for a given output device. It is tempting to use the finest possible halftone to make the halftone dots as small and therefore invisible as possible. However, for AM screening, the number of reproducible gray levels may be severely limited when too fine a screening is chosen. For AM screening, when optimizing the screening method for a given application, there is a basic trade-off between screen ruling, addressability and gray levels. When using a printing system where any given addressability spot can only be either black or white, the number of tone values can be calculated using the equation: Number of tone values = (addressability / screen frequency)² = (spi / lpi)². (Note: Spots per inch (spi) is the correct term, dots per inch (dpi) is a wrong term because dots are and always have been halftone dots not addressability spots).

For FM screening, there is no screen ruling and therefore no restriction on gray levels, however, FM screening is inherently noisy, particularly when the FM screening dots are larger than 21 microns.

At an addressability of 812 spots per inch and an AM screen ruling of 180 lpi, there are only (812 / 180)² = 20.4 gray levels. This is not enough for a high quality reproduction. There are two methods that can be used to hide the banding (posterizing) that would occur: the RIP can add a small amount of noise to the image, and/or supercell screening can be used. (Supercell screening places more than one halftone dot in a single screening cell. Because the supercell is larger than a single cell, more gray levels can be reproduced. One of the drawbacks for this is that each dot may potentially be slightly different in size from its neighbor even in a uniform tint, see for instance the 10% dots in **Figure 3**.) Both methods reduce spatial resolution somewhat, but a good compromise was found for Indigo which makes it possible to reproduce smooth gradients.

There is one problem that remains: the system is not able to print really small dots like 16 microns which is required for a 1% dot of a 180 lpi halftone. One single spot at 812 spi has a side length of 31 microns which represents a 4.8% dot area at 180 lpi. Therefore, what is done in a system like this is to skip a few halftone dots at tone values of less than 6 % in order to obtain a smooth start of a gradient as shown in **Figure 3**.

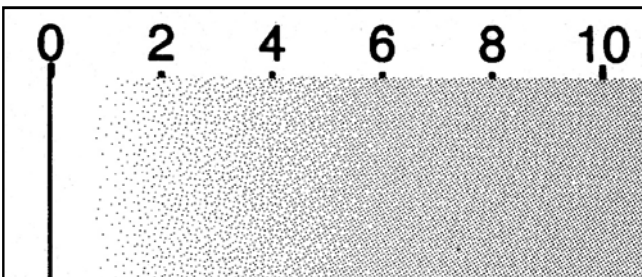


Figure 3. Highlight end of a gradient printed at 180 lpi on HP Indigo 3000 at 812 spi

This improves tone reproduction in the highlights, but it makes the dot pattern more perceptible. This would not be acceptable for a high quality photographic reproduction. But as a user, one can employ one of the following two strategies to make this dot pattern much less visible. Both involve using more than just black ink for the reproduction. The additional inks add more light colored dots, which results in a much finer effective screen frequency, and because these dots have a low density, their contrast with the paper is lower and therefore they are less visible. The first method uses the normal CMY inks to support the black while the second method uses additional gray inks.

Gray Ink Selection

The first step in the process of gray ink selection is determining how many gray inks will be used in the system. If only one ink station is available, the choice is simple. When deciding how light or dark the single gray should be, there is a tradeoff between graininess in the highlights versus maximum black density. As a starting point, the gray ink should be visually about halfway between paper white and the darkest black (100% gray and 100% black). A darker gray ink will help you achieve a darker black point, while a lighter gray will result in smoother tones in the highlight regions.

If more than one ink station is available, the tradeoff becomes less of a problem. Having access to both a light and a dark gray will allow for smoothness throughout the tonal range with a reasonably dark black point. However, each additional gray ink adds another impression to the process, which increases cost and lowers throughput. Using only 1 gray ink along with black has the advantage of only requiring 2 impressions, which represents a 100% improvement in throughput over traditional 4-color CMYK printing at a lower cost per page. If speed and cost is not an issue, the ultimate setup for the reproduction of high quality black and white prints could involve the use of gray/black inks in all seven of the Indigo ink stations.

The HP Indigo Ink Mixing System allows for the mixing and use of custom inks. In addition to operating a media certification program for third-party manufacturers developing substrates for HP Indigo presses, RIT also mixes custom spot-color HP ElectroInks for HP Indigo customers. This allowed the authors to experiment with different combinations of gray inks.

Ink Separation

Once the choice to use light inks is made, it is necessary to separate the single channel into multiple channels. In the case of black and white printing, the input can be seen as a single grayscale channel and the output as multiple gray/black channels. The stitching point, or transition point from one ink to the next, will be determined by how light or dark the gray inks are. The most basic ink separation involving 1 gray ink and 1 black ink is shown on the left in **Figure 4**.

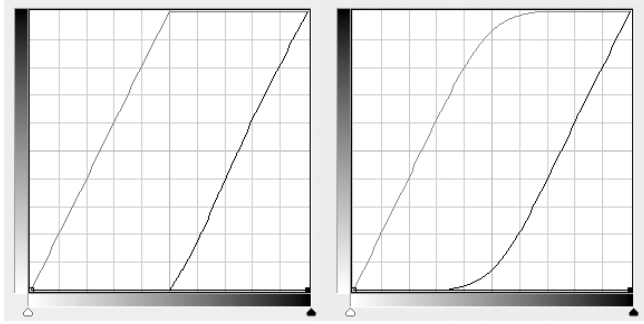


Figure 4. Ink separation curves without overlap (left) and with overlap (right)

The gray ink is used in a linear fashion from white to the midpoint, and black ink is used in a linear fashion from the midpoint to black. However, because there is no overlap in the transition from one ink to the next, there is a risk of introducing contouring artifacts. To minimize contouring, it is recommended that adjacent inks overlap each other, as shown on the right in **Figure 4**. To test for contouring, a spherical gradient was printed with gray and black inks using these two separation curves, a scan of the resulting print is shown in **Figure 5**.

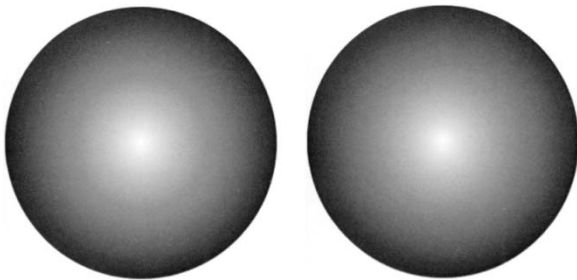


Figure 5. Spherical gradient printed using ink separation curve with no overlap (left) and with overlap (right). Note: printed copy of this paper may not show contouring in the gradient on the left and lack of contouring on the right.

For offset printing it is necessary to limit the total area coverage (TAC) of inks because they are printed on top of one another while the previously printed inks are still wet (this is called wet trapping). TAC values of around 300% are often used. On the Indigo press, each ink is dry before the next one is applied, therefore TAC may be allowed to be higher.

Workflow of RIT Experiment

The experiments performed at RIT were conducted independently of those at HP Labs. Thus, they are representative of how a real-world customer can utilize their digital press in new and interesting ways. This workflow was limited to producing the optimum reproductions from silver halide prints. The original silver halide photographs were scanned using a colorimetrically characterized BetterLight camera. The resulting RGB image was

converted to grayscale mode in Adobe Photoshop. Two approaches were used to attempt to print high quality reproductions on an Indigo press, one using standard CMYK (process) inks and the other using 3 custom gray inks (L* of 50, 75 and 30) and the standard process Black. We refer to this method as GGGK printing. The Indigo Press was profiled using GretagMacbeth ProfileMaker software, and separations were created. However, it was found that the separation controls in this software were limiting, and so it was decided to construct separations in Adobe Photoshop using the channels command and shaping the tone reproduction for each channel using the Curves tool. The fully rendered files were then printed on the Indigo using NO COLOR MANAGEMENT.

Tone Reproduction Curves

In Photoshop, a single grayscale image was duplicated into 4 channels, using Multichannel mode. Then, using Curves, the tone reproduction for the 4 channels was adjusted as shown in **Figure 6**. Then, the 4 channels were converted to CMYK mode. The CMY relationships are designed to result in a neutral gray. Tone values of less than about 8% have no black. Making them with CMY only means that more lower contrast dots are used, resulting in a smoother tone. The CMY contribution to image contrast is only important in the highest highlights and the deep shadows. In the midtones, the CMY curves are kept low and flat because if the ink balance on the press is unstable (not gray), the low values have little effect. Nevertheless, these small CMY dots in the midtones help to increase effective screen frequency and thereby reduce granularity of the image. In the shadows the CMY colors help to add density. They are covered with a lot of black, and therefore, if there is a CMY ink unbalance, it is not visible.

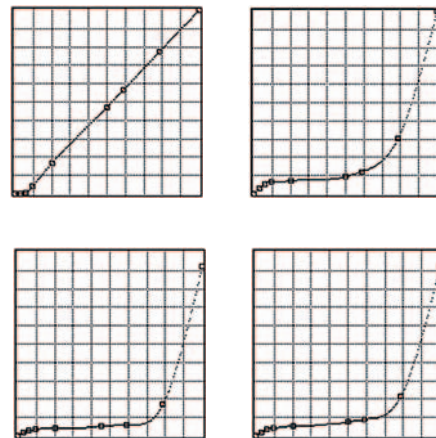


Figure 6. Separation curves for CMYK method (Black, Cyan, Magenta and Yellow curves shown)

A sample set of about 25 people agreed that the 4 color CMYK images were acceptable quality.

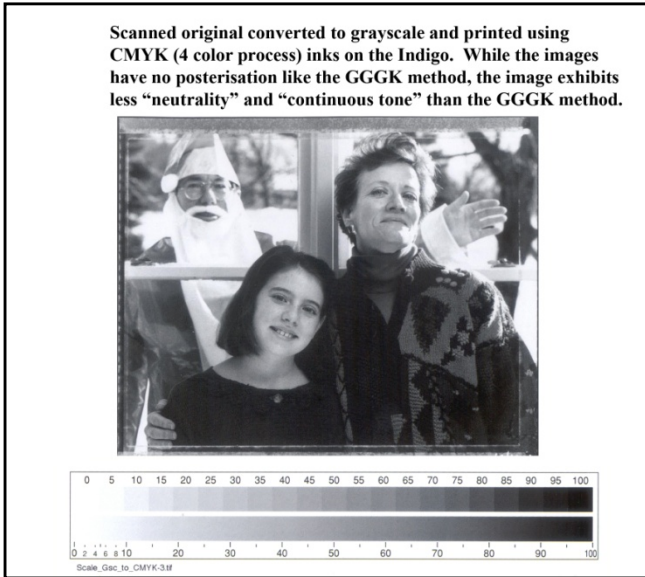


Figure 7. Scan of CMYK print.

Yet, many observers preferred the smoothness of the continuous tones that was achieved with the GGGK inks. This approach definitely has merit. The choice of three grays rather than just one or two was arbitrary. The printing units were available, so three were tried, assuming that more is better. The assumption was that the actual curves were not very critical, because a transfer curve will have to be used anyway to obtain the optimum tone reproduction. Basically the next darker gray will have to start when the previous lighter gray levels off. In the very dark areas the light gray will not contribute much, so it can be reduced (to save ink). However, it might be useful to seal the paper surface and help the darker inks to hold out better.

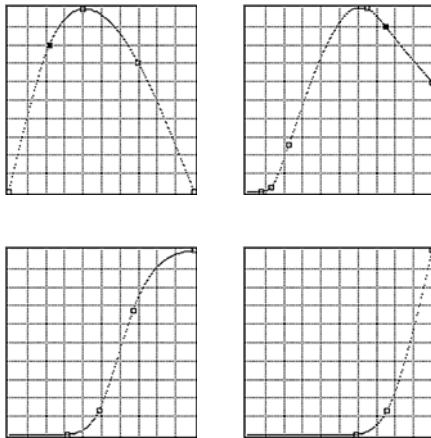


Figure 8. Separation curves for GGGK (Light Gray, Medium Gray, Dark Gray and Black curves shown).

However, our determination of the separation curves was by trial-and-error. While our sample audience (and the artist) did prefer the images obtained using the GGGK method, our

separation curves created posterization in some images at transition points. This is shown in Figure 9.

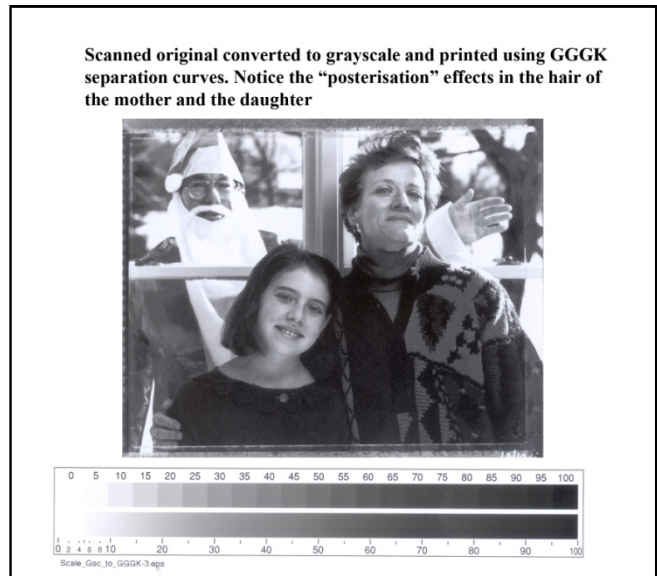


Figure 9. Scan of GGGK print.

Future Work

Our work clearly indicated the advantage of using the GGGK method – the images were neutral and showed noticeably better continuous tone than the CMYK approach. However, our transfer curves and the separations generated from such curves produced unacceptable posterization in transition areas between two curves. The authors are confident that these problems can be eliminated by using better mathematical models based on Neugebauer equations. This work will be completed in early 2009 and the results will be reported in a future publication.

References

- [1] G. Golodetz, U. Chatow, K.W. Koh, I. Tasts, Digital Offset Printing – Going Beyond 4 Colors, NIP 22 (2006).
- [2] K.W. Koh and E. Chatow, Indigo Light Inks: Raising the Bar for Image Quality, NIP23 (2007).

Author Biography

Kok-Wei Koh earned his B.S. with distinction in Computer Science (*magna cum laude*) from the University of Washington, Seattle, in 1994, and his M.S. in Computer Science from Stanford University in 2002. He has been working in the Print Production Automation Lab of HP Labs in Palo Alto since 2000, where he conducts research experiments on all things color related.

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