Photo Quality Printing on a Digital Press

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Abstract

In this paper, we will address the issues and the challenges for achieving photo-quality output with bi-level digital printing technologies. We will present the case study of transforming a 4-color Hewlett Packard Indigo liquid electrophotographic digital press, into a 6-color printer that can print images that are comparable, in terms of image quality and image permanence, to the traditional prints produced on silver halide photographic paper. We will discuss the requirements for gamut size, inks, color separation, halftoning and image permanence. We will describe the technologies and the methods needed to meet the requirements for photo-quality output.

Introduction

The photographic industry is going through the digital revolution. The revolution that has started on the capture side with the dramatic increase in the sales of digital cameras is now spreading to the photofinishing side. The increased affordability of the digital capture systems such as digital cameras and scanners, the rapid increase in the number of image digitization services is transforming the photographic industry and pushing the photofinishing side of the industry to become digital as well. Meanwhile, a similar revolution fueled by the customization and the cost advantages of a totally digital workflow, is going on in the commercial printing market where digital presses are rapidly replacing analog presses.

In the last year, we have carried out a technical feasibility study aimed at the intersection of these two revolutions. We have investigated the issues and challenges in transforming a commercial printing digital press intended for offset printing, into a digital photofinisher. We started out with a 4 color Hewlett Packard Indigo LEP (liquid electrophotographic) digital press. In its default configuration, this press is a CMYK (cyan, magenta, yellow, black) bi-level digital press intended primarily for offset-quality commercial printing applications. The press contains 3 additional marking systems, which may be used for either spot color inks or the additional inks in Hewlett Packard Indigo's proprietary hi-fi 6 ink system, Indichrome. The marking technology is liquid toner-based electrophotography.[1]

To enhance the image quality of the photos printed, we added two more colorants (light cyan and light magenta) to this press and investigated the following areas for further improvement: gamut size and inks, color transitions, dot visibility, color separation, grain, halftoning and image permanence. We address the challenges and the necessary changes in these areas in detail below.

Gamut and Inks

One of the first challenges in creating a photofinisher from a printer using a technology other than exposing silver halide paper is to attain the gamut of the silver halide papers. In its original configuration, the Hewlett-Packard Indigo digital press has a gamut very similar to the one defined by SWOP™ (Specifications for Web Offset Publications).[2] This original gamut is considerably different than the gamut of a typical silver halide paper as compared in Fig. 1.

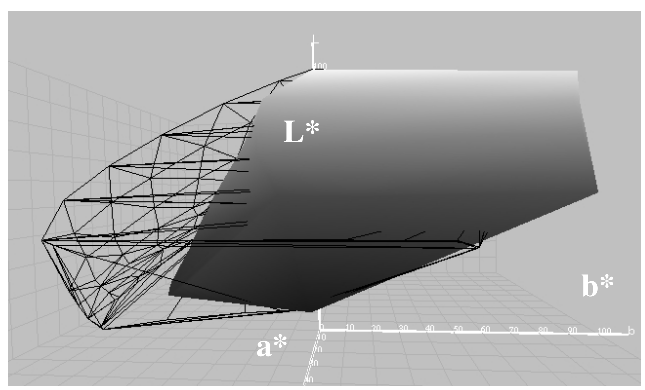

Figure 1. Comparison of the gamut of the initial configuration of the digital press (shown by the color solid) and the gamut of a typical silver halide paper (shown by the wire mesh).

The differences in the gamuts are noticeable in the dark blue, purple, magenta, yellow and light green regions of the color space. The cause of this gamut mismatch is the difference in the color coordinates of the inks of the digital press and the color coordinates of the resulting colors in the exposed silver halide paper as shown in Fig. 2, especially in the magenta and the yellow colors. The magenta of the commercial printing press is considerably more reddish i.e. has a significantly lower b* value than the silver halide magenta. The yellow of the commercial printing press is on the other hand is greener i.e. has a lower a* value than the silver halide yellow. To attain full coverage of the silver halide paper gamuts, the magenta and the yellow inks of this digital press (or any other offset printing oriented printer) need to be changed. To find the optimal inks, spectral characterization of the press and empirical tests can be used jointly for an efficient search.

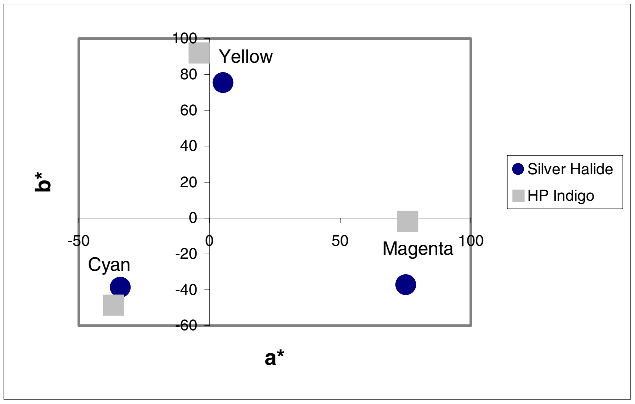

*Figure 2.CIE a*b* coordinates of the original inks of the Hewlett-Packard Indigo digital press(shown by the squares) and of the resulting colors in the exposed silver halide paper(shown by the circles).*

Light Inks and Color Separation

The reduction of dot visibility is another important step towards achieving image quality that is comparable to continuous tone silver halide prints. The use of light colorants is an effective way of reducing the visibility of dots in bi-level printing devices in order to minimize the appearance of grain and to achieve smooth color transitions from light to dark tones.

To maximize the effectiveness of the light colorants, care must be taken to ensure that they are neither too light nor too dark. While a lighter colorant will result in reduced first dot visibility, it will also lead to a harsher and more visible transition when dark inks are first introduced. A darker light colorant will have a smoother transition to from light to dark ink, but will result in a more visible dot when first introduced. Therefore, when selecting the concentration of the light colorants, there is a tradeoff between first dot visibility and the light to dark transition.

Another step towards achieving photographic output is to ensure that appropriate inks are used in the right amounts and ratios throughout the various parts of the color space. For example, in the transition from white to black, it is advantageous to start with some combination of light cyan, light magenta and yellow ink for the light gray tones, slowly introducing dark cyan and dark magenta for the medium gray tones, and finally introducing black ink for the dark gray to black tones. Not counting the yellow ink, the light colorants have the lowest dot visibility, followed by the dark colorants, followed by the black ink. Therefore, a neutral ramp that is constructed this way will have a smoother appearance than one constructed entirely from using black ink. Care must be taken when calculating the proper ratio of the six inks in order to maintain a neutral hue from white to black.

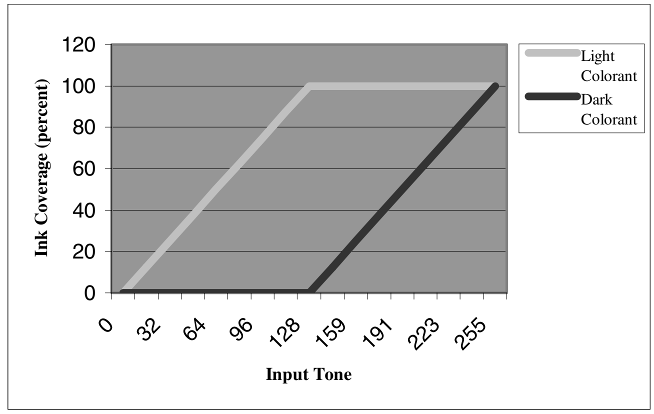

Figure 3. An example ink transition from light to dark colorants of a non-ink limited printing system. Note how the light colorant remains at 100% while the dark colorant is being introduced.

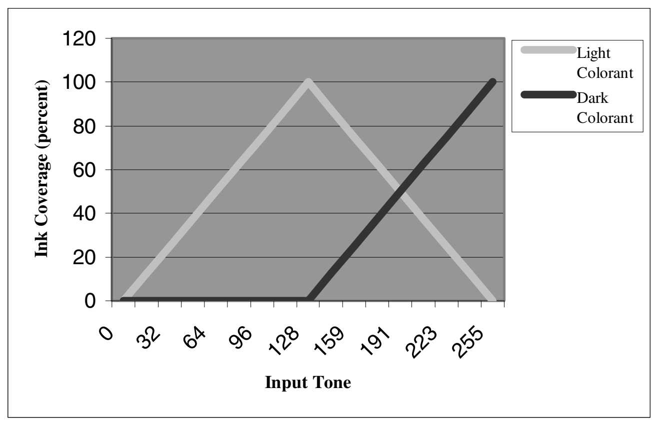

Figure 4. An example ink transition from light to dark colorants of an ink limited printing system. Note how the light colorant has to be reduced as the dark colorant is being introduced.

Liquid electrophotography technology has the rare advantage of being able to lay down up to 100% of all 6 colorants at any place (Fig. 3), and therefore, it does not have ink volume limitations that ink jet and other marking technologies have (Fig. 4). This simplifies the color separation process by allowing the light colorants to remain at 100% while the dark colorants are being ramped in.

Halftoning

Halftoning method is a major differentiating factor in the image quality obtained from printers. Digital printing technologies usually have an addressable resolution of R x sR dpi, where s refers to the factor by which the horizontal addressability is increased. This may be viewed as an R x R native resolution with s sub-pixels per pixel. Frequency modulation (FM) halftoning methods such blue-noise dithering,[3] produce good detail rendition, but for reproducing smooth skin tones, clustered-dot halftoning methods are preferred for use in liquid electrophotographic photofinishing (although FM halftoning is preferred in inkjet photofinishing) depending on the target resolution and dot development characteristics.

Like laser printers, clustering of individual printer dots promotes stable printing. This is accomplished with either conventional clustered dot amplitude modulation (AM) halftoning, or stochastic hybrids (a.k.a. AM-FM halftoning).[4] While AM-FM hybrids provide moiré resistance, better detail rendition, smooth tone transitions, and eliminate rosettes, conventional AM screens are robust and have good reproduction of flat tints and tend to smooth variations in skin texture.

Perceived graininess is reduced over results produced at the native resolution by using the sub-pixel addressability. This means that the dots grow in increments of a sub-pixel, instead of a whole pixel so that the transition between levels is perceptually smooth. Figure 5 shows how sub-pixel modulation is used to minimize perceptual quantization error. Using sub-pixel addressability also means that the dots are grown in elliptical fashion to ensure circular low-noise printed dot clusters. The aspect ratio of the growth depends on the number of sub-pixels allowed per native resolution pixel.

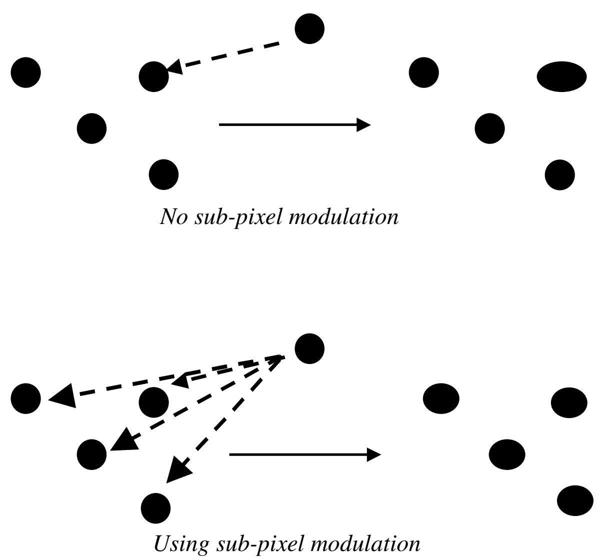

Figure 5. Effect of sub-pixel modulation. With no sub-pixel modulation a dot cluster grows by a whole pixel. Using sub-pixel modulation allows each dot to grow over more levels by distributing dot growth over more dot clusters. The dashed arrows illustrate how sub-pixels are distributed when the tone level is increased by one whole pixel.

Image Permanence

Image permanence is one of the requirements that have to be considered for a photofinishing printer. In general, images printed on different types of printers change their appearance over time. The goal for a non-silver halide photofinisher is to reach an image permanence performance, which is comparable to that of traditional silver halide prints. Performance refers to measured values as well as visual appearance. The amount and type of changes occurring within a certain time frame have to be below certain thresholds to preserve the original appealing appearance of the output.

Image permanence can be subdivided into 4 categories: lightfastness (light fading stability), dark storage stability, humidity fastness and water fastness. Lightfastness has attained the highest attention in the industry so far. The factors determining lightfastness and image permanence in general are media, inks (different performance for dye and pigment based inks), whether diluted inks are used or not, lamination, intensity of the average illumination, temperature, humidity and air pollutants. Consumers should be aware that the appearance of a print after 10, 20, 30 years depends not only on the ink/media/lamination combination, but also on the storage conditions during all those years. High illumination, high temperature and high humidity can have a very negative effect on the appearance.

The most important factor in image permanence is the inks, specifically the pigments and the dyes in the inks. Trying to achieve a high degree of light fading stability and a large gamut at the same time can pose a challenge for the ink development due to the rarity of pigments and dyes that have both of these desirable properties. In our case study, we have printed on special photo media using 6 pigment-based inks that were chosen to attain both of these properties. Two of the inks had light dye loads and the prints were laminated at the end.

The appearance of a print (performance of the ink/media/lamination combination) after a number of years can be generated to a certain degree of accuracy by exposing it to very bright light in a controlled environment (certain temperature, certain humidity). Lighfastness tests are based on this capability to simulate the longtime exposure of a print to typical office conditions by exposing it to more extreme conditions for much shorter periods.

In specific, color charts consisting of ramps going from minimum density to maximum density for the primary and secondary colors as well as from black to white are printed and put into fadometers. Density measurements are performed in regular intervals in order to measure the color fading (change in density) and to determine the time until a particular percentage of dye loss is reached. Other measured quantities are color balance in compounds as well as color changes in general. Within the industry, two sets of criteria, the first one provided by an ANSI-Standard and the second one provided by the Wilhelm Imaging Inc., have been well established. Details of these criteria can be found in [5] and [6]. When comparing the results of lightfastness tests, it is very important to consider the specific conditions under which the tests have been performed. Changing the conditions from one set to another set can result in changes of the number of years until the fading criteria is reached by a factor of two.

An image permanence area, besides lightfastness, which is gaining more attention from the industry recently is the dark storage stability. It refers to fading, color balance changes and discoloration that occur over time in the dark. The remaining two categories of image permanence, water fastness and humidity fastness, are quantified with other tests. In the specific case of the Hewlett-Packard Indigo LEP technology, water fastness is not a problem because of the use of lamination. Humidity fastness should be tested, but is not expected to be an issue because of the pigment-based inks.

Conclusion

We have addressed the issues and the challenges for achieving photo-quality output with bi-level digital printing technologies. We presented the case study of transforming a 4-color Hewlett Packard Indigo liquid electrophotographic bi-level digital press, into a 6-color printer that can print images that are comparable, in terms of image quality and image permanence, to the traditional prints produced on silver halide photographic paper. Our preliminary results show that with the changes in the inks, the color separation and the halftoning method we have proposed above, it is possible to approach silver halide photo quality with bi-level digital color presses.

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Biography

A. Ufuk Agar received the B.S. degrees in electrical engineering and mathematics from Bogazici University, Istanbul, Turkey, in 1992 and the M.S. and Ph.D. degrees in electrical and computer engineering from Purdue University, West Lafayette, IN in 1995 and 1999, respectively. Since 1999, she has been working in the color imaging and printing technologies department in Hewlett Packard Laboratories in Palo Alto, CA where she is senior research scientist.

Gary Dispoto received B.S. degree in electrical engineering from Stanford University in 1985, an M.S. from Stanford in 1989, and an MBA from Santa Clara University in 1992. He joined HP Labs in 1985 as a researcher in the then new-to-HP field of digital color reproduction, where he has worked on many aspects of color printing, color management, and color science. He is currently project manager for color science and reproduction at HP Labs.

Ingeborg Tastl is a digital color imaging scientist at Hewlett-Packard Laboratories working in the area of digital imaging and printing since April 2001. Before that her focus point was in the area of digital photography while working at Sony's US Research Laboratories and at the Ecole Nationale Superieure des Telecommunications in Paris. She got her M.S. degree and her Ph.D. degree in computer science from the Vienna University of Technology, in Austria. She is the SID General Chair for the 2002 IS&T/SID Color Imaging Conference.

Kok-Wei Koh earned his B.S. with distinction in Computer Science (magna cum laude) from the University of Washington, Seattle, Washington, in 1994. He joined Hewlett-Packard's Vancouver Printer Division in 1997 and developed software drivers and color tables for the company's inkjet printers. He has been working in the color imaging and printing technologies department of Hewlett-Packard Laboratories, Palo Alto, California since 2000, and earned his M.S. in Computer Science from Stanford University in 2002.

Niranjan Damera-Venkata received the B.E. degree in Electronics and Communication Engineering from the University of Madras, Madras, India, in 1997 and the M. S. and Ph. D. degrees in Electrical Engineering from The University of Texas at Austin, Austin TX in 1999 and 2000 respectively. Since July 2000 Dr. Damera-Venkata has been with the Imaging Technology department at Hewlett-Packard Laboratories where he conducts research in the areas of multimedia analysis and digital halftoning.