Registration Error Measurement and Compensation Method for Modular Printing Systems

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Abstract

A Modular Printing (MP) architecture can significantly reduce hardware cost and improve configurability of digital printing systems. However, image-to-image misregistration as the result of paper handling and multiple imaging modules could introduce halo and halftone moiré artifacts and thereby present a challenge for print quality control. In MP systems, paper passes multiple imaging, development and fusing stations. Differences among subsystems of the print engines contribute to misregistration on the prints. In this paper, we present a method to measure and characterize the image-to-image (I-to-I) misregistration in MP systems. Based on the misregistration measurements, we can parse the misregistration into four main types: translation, rotation, magnification, and residual deformation. A parameterized digital compensation method can reduce misregistration for different media types based on the measurement.

Introduction

MP, Modular Printing, [1] systems use an individual printing engine as a station in a multiple-station printing system to achieve high productivity and configurable architectures. When media go through multiple print engines, each print engine images certain portions of page content on the media. One print engine can image a particular color plane, such as a spot color or one or more of the primaries, cyan (C), magenta (M), yellow (Y) or black (K). One print engine can also image one side of the media while a subsequent print engine images the other side. The multiple print engines could be designed to operate in a serial or parallel manner. In MP, paper handing and variations between the print stations have the potential to significantly affect the resultant image. Front-to-back, image-to-paper and color-image-to-color-image variation in MP include the variation between individual print engines instead of the variation between pages in a single engine regular printing configuration. Several authors have characterized the impact of image-to-image (I-to-I) misregistration on color shift [2] and moiré [3][4]and halo, and have shown that the effects can be quite significant.

A measurement method that requires scanner calibration has been proposed for image-to-paper misregistration in a regular printing system [5]. Methods have been proposed on the misregistration compensation [6][7][8] but not on the measurement of image-to-image registration errors.

In this paper, we develop a relative measurement method that does not require scanner calibration to measure and characterize the I-to-I misregistration in MP systems. We first describe the sources of misregistration. We then discuss misregistration measurement target design and then the measurement procedure. The measured relative misregistration is decomposed into translational and rotational sources related to paper path, which we capture in a paper path profile. The residual misregistration is from media deformation due to fusing in the multiple print engines. A magnification factor is generated to capture this deformation. Digital compensation is applied using the parameterized paper path profile and the media magnification and we show the improved registration in simulation.

Sources of Misregistration

In MP systems, image-to-image registration error has multiple sources. Without loss of generality, we analyze the registration error between any two print stations where each print station consists of only one print engine as shown in Fig. 1. There are 5 major sources of misregistration shown in Fig. 1: within page distortion due to the imager in the first and second engine (1, 4); fuser distortion in the first and second print engine (2, 5); translation and rotation distortion due to media handling in the paper path (3). Characterizing the misregistration through mechanical analysis of the above process would be a complex effort and subject to environmental variations. We propose an empirical characterization that uses a test target and printing and measurement to develop the misregistration characterization. The characterization will provide distances for same image points written by the different print engines.

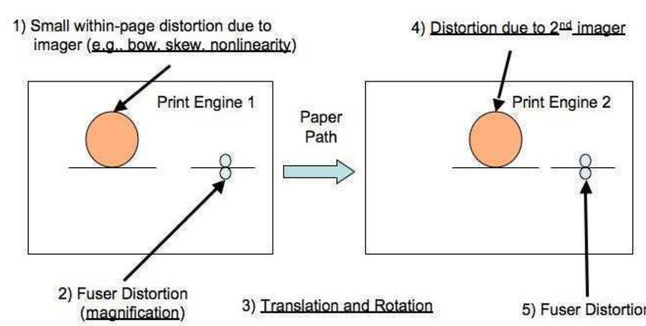


Figure 1. *Source of Misregistration in MP systems*

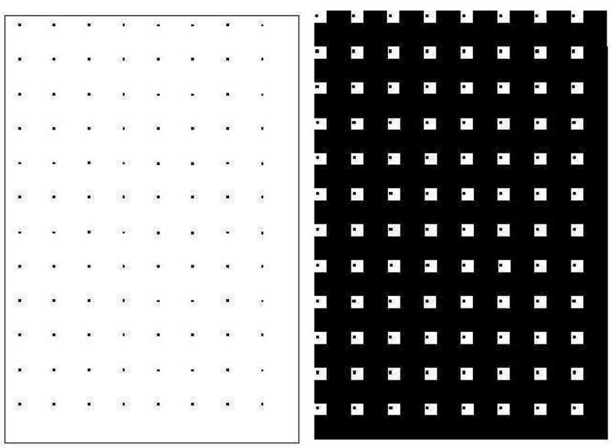
Target Design and Misregistration Measurement

We have designed two types of test pages to measure the misregistration: one with low toner coverage (Type I) and the other with high toner coverage (Type II); see Fig. 2. The resolution is 600 pixel-per-inches with 3-by-3 pixel square dots. We refer to the 3-by-3 pixel square as a dot hereafter. Dots are placed on the page with a 300 pixel period in both horizontal and vertical directions. The Type I test page has only printed dots and the remainder of the area is left white. The Type II test page leaves a small area surrounding the dot white but fills the remaining area with 100 percent coverage of the given process colorant.

We simulate a modular printing system using a laser printer, where a test sheet is printed with one colorant, then placed back in the paper tray and printed with a second colorant. The grid of dots allows us to sample misregistration from colorant to colorants for the entire page at the dot locations. Misregistration between the grid dots can be estimated by interpolating between nearby dot measurements.

We create multiple print samples with different colorants using different media types. We use four types of paper in our study: Business 4200 (24lb), Recycled (20lb), Image Elite 25% Cotton (20lb) and Digital Color Xpression (32lb). The test page prints are scanned using EPSON GT3000^{TM}.

The translation and rotation model of the relative displacement is constructed and parameters are derived for both translation and rotation displacement. The residual displacement from several measurements are used to construct a media profile that quantifies the amount of deformation as the result of media going through fusing multiple times in MP systems. Parameterized digital compensation based on the analysis is performed to reduce misregistration.



(a) (b)

Figure 2. *(a) Test Pattern with low toner coverage (b) Test Pattern with high toner coverage*

Relative Displacement

For MP systems, the image-to-paper and image-to-image misregistration can be measured in absolute distance, i.e. distance of imaged pixel to paper edge. However, it is the relative distance between the imaged pixels from different print engines that causes color shift, moiré and halo artifacts. An example of the proposed relative displacement measurement is shown in Fig. 3. Compared to absolute measurement of dot positions, measurement of the relative displacement reduces the error introduced by the measuring device, thus greatly simplifies the measurement process over other proposed methods.

In Fig. 3, without loss of generality, we define the top line of dots as being printed by the first print engine and the bottom line printed by the second print engine. L denotes the distance between the first dot and the last dot of the first engine and ΔL denotes the distance between the last dot of the first and second engine. The ΔL measurement is relative to the two dots being measured for image-to-image misregistration, compared to the L measurement, which gives the absolute position of the dots independently. Assume the measuring device has a fractional measurement error e. The errors due to the measurement device for absolute distance $Error_{absolute}$ and relative distance $Error_{relative}$ are given in Eq. (1). To understand the differences in error, consider that ΔL is on the order of a fraction of a millimeter and L is on the order of multiple inches. Hence, measuring image-to-image misregistration via ΔL rather than L results in significantly less error.

$$\begin{aligned} Error_{absolute} &= e * L \\ Error_{relative} &= e * \Delta L \end{aligned} \tag{1}$$

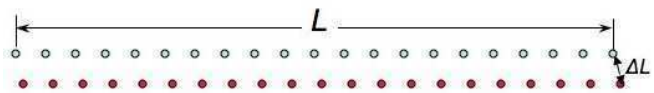


Figure 3. *Relative Displacement v.s. Absolute Displacement*

Translational and Rotational Displacement Model

Ultimately, we desire to pre-distort a digital image separation prior to printing according to an inverse of the expected distortion. It is useful to utilize a parameterized model to characterize the expected distortion. We parameterize the distortion using a translation, rotation, and residual displacement

The test targets shown in Fig. 2 are printed using the simulated modular printing system described above. Multiple copies of the same test pattern are printed and scanned. The grids of dots printed by the first and second print engine are detected and the center of each dot is located. The origin of the coordinate system is set at the center location of the first dot of the first grid. A cost function of two grids G_1 and G_2 is defined as

$$E(G_1\ G_2) = \sum_{i=1}^{N} dist(L_{(1\ i)}\ L_{(2\ i)}) \tag{2}$$

where $L_{(1\ i)}$ and $L_{(2\ i)}$ denote the location of the i-th dot of the first and second grid respectively and $dist(a\ b)$ denotes the Euclidean distance between point a and b. The cost function E measures the accumulative distance of all N dots between the first and the second grid. Assuming the paper path only has translational and rotational misregistration, we minimize the cost function via rotational angle α, horizontal translation h and vertical translation v:

$$(\hat{\alpha}\ \hat{h}\ \hat{v}) = \underset{\alpha\ h\ v}{\arg\min}\, E(G_1\ TR(G_2\ \alpha\ h\ v)) \tag{3}$$

The function $TR(G_2\ \alpha\ h\ v)$ is the rigid body transformation function that horizontally and vertically moves the dots in G_2 by h and v respectively and rotate with respect to the origin of G_2 by angle α. The set of optimized parameter $(\hat{\alpha}\ \hat{h}\ \hat{v})$ that minimize the cost function E is the parameter set in the modular printing system to reduce image-to-image registration error with respect to the first print engine.

Residual Misregistration

Residual misregistration can be attributed to media deformation as the result of going through multiple fusing processes in a MP system. A measure of the residual error will remain after removing the translational and rotational registration error from the measurements of the printed images. Residual misregistration averaged over the repeat prints for four paper types is shown in Fig.4. Examining the figure, we see that the residual misregistration is media type dependent and tends to have spatial trends. In some cases the spatial trends can be modeled as a simple shrinkage. Fig. 5 shows the effect of modeling the residual error for one paper type as magnification, and removing that magnification error as well as translation and rotational from the average error.

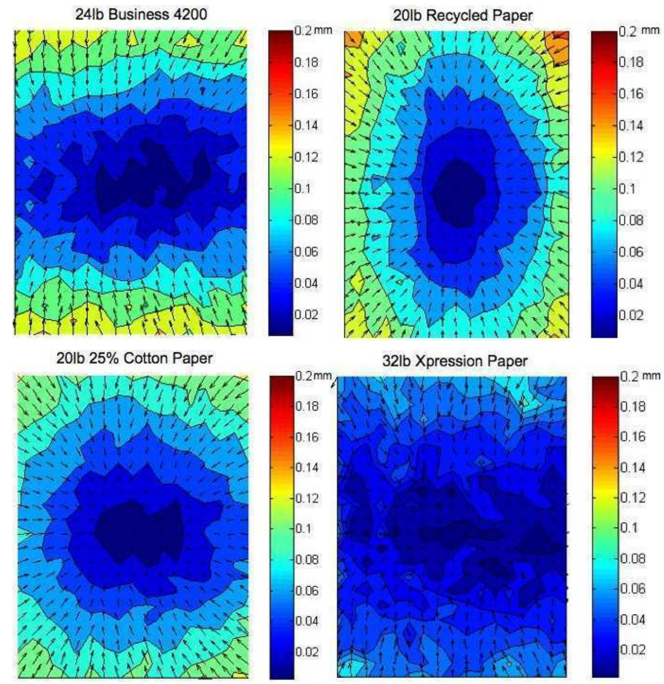


Figure 4. *Average Low Toner Coverage Residual Misregistration Profile after Translational and Rotational Misregistration are Removed*

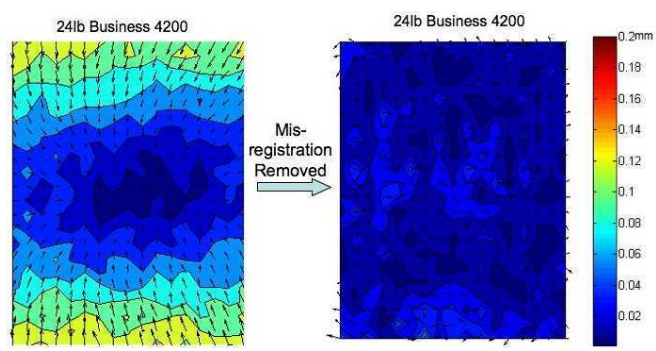


Figure 5. *Average I-to-I Misregistration after Removing Rotation, Translation and Residual (magnification) Misregistration*

Results

Multiple copies of the same testing page Type I and Type II were printed using the simulated modular printing system described above. Only one media type was printed and analyzed for Type II test page due to limited resources. Pages were scanned and 95 percentile of the relative misregistration were computed. Translational, rotational misregistration and residual misregistration profile in terms of magnification were derived for each test page printed and each media type used. Overall Image-to-image misregistration and translational offset ($\hat{h}$ $\hat{v}$) are shown in Table 1 and Fig. 6. In Fig. 6, each point represents the relative misregistration of one printout of each media group and we can observe the translational offset is independent of the media type. Toner area coverage does affect the amount of misregistration as shown in Fig. 7 and the toner coverage affects the I-to-I misregistration.

Image-to-Image Misregistration (95 percentile) Before and After Digital Compensation

Type I Test page with low toner coverage (μm)		
Paper Type	Compensation Applied	Residual Displacement
Business 4200	No Correction	460
	Rotation & Translation	156
	Magnification	108
Recycled 20lb	No Correction	387
	Rotation & Translation	159
	Magnification	78
Image Elite	No Correction	336
	Rotation & Translation	131
	Magnification	70
Digital Xpression	No Correction	478
	Rotation & Translation	99
	Magnification	91

Conclusions

Modular Printing systems achieve high productivity with less cost by using currently available technologies and products. The misregistration from engine variations, media handling and media deformation through multiple fusing processes generates objectionable imaging artifacts. In order to digitally compensate for the misregistration, a low cost, fast and accurate measurement process needs to be defined. In this paper, we proposed a relative measurement method to measure and characterize the misregistration in MP systems. We described the misregistration measurement target design and the printing and measurement procedures. The measured relative misregistration is decomposed to three mechanical sources related to paper path. Media profile was generated to capture the deformation as the result of multiple fusing. We also find the toner area coverage affects the image-to-image registration and the digital compensation result. The digital compensation using these parameters can significantly reduce the I-to-I misregistration in MP systems.

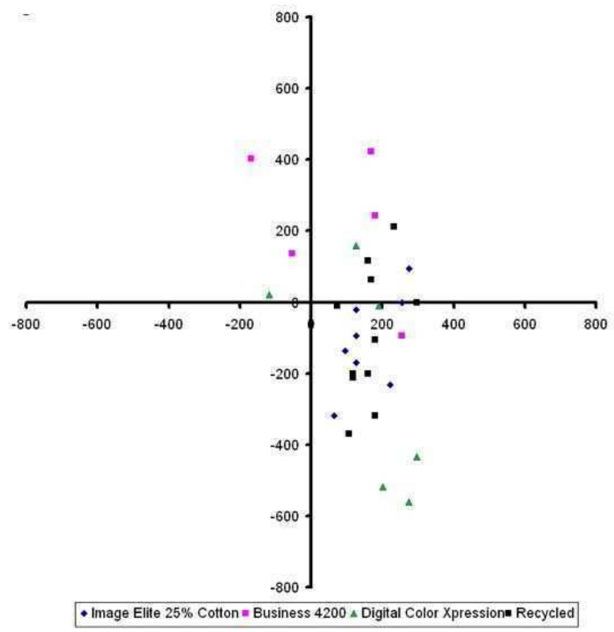


Figure 6. *Translational Offset of Type I Pattern (μm)*

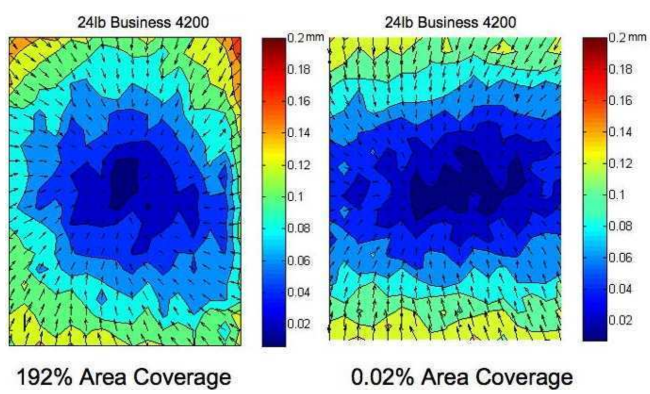


Figure 7. *Residual Misregistration Profile Comparison between High and Low Toner Area Coverage*

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Mu Qiao received his Bachelor, Master and Ph.D. degree from Electrical and Computer Engineering of Purdue University in 2002, 2004 and 2008 respectively. He currently works in Shutterfly as an imaging science engineer. Before joining Shutterfly, he worked at Xerox Corp. in 2007 as a summer research intern in Xerox Innovation Group and returned to Xerox in 2008 as full time employee in Global Production Delivery Group. His research interests are image processing and analysis, color management, variable data printing, and document management.