A Digital Proofing Study for Taiwan's Digital Archive Programs

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Abstract: In the digital era, countries all over the world devote time to digitize their cultural treasures and heritage. By the means of digitalization, human can preserve and utilize critical cultural heritage. In the process of digitalization, operators would like to output the digital files of artworks to preserve cultural treasures. Thus, the duplication and printing of the digital files for artworks have become a new business in recent years in Taiwan. For printers, it is an excellent opportunity to expand their business to provide service for the digital archive industry because of the increasing needs of the market and advanced development in digital proofing technology. In Taiwan, high-end (large-format) inkjet printers are the most widely used devices in printing industry to meet all requirements for printing high-quality images. Unfortunately, the industry does not have color attribute specifications and assessment standards to follow. Therefore, establishing a set of color attribute specification of digital proofing to provide Taiwan's digital archive program with a reference for quality assessment is the main purpose of this study.

This study was an experimental research in nature to investigate the characteristics of digital proofing industry. The construction of digital color specifications could assist printers to meet digital archive industry's requirements for high-quality images reproduction in a very efficient and effective fashion. Furthermore, the practical specifications could be incorporated into assessment processes as an evaluate mechanism to guarantee the digital files output of Taiwan's digital archive program could reach the required quality levels.

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1. Introduction

In recent years, mankind is facing critical cultural and social change, including changes in the means of communication from printed matter to electronics, and other changes to the way of life in society. With the advancement in information and communication technologies, our cultural treasures and heritage can be preserved and utilized in the digital era. Due to be aware of the importance of cultural preservation, the national digital archive programs such as the National Digital Archive Program of National Science Council of Executive Yuan, the National Repository of Cultural Heritage of Council for Cultural Affairs, Executive Yuan, Challenge 2008: National Development Plan (2002-2007) are devoted to promote and coordinate content digitalization and preservation at leading museums, archives, universities, research institutes, and other content holders in Taiwan.

In the process of digitalization, operators would like to output the digital files of artworks to preserve cultural treasures. Furthermore, these duplications of artworks could be transformed into new value-added products and promote the related culture and arts. Thus, the duplication and printing of the digital files for original artworks, such as oil painting, watercolor painting, calligraphy, etc., have become a new business in recent years in Taiwan. For printers, it is an excellent opportunity to expand their business to provide service for the digital archive industry because of the increasing needs of the market and advanced development in digital proofing technology. Digital proofing systems have been gaining in popularity, due to better color accuracy, faster turnaround, and greater acceptance by customers. In Taiwan, high-end (large-format) inkjet printers are the most widely used devices in the printing industry and meet all requirements for printing high-quality images. These printers have the capability to print high-quality fine art images in black/white or full color on various substrates. Furthermore, it prints wider color gamut than does an offset press. With these advantages, inkjet printers are an excellent choice for duplicating artworks.

1.1 Purposes of the Study

The national digital archive programs have proceeded to generate digital content for three years. However, the quality control and monitoring of their digital archives have not had a complete mechanism. In the part of digital files output, the industry does not have color attribute specifications and assessment standards to follow. For the printers, in order to output optimum color prints, they often waste much time to conduct a series of trial-and-error tests. For the government organizations, there are no industry-wide specifications to ensure the digital archive output meet the desired quality levels. Therefore, establishing a set of color attribute specification of digital proofing to provide Taiwan's digital archive program with a reference for quality assessment is the main purpose of this study.

1.2 Limitations of the Study

The following limitations must be considered when interpreting the results of this study:

1. The participants were not randomly selected; instead they volunteered to partake in the study.
2. No two proofing systems were the same. They varied in machines, materials, and environmental conditions and their influence on the results of the study was not investigated.
3. Participating companies had their own proofing crews; hence their working performances were possible to be identical and therefore not investigated.
4. A wide variety of proofers were employed for this research. Their make, ages, numbers of ink units, and physical conditions of the proofers differed. Their effects on the results were not discussed.
5. The type of inks, raster image processor software, and other proofer materials were not controlled. Their effects on the results of this study were not explored.
6. Several brands and weights of substrates were used for the study. Differences in the color characterizations of the individual stocks were not investigated; however, for final analyses the samples were divided into three subgroups, coated paper, uncoated paper, and fiber substrate.

2. Methodology

This study was designed to establish a set of color attributes specification of digital proofing for Taiwan's digital archive programs. The result of this research was a realistic industrial profile, based on real-world operating parameters by major printers in Taiwan. To meet this requirement, the participants were asked to run their proofers based on their in-house standard operating procedures and conditions. The dependent variables of this study include densitometric attributes such as solid ink density (SID), tone value increase (TVI), print contrast (PC), and spectrophotometric evaluation (color gamut).

2.1 Population and Samples

The target population of this study includes local printing companies and printing service bureaus that have participated in any national digital archive programs and provided artwork-duplication related services in Taiwan. A list of potential participants was recommended by the National Science Council (NSC) of Executive Yuan and the National Repository of Cultural Heritage (NRCH) of Council for Cultural Affairs, Executive Yuan, Printing Industry of Taiwan (PIT), and Printing Technology Research Institute (PTRI) of Taiwan. The selected participants are quality conscious enough to have invested considerable time, materials, and effort in participating in this study with no monetary compensation. The participants were asked to submit coated, uncoated, or fiber substrates. The fiber substrate was employed in this study because of its advantages of non-reflection, not easy to tear, crease-free, with the perfect cutting edge and easy to store.

More than 100 high-quality printing companies and printing service bureaus were selected finally and they were called and invited to participate in the study by the author. Fifty-four companies (42 from the north, 10 from central, 1 from the south, and 1 from the east of Taiwan) submitted 90 sets of printed samples for this study. Among the printed samples, 62 sets were printed on coated paper, 22 sets on uncoated paper, and 6 sets on fiber substrate.

Each participant was asked to submit at least 10 printed sheets. The information about the participants (categorized by the company location and type of substrate used) and their submitted sample sizes are displayed in Table 1.

Table 1. The information about the participants and their sample sizes

Location		**North**	**Central**	**South**	**East**	**Total**
No. of Participants		42 companies	10 companies	1companies	1companies	54 companies
No. of Sets Submitted	Coated	47 sets	13 sets	1 set	1 set	62 sets
	Uncoated	18 sets	4 sets	0 set	0 set	22 sets
	Fiber	6 sets	0 set	0 set	0 set	6 sets
No. of Sheets Sampled	Coated	470(47×10)	130 (13×10)	10(1×10)	10(1×10)	620 sheets
	Uncoated	180(18×10)	40 (4×10)	0	0	220 sheets
	Fiber	60 (6×10)	0	0	0	60 sheets

2.2 The Test Form

A digital four-color test form was designed for this study (as shown in Figure 1). The test form is A3 (11.69x16.54-in) in size which includes test targets and photographic images. The photographs in the test form are GATF test images that emphasize different color reproduction challenges. The other process characterization targets in the test form include:

- ♦ Tone scales of CMYKOG,
- ♦ Ink coverage target,
- ♦ GCA/GATF Proof Comparator III test target,
- ♦ CMYKRGB and 3K solid patches,
- ♦ CMYKRGB and 4K tint patches (5%~100%, in a 5% interval),
- ♦ CMYK tint patches of highlights (1%~10%),
- ♦ CMYK tint patches of shadows (90%~100%),
- ♦ Gray balance chart,
- ♦ Micro line target.

The test form was available in CD-ROM containing TIFF files and sent to participants.

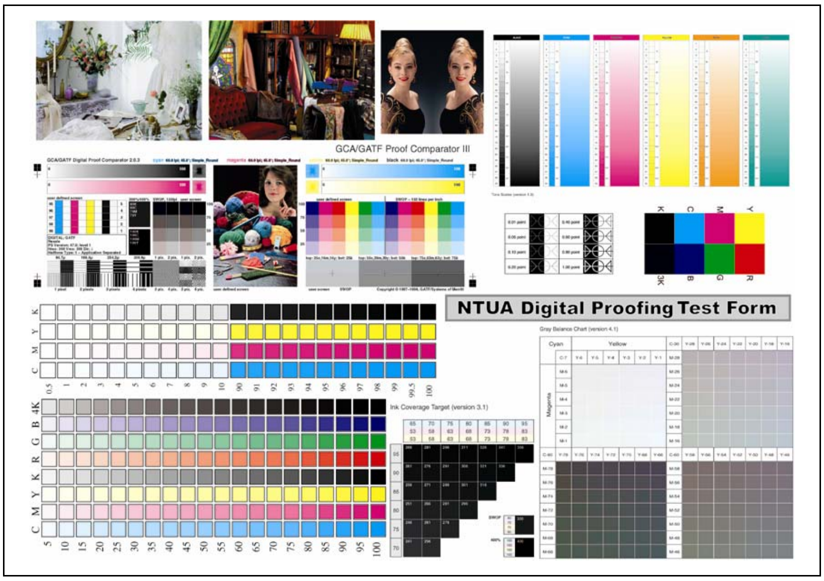

Figure 1. Digital Test Form

2.3 Research Procedure

After receiving the test form, participants were asked to print the file at 720 dpi resolution based on their in-house standard operating procedures and conditions. In addition, they were asked to complete a questionnaire that was designed to survey the local high-quality printing companies and printing service bureaus to construct the attribute profile for digital proofing industry of Taiwan. The questionnaire consists of two categories: (1) company basic information, including location, age, current numbers of employees, previous year revenue, and digital proofing equipment; and (2) company equipment and materials used for the study, such as type of proofer, ink, RIP software, substrate, etc.

All of the participants used six- to eight-color inkjet proofers to print the test form for the study. The equipment and materials used in this study were summarized in Table 2. It took more than six months for collecting printed samples, from contacting potential participants to receiving the printed sheets.

Table 2. Equipment and materials used in the study

Type		Description
Inkjet Proofer		Including Agfa Grand Sherpa 50, Dupont Color Proofing, Epson Stylus Pro series (4000, 9000, 9600, 10000, 10600), and HP Designjet series (5000, 5500). Most proofers used were Epson Stylus Pro series (68.9%), followed by HP Designjet series (20%).
RIPs		Including Agfa Apogee PDF RIP, Best (EFI now) Colorproof, CGS ORIS Color Tuner, Compose Harliquin Express RIP, Dupout Artistli, GMG ColorProof 04, and others. Most RIPs used were Compose Harliquin Express RIP (37.8), followed by Best (EFI now) Colorproof (13.3%), and CGS ORIS Color Tuner (11.1%).
Ink Type		47.8% of the companies used pigment ink 52.2% of the companies used dye ink
Substrates	Coated Substrate	Including Butterfly SG120 Semi-Glossy Proof Paper, EasiColor EP517 Phoro Grade Semi-glossy Proof Paper, EasiColor EP515 Semi-Glossy Proof Paper, EasiColor EP313 Semi-Glossy Proof Paper, EPSON photo grade semi-gloss paper, Epson Photo Quality Ink Jet Paper, Hoest heavy Coated Paper, etc.
	Uncoated Substrate	Including Butterfly Matte Proof Paper, EasiColor EP209 Premium Proof Paper, EasiColor EP212 Premium Poster Paper, etc.
	Fiber Substrate	including Satin, Fabric, and non-woven material

2.4 Data Collection

Every proofer was required to print at least 10 sheets. Finally, 620 coated, 220 uncoated, and 60 fiber stocks were collected for this study. Status "T" density readings were made from those samples, with a X-Rite 530 reflection spectrodensitometer using Murray-Davies equation (n = 1), on the solid ink density, regular dot areas (10%, 25%, 50%, 75%, 90%), and 75% print contrast,. Colorimetric readings were also made with X-Rite 530 reflection spectrodensitometer to measure L*a*b* color. SPSS 12 and Minitab 14 statistical software packages were used for data analyses. Due to time constraint, each specific patch on the sampled sheets was read only one time.

3. Overall Results

This section describes the overall results and findings obtained through data analyses. Each sub-section gives a brief description of a particular print attribute and its specifications.

3.1 Solid Ink Density (SID)

Solid density refers to the light-stopping power of color on paper, measured through the complementary-colored filter. Typically an inkjet printer has more chroma than a press. In color-proofing workflows, the setup of solid ink density is a vital factor to achieve an optimum print. Once the right amount of solid ink density is determined, the RIP software automatically optimize the steps for the target linearization, that is, enables a printer to deliver ink on a particular media optimally so that an image's tones can be correctly reproduced. Different linearization settings and profile combinations will affect the final prints.

Table 3 shows the SIDs of the coated, uncoated, and fiber stocks. The overall average SID of the coated paper were 0.90 for yellow (Y), 1.38 for magenta (M), 1.38 for cyan (C), and 1.65 for black (K). The averages SIDs of the uncoated stocks were 0.87 for Y, 1.19 for M, 1.19 for C, and 1.33 for K. As for the fiber substrate, the average SID for YMCK was 0.68, 1.09, 1.00, and 1.22, respectively. It is interesting to note that the S.D. (Standard Deviation) values of the solid ink density reading for the uncoated stock were greater than those of the coated and fiber stocks in all four colors.

Table 3. Descriptive statistics of solid ink density on different substrates

Color	Coated Paper		Uncoated Paper		Fiber Substrate	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Y	0.90	0.12	0.87	0.15	0.68	0.07
M	1.38	0.21	1.19	0.26	1.09	0.08
C	1.38	0.23	1.19	0.28	1.00	0.08
K	1.65	0.25	1.33	0.27	1.22	0.10

3.2 Tone Value Increase (TVI)

Table 4 depicts the 10-90% tone value increase statistics for the coated, uncoated, and fiber stocks. The average TVI values of coated papers showed that black color had the greater TVI than those of the other three colors, followed by cyan, magenta, and yellow at 25%, 50% and 75% tints. Moreover, the greatest TVI variation, in terms of standard deviation (S.D.) value, was found in black color for most of tone levels.

The average TVI values of the uncoated paper shown in Table 4 reveals that black color had the largest amount of TVI between 25%-90% tints, followed by cyan, yellow, and magenta. The least amount of TVI occurred in magenta at all tone values. In addition, black had the greatest standard deviation (S.D.) amount of TVI at all tone values, excluding 90% tints. The least TVI variation occurred in cyan at all of the five tone levels.

As shown in Table 4, the average TVI values of fiber substrate showed that cyan color had the greatest TVI values, followed by magenta, yellow, and black at

25%, 75% and 90% tone levels. The data shows that the least TVI variation was found in magenta at all tone levels and this phenomenon is different from the coated and uncoated stocks.

Table 4. Statistics of 10%~90% tone value increase (TVI) values

Color		Coated Paper		Uncoated Paper		Fiber Substrate	
		Mean	S.D.	Mean	S.D.	Mean	S.D.
10% TVI	Y	6.70	4.97	7.70	4.79	16.32	3.35
	M	6.50	4.56	5.05	4.03	16.02	3.01
	C	7.40	5.30	6.63	3.68	16.68	5.22
	K	7.58	5.18	7.32	5.90	14.00	3.49
25% TVI	Y	10.44	6.55	12.47	5.80	19.02	5.79
	M	10.69	6.40	9.86	5.05	20.10	2.63
	C	12.27	7.00	12.42	4.48	22.62	4.42
	K	12.81	7.26	14.92	8.80	17.15	3.03
50% TVI	Y	12.48	6.15	15.41	5.05	16.43	6.45
	M	13.47	6.45	14.08	6.19	23.23	2.09
	C	15.71	6.56	17.22	4.86	22.72	3.96
	K	16.41	7.01	19.87	8.54	19.55	2.90
75% TVI	Y	10.31	3.69	11.52	4.47	14.52	1.53
	M	10.54	4.35	10.87	4.30	17.12	1.15
	C	12.20	4.46	12.80	3.96	17.22	2.77
	K	12.36	4.62	14.08	5.22	12.70	1.75
90% TVI	Y	5.33	2.44	5.58	2.92	6.63	1.06
	M	5.42	2.26	5.51	2.49	8.03	0.82
	C	6.15	2.05	6.26	1.87	8.62	1.12
	K	6.00	2.58	6.70	2.48	4.92	1.78

The TVI curves for 10%-90% tints are exhibited in Figure 2. It shows the fiber substrates (dashed line) had greater TVI than did the coated and uncoated paper at all tone levels in all colors (with the exception of black color at 50%, 75%, and 90% tints). Furthermore, a comparison of TVI curves of the coated (thick line) and uncoated stock (thin line) shows that TVI values of the uncoated stocks are greater than those of the coated stocks at all five tone levels in all four colors, except for 10% and 25% tints of magenta. However, TVI curves of the coated and uncoated paper were similar in magenta and cyan. It is important to note that the TVI curve of fiber stocks was not as smooth as those of coated and uncoated stocks; in other words, the tone jump phenomena of the fiber stocks is quite obvious. The greatest TVI occurred at between quartertones and midtones in yellow and cyan colors, and between midtones and three-quarter tones in magenta and black colors. It is suspicious that the attributes of fiber substrates are unpredictable.

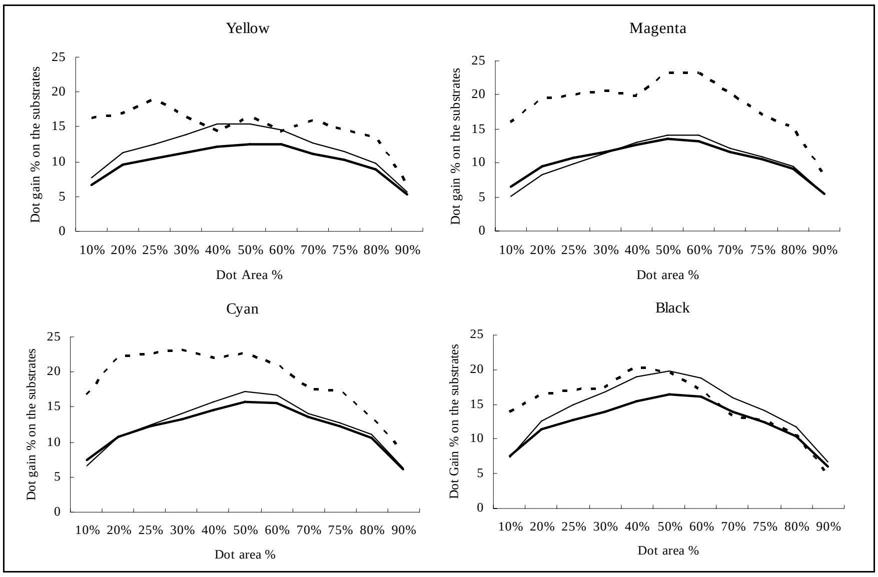

Figure 2. 10%~90% TVI curve
Note: Thick line represents coated paper
Thin line represents uncoated paper
Dashed line represents fiber substrate

3.3 Print Contrast

Print contrast (PC) is a print index calculated from the solid ink patches and 75% tint patches. The value relates to the degree of contrast between the three-quarter tone and the solid. In other words, it is a measure of shadow contrast and is the degree to which viewers can distinguish printed tones in the shadow area of a reproduction. In general, the higher the print contrast the better the shadow detail rendition.

Table 5 shows the average print contrast values found in this study. For both the coated and fiber stocks, the greatest print contrast was found in black color (45.4% for the coated and 37.9% for the fiber); follow by magenta (42.81% for the coated and 24.32% for the fiber), cyan (39.99% for the coated and 21.18% for the fiber), and yellow (31.69% for the coated paper and 19.95% for the fiber). As for the uncoated stock, the greatest print contrast was found in magenta (36.72%), follow by cyan (34.19%), black (33.92%), and yellow (28.08%). In addition, the least variation of print contrast was found in yellow color for the coated and uncoated samples. It is interesting to note that the coated paper had better print contrast values than did the other two stocks in all four colors. The print contrast values of the fiber stocks were smallest among the three stocks (except for black color).

Table 5. Statistics of print contrasts

Color	Coated Paper		Uncoated Paper		fiber substrate	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Y	31.69	5.20	28.08	6.30	19.95	3.88
M	42.81	8.31	36.72	9.35	24.32	2.86
C	39.99	10.74	34.19	10.39	21.18	5.21
K	45.40	9.03	33.92	11.73	37.90	1.95

3.4 Color Gamut

Color Gamut is the entire range of colors available on a particular device such as a scanner, monitor, proofer or printer. Generally speaking, a proofer prints wider color gamut than does an offset press. Figure 3 illustrates the color gamut of the coated paper at 100% (outer gamut), 75%, 50%, and 25% (inner gamut) tints in this study. As shown in Figure 3, for the coated paper, wider color gamut were found in yellow, green, red, and magenta colors at all tints. However, the cyan and blue colors are less saturated than the other colors.

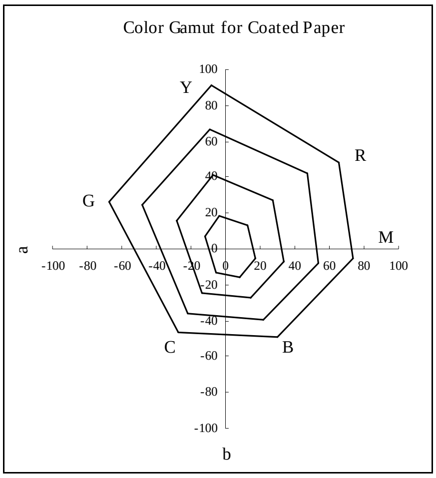

Figure 3. The color gamut of the coated paper

Figure 4 displays the color gamut of the uncoated paper at 100%, 75%, 50%, and 25% tints. As shown in Figure 4, for the uncoated paper, wider color gamut were found in yellow, green, red, and magenta colors at all tints. The cyan and blue colors are slightly less saturated than the other colors.

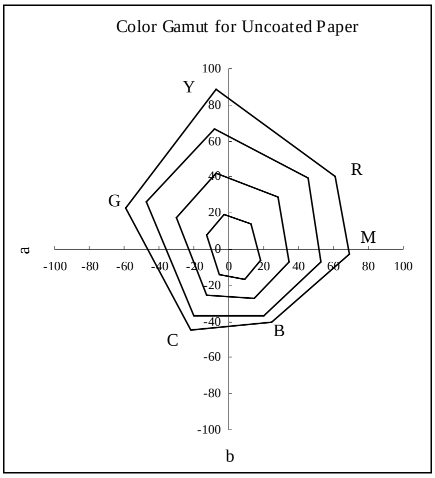

Figure 4. The color gamut of the uncoated paper

Figure 5 illustrates the color gamut of the fiber substrate at 100%, 75%, 50%, and 25% tints. As shown in Figure 5, for the fiber substrate, wider color gamut was found in yellow and red colors at all tints. The green, cyan, and blue colors are less saturated than the other colors. The color reproduction between 100% and 75% tone levels in green, cyan, and magenta is poor.

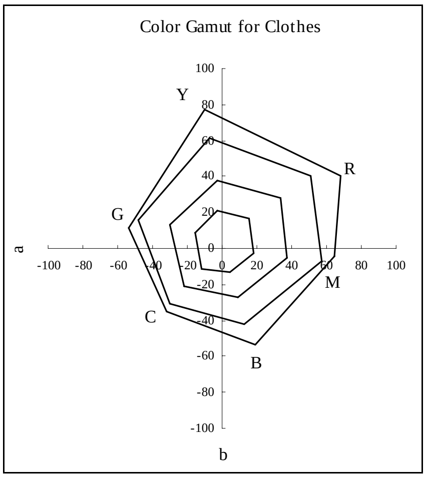

Figure 5. The color gamut of the fiber substrate

Below is a series of four diagrams illustrating color gamut of the three substrates at 100%, 75%, 50%, and 25% tints, respectively. As shown in Figure 6, the coated paper (thick line) had the widest color gamut and the fiber substrate had the narrowest color gamut among the three substrates at solid patches. At the 75% and 50% tints, the color gamut of the coated paper is similar to that of the uncoated paper (see Figure 7 and Figure 8). Fiber substrate had wider color gamut in red and cyan colors.

As for the 25% tint, Figure 9 shows that fiber substrate (dashed line) had better color gamut performance in all six colors, with the exception of blue. To sum up, the coated stock had wider color gamut than did the uncoated and fiber stocks at solid patches. In general, the fiber substrate had wider color gamut at 75%, 50% and 25% tints (except for yellow and green colors at 75% tint, yellow and blue color at 50% tint, and blue at 25% tint).

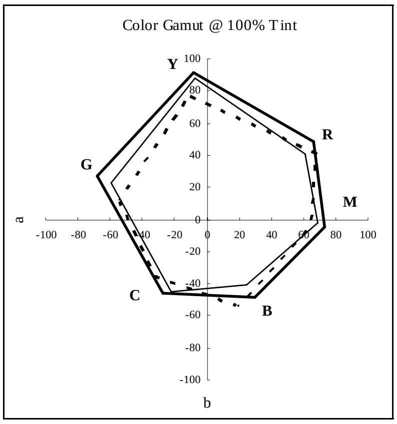

Figure 6. The color gamut at 100% tint

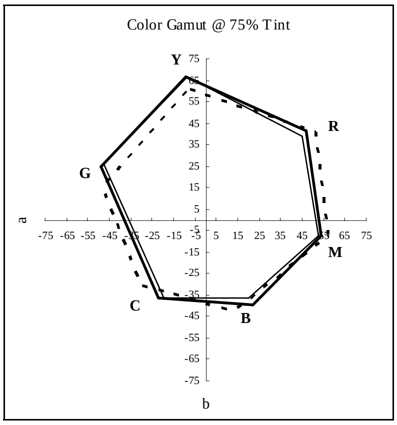

Figure 7. The color gamut at 75% tint

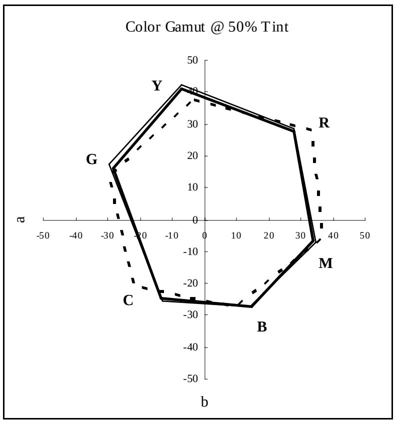

Figure 8. The color gamut at 50% tint

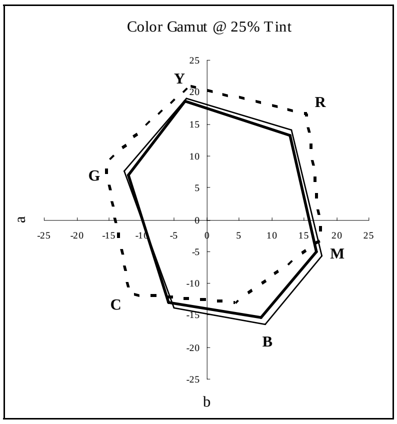

Figure 9. The color gamut at 25% tint

Note: Thick line represents coated paper;
Thin line represents uncoated paper;
Dashed line represents fiber substrate.

4. Conclusions

The result of this research was a realistic industrial profile based on real-world operating parameters from major inkjet printers in Taiwan. Substrate is definitely a dominant variable in predicting and reproducing color. This study established a set of color attribute specification of digital proofing for coated paper, uncoated paper, and fiber substrate to provide Taiwan's digital archive program with a reference for image quality control and assessment. It is important to mention that the fiber substrate used in the study is somewhat new, as a substrate, for 2D artworks duplication in Taiwan's digital archive industry.

The study found that the printing quality on the paper substrates was better than that on the fiber substrates. Solid ink density of the coated paper was generally greater than that of the uncoated and fiber stocks. Standard deviation values of solid ink density readings for the uncoated stock were greater than those of the coated and fiber stocks in all four colors. The fiber substrates had greater tone value increase than did the coated and uncoated stocks at all tone levels in all four colors. In addition, the tone value increase curve of the fiber stocks was not as smooth as those of the coated and uncoated stocks, resulting in obvious tone jump phenomena. The coated paper had higher print contrast values than did the other two stocks in all four colors, while the fiber stocks had lower print contrast values. When it comes to color gamut comparison, the coated stock had wider color gamut than did the uncoated and fiber stocks at solid patches, while the fiber substrate had wider color gamut at 75%, 50% and 25% tints.

The study also found that dye ink did provide bright colors with a broad gamut for fiber substrate; however, the color of dye ink starts to fade away in about two weeks. This study suggests that the fiber substrates printed using dye-based ink can be applied in exhibition posters or similar products which do not require high quality color longevity.

5. Recommendations

In order to render correct and detail color for original artworks, it is necessary to choose suitable substrates if one wishes to duplicate the artworks to preserve the originals. Although the print quality of the fiber stocks is not as good as expected, the fiber substrate still has the advantages of non-reflection, not easy to tear, crease-free, with the perfect cutting edge and easy to store. Thus, a further study is recommended to investigate how to apply color management systems (CMS) to control and then improve color reproduction quality for various fiber substrates.

The results of the study are expected to be applied to related areas, such as lithographic printers, service bureaus, and in-house printers, etc. In addition, the results could be used as practical references for other government organizations or programs, such as the National Digital Archive Program of National Science Council, the National Repository of Cultural Heritage of Council for Cultural Affairs, Challenge 2008: National Development Plan (2002-2007), Digital Archive Center of universities in Taiwan, Municipal Cultural Center, National Museums, Fine Arts Museums, etc.

The construction of digital color specifications (see Appendix I) could assist printers to meet digital archive industry's requirements for high-quality images reproduction. Furthermore, the practical specifications could be incorporated into image assessment processes as an evaluation mechanism to ensure the digital image printouts of Taiwan's digital archive programs meet the required quality levels.

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Appendix I

The summary of color characteristics

		Coated Paper	Uncoated Paper	Fiber Substrate
Solid Ink Density (SID)	Y	0.89 – 0.91	0.85 – 0.88	0.67 – 0.70
	M	1.36 – 1.40	1.16 – 1.22	1.07 – 1.11
	C	1.36 – 1.40	1.16 – 1.22	0.98 – 1.02
	K	1.63 – 1.67	1.30 – 1.36	1.19 – 1.24
50% Tone Value Increase (TVI)	Y	12.1 – 12.9	14.8 – 16.0	15.0 – 17.8
	M	15.3 – 16.1	16.7 – 17.8	22.8 – 23.7
	C	13.0 – 13.9	13.4 – 14.8	21.8 – 23.5
	K	15.9 – 16.9	18.9 – 20.8	18.4 – 20.1
Print Contrast (PC)	Y	31.3 – 32.0	27.4 – 28.8	19.1 – 20.8
	M	42.3 – 43.4	35.7 – 37.7	23.8 – 25.1
	C	39.3 – 40.7	33.0 – 35.3	20.2 – 22.3
	K	44.8 – 46.0	32.1 – 35.2	37.5 – 38.4

Note: The tolerance is a statistical precision evaluation of derived from computing the 90% confidence interval of the mean.