Visual Communications Journal

Spring 2015 – Volume 51, Number 1

Effect of Digital Halftoning on the Print Attributes of Multicolor Electrophotographic Digital Printing

H. Naik Dharavath, Ph.D. – Mark Snyder, Ed.D.

GRAPHIC COMMUNICATIONS EDUCATION ASSOCIATION

Visual Communications JOURNAL

Volume 51 • Number 1

SPRING 2015

Acknowledgements

Editor

Dan Wilson, Illinois State University

Cover Design

Ranyah Al-Hebshi
Instructor, Monika Zarzycka

Page Design, Layout, and Prepress

Janet Oglesby and Can Le

Printing, Bindery, and Distribution

Harold Halliday, University of Houston
University of Houston Printing and Postal Services

About the Journal

The *Visual Communications Journal* serves as the official journal of the Graphic Communications Education Association, and provides a professional communicative link for educators and industry personnel associated with design, presentation, management, and reproduction of graphic forms of communication. Manuscripts submitted for publication are subject to peer review. The views and opinions expressed herein are those of authors and do not necessarily reflect the policy or the views of the GCEA.

Article Submission

Please follow the guidelines provided at the back of this *Journal*.

Membership and Subscription Information

Information about membership in the Association or subscription to the *Journal* should be directed to the GCEA First Vice-President.

Reference Sources

The *Visual Communications Journal* can be found on EBSCOHost databases.
ISSN: Print: 0507-1658 Web: 2155-2428

Effect of Digital Halftoning on the Print Attributes of Multicolor Electrophotographic Digital Printing

by H. Naik Dharavath, Ph.D. • Central Connecticut State University & Mark Snyder, Ed.D. • Millersville University

Introduction

Over the past two decades, the printing industry has been revolutionized. Technology, workflow, management strategy, markets, and customer expectations have changed. The value and role of printing is changing. Today the use of print is merged across multiple communications channels, such as web, mobile, and social media.

Due to advancements in computer networking and digital printing technologies, color print media is essential as part of the mix a communication channels. Modern color printing has evolved from a craft-oriented technology toward a color management science. This demands greater color reproduction control among the devices used in the print and imaging industry.

A continuous tone color photograph is composed of a full spectrum of shades and color, from near white to dense black. The method by which continuous tone photographic images are transformed to a printable image is called halftoning. In this method, varying percentages of the printed sheet are covered with halftone dots to represent the varying tones in the image. In the conventional halftoning process, these dots are equally spaced. However, the size or diameter of the dots will vary according to the different amounts of light that is reflected from the different tones. The ink printed for each dot has the same density. At normal viewing distance, the dots of a printed image create an optical illusion of a continuous tone image. Because the dots vary in size and are equally spaced from one another, the conventional halftoning process is referred to as amplitude modulated (AM) screening (see Figure 3). "Amplitude" relates to the relative size of the dot.

In AM screening, some devices and plates are not capable of holding such fine detail which can lead to tone breaks giving the impression of some posterization. However, for several decades, digital imaging technology has been capable of reproducing images using an alternate screening method based on a pseudo-random distribution of consistent small dots. While these dots remain the same size throughout, the number of the dots varies in a given area to produce tonal variations throughout an image. Because the number of dots changes instead of the dot size, this is called "frequency" modulated (FM) screening. The motivation of this research is to study the consistency of digital screening applications and to quantify the quality of digital color printing, leading to a better understadning of the differences between AM and FM screening for a given digital press.

Literature Review

Digital print technologies can be described as methods that do not use image carriers such as printing plates. Traditional printing methods such as offset lithography and flexography use different types of plates, while gravure uses an engraved cylinder to transfer the image, and screen printing uses stencils applied to framed mesh material. Each of these traditional printing methods uses pressure, or force, supplied by a machine to transfer some form of ink to the substrate. The goal of traditional printing methods is mass reproduction of the same imaged product.

Digital printing methods differ in that they usually do not have a direct physical impact on the substrate. Inkjet printing utilizes different methods of transferring liquid ink droplets to a substrate to create an image. Electrophotography employs charged toner particles that transfer electrostatically to the substrate and create an image that is fused to the surface. Electrophotographic and inkjet printing generate the majority of digitally printed materials although other methods, such as thermal transfer and ion deposition can be used.

The technology of interest for this study is dry-toner electrophotography. The advantage of dry, toner-based digital print technology is that it can create variable images from one sheet to the next and it is more cost-effective for shorter production runs. Digital printing requires limited set-up of equipment to produce imaged products on demand and there is much less production waste. Additionally, the printing requires less skill of the person generating the imaged products than traditional printing methods.

In the digital printing environment, the screening software can create both AM and FM halftone screens. Screening software in the raster image processor (RIP) of a digital printing press applies a digital dot pattern to the color image during printing. Introduction of digital screening technology for the halftone reproduction process began in the early 1970's. According to Lau & Arce (2008), "the halftoning process of projecting a continuous-tone original through a halftone screen has been replaced with a raster image processor." They continue:

"When first introduced, RIP's imitated the halftone patterns of contact screens … forming a regular grid of round dots that vary in size according to tone. These techniques are commonly referred to as amplitude modulated or AM digital halftoning due to their modulating of the size of the printed dots" (2008, pg 4). Turning to the advent of FM screening (see Figure 3), Lau & Arce stated, "early FM halftoning techniques … suffered from a periodic structure that added an unnatural appearance." A better approach was developed that "proposed the revolutionary error-diffusion algorithm … leading to a stochastic arrangement of printed dots" (2008, pg 5). This technique was incorporated with electronic dot generation via high-end electronic color scanners to create an alternative to traditional photomechanical screening techniques (Stanton & Warner, 1994). In FM screening (see Figure 3), the tonal range is reproduced better because all the dots are the same size, it is only their frequency that changes.

Today, most digital printing environments utilize a digital halftoning process for color output. A simple digital image could be a binary picture, [h(x, y)], with each point being either completely black or completely white (Pnueli & Bruckstein, 1996). A digital halftone is a pixel map, with bit depth, that gives the impression of an image containing a range of gray shades, or continuous tones. An 8-bit grayscale image contains 256 different levels of gray (from white to black). Advancements in digital technology enable the industry to engage in short-run color printing that can achieve levels of color quality comparable to the traditional offset printing process. Also, modern digital printing employs various screening techniques for digital color output.

One question emerged from exploring differences between printing methods: is it appropriate to compare digital printing systems through measures of quality (such as dot gain) used for traditional printing? The response to this is debatable and also dependent on what variables are examined as well as the measures used. In the case of dot gain, it seems there is evidence to support a study of "digital dot gain" [(see Figure 1), Lawler, 1997]. Dot gain occurs when printed dots increase beyond their intended size due to technical processes involved in creating printed material.

Goyat, Amaranand & Kuldeep, (2011) studied dot gain in digital printing as it related to cylinder pressure and toner-based liquid ink. Their study utilized samples created by an HP Indigo 5500 digital press. Since that machine is a unique hybrid offset/digital press, the results revealed dot gain from cylinder pressure on "electro-inks", and may not be generalizable to this study. In 2003, McIlroy posited "all printing processes exhibit dot gain, or more correctly, tone value increase, to varying extents."

Schematic illustration of dot gain. (Source: http://www.imaging-resource.com/TIPS/LAWLER/DOTGAIN.PDF)

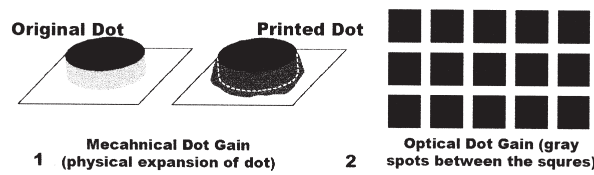

Figure 1

McIlroy continued by stating, "this includes desktop inkjets, laser printers, digital presses, and any conventional printing press" (p. 261). This establishes not only that dot gain is likely to be a measurable factor in digital print but provides a basis for defining dot gain and how to measure it. Leurs supports this definition and further refines it by stating "Dot gain is sometimes referred to as TVI (tone value increase). TVI is a more generic description of the difference in tone value between a requested value and the final output. It is also a more suitable name for processes in which devices may not actually deliver a dot in the final output" (2013). This explanation is particularly useful in relating dot gain to various methods of screening for digital print—which this study intends to investigate by comparing traditional halftone screening methods and stochastic screening methods.

In 1999, Lau, Arce & Gallagher explored digital halftoning methods and observed that "FM halftones are more susceptible than AM halftones to printer distortions such as dot gain, the increase in size of a printed dot from its intended size" (p. 1575). They also concluded that the "major relationship between halftone patterns and the amount of dot gain seems to be the perimeter-to-area ratio of printed dots. That is, the halftone screen having the greatest perimeter-to-area ratio of printed dots will be far more susceptible to the distortions caused by dot gain. FM halftoning, having a much higher ratio than AM halftoning, is, therefore, more susceptible" (p. 1577). Their research involved the development of dithering techniques that offered control of stochastic dot patterning through an algorithm that was less complex than existing solutions and these could also be tuned to varying printer characteristics by adjusting pattern coarseness.

Electrophotographic printing technologies today have reached a level of quality that is comparable to traditional printing methods. In studies of print quality using process color ink systems, there are a number of variables that may cause tonal variations. This is no different when using dry toner-based colorants found with electrophotography systems. Environmental, mechanical, and technical issues, such as dot gain, can have negative influences on the accuracy of color reproduction. Measuring, and recording, certain print characteristics may enable the technologist to make controlled adjustments and then check these variables to see if positive changes can be affected and maintained. Factors such as print contrast and gray balance were selected as the print attributes to be evaluated for this study. These were chosen as they are established quality measures that might influence colorimetric change.

Print contrast is related to dot gain. In traditional print methods, print contrast is a good indicator of print quality of detail held in shadow areas. If unable to maintain print contrast detail in the tones from 75% and up, an image will show large, "flat" black shadow areas. Print contrast is calculated by the formula $[D_t - D_s / (D_s) \times 100\%]$, where D_s is the density of the solid area and Dt is the density of the (75%) tinted area.

Chroma and Hue (C* and H*)

The L* c* h* color space uses the same coordinates as the L* a* b* color space, but it uses cylindrical coordinates instead of rectangular coordinates. In this color space, L* indicates lightness and is the same as the L* of the L* a* b* color space, C* is chroma, and h* is the hue angle. The value of chroma C* is 0 at the center and increases according to the distance from the center (See Figure 2). Hue angle h is defined as starting at the +a* axis and is expressed in degrees; 0° would be +a* (red), 90° would be +b* (yellow), 180° would be –a* (green), and 270° would be b* (blue). Metric chroma C* and the Metric hue angle h* are defined by the following formulas (Morovic, J., Green, P., & MacDonald, L. (2002):

Metric chroma $C^* = \sqrt{(a^*)^2 + (b^*)^2}$

Metric hue angle: $h^*_{ab} = tan^{-1}\left(\frac{b^*}{a^*}\right)$

where: a*, b* are chromaticity coordinates in L* a* b* color space. Difference in the chroma C* of two colors (or gray of AM vs. FM screened image), can be calculated by using the following formula (Morovic, J., Green, P., & MacDonald, L. (2002):

$\Delta C^* = (a_1{}^{*2} + b_1{}^{*2})^{1/2} - (a_2{}^{*2} + b_2{}^{*2})^{1/2}$

$\Delta C^* = C^*_1 - C^*_2$

where: 1 = C* of AM Screened Image Color and 2 = C* of FM Screened Image Color.

Gray balance is the proper percentage of combinations of cyan, magenta, and yellow inks that produce neutral shades of gray. Hue shifts will occur when there is any imbalance of one of the components. Gray balance is a significant factor in determining overall color gamut. Gray balance can be determined by careful evaluation of a full set of tint charts printed with process inks. Colorimetric methods are used to determine if the hue of gray is desirable in order to make sure that the black ink scale is neutral. Calculation of ΔH* or ΔC* (or C*) requires colorimetric data from the L* a* b* model.

Hue difference (ΔH*) is calculated by the following formula (Morovic, J., Green, P., & MacDonald, L. (2002):

$\Delta H^* = \sqrt{(\Delta E^*ab)^2 - (\Delta L^*)^2 - (\Delta L^*)^2}$

$= \sqrt{(\Delta a^*)^2 + (\Delta b^*)^2 - (\Delta C^*)^2}$

Amplitude Modulated (AM) vs. Frequency Modulated (FM) Screening

As stated earlier, industry has utilized the electronic version of AM screening in the film-based workflow. Although FM screening became available during the early 1990's, the printers using a film-based workflow generally did not adopt it. The microdot was difficult to transfer clearly to the plate via the vacuum frame. Any variation

Schematic of L* c* h* coordinates. Hue difference (ΔH*) is calculated by the following formula (Morovic, J., Green, P., & MacDonald, L. (2002)

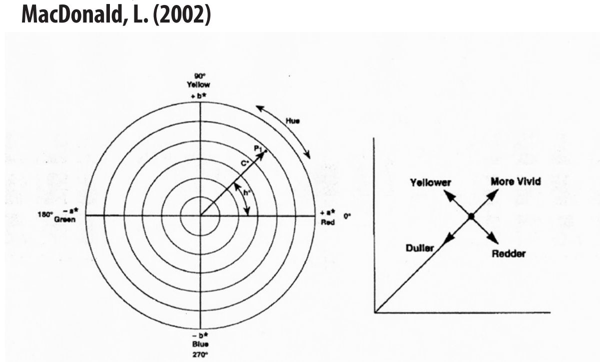

Figure 2

in the film-to-plate creation process would distort the final FM tone values, making the process unreliable. As a result, FM screening didn't gain popularity in the industry initially. In the last five years, those using a digital printing workflow began to adopt FM screening technology in larger numbers..

AM screening creates the illusion of tonal values by altering the size of the uniformly spaced dots. FM screening creates this illusion with small, randomly spaced spots. More spots create shadow and less spots create highlight in the image. The random nature of the spots eliminates the possibility of moiré and other AM screening artifacts. The spacing of fixed distances in between the dots that form an image results in loss of details in AM screening. In FM screening, loss of detail is minimized due to the small dot size and close spacing of microdots (see Figure 3). Another limiting factor of AM screening is the ability to maintain dots at low and high ends of the tonal range. As screen frequency increases, it becomes difficult to hold a clear highlight area in an image. FM screening also uses very small dots, so this problem will also be present in FM screening (Chung & Ma, 1995).

FM vs. AM screened image. (Source: http://coloursplash.eu/)

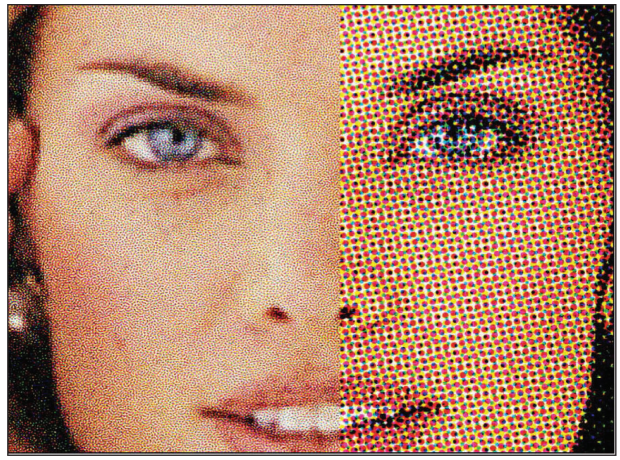

Figure 3

Purpose of the Research

The purpose of this research was to determine the difference in print attribute drift between Amplitude Modulated (AM) and Frequency Modulated (FM) for one digital printing device. The print attributes are individual characteristics within the printing process that can be monitored during the production process so as to maintain color consistency. Only the attributes of print contrast (PC), dot gain (DG), gray balance (GB) and color variation of halftone dots (at 25%, 50%, and 75%) were tested to examine the differences in run variation between the two screening technologies for a selected digital press. The following questions were investigated:

1. Is there a difference in the variation of print contrast (PC) (of CMYK) between the AM and FM screened digital printed image over the course of a run?
2. Is there a difference in the variation of dot gain (DG) (of CMYK), at 50% dot area, between the AM and FM screened digital printed image over the course of a run?
3. Is there a difference in the variation of gray balance (GB) (of CMYK) between the AM and FM screened digital printed image over the course of a run?
4. Is there a difference in color (CMYKRGB) shift at highlights (HL), mid-tones (MT), and shadow (SD) areas between the AM and FM screened digital printed image over the course of a run?

Limitations of the Study

No mathematical equations or computer programing techniques were applied to screening methods. Printing for this experiment was completed by using the default screening options available in the raster image processor (RIP) application Creo IC-307 Print Controller on a Konica-Minolta C6000 bizHub color printer. The print characteristics associated with the AM and FM screened images are characterized by, but not restricted to, inherent limitations. For example, type of printing process, type of substrate, type of colorant, etc. There are several variables affecting the facsimile reproduction of AM and FM screened images and most of them are mutually dependent on each other. The scope of the research was delimited by the only available color electrophotographic printing system and materials used at one university graphics technology laboratory–and the findings are not expected to be directly transferable to other printing devices. Only attributes such as print contrast, dot gain, gray balance and tonal color variations were used to compare the two screening technologies because they were attributes that could be measured using patches made up of dots or screened tint percentages. Print attributes that utilize solid ink patches only were not compared, as one could expect similar results from both screening technologies. The research methodology, experimental design, and statistical analysis were all selected in alignment with the purpose of the research with full awareness of the aforementioned delimitations. A total of 200 prints (copies) were printed, 100 for each screening technique of the same image on 80 lb. matte-coated paper (K = 2, n = 100, N = 200).

Research Methodology

The experiment was conducted in a color managed workflow. The digital color press used in this experiment was a Konica-Minolta C6000 bizHub color digital press. It used a Creo IC-307 raster image processor (RIP) server (front-end system) with AM and FM screening applications. Mohawk 80 lb., matte-coated digital color printing paper was used for printing of both screening samples. Each screening sample run in the experiment was considered as a group, noted by letter "K" (K = 2). One hundred samples for each group were printed, noted by letter "n" (n = 100). For the two groups, a total of 200 samples were printed, noted by letter "N" (N = 200). A one-page 11" x 17" custom test image (CCSU Test Image) was created for proofing and printing use for the experiment. The test target contained the following elements: an ISO300 target and generic images for subjective evaluation of color, an ISO 12647-7 control strip, and a SpotOn! control strip. Colorimetric data was captured using an X-Rite EyeOne spectrophotometer from the printed samples.

Printer Calibration & Color Management

One of the important issues in getting acceptable print quality is maintaining a stable level of toner density in the Konica-Minolta bizHub C6000 digital press used for the experiment. Fluctuation may result from many controlled and uncontrolled variables, such as room humidity, temperature, printer settings, paper, age of toner, and inaccurate calibration or linearization of the printer. Therefore, calibrating the printer daily was very important. The calibration process for the printer used in the experiment was performed per the guidelines given by the device manufacturer. The CMYK calibration chart was printed via the Creo IC-307 RIP application with both screening technique options, but without using any previous calibration data, at 190 LPI (see Figure 4).

An X-Rite EyeOne Pro spectrophotometer was used to scan the printed chart. The device was calibrated prior to using it to calibrate the printer (or measure the chart). The calibration data (CMYK density ranges) was saved in the calibration lookup tables of the RIP and a calibration curve was created (see Figure 5). Density or Dot values were not altered for the experiment. Device (digital press) manufacturer guidelines were followed to keep the variables consistent throughout the experiment.

Test Image for Printing

An 11″ x 17″, one-page, custom test image was created for proofing and printing use for the experiment (see Figure 6). The test target contained the following elements: IT8.7/4 target with 378 patches, an ISO 300 and custom images for subjective evaluation of color, an ISO 12647-7 control strip, and a SpotOn! control strip. Color management settings were disabled in the Adobe InDesign CS6 page layout application. All of the image elements were imported into the page layout program, and a PDF file was made without compressing the image data.

The PDF file was sent to the Konica-Minolta C6000 Digital Press RIP (Creo IC-307 Print Controller). In the color management option of the RIP, adjustments were made to print the test image, which included the following: a specific rendering intent, specific predefined (default) recommended profile, lines per inch (LPI), AM/FM screening, and calibration data. In the CMYK emulation option of the RIP, adjustments were made to emulate the printing with a default profile and to print the test image with various AM and FM screening options. A recommended default destination profile was used to print the images. The device manufacturer recommended these two default profiles as predefined printing profiles. The final color printing/output was limited to these profiles, and other image color adjustment techniques were applied (rendering intents, LPI, calibration curve, etc.). The same test image file was used for printing with both

CMYK printer calibration chart (for Konica-Minolta bizHub C6000).

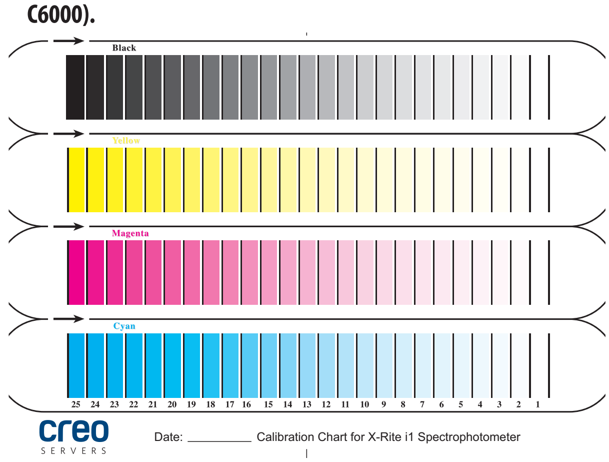

Figure 4

screening (AM and FM) options. A 1200 x 1200 dot per inch (DPI) resolution was used for printing with the AM screening technique, – and for printing with FM screening, 600 x 600 DPI was used because for FM screening the RIP supports only 600 x 600 DPI.

Calibration curve of CMYK SID and CMYK dots.

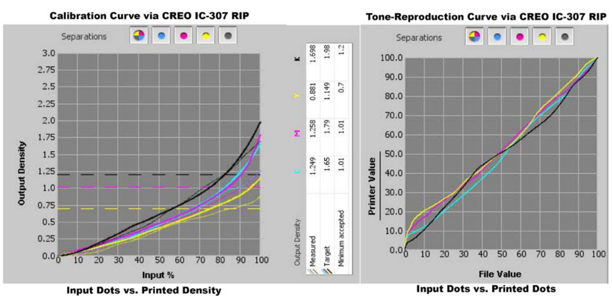

Figure 5

Printed Color Samples for the Analysis

Colorimetric data for each group was generated from the printed colors using an Konica-Minolta's (KM) FD-5 spectrodensitometer and an X-Rite EyeOne Pro spectrophotometer with interface applications, such as SpotOn!, X-Rite Color Port, and ProfileMaker (PM). Dot gain values at 50% tones and solid ink densities of printed samples from both screening options were measured by using the SpotOn! application. The colorimetric data (measured via Color Port) from IT8.7/4 target was used to create the device profiles (see Figure 8) of AM and FM screens by using the PM application. Additionally, L* a* b* data was also collected from the CMY gray patches to determine the gray balance deviation of both screens. A total of 160 printed sheets were measured, 80 for each screening option (K = 2, n = 100, N = 200). The 378 patches target contained only a small subsample of an IT8.7/4 target. It contained very few patches to prove an accurate match to a specific industry standard. However, it contained enough patches to monitor the accuracy of a color reproduction system against a reference target, such as the IT8.7/4. Table 1 presents the variables, materials, conditions, and equipment associated with the scanner, monitor, and printer of this experiment (see Table 1).

The sample size was selected in order of the specific confidence interval ($\alpha = 0.05$). A random sampling technique was used to identify the sample size because of the large size (N = 100) of the total population. After the samples were printed, multiple devices were used to collect the colorimetric data from each sample. Glass, G.V. & Hopkins, K.D. (1996), provides an objective method to determine the sample size when the size of the total population is known. The total population for this study was 100 (N) printed sheets for each screening option (AM and FM). The following formula was used to determine the required sample size, which were 80 (n) printed sheets of each screening option for this study.

$n = \chi^2\, NP\,(1-P) / d^2\,(N-1) + \chi^2\, P\,(1-P)$

n = the required sample size

χ^2 = the table value of chi-square for 1 degree of freedom at the desired confidence level (3.84)

N = the total population size

P = the population proportion that it is desired to estimate (.50)

d = the degree of accuracy expresses as a proportion (.05)

Test image for printing with digital AM and FM screening techniques

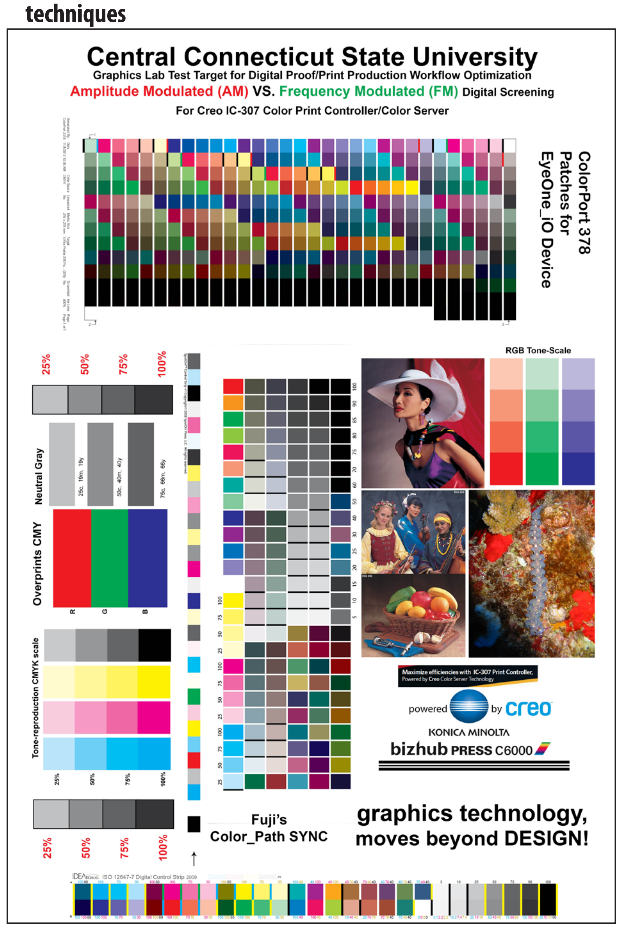

Figure 6

Two sets of print runs (2 groups, K = 2) were conducted. Each run with 100 samples used each screening technique (AM and FM). From each sample, a total of 80 samples were pulled randomly. A total of 160 random samples were pulled for the purpose of data collection. Colorimetric data (L* a* b*) and densitometric values of these 80 were measured (AM screen samples) by using a spectrophotometer. The same procedures were applied for the second group (FM screen samples). Densitometric and colorimetric data was collected for the following print attributes: SID, Dot Gain, Print Contrast, Gray Balance, and Color variation among both screened printed samples.

Statistical method applied for the experiment data analysis

Microsoft Excel was used to analyze the collected data to determine the colorimetric variation (COLVA) among the two screening methods. Since K = 2, no inferential statistics were used to determine the significant differences that exist among the (K = 2, n = 100, and N = 200) group mean color deviations of the various screening methods. Only descriptive statistics were used.

Table 1: Experimental and Controlled Variables

Variable	Material/Condition/Equipment
Test images	Custom Test Target
Control strips	ISO 12647-7, and SpotOn!Press
Profiling Software	X-Rite Profile Maker 5.0.10
Profile Inspection Software	Chromix ColorThink-Pro 3.0
Image Editing Software	Adobe PhotoShop CS-6
Page Layout Software	Adobe InDesign CS-6
Source Profile (RGB)	Adobe 1998.icc
Emulation Profile (CMYK)	None
Destination Profile (CMYK)	Custom, Konica-Minolta.icc
Color Management Module (CMM)	Adobe (ACE) CMM
Rendering Intents	Absolute
Computer & Monitor	Dell OPTIPLEX/LCD
Raster Image Processor (RIP)	Creo IC-307 Print Controller
Printer	Konica-Minolta bizHub C6000 Color Laser
Achieved CMYK SID for both print runs	C = 1.24; M = 1.27; Y = 0.89; and K = 1.59
Screen Ruling	190 LPI
Print Resolution for AM Screen	1200 x 1200 DPI
Print Resolution for FM Screen	600 x 600 DPI
Toner	Konica-Minolta Color Laser
Paper (sheetfed)	MOHAWK 80 lbs. matte-coated
Type of Illumination/ Viewing Condition	D50
Color Measurement Device(s)	X-Rite Eye-One-PRO Spectrophotometer with Status T, 20 angle, and KM's FD-5 Spectro-densitometer
Data Collection/Analysis Software	SpotOn! Press, and MS-Excel

Data Analysis and Research Findings

The descriptive statistical method was used to analyze the collected data. Subjective judgment on color difference was not used in this study. The subjective judgment of color difference could differ from person to person. For example, people see colors in an image not by isolating one or two colors at a time (Goodhard & Wilhelm, 2003), but by mentally processing contextual relationships between colors where the changes in lightness (value), hue, and chroma (saturation) contribute independently to the visual detection of spatial patterns in the image (Goodhard & Wilhelm, 2003). Instruments, such as colorimeters and spectrophotometers, could eliminate the subjective errors of color evaluation perceived by human beings.

Print Contrast (PC)

The mean scores and the standard deviations associated with the print contrast of AM and FM (CMYK) screened images are compiled in Table 2. Numerical differences were found when comparing the print contrast of the AM screened image to the FM screened image on all four-color inks (CMYK). The print contrast in two (CM) of four color inks (CMYK) of the FM screened image was higher than the AM screened image, while yellow color print contrast was higher in the AM screened image. No difference was found in the black color print contrast of either screened images. A low print contrast indicates loss of details in shadow areas, while high print contrast requires both high density and sharp printing to maintain the shadow details. It was determined by the researchers that the FM screened image presented sharper pictorial information when compared to the AM screened image.

Shadow detail of the FM screened image was noticeably better than the AM screened image. This visual result is in agreement with the print contrast values of the two screening methods. The largest print contrast was found in cyan color: 38% for the FM screened image and 37% for the black color of the AM screened image. In addition, cyan color of the AM screened image had the smallest standard deviation when compared to the other colors (see Table 2).

Dot Gain (DG)

The mean scores and standard deviations associated with the measured dot gain at the 50% dot area of AM and FM (CMYK) screened images are compiled in Table 3. Using the systems tested, the greatest amount of variance between the screening technologies was evident in Yellow and Magenta. Even though yellow showed the greatest difference between screening methods with 3.13% variation in dot gain, it was the most consistently reproduced color between the samples in each category as evidenced by the standard deviation calculations. Cyan and Black provided similar results between the two screening methods, yet black produced, by far, the most gain at over 25% in the midtones. FM screened black midtone dots also produced the widest range of variation among the samples tested with a standard deviation value of nearly 4% (see Table 3).

Gray Balance (GB)

Three levels of gray patches were printed to determine gray balance results of both screening systems. Highlight gray was made-up of cyan 25% dots, 19% magenta, and 19% yellow; for midtone gray, the cyan 50% dots, 40% magenta, and 40% yellow; for shadow gray, the cyan 76% dots, 66% magenta and yellow 66%. These patches were part of the printed test image, 100 copies of each group. Printed patches of gray were measured in colorimetric L* a* b* mode to determine the visual/numerical gray differences of the both screened image/colors. The average L* a* b* values for the three different levels (highlight, midtone and shadow) were plotted for each screening method (see Figure 7). In general, the gray balance in the shadow (or three-quarter) tone tended toward a yellowish cast with the FM screened samples being the most visually evident. Color casts in the midtone grays were much less noticeable but tended toward green based on plotted measurements. In the highlight (or quarter) tones it was also visually difficult to discern any color cast, however a slight bluish cast was measured (see Figure 7).

Table 2: Comparison of Mean Scores (AM and FM screening) of CMYK Print Contrast at 75% Tint

	AM Screen N = 80		FM Screen N = 80	
Process Ink	M (%)	SD (%)	M (%)	SD (%)
Cyan	35	0.56	38	1.00
Magenta	33	2.00	39	2.22
Yellow	31	1.00	29	1.00
Black	37	1.00	37	1.00

N = Randomly pulled samples; M = Mean (average); SD = Standard Deviation

Color Difference at Various Tones (25%, 50%, and 75% of CMYK RGB)

Color variation at 25%, 50%, and 75% dot areas of the samples were measured in the CIE L* a* b* color mode and a 2D gamut was constructed for visual comparison of colors for both screened images (see Figure 8). Image color profiles of both screened versions were also mapped with the color variation data. While comparing the colors, no visual differences were noticed among the FM and AM screened colors, except the noticeable difference in the color hues (L* a* b* values) at 25% of red (AM = 86.23, 15.48, 7.41; vs. FM = 85.98, 14.94, 11.10) and green (AM = 87.88, -11.23, 2.05; vs. FM = 88.06, -12.12, 4.56) colors of both screens.

Conclusions

The conclusions of this study are based upon an analysis of the data and major findings. The findings of this study represent specific printing or testing conditions. The screening technologies, paper, toner, imaging system, and printing process that were used are important factors to consider when evaluating the results. The findings of the

Table 3: Comparison of Mean Scores (AM and FM screening) of CMYK Dot Gain (DG) at 50% Dot Area

	AM Screen N=80		FM Screen N=80	
Process Toner	M (%)	SD (%)	M (%)	SD (%)
Cyan	16.98	1.49	16.59	1.09
Magenta	11.96	0.61	13.61	1.58
Yellow	15.37	0.88	18.50	0.85
Black	25.78	1.63	25.78	3.92

N = Randomly pulled samples; M = Mean (average); SD = Standard Deviation study cannot be generalized to other printing conditions. However, others who use their systems to produce similar tests and compare results to the outcomes of this study may find it meaningful and useful. The results of this research study comparing amplitude modulated (AM) screening with frequency modulated (FM) screening suggest that FM screening provides greater print contrast than AM screening under the specific printing conditions used. This provides greater detail in the shadow areas (CMY) of printed images. The black toner print contrast ran counter to this conclusion, which suggests the need for further study to explore factors or variables that may have contributed to this result.

Gray Balance difference of AM and FM screening techniques.

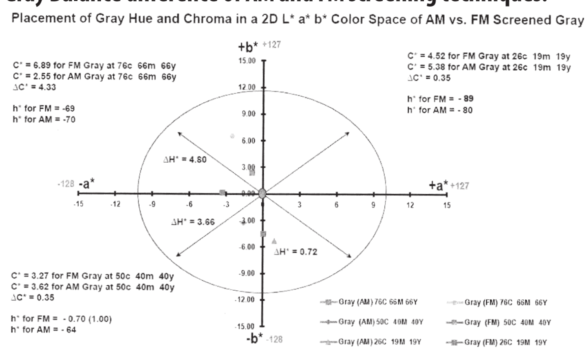

Figure 7

Measurable differences were identified when testing for dot gain in 50% control patches – verifying that dot gain does occur in toner based systems. Even small differences in dot gain at the midtone area can lead to color shift. Accurate calibration was performed as per the vendor guidelines. Numerical difference was found when comparing the dot gain of the AM screened image to the FM screened image on all four toner colors (CMYK). This may be due to the screening method used. Dot gain in two (M & Y) of four (CMYK) color toners of the FM screened image was much higher than the AM screened image, while amount of dot gain of cyan and black colors were similar in both variations of screened images. The greatest dot gain at 50% dot area was found in the black color of both screened images.

Comparing gray balance, each screening technique produced completely different gray hues, some with color casts. Numerical and visual differences do exist in comparing the gray balance of AM vs. FM screened images (see Figure 7). The measured L*a*b* values were different for AM and FM screened highlight, midtone and shadow test patches. However, the plotted values showed a pattern

Color differences of AM and FM screening techniques.

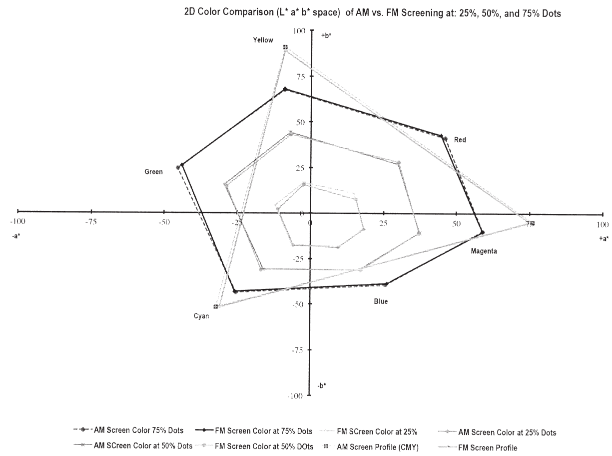

Figure 8

in that each screening method showed a tendency toward similar color casts based on the tonal level. For example, highlight tones showed a bluish cast; midtones a greenish cast; and shadow tones showed a yellowish cast in each screening method. Most of these differences were hard to discern, but some were visually evident.

References

Chung, R. & Ma, L.L. (1995). Press Performance Comparison between AM and FM Screening. TAGA Proceedings 1995. TAGA, Rochester, New York.

Glass, G. V., & Hopkins, K. D. (1996). Statistical methods in education & psychology. Boston, MA: Allyn & Bacon.

Goodhard, M. M., & Wilhelm, H. (2003). A new test method based on CIELAB colorimetry for evaluating the permanence of pictorial images.

Lau, D., Arce, G., & Gallagher, N. (July, 1999). Digital halftoning by means of green-noise masks. Journal of the Optical Society of America, 16, (7), pp. 1575–1586

Lau, D. & Arce, G. (2008). Modern Digital Halftoning. Boca Raton, FL: CRC Press.

Lawler, B. (1997). Know the enemy: Understanding dot gain and its effects. [Available: Online] http://www.imaging-resource.com/TIPS/LAWLER/DOTGAIN.PDF. [Retrieved: Feb. 9, 2015]

Goyat, A., Amaranand, & Kuldeep, S. (2011). The pressure between cylinders and its effect on dot gain in digital press (liquid based). International Journal of Advances in Engineering Sciences, 1 (4), pp. 11–17.

Leurs, L. (2013, August 8). Dot gain: What it is and how to compensate for it.

Morovic, J., Green, P., & MacDonald, L. (2002). Color engineering (pp. 297–314). NY: John Wiley & Sons.

McIlroy, T. (2003). Composition, design & graphics. In William Kasdorf (Ed.), The Columbia Guide to Digital Publishing, (pp. 219–323). New York: Columbia University Press.

Pnueli, Y. & Bruckstein, A. (1996). "Gridless Halftoning: A Reincarnation of the Old Method". CVGIP: Graphical Model and Image Processing, 58 (1), pp. 38–64.

Stanton, A., & Warner, R. (1994). An Analysis of Sheetfed Print Attributes. TAGA Proceedings 65. TAGA, Rochester, NY.

Manuscript Guidelines

Eligibility for Publication

Members of the Graphic Communications Education Association, or students of GCEA members, may publish in the *Visual Communications Journal*.

Audience

Write articles for educators, students, graduates, industry representatives, and others interested in graphic arts, graphic communications, graphic design, commercial art, communications technology, visual communications, printing, photography, desktop publishing, or media arts. Present implications for the audience in the article.

Types of Articles

The *Visual Communications Journal* accepts four levels of articles for publication:

1. Edited articles are accepted or rejected by the editor. The editor makes changes to the article as necessary to improve readability and/or grammar. These articles are not submitted to a panel of jurors. The decision of the editor is final.
2. Juried articles are submitted to the editor and are distributed to jurors for acceptance/rejection. Juried articles are typically reviews of the literature, state-of-the-art technical articles, and other nonempirical papers. Jurors make comments to the author, and the author makes required changes. The decision of the jurors is final.
3. Refereed articles are submitted to the editor and are distributed to jurors for acceptance/rejection. Refereed articles are original empirical research. Jurors make comments to the author and the author makes required changes. The decision of the jurors is final.
4. Student articles are submitted by GCEA members and are accepted/rejected by the editor. These articles are not submitted to a panel of jurors. The editor's decision is final. Please be aware that poorly written student papers will be rejected or returned for editing.

Submittal of Manuscripts

All manuscripts must be received by the editor no later than December 15th to be considered for the spring *Journal* or by June 15th to be considered for the fall *Journal*. Include digital copies of all text and figures. Prepare text and artwork according to the instructions given in these guidelines. Be sure to include your name, mailing address, e-mail address, and daytime phone number with your materials. E-mail all materials to the editor (address shown below).

Acceptance and Publication

If your article is accepted for publication, you will be notified by e-mail. The *Visual Communications Journal* is published and distributed twice a year, in the spring and in the fall. Printed copies are mailed to GCEA members. A PDF version of the *Journal* is published online at www.GCEAonline.org.

Notice

Articles submitted to the *Journal* cannot be submitted to other publications while under review. Articles published in other copyrighted publications may not be submitted to the *Journal*, and articles published by the *Journal* may not be published in other publications without written permission of the *Journal*.

Submit All Articles and Correspondence to:
Dan Wilson, dan.wilson@illinoisstate.edu
or check www.GCEAonline.org for contact information for the GCEA First Vice-President.

See following page for style guidelines

Manuscript Form and Style

- Prepare manuscripts according to the APA style, including the reference list.
- List your name and address on the first page only. Article text should begin on the second page.
- Provide a short biography for yourself that can be used if the article is accepted for publication.
- All articles must be submitted in electronic form on a CD-ROM or as an email attachment.
- Submit a Microsoft Word document, maximum of 10 pages (excluding figures, tables, illustrations, and photos). Do not submit documents created in page-layout programs.
- Word documents must have been proofread and be correct.
- Call out the approximate location of all tables and figures in the text. Use the default style "Normal" on these callouts. The call-outs will be removed by the designer.
- Use the default Word styles only. Our designer has set up the page layout program styles to correspond to those style names.
    - Heading 1
    - Heading 2
    - Heading 3
    - Normal

Graphics

- Be sure that submitted tables and other artwork are absolutely necessary for the article.
- Write a caption for each graphic, include captions in a list at the end of your Word document.
- Electronic artwork is preferred and should be in PDF or TIFF format.
- Send all artwork files and hard copies of these files with your submission.

Tables

- Set up tables in separate documents, one document for each table.
- Do not attempt to make it "pretty." Use the default Word style "Normal" for all table text. Do not use any other formatting.
- Do not use hard returns inside the table ("enter" or "return").
- Get the correct information into the correct cell and leave the formatting to the designer.
- Tables will be formatted by the designer to fit in one column (3.1667" wide) or across two columns (6.5" wide).

Artwork

- Scan photographs at 300 ppi resolution.
- Scan line drawings at 800 ppi resolution.
- Screen captures should be as large as possible.
- Graphics should be sized to fit in either one column or across two columns.
    - One column is 3.1667" wide, two columns are 6.5" wide.
    - Graphics may be larger than these dimensions, but must not be smaller.