An Experimental Research to Compare Devices for Measuring Aluminum Lithographic Printing Plates

Yung-Cheng Hsieh*, Ph.D
Yu-Ju Wu**
Wha-Hwat Lin**

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This research was experimental in nature and aimed to: (1) explore the feasibility of adopting a Micro Optical Image Capture System (MOICS) to measure halftone dots on offset metal printing plates, (2) investigate the differences in the measuring results of the three instruments: MOICS, Charge Coupled Device (CCD) Plate Dotmeter, and Conventional Reflection Densitometer, and (3) study the reliability and validity of MOICS when measuring metal plates. The three instruments were used to read conventional PS plates, photopolymer CTP plates, and thermal CTP plates. Forty plates were made resulting in a total of 120 plates. Plate dots at 10%, 25%, 50%, 75%, and 90% tone values were measured and their area readings were entered onto Minitab and SPSS statistical software packages for final analyses.

The major findings of this study are: (1) The measuring results of MOICS on the metal printing plates were highly reliable and valid. (2) There existed significant differences between the measuring results of the three instruments at 10%, 25%, 50%, 75%, and 90% tints. (3) The measurements and calculations for the halftone dots on the plates of the self-established MOICS device involved in several steps and its process were relatively time-consuming. Further studies are recommended on how to integrate CCD Camera, digital video processing system, and image analysis and computation software application to build a compact and hand-held instrument.

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*Associate Professor, Department of Graphic Communication Arts, Dean of Student Affairs, National Taiwan University of Arts, Taipei, Taiwan
E-mail: t0308@mail.ntua.edu.tw or hsiehisu@ms23.hinet.net
**Graduate Student, Graduate School of Applied Media Arts, National Taiwan University of Arts, Taipei, Taiwan

1. Introduction

The advent of Computer to Plate (CTP) system has increased the attention and need of monitoring and assessing plate dot reproduction quality. Measuring and controlling halftone dots on the printing plate play a vital role in the printing process control. In the printing industry, densitometers are the most widely used instruments to measure halftone dot areas on film and paper. However, reflection readings from printing plates, especially metal plates, using densitometers do not, in many cases, provide realistic dot area measurements in highlights and quartertones. In fact, several studies indicated that dot areas calculated from reflection measurements on metal printing plates are not always predictive on press. Therefore, having a reliable and valid instrument to measure halftone dots on printing plates is desirable for every printer.

1.1 Motivation and Need of the Study

Reflection densitometers have been used in the printing industry to measure dot area and other print attributes on paper for many years, but the size of the dot on the printing plate historically was never even tracked in the analog process because it has been known that it was difficult to measure. The important comparison has always been between the film and printed sheet. Many printers are unaware that there is usually a 2-8 percent midtone dot size change from film to plate. It has always been risky if we pay attention only to the total dot gain of the process because without quality plates, it is impossible to achieve quality print. Now as the printing industry begins its effort to replace the traditional film and analog plate system with a CTP system, it becomes necessary to finally resolve the issues of how printers control and monitor the dot size on the printing plate, what plate measuring devices printers should choose, and what the reliability and validity are for those devices.

1.2 Purposes of the Study

Based on the need of the study, this study was designed to:

- explore the feasibility of adopting a Micro Optical Image Capture System (MOICS) to measure halftone dots on aluminum offset printing plates,
- investigate the differences in the measuring results of the three devices: MOICS, CCD Plate Dotmeter, and Conventional Reflection Densitometer,
- study the reliability and validity of the three measuring devices when they are employed to measure aluminum offset printing plates. In this study, the three devices were used to read conventional PS plates, photopolymer CTP plates, and thermal CTP plates.

1.3 Limitations of the Study

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

1. Due to budget constraint, the metal printing plates used in this study were limited to the aluminum-based plates only: one of the most commonly used conventional PS plates and two types of the most popular CTP plates used in Taiwan (photopolymer and thermal CTP plates)
2. No two plate output systems were the same; they varied in machines, materials, and environmental conditions. Therefore the working performances of the platesetters used in this study were not investigated.
3. Three different plate output systems and three different plate measuring devices were employed for this research. Their designs, components, ages, and other physical and chemicals conditions differed. Their effects on the results of this study were not explored.
4. Only black-color test form was designed for the experiment.
5. This study tries not to name the manufacturers of the densitometer and CCD-based dotmeter to avoid commercial promotion.
6. The image analysis function used for the Micro Optical Image Capture System was a combination of several functions in Photoshop. According to the author’s previous study published in 2002 (Hsieh, 2002), Photoshop is a cost-effective and valid method to compute dot size on non-porous surfaces.
7. No replication was done for this study.

2. Review of Related Literature

This section discusses the problems with measuring metal-based offset printing plates with conventional reflection densitometers and describes the measuring devices used for measuring aluminum-based printing plates.

2.1 Dot Area Measurement on Aluminum Lithographic Plates

Traditionally densitometers have been used to measure halftone dots on lithographic film and press sheet. However, measuring printing plates with densitometers has been considered a risky matter for many printers. Image uniformity is critical in obtaining accurate plate measurements. An uneven plate coating might not affect the printed result, but it will produce errors in the measurement of the plate.

Printers can measure dot area value on aluminum plates with a densitometer, but the consistency and accuracy of the data are questionable. First, printing plates usually encompass a very limited range of reflectance (about.50), compared to a density range of ink on paper (about 1.6). Due to this difference in density range, a densitometer must be much more precise to measure dot area on plates with the same amount of accuracy. The great variety and non-standard nature of the colorants used to create the image area on lithographic printing plate is also another concern. A third unknown factor is whether the optical size of a dot on the printing plate is a true dot indicator of the printing size of that dot after the plate has been running on the press for a short while (Stanton, et al. 1996).

Plate coatings are grainy and uneven, thus light bounces everywhere in reflective mode. Not surprisingly, the density information changes across the plate ("The beauty of seeing," 1998). Grained aluminum usually contains directional markings due either to initial brush graining or the original rolling and gauging process. Under microscopic examination with directional lighting the effect is clearly visible. This brushed pattern improves the performance of the plate on press, but causes light to be reflected non-uniformly. Attempts to measure the appearance of the aluminum background will produce varying results depending on the orientation of the densitometer ("Dot Area Measurements," n.d.).

It is well known that densitometers calculate density information based on the reflectance of light. Fenster (1999) stressed that because many plates in use today do not use emulsion colorants that are dark enough, nor plate surfaces that are light enough, to provide enough contrast between the emulsion and the background, measurements of the plate emulsion and the plate surface tend to be less sensitive and subsequent dot area calculations less repeatable.

For these and other reasons, many printers have shied away from making reflection measurements of printing plates. However, some industry users report their success on using reflection densitometers to measure and control plate dot area values for the purpose of establishing process control. In fact, some specially designed densitometers can be used to determine the plate dot area on a step wedge. Hinson (1998) emphasized that this is best done by always holding the densitometer in the same orientation to the plate grain, re-zeroing on base next to each scale step and applying an n-factor to the dot area calculation. An n-factor is used to compensate for the grain and other reflective properties of the plate's base and image area.

In summary, the reliability and validity of using a densitometer to measure aluminum printing plates is a function of:

- Instrument's optical design,
- Plate grain type and depth of the exposed and processed plate,
- Plate grain direction of the exposed and processed plate,
- Plate emulsion color of the exposed and processed plate,
- Plate surface color of the exposed and processed plate, and
- An empirically-determined n-factor value used for the Yule-Nielsen formula.

2.2 Devices for Measuring Aluminum Printing Plates

Densitometers, colorimeters, and spectrophotometers are the most widely used devices to measure press sheets in the printing industry. They provide important information that helps to control the color reproduction process, but not all of them are reliable and valid for measuring printing plates, especially aluminum-based plates. Along with the advent of CTP system is the concern of how to measure the plates. Three primary measurement systems are currently utilized by printers for reading lithographic printing plates: color reflection densitometer, CCD-based dotmeter, and micro image capture system with image analysis software application. These three systems have not been compared for the validity and reliability.

Reflection Densitometer

Color reflection densitometer measure the difference between the amount of light projected onto a sample and the amount of light either reflected back or transmitted by the sample. Reflection densitometers are probably the most convenient and inexpensive devices for measuring printing plates, but some printers and researchers do not think they are accurate and precise enough to read halftone dots on aluminum printing plates. The only way that a densitometer can be used as a dotmeter for plates is by careful calibration of the black and white levels within close proximity of the target area, assuming the “n” factor for the plate is known.

The plate-reading densitometer used for this study is a portable color reflection model with integral LCD readout and a full graphics panel that is menu driven. With fully automatic operation, this device has special features including press performance graphs and full print report compilation. This fully featured model includes density readings, dot gain, automatic operation, and a special setting for plate measurement of the halftone dot area using the Yule-Nielsen formula. In this study, the n-factor value was 1.15 based on the manufacturer’s recommendation (“Operating Manual,” n.d.).

CCD Dotmeter

The second category of plate-reading device is CCD-based dotmeter. A dotmeter works on the principle of combining a CCD camera with a microscope. The camera takes a snapshot of the area being measured and literally counts the black and white pixels in the image. Rather than taking an average of dot density, as with a densitometer, the dotmeter is actually measuring image area and providing an absolute value of dot coverage (Imhoff & Elmy, 2000).

The dotmeter used for this study is a hand held unit specifically designed to measure dot size and coverage on plates. This small, hand held instrument is an integrated CCD Camera, digital video processing system, and software application. Its operation is the same as when using a densitometer, except there are no moving parts contend with. Basically, it works by recording two calibrated values from the plate, one for the plate emulsion and the other for the plate base. The internal processor then uses these to set a threshold that is used to evaluate the 60,000 pixels in the frame. If 30,000 are black and 30,000 are white, then the result is 50%. Unlike densitometer-based plate measurements, this dotmeter does not require guessing at the 50% tint value, nor does it require setting "n" factors.

Micro Optical Image Capture System

The third category of plate-reading device is a micro optical image capture system (MOICS) in combination with image analyzer. For many years, plate manufacturers and other research laboratories around the world have used video techniques involving either planimeter or computed results. Usually a photomicrograph is taken of the dot, which is then put on a digitizing tablet and traced around by hand, and a judgment made of the dot edge. The area of the dot is then calculated by the computer (Imhoff & Elmy, 2000).

Using a microscopic picture of the halftones imaged on the plate, outlining these halftones using either a computer program or manually, and then computing the area inside of the outlined dots; this is still a very operator dependent method, while inherently accurate (Fenster, 1999). Usually this method uses microphotographs of the plate, and manual tracing of the dot outlines by an operator using a planimeter. That would then be used to calculate the area within the outlined dots.

A major advantage of this system is its optical measurements at no less than 20x magnification; the disadvantage however, is the lack of auto-shot thresholding. Other advantages include, but not limited to: the measurement is not affected by most variations in background, a highly adjustable stable light source and captured images can be saved to a Mac or PC and examined on the screen or be printed on photographic paper with a high-end color video printer.

The MOICS (See Appendix I) used for this experiment is a specially designed unit that consists of:

- high precision optical microscope (20X ~ 1800X)
- high precision XY-table
- halogen lamp, cool light source
- CCD Video Camera
- 15" LCD monitor
- digital video processing system
- computer system
- software application
- Sony color video printer.

In this experiment, the area computation of captured dot images was done with the method recommended by Dr. Hsieh's recent research published in 2002 (Hsieh, 2002). In that study, he proposed a method consisting of certain functions in Photoshop to calculate halftone dot areas, especially for non-porous substrate. According to the study's results, Photoshop is not only a cost-effective method, but also the result of its image analysis and computation is reliable and valid.

3. Methodology

This section describes the test form, procedures, data collection, experimental materials and conditions of the study. The test form and data collection process are also presented as follows.

3.1 The Test Form

An original black color test form was designed for this study (See Appendix II). It consists of photographic images test targets. Twelve step wedges located at each side of the test form. The step wedge is ranged from 5% to solid, in increments of 5%. The photographs on the test form are GATF test images, which emphasize different color reproduction challenges.

3.2 Experimental Procedure

Three participants were provided with a CD-ROM containing the TIFF file of the test form. They were asked to output the file at 175 lpi screen ruling and not to apply any compensation for dot gain. The two CTP plate output systems were optimized and linearized before the experiment and the exposure levels were processed according to the manufacturer's recommendations.

The Screen MTR 1100 imagesetter was utilized to output the computer-generated film for the conventional PS plates and was calibrated and linearized before the experiment. The measurement of dot areas on the film was done with an X-Rite® 341DTP transmission densitometer. It was also used for the imagesetter calibration and linearization. Extreme care was taken to standardize the exposure level and development time for the PS plates. The UGRA Plate Control Wedge was used to determine the correct exposure amount for the PS plates. Each of the three participants was asked to output 40 plates and each individual plate output process was carefully observed on site by the research team. Consequently, a total of 120 plates were collected and measured at the National Taiwan University of Arts.

3.3 Data Collection

The protective layers (gumming) were washed off before measuring the printing plates. Three different measuring devices, color reflection densitometer, CCD plate dotmeter, and MOICS were used to read the plates. Each device was applied to read the 10%, 25%, 50%, 75%, and 90% tint patches on the plates for all of the three types of plates (conventional PS, Photopolymer CTP, Thermal CTP).

During the whole measuring process, the printing plates were leveled on an even table surface. All four feet of the measurement devices were rested fully on the plates to prevent the devices from wiggling. All measurements from the plates were taken with the devices in the same orientation. Consistency of instrument reading based on rotated plate orientation was not investigated. For all plates, readings were made from the left side to the right side of each plate, there was no rotation, and the direction of device movement was the same.

For densitometric measurement, status "T" density readings were made from the plates with a color reflection densitometer using Yule-Nielsen equation with an n-factor value of 1.15, recommended by the densitometer manufacturer. According to the manufacturer's operating manual ("Operating Manual," n.d.), the light trap effect can be corrected by using the Yule-Nielsen equation for the calculation of the dot area of printing plates, and 1.15 is a practical n-factor value for measuring aluminum printing plates. The densitometer used to read the plates was calibrated and maintained based on the manufacturer recommendations to assure data reliability.

4. Results and Findings

This section reports the overall results and findings obtained through analyses of the data obtained from the complex measurement on the three types of plates. All the analyses were done with SPSS 11 and Minitab 13 statistical software packages. It is important to note that each specific patch on the plates was read only one time due to time constraint; in other words, the plate reading recorded is a single reading, not an average value from multiple readings. In the tables and figures presented in this paper, "DA" represents the "dot area" readings form the devices, the MOICS is denoted with "M", the CCD dotmeter is denoted with "A", and the densitometer is denoted with "G".

4.1 Basic Statistics of the Readings from the Three Devices

The results of dot area measurement on the PS plates from the MOICS, CCD Dotmeter, and Densitometer are shown in Table 1. Average dot area values reported by MOICS were closest to the original tone values at all five tone levels, except the 90% tone. The average dot area readings reported by the MOICS were most deviated from the original tone values at all five tone levels. According to the calculations, the dot area readings with MOICS on the PS plates tended to be closer to the original tone values than those with the other two devices. On the other hand, closer examination on the standard deviation values for the three measurements shows that the CCD dotmeter yielded the least amount of measurement variability on the PS plates. This implies that the dotmeter might be the most stable device to read PS plates. It is important to note that the **bold** number in Table 1, Table 2, and Table 3 shows the average reading of a particular device is closest to the true tones among the three; the **Italic** number represents the least variation group.

Table 1. Basic statistics of the readings from the conventional PS plates

Conventional PS Plates (sample size = 40)						
Tint Patch	MOICS		CCD Plate Dotmeter		Densitometer	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
10%	**12.1555**	2.5717	4.3000	*.4641*	6.7250	.6789
25%	**25.7665**	2.4422	17.4250	*.5006*	18.7250	1.0374
50%	**48.6630**	2.0002	41.4000	*.4961*	40.7500	.8697
75%	**74.0368**	1.2887	72.1250	*.3349*	68.4500	.5970
90%	88.5763	.7316	**89.6750**	*.4743*	86.3250	.4743

The results of dot area measurement on the photopolymer CTP plates with MOICS, CCD Dotmeter, and Densitometer are shown in Table 2. Observations made from the mean numbers in Table 2 are as follows: (1) the readings made with the densitometer in the 10% and 25% tone areas were closest to their original tone values, (2) the average readings reported by the MOICS in the midtone areas were closest to the 50% tone value, and (3) the readings made with the CCD dotmeter at the 75% and 90% tone levels were closest to their original tone values. Analysis made from the standard deviation numbers in Table 2 are as follows: (1) the variability of the dot area readings made with the densitometer was greater than that of the other two devices in every tone level measured, (2) the reading variability of the MOICS at the 10%, 50%, and 90% tints was the smallest among the three devices, and (3) the reading variability of the dotmeter at the 25% and 75% tints the smallest.

Table 2. Basic statistics of the readings from the photopolymer CTP plates

Photopolymer CTP Plates (sample size = 40)						
Tint Patch	MOICS		CCD Plate Dotmeter		Densitometer	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
10%	8.3788	*.3506*	6.8250	.3848	**10.4750**	1.2192
25%	22.8805	.3627	20.8500	*.3616*	**23.9750**	1.1655
50%	**44.4620**	*.3803*	42.7250	.5986	44.1250	.9920
75%	70.0660	.3632	**70.9750**	*.3572*	68.6000	.7779
90%	84.5570	*.2734*	**86.1750**	.4465	84.5500	.6775

Table 3 displays the basic statistics of the measurements on the thermal CTP plates with the MOICS, CCD Dotmeter, and Densitometer. Some observations made from the mean and standard deviation numbers in Table 3 are as follows: (1) the readings made with the MOICS in the all five tone levels, except the 10%, were closest to their original tone values, (2) the variability of the dot area readings made with the MOICS was less than that of the other two devices in the 50%, 75%, and 90% tone levels, (3) the least measurement variability was found in the readings made with the CCD dotmeter at the 10% and 25%% tone levels, (4) the readings reported by the densitometer at all five tone levels were most deviated most from their original tone values, and (5) the reading variability of the densitometer was the greatest among the three devices. In brief, one conclusion can be drawn: the MOICS appears to be an excellent device to measure halftone dots on thermal CTP plates; on the other hand, the densitometer might not be the most favorable device to read halftone dots on thermal plates.

Table 3. Basic statistics of the readings from the thermal CTP plates

Thermal CTP Plates (sample size = 40)						
Tint Patch	MOICS		CCD Plate Dotmeter		Densitometer	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
10%	9.4848	.4616	6.9500	*.3162*	**9.6000**	1.0813
25%	**24.2967**	.5263	21.5750	*.5006*	23.6000	.8412
50%	**49.1417**	*.5714*	47.4500	.9594	46.5000	.7161
75%	**75.2285**	*.5609*	76.7500	.8697	71.8750	.5633
90%	**90.7558**	*.3771*	93.2750	.7157	88.6750	.4743

4.2 Differences in the Dot Area Readings between Devices

In this section, One-way ANOVA and Paired-t Test statistical procedures were employed to determine whether the differences in dot area readings on the three plates between the devices were significant. The hypothesis being tested was whether the reading difference between devices was equal to zero. The significant level (α) was set at .05 for all tests. The results of for the PS, photopolymer CTP, and thermal CTP plate are exhibited in Table 4, Table 5, and Table 6, respectively.

Table 4 demonstrates that the differences in dot area readings on the PS plates between devices in each of the three pair at all five tone levels were significant. Table 5 reveals significant differences in dot area readings on the photopolymer CTP plates of MOICS versus Dotmeter and Dotmeter versus Densitometer. In MOICS versus Densitometer, the reading differences were significant only at the 10%, 25%, and 75%. Table 6 shows the differences in dot area readings on the thermal CTP plates between devices in all the three cases, at all five tone levels were significant, with the exception between the MOICS and Densitometer at the 10% tone value.

Table 4. Hypothesis testing on the dot area differences between devices for the PS plates

Tint Patch	MOICS vs. Dotmeter		MOICS vs. Densitometer		Dotmeter vs. Densitometer	
	Ha: $\mu_M \neq \mu_A$		Ha: $\mu_M \neq \mu_G$		Ha: $\mu_A \neq \mu_G$	
	p value	significance	p value	significance	p value	significance
10%	.000	yes	.000	yes	.000	yes
25%	.000	yes	.000	yes	.000	yes
50%	.000	yes	.000	yes	.000	yes
75%	.000	yes	.000	yes	.000	yes
90%	.000	yes	.000	yes	.000	yes

Note: significant level (α) = .05; μ denotes the mean of dot area readings

Table 5. Hypothesis testing on the dot area differences between devices for the photopolymer CTP plates

Tint Patch	MOICS vs. Dotmeter		MOICS vs. Densitometer		Dotmeter vs. Densitometer	
	Ha: $\mu_M \neq \mu_A$		Ha: $\mu_M \neq \mu_G$		Ha: $\mu_A \neq \mu_G$	
	p value	significance	p value	significance	p value	significance
10%	.000	yes	.000	yes	.000	yes
25%	.000	yes	.000	yes	.000	yes
50%	.000	yes	**.056**	**no**	.000	yes
75%	.000	yes	.000	yes	.000	yes
90%	.000	yes	**.953**	**no**	.000	yes

Note: significant level (α) = .05; μ denotes the mean of dot area readings

Table 6. Hypothesis testing on the dot area differences between devices for the thermal CTP plates

Tint Patch	MOICS vs. Dotmeter		MOICS vs. Densitometer		Dotmeter vs. Densitometer	
	Ha: $\mu_M \neq \mu_A$		Ha: $\mu_M \neq \mu_G$		Ha: $\mu_A \neq \mu_G$	
	p value	significance	p value	significance	p value	significance
10%	.000	yes	**.533**	**no**	.000	yes
25%	.000	yes	.000	yes	.000	yes
50%	.000	yes	.000	yes	.000	yes
75%	.000	yes	.000	yes	.000	yes
90%	.000	yes	.000	yes	.000	yes

Note: significant level (α) = .05; μ denotes the mean of dot area readings

4.3 The Reliability of the Measuring Devices

Reliability is the extent to which a measuring device is consistent in measuring whatever it measures. Strictly speaking, reliability refers to the data resulted from the measuring device rather than to the device itself (Ary, Jacobs, & Razavieh, 1996).

In this study, Cronbach α (internal reliability coefficient) values were computed to determine the internal reliability of the instruments. In other words, the α index was used to assess the consistency of the dot area readings on the printing plates for the three measuring devices. In general, a Cronbach α value greater than .70 is necessary to declare that a measuring device is reliable. The overall Cronbach α values for the instrument of this study were reported in Table 7. The table indicates that the Cronbach α values of the MOICS and densitometer were greater than .70 (.84 for MOICS and .71 for densitometer), but the α value of the dotmeter was only .49. The results imply that the MOICS had the greatest consistency in measuring dot size on the aluminum-based lithographic printing plates, and the dotmeter for this experiment might not be a reliable device for measuring halftone dots on the printing plates.

Table 7. The reliability analysis for the three systems

System	Cronbach Alpha
Micro Optical Image Capture System, MOICS	.8431
CCD Dotmeter	.4878
Densitometer	.7108

4.4 The Validity of the Measuring Devices

Validity refers to the extent to which a measuring device measures what it is intended to measure and it is actually determined based upon the data resulted from the measuring device (Ary, Jacobs, & Razavieh, 1996). In other words, validity is used to determine how well a measuring device measures what it intends to measure.

This experiment performed Factor Analysis statistical procedure in SPSS to assess whether the three devices really measure what they were supposed to measure. Factor analysis is often used to investigate the *construct-related* validity of an instrument by identifying a small number of factors (constructs or components) that explain most of the variance observed in a much larger number of manifest variables. The term *construct* refers to a factor that is not itself directly measurable but that explains observable effects. Construct studies combine logical and empirical approaches. One aspect of the logical approach is to ask if the underlying elements the device measures are the elements that make up the construct. In this study, the construct is the halftone dot area element.

The Principal Component Analysis with an eigenvalue of 1.00 was used to extract the underlying constructs for all the readings obtained from the three different plates for each of the measuring devices. In this experiment, it was assumed three factors should be identified if a measuring device was valid to read halftone dots on the aluminum plates, because there were "three" different types of plates being measured. This study only presents three evidences of describing construct validity for the measuring devices: Total variance explained by the identified factors (components or constructs), Rotated component matrix, and Component plot in rotated space.

Table 8, Table 10, and Table 12 show the eigenvalues associated with each factor before extraction and after rotation for each of the three data sets obtained from the MOICS, dotmeter, and densitometer. Before extraction, SPSS identified 15 components within the data set simply because there should be as many eigenvectors as there are variables and so there are as many factors as variables. The eigenvalues associated with each factor represent the variance explained by that particular component and SPSS displayed the eigenvalue in terms of the percentage of variance explained. Note that the first few factors revealed relatively large amounts of variance (especially factor 1) whereas subsequent factors explain only small amounts of variance. The factors with an eigenvalue greater than 1 were extracted, and the eigenvalues associated with these factors after rotation are displayed (and the percentages of variance explained) in the column labeled *Rotation Sums of Squared Loadings*. Rotation has the effect of optimizing the factor structure and one consequence is that the relative importance of the three factors is equalized.

Table 9, Table 11, and Table 13 illustrate that the rotated component matrices for the data sets obtained from the three devices, respectively. The rotated component matrix is actually a matrix of the factor loading for each variable onto each factor. Several facets are very important to interpret these rotated factor-loading matrices. First, factor loadings less than .50 were not shaded. Second, the factor loadings for each variable onto the same construct (component or factor) should be grouped together if a device was a valid instrument to measure that particular underlying construct. In this experiment, three different types of plates were being measured and hence three factors identified were expected and factor loadings for the same plate should have been grouped together with the loading values greater than 0.50. Third, each number in the tables represents the partial correlation between the item and the rotated factor (component). These correlations can help us formulate an interpretation of the factors or components by discovering a common thread among the variables that has large loadings for a particular factor or component. Fourth, the higher the factor loading values, the more valid the measuring device is for measuring that particular underlying construct (factor). In general, values between 0.5 and 0.7 are mediocre, values between 0.7 and 0.8 are good, values between 0.8 and 0.9 are great, and values above 0.9 are superb.

Another evidence to determine whether a device is valid to read the printing plates is the *component (factor or construct) plot*. The component plots in rotated space for the MOICS, dotmeter, and densitometer are exhibited in Figure 1, Figure 2, and Figure 3, respectively. The plot shows the three-dimensional view of the components (factors or constructs) after rotation. When interpreting these plots, one must consider several aspects. First, the variables (items) formulated onto (strongly correlated with) the same component would be closely clustered together. Second, the more clustered the variables were together; the more valid the device was to measure that particular factor formulated by these variables. Third that dot area readings at all five tone levels for a particular type of plate would be closely clustered together therefore, it was expected that three apparent clusters would be revealed in the component plots since three different types of printing plates were measured.

The Validity Analysis of the MOICS

Three factors were identified in Table 8 and they explained the total variance of 76.61% in the dot area readings at all five tone levels on the three types of plates collectively. The number of components (factors or constructs) identified was also expected because the MOICS was used to read three types of plates: PS, photopolymer CTP, and thermal CTP plates. In addition, the percentage of the total variance explained by the three significant factors (76.61%) was greater than 70%, which reveals that the MOICS is a valid instrument to read the halftone dots on aluminum plates.

Additional strong evidences to support that the MOICS is a valid device to read the printing plates are shown in Table 9 and Figure 1. Table 9 exhibits the rotated component matrix for the readings with MOICS and Figure 1 displays the component plot in rotated space. The factor loadings for each item (variable) on the components (factors) after rotation were categorized into three apparent groups. Average readings at all five tone levels on the PS (denoted by PS), photopolymer CTP (denoted by PP), and thermal CTP (denoted by TML) plates were categorized into three distinct groups as indicated by the shaded area, respectively. Similarly, Figure 1 reveals three apparent clusters, one for the PS plates, one for the photopolymer plates, and one for the thermal plates.

In addition, the factor loading values shown in Table 9 are all greater than 0.70 for the three factors, excluding the variable M_25_TML, which represents the mean values of the dot area readings at the 25% tints on the thermal plates. It is also important to note that the MOICS is a better device to measure PS plates than to measure photopolymer and thermal plates, because, the overall factor loading values of the PS-plate matrix are greater than those of the other two plate matrices.

Table 8. The total variance explained by identified factors for the MOICS

Compo-nent	Initial Eigenvalues			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	6.032	40.211	40.211	4.456	29.707	29.707
2	2.868	19.120	59.331	4.059	27.058	56.765
3	2.591	17.276	76.607	2.976	19.842	76.607
4	.890	5.936	82.543			
5	.642	4.282	86.826			
6	.494	3.296	90.122			
7	.431	2.871	92.993			
8	.259	1.728	94.721			
9	.237	1.580	96.301			
10	.173	1.153	97.454			
11	.137	.916	98.370			
12	.105	.698	99.068			
13	.071	.470	99.538			
14	.038	.254	99.792			
15	.031	.208	100.000			

Note: Extraction method is Principal Component Analysis

Table 9. Rotated component matrix for the MOICS

	Component		
Items	1	2	3
M_10_PS	**.848**	.222	.257
M_25_PS	**.932**	.273	5.106E-02
M_50_PS	**.951**	.202	4.512E-02
M_75_PS	**.954**	.203	1.116E-02
M_90_PS	**.934**	-7.979E-02	5.393E-02
M_10_PP	.316	**.824**	8.641E-02
M_25_PP	.121	**.899**	5.541E-02
M_50_PP	9.667E-02	**.875**	.190
M_75_PP	.151	**.864**	.186
M_90_PP	8.473E-02	**.888**	-6.878E-02
M_10_TML	4.332E-02	.160	**.732**
M_25_TML	2.834E-02	2.016E-02	**.537**
M_50_TML	2.058E-02	4.670E-02	**.906**
M_75_TML	.102	-2.978E-02	**.764**
M_90_TML	.104	.171	**.766**

Note: Rotation method is Varimax with Kaiser Normalization
PS: PS plate; PP: Photopolymer plate; TML: Thermal plate

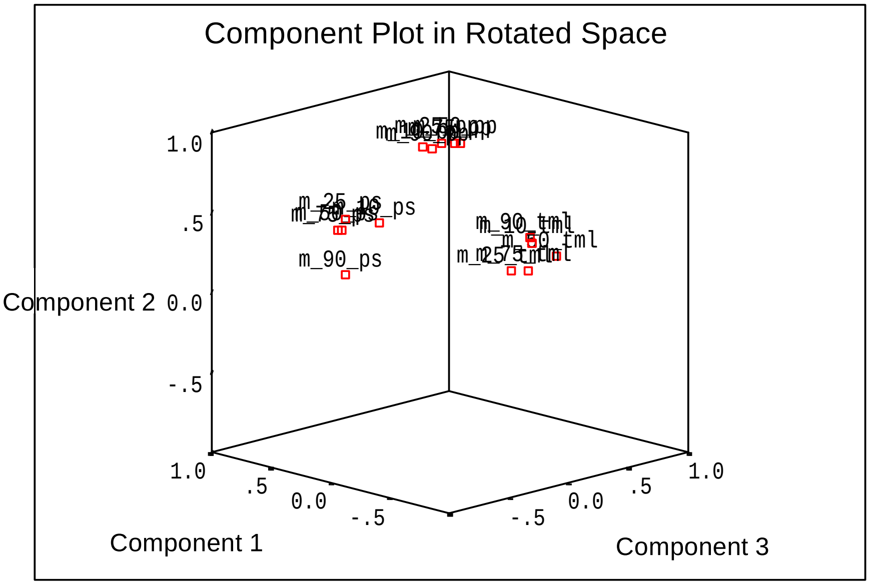

Figure 1. Component plot in rotated space for the MOICS

<u>The Validity Analysis of the CCD Dotmeter</u>

According to the sums of squared loadings shown in Table 10, five components (factors) were identified and they explained total variance of 68.48% in the dot area readings reported by the CCD dotmeter at all five tone levels on the three types of plates cumulatively. The number of factors extracted was more than what was expected (the expected number was three), and the percentage of the total variance explained by the five factors was less than 70%. It appears that the dotmeter might not be a valid instrument to read the halftone dots on aluminum plates. Further evidences can be found in Table 11 and Figure 2.

Table 11 exhibits the rotated component matrix for the dot area readings measured with the dotmeter and Figure 2 displays the component plot in rotated space. Average readings at all five tone levels on the PS, photopolymer, and thermal plates should have been categorized into three distinct groups. Unfortunately, Table 11 does not exhibit three apparent groups; instead five indistinct groups were formed as indicated by the shaded data. Similarly, Figure 2 does not show three apparent clusters: one cluster for the PS plates, one for the photopolymer plates, and one for the thermal plates. In this study, the readings on the plates of a measuring device were considered valid (or accurate) only if its factor loading values for the same type of plates were grouped together with the values greater than 0.70. Unfortunately, this phenomenon did not occur (see Table 11 and Figure 2). Neither of the expected results matched the real data, thus more evidence is needed to conclude that the dotmeter is a valid instrument to read the halftone dots on the aluminum plates.

Table 10. The total variance explained by identified factors for the dotmeter

	Initial Eigenvalues			Rotation Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.272	21.814	21.814	2.503	16.687	16.687
2	2.245	14.969	36.783	2.325	15.503	32.190
3	2.022	13.478	50.262	1.948	12.988	45.178
4	1.596	10.638	60.900	1.881	12.541	57.718
5	1.138	7.585	68.484	1.615	10.766	68.484
6	.838	5.586	74.070			
7	.728	4.852	78.923			
8	.635	4.230	83.153			
9	.540	3.598	86.751			
10	.480	3.198	89.949			
11	.440	2.931	92.880			
12	.352	2.349	95.229			
13	.307	2.046	97.275			
14	.304	2.029	99.304			
15	.104	.696	100.000			

Note: Extraction method is Principal Component Analysis

Table 11. Rotated component matrix of the CCD Dotmeter

	Component				
	1	2	3	4	5
A_10_PS	.090	**.622**	.0670	.275	-.285
A_25_PS	-.050	**.745**	-.110	.153	-.215
A_50_PS	-.120	.353	.033	**.716**	.183
A_75_PS	-.252	.321	-.150	**.637**	-.244
A_90_PS	-.424	**.723**	-.088	-.018	.143
A_10_PP	.094	-.101	**-.783**	.213	-.235
A_25_PP	.157	-.301	-.029	.067	**.730**
A_50_PP	.159	-.168	.032	**.830**	-.077
A_75_PP	.050	-.152	**.791**	.247	-.116
A_90_PP	.065	.012	**.792**	-.055	-.255
A_10_TML	.343	**.663**	.096	-.084	.122
A_25_TML	**.792**	.087	.076	.095	-.040
A_50_TML	**.830**	.035	-.021	-.028	.254
A_75_TML	**.831**	-.153	-.063	-.177	.273
A_90_TML	.212	.095	-.114	-.117	**.740**

Note: Rotation method is Varimax with Kaiser Normalization
PS: PS plate; PP: Photopolymer plate; TML: Thermal plate

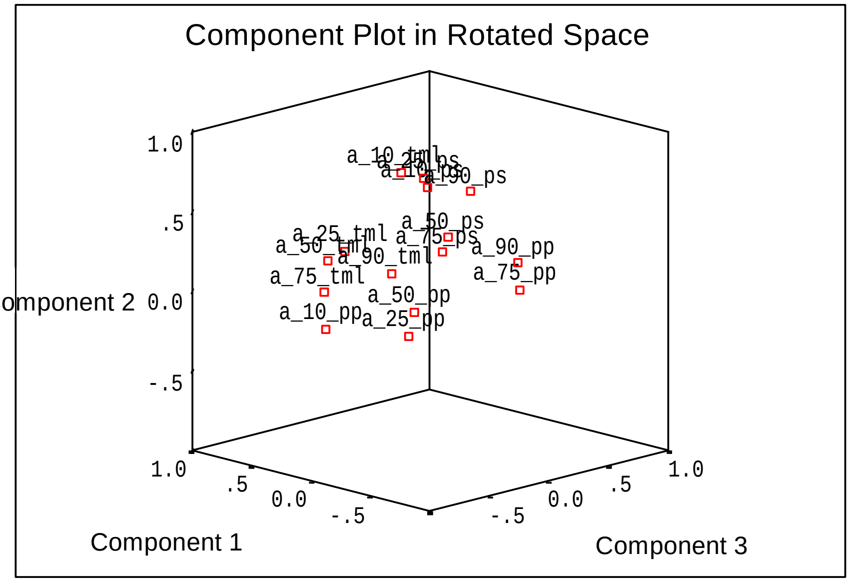

Figure 2. Component plot in rotated space for the dotmeter

<u>The Validity Analysis of the Densitometer</u>

Table 12 illustrates that five factors were identified and they explained 73.96% of the total variance in the dot area readings measured with the densitometer at all five tone levels on the three types of plates collectively. The number of factors identified was more than what was expected (the expected number was three), although the percentage of the total variance explained by the five factors is greater than 70%. It appears that the densitometer might not be as good as the MOICS in reading the halftone dots on aluminum plates, in terms of the number of factors extracted and their ability of explaining variance of the dot area readings on the printing plates. Further evidences can be found in Table 13 and Figure 3.

Table 13 exhibits the rotated component matrix for the dot area readings measured with the densitometer and Figure 3 displays its component plot in rotated space. As shown in Table 13, three apparent groups were not found; instead five indistinct groups were formed as indicated by the shaded data. Likewise, Figure 3 does not exhibit three apparent clusters, but it still reveals an important message – the readings of the same type of plates tend to be clustered together. Neither of the expected results matched the real data, thus more evidence is required to conclude the validity of densitometer to read the halftone dots on the aluminum plates.

Table 12. The total variance explained by identified factors for the densitometer

	Initial Eigenvalues			Rotation Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.915	26.100	26.100	2.715	18.098	18.098
2	2.812	18.744	44.844	2.553	17.020	35.118
3	1.923	12.819	57.664	2.341	15.606	50.724
4	1.409	9.391	67.055	1.827	12.179	62.903
5	1.036	6.906	73.961	1.659	11.058	73.961
6	.910	6.064	80.025			
7	.702	4.682	84.707			
8	.689	4.591	89.298			
9	.405	2.700	91.998			
10	.344	2.291	94.289			
11	.279	1.863	96.152			
12	.213	1.418	97.570			
13	.178	1.188	98.758			
14	.127	.847	99.605			
15	.059	.395	100.000			

Note: Extraction method is Principal Component Analysis

Table 13. Rotated component matrix of the Densitometer

	Component				
	1	2	3	4	5
G_10_PS	-.204	.316	.129	.249	**.546**
G_25_PS	.024	**.764**	-.077	.097	.025
G_50_PS	.114	**.797**	-.197	.140	.072
G_75_PS	.255	**.709**	-.402	.037	.078
G_90_PS	-.037	**.753**	.273	-.142	-.225
G_10_PP	.221	.015	-.045	**.910**	.038
G_25_PP	**.652**	.171	.198	.651	.034
G_50_PP	**.696**	.191	.072	.546	.085
G_75_PP	**.892**	-.099	-.053	.145	.045
G_90_PP	**.877**	.089	-.060	.036	-.081
G_10_TML	-.143	-.079	**.841**	-.019	-.209
G_25_TML	-.011	.052	**.662**	.149	.255
G_50_TML	.137	-.189	**.775**	-.046	.193
G_75_TML	.037	-.190	.493	-.342	**.559**
G_90_TML	.172	-.098	.029	.017	**.910**

Note: Rotation method is Varimax with Kaiser Normalization
PS: PS plate; PP: Photopolymer plate; TML: Thermal plate

Again, the readings on the plates of a measuring device were considered valid (or accurate) only if its factor loading values for the same type of plates were grouped together with the values greater than 0.70. Unfortunately, according to Table 13 and Figure 3, one of these conditions did not occur. The percentage of the total variance explained by the five factors (see Table 12) and the way the variables formulated onto each of the five factors (see Table 13 and Figure 3) reveals that the densitometer is a better device for measuring halftone dots on the aluminum printing plates than the CCD dotmeter, but a worse device than the MOICS.

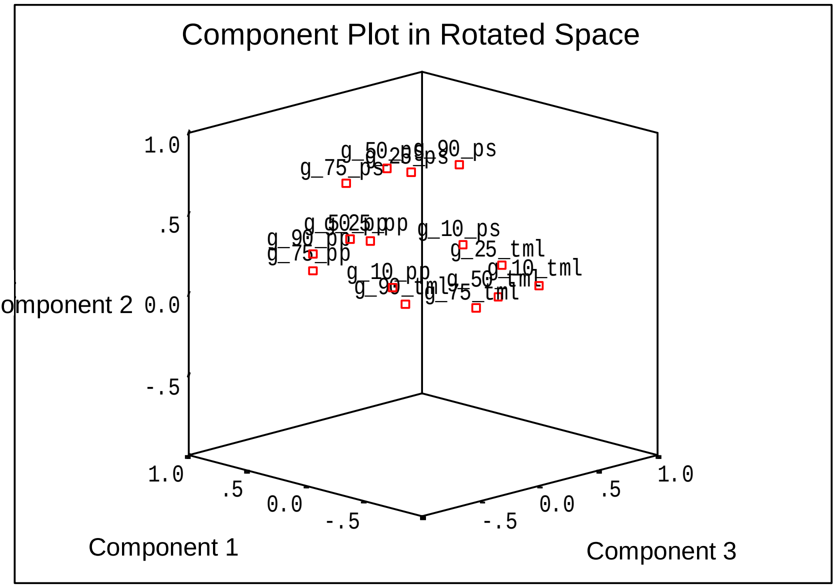

Figure 3. Component plot in rotated space for the densitometer

5. Conclusions and Recommendations

Within the limitations and constraints of this study, the major findings of this study are:

1. Significant differences existed in the dot area readings measured with the three devices at the 10%, 25%, 50%, 75%, and 90% tone levels.
2. The differences in dot area readings on the *PS* plates between devices for each of the three device comparisons at all five tone levels were significant.
3. Significant differences existed in dot area readings on the *photopolymer CTP* plates between devices MOICS vs. Dotmeter, and Dotmeter vs. Densitometer. In MOICS vs. Densitometer, the reading differences were significant only at the 10%, 25%, and 75% tone levels.

4. The differences in dot area readings on the *thermal CTP* plates between devices in all the three device comparisons at all five tone levels were significant, with the exception between the MOICS and Densitometer at the 10% tint.
5. Overall results of the reliability analyses show the Cronbach α values of the MOICS, densitometer, and dotmeter were 0.84, 0.71, and 0.49, respectively. The results imply that the MOICS has the greatest consistency in measuring halftone dots on the aluminum-based lithographic printing plates and the dotmeter used in this study is not a reliable device for measuring halftone dots on the plates.
6. The halftone dot readings of the MOICS on the aluminum-based lithographic printing plates are highly reliable and valid.
7. The percentage of the total variance explained by factors and the way variables formulated onto the factors show that the densitometer is a better device for measuring halftone dots on the plates than the CCD dotmeter, but a worse device than the MOICS.
8. A further study is necessary to investigate the reasons for the inaccuracy and inconsistency of the dot area measurements made with the dotmeter.
9. It is relatively time consuming to measure and calculate halftone dots on the plates of the MOICS device. In this study, the process required that the human operator decided where to threshold the image (to define the border between the black and white levels of the plate). However, such an instrument is not particularly portable or quick to make readings. Therefore, it is recommended that a study on how to integrate CCD Camera, digital video processing system, and image analysis and computation software application into a compact and hand-held instrument, be conducted. The printing industry needs a plate-reading device that possesses high reliability, validity, and portability.

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Appendix I. The MOICS Used for this Study

Appendix II. The Test Form