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Effect of Ink, Substrate, and Target Line Width on the Line Quality Printed using Dimatix DMP Inkjet

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Abstract

In this research, the image quality analysis is conducted for inkjet lines printed on substrates. ISO 24790 compliant lines are designed and printed on a substrate with a drop-on-demand inkjet printer. This study analyzes three print quality attributes of line: width, blurriness, and raggedness. The research used cyan, magnetic and standard inks to print the same design on various substrates having differences in gloss and texture. The chosen inks were measured using a rheometer to determine a viscosity range. The effects of substrate structural parameters, such as texture, finishing, weight, and ink type on line quality, are discussed. The printed lines were measured using a charged coupled device camera. The print attributes were measured, and statistical analysis was conducted. Based on this analysis, it was observed that substrate has significant effect on all the response variables. The substrate which produced best result is luster for raggedness and line width conformity and matte for blurriness. Ink has significant effect on the line width conformity and raggedness whereas there is no significant effect of inks on blurriness. There is no effect of increase in the line width on any of the response variables. A design of experiment methodology was successfully implemented to determine the effect of surface properties of the substrate and the effect of ink properties on print quality.

Motivation

Inkjet printing is the mainstream technology which had been extensively researched. With the advancement of technology there is need to standardize the non-impact printing. With this standardization ISO came up with a standard which defined parameters to access the print quality of the printed sample.[2] This standard was ISO 13660, later this had been revised to ISO 24790. There are various parameters listed in the standard 13660 that were extensively analyzed before this standard was released and even after its release. [1,4,5] The subjective analysis and objective analysis have been the topics of discussion with regards to the print quality analysis. Subjective analysis is related to the human perception whereas objective analysis is related to the machine measurement.[3]

Problem

Studies have been conducted with respect to the physical attributes of ink with respect to the drop formation, jetting velocity and found there is significant importance of the physical attributes of ink on the print quality. [6] There is also importance of the designing of the line widths for analyzing the line qualities. The line width analysis has been conducted on the textile substrate to understand the influence of the inkjet inks on the surface of the fabrics. Inks of different compositions have been printed and assessed to see how these inks interact with the structure of the fiber and how the image quality is affected. The experiment includes the line width analysis have been done for digital printers with different addressability by using different inks and substrates. Line being printed in vertical and horizontal directions. How the direction of the printing influences raggedness, blurriness effect is discussed earlier. [8]

As there is also rise in the print paper because of the rise in the décor printing, photographic printing, signage industry, packaging industry. There is rising demand for the analysis of the interaction between the inks of different composition with various substrates. This paper is concerned with the line quality analysis of inkjet lines printed on substrates of different textures like matte, luster, and canvas with cyan, magnetic and standard inks. ISO 24790 compliant lines are designed and printed on the photopaper with the drop on demand inkjet printer. This study analyzes 3 print quality attributes like line width conformity, blurriness, and raggedness.

Theoretical Basis

The theoretical basis for this research consists of three parts print quality, ISO 24790 standard on which this study was conducted and Design of Experiment (DOE). Print quality (PQ) is defined as quality of a hardcopy output of a printer. ISO-13660 defined 14 print quality attributes to solve some problems related to PQ

Line quality is used to assess the line output of printers. The attributes of line quality are line width, raggedness, and blurriness (ISO, 2017). Line quality attributes (defined below) are important to this study.

- Blurriness: "Appearance of being hazy and indistinct in outline, a noticeable transition of darkness from line element to background substrate whose intended transition width is zero" (ISO, 2017, p.2).
- Raggedness: "Appearance of geometric distinction of an edge from its ideal position" [2]
- Line Width: "Average stroke width, where the stroke width is measured from edge to edge along a line normal to center line of the image element" [2]

ISO 24790:2017 specifies device-independent image quality attributes, measurement methods, and analytical procedures to describe the quality of output of images from printers [2]. The attributes, methods, and procedures rely on measurable properties of printed text and graphic images.

This study relies on Design of Experiments (DOE). This experiment has various parameters that must be discussed, including the process parameters, target parameters (line width), and the variability with respect to the desired line width. DOE is a strategy for planning and analyzing experiments that assists in planning the experiment in order to collect the required data to support statistical analysis. Factorial design experiments are used to study the effects of experimental factors on response variables in experiments involving two or more factors.

Factorial design estimates the effect of each factor at several levels. There are two kinds of effects which can be investigated using this method. One is the main effect, and the other is the interaction effect. The effect of single factor on a response variable due to variation in the level of that factor is called a main effect. The effect of simultaneously changing the levels of two or more factors on a response variable is called an interaction effect.

Approach

The methodology consists of the steps required to conduct preliminary testing, design test target and generate samples for measurement followed by the steps required to analyze these samples and draw conclusions. The methodology is divided in to eight steps which are outlined in the figure shown below

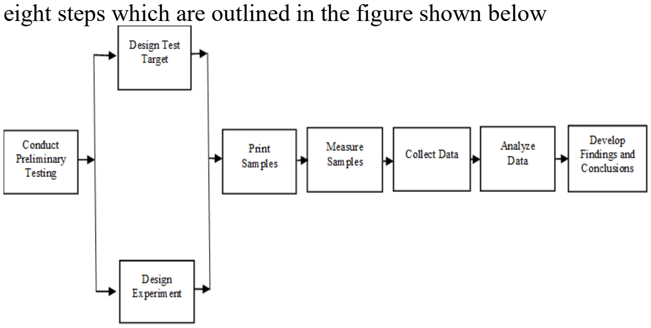

Figure 1. *Workflow of the Experimental Process*

A test target was developed in compliance with ISO 24790 standard. The target includes four different lines of different line widths. Personal Image Analysis System (PIAS-II) was used to measure the required line quality attributes. The designed line widths chosen for this study were 63.5 µm, 95.3 µm, 190.5 µm and 317.5 µm. The resolution of the printer set to print this target was 800dpi.

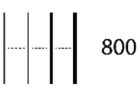

Figure 2. *Test Target Design*

DOE approach was applied in this study. DOE is a strategy for planning and analyzing that assists in planning the experiment to collect thee required data to support statistical analysis. DOE has many methods for data analysis, but this research utilizes full factorial design methodology with two factor three levels and two replicates.

The next step was to choose the desired substrates and inks. Three inks cyan, MICR and DMP model ink with viscosities of 3cPs, 6.19cPs and 14.76cPs respectively were chosen. The factors that could affect the quality were controlled on the printer, these factors include printhead temperature, platen temperature, waveform pattern, nozzle voltage, standoff distance and sabre angle.

The samples were printed with Fujifilm Dimatix DMP 3000 printer. These samples were printed with three inks on three various substrates. Total 18 samples were printed (9 runs of each experiment x 2 runs are repeated twice).

Line quality attributes were measured using the PIAS-II instrument. The data was collected, and a statistical analysis tool DOE was used to create a data input for the designed experiment. An ANOVA was conducted to test factors and interaction for significance. Finally, main effects due to ink and substrate and interaction effect between them were analyzed.

Results

Total there were 12 DOE which were analyzed. Each DOE was analyzed based on the Analysis of Variance (ANOVA) table, main effects chart and interaction effect chart. The result of only one DOE was discussed later in the conclusions summary of all the 12 DOE's is provided.

It was observed that some of the response variables are affected due to the factors, but others were unaffected.

The results are discussed in terms of three aspects effects of substrate on response variable, effects of ink on response variable and effect of line width on response variables.

Ink has a substantial effect on conformance to specified line width as seen in figure 3. In particular, the use of standard ink increases non-conformance, while MICR ink decreases it. Substrate also affects conformance to specified line width. This is primarily due to the effects of the luster and canvas substrates. With luster conformity improves, and conformity worsens with canvas.

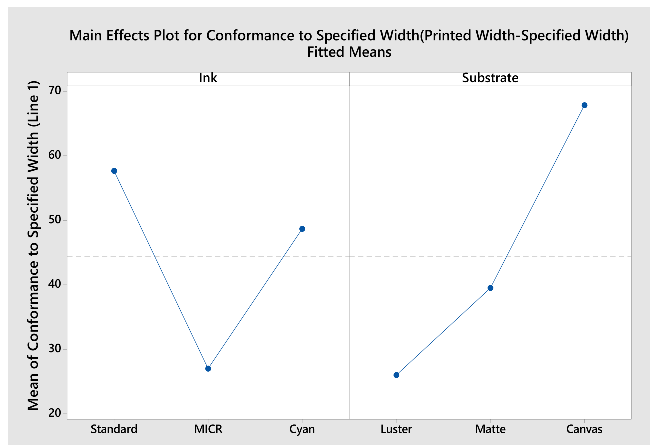

Figure 3. *Main Effects Plot for Printed Width Nonconformance to Line 1 Specified Width (63.5 µm). The Main Effects chart plots observed Line nonconformance (µm) on the vertical axis versus the levels of inks and substrates investigated on the horizontal axis. The dashed line is the mean effect of all inks and all substrates. If the null hypothesis is true, the observed effects will be close to this line. The greater the distance between a factor's effects and the mean line, the greater the likelihood that a real effect is present.*

Figure 4 plots the ink and substrate interaction. Both plots present the same information, so we only need to discuss one of them. Examining the Substrate*Ink plot, note that the lines should all have the same shape of the Substrate Main Effect plot. In fact, only one line (standard ink) has this shape; MICR and cyan are straight lines. This indicates that there is an interaction between ink and substrate. Looking more closely, this is primarily due to the unexpectedly high level of nonconformance observed when canvas is printed with standard ink.

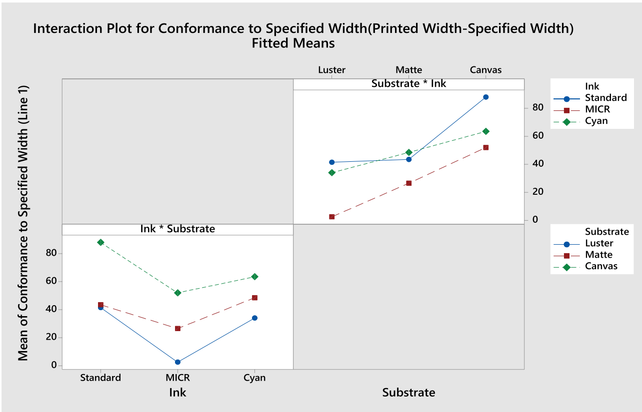

Figure 4. Interaction Plot for Printed Width Non-Conformance to Line 1 Specified Width. If the null hypothesis is true, the interaction plot will display family of three lines, all having the same shape as the Main Effect plot for the first variable listed in the interaction. If all three lines do not share this shape, an interaction is present.

To determine if the effects are real and repeatable an analysis of variance was performed. The results of this analysis are summarized in Table 1. As Table 1 demonstrates, the effects of ink and substrate on conformance to specified line width are significant at a level of $p < 0.001$. Based on this, the result suggests a greater than 99.8% confidence that these effects are real and repeatable. Similarly, the effect of the Ink*Substrate interaction is significant at a level of $p = 0.045$. Based on this, the researcher has 95.5% confidence that the interaction effect is real and repeatable.

Analysis of Variance for Conformance to Specified Line Width(Line 1)

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	*p*-value
Model	8	9067.4	96.13%	9067	1133	<0.001
Linear	4	8451.9	89.60%	8451	2112	<0.001
Ink	2	2981.8	31.61%	2981	1490	<0.001
Substrate	2	5470.1	57.99%	5470	2735	<0.001
2-Way Interaction	4	615.6	6.53%	615	153	0.045
Ink*Substrate	4	615.6	6.53%	615	153	0.045
Error	9	365.5	3.87%	365	40	
Total	17	9432.9	100.00 %		1133	

Conclusions

The research hypotheses state that the choice of substrate, ink and target line width (factors) affect line width conformity, raggedness and blurriness (response variables). The following sections analyze the effect of each factor on the response variables.

Substrate has statistically significant effect on all the response variables. The best surface for width conformance and raggedness is luster followed by matte and then canvas. The best surface for blurriness is matte followed by luster and then canvas.

Effect of Substrate on Performance Metrics

Performance Metrics	Statistical Significance	Best	Middle	Worst
Width Conformance	Significant (99.9% Confidence)	Luster	Matte	Canvas
Raggedness	Significant (99.9% Confidence)	Luster	Matte	Canvas
Blurriness	Significant (99.9% Confidence)	Matte	Luster	Canvas

Ink has statistically significant effect on width conformance and raggedness but statistically insignificant effect on blurriness. The effects due to inks are due to surface tension and viscosity. Droplet scatter and spread are the reasons for line width conformance which results in MICR to be the best followed by Cyan and then standard ink. Raggedness also has similar result as line width conformance.

Effect of Ink on Performance Metrics

Performance Metrics	Statistical Significance	Best	Middle	Worst
Width Conformance	Significant (99.9% Confidence)	MICRr	Cyan	Standard Ink
Raggedness	Significant (90 .8% to 99.9% Confidence)	MICR	Cyan	Standard Ink
Blurriness	Not Significant	NA	NA	NA

Line width does not appear to have meaningful effect on width conformance and raggedness. Blurriness shows slightly increasing trend as the line thickness increases.

Effect of Line Width on Performance Metrics

Performance Metrics	Line 1	Line 2	Line 3	Line 4
Width Conformance(µm)	44.44	50.14	57.94	47.61
Raggedness(µm)	9.61	9.55	10.16	10.50
Blurriness(µm)	128.89	156.39	187.61	179.67

In the current research, results were analyzed using designed experiments, analysis of variance, and hypothesis testing. This allowed the researcher to draw statistically valid conclusions concerning the significance of factor effects on response variables. This approach was not observed in most previous studies. In prior studies related to the present research, researchers defined "significance" subjectively or comparatively. In order to compare present and prior conclusions, the researcher applied similar standards of "significance" to his research.

The present research has implications for multiple parties in the graphic art industry. This type of research can also be extended to the novel printing inks on various types of substrates tested in the field of printed electronics and flexible electronics.

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Mihir Ravindra Choudhari obtained his bachelors in Electronics and Tele-Communications Engineering at Savitribai Phule Pune University in India in 2015. He obtained his Masters in Print Media at Rochester Institute of Technology in May 2019. His research was on Inkjet printing technology with focus on the inks used in graphic communication and how the print quality is affected because of the substrate texture. Currently he is working as Artwork & Print Production Engineer at Acelity, San Antonio,TX. His interests include inkjet, materials included in inkjet, conductive printing, workflows in graphic communication, color management in graphic arts.