

Measurement and Analysis of Color Registration Errors of Print Engines

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Abstract

This paper describes an automatic, repeatable system to quantify print engine color registration at multiple points on a page, and discusses test target design, image acquisition and data analysis.

Measurements from six color laser printers were used to develop these techniques, and the results illustrated considerable localized registration variations within a page in both process (paper-movement) and lateral directions.

Introduction

Evaluation of image quality plays a critical role in all stages of an imaging system's development cycle. Benchmarking, prototype verification, engineering and development testing, pre-production trials, and production runs all require some level of image quality analysis. Subjective image quality analysis allows quick feedback from trained observers as to perception, preference and acceptability. Quantitative analysis provides the objectivity and repeatability necessary for true process tracking and improvement. A goal is to correlate results of preference and attribute-based evaluations with those from metric-based calculations.

A number of image acquisition and evaluation systems have been described in the literature^{1,2,3,4}. This report addresses one image quality attribute, color printer registration. A printer's color registration characteristics can affect other image quality attributes including text and line quality, color rendition and uniformity. The focus of this activity was to quantify the process-direction (paper movement) and lateral-direction (orthogonal to paper movement) misregistration of cyan, magenta and yellow printed images with respect to black.

The Image Analysis System

The Test Target

The registration target can be encoded as a bit map, a PostScript file, or be printed from an application, depending on the state of engine development and the assessment intent. For the purposes of this test, a PDF test target (with

no compression) was used as the basis of this analysis. The target layout consisted of 18 rows and 24 columns (defined in short-feed terms), or 432 individual registration patterns. The details of one of the patterns is shown in Figure 1.

Printing the Test Target

The registration characteristics of six color laser printers were analyzed for this report. The printers included both four-pass and tandem, and a range from budget desktop to heavy duty workgroup was represented.

For registration results that are most representative of the overall performance of the marking engine, there are several recommendations that we followed:

1. Avoid printing with a cold machine (i.e., condition the engine first)
2. If the printer has a registration utility, use it to return the printer to the manufacturer's specification.
3. Sample wisely.

For the prints included in this analysis, after engine conditioning and calibration, 50 pages of different test targets were selectively interleaved with 50 prints of the registration target. Different sampling strategies should be considered for specific printers based on their architecture. For example, consecutive samples should be measured for B3-size printers printing two letter-size pages on one drum at the same time, such as the HP 8550. The target was printed on one paper type, HammerMill Laser Print.

Registration Error Calculations

Figure 1 illustrates the pattern used to quantify printer registration. Assuming the lead edge is at the top of Figure 1, the horizontal lines are used to measure process-direction (paper movement direction) registration. An identical vertical pattern was used for lateral registration measurements. The calculations for cyan are illustrated and are based on measurements of the distances between the centroids of each of four lines:

The black reference lines, K_1 and K_2 ,

The black, K_3 , and cyan, C_1 , both having the same nominal vertical locations.

The two errors, E_1 and E_2 , were calculated.

E_1 is the distance of the black line that is nominally adjacent to the cyan line from the leading black line, compared with the distance of the cyan line from the leading black line.

$$E_1 = (K_1 - K_3) - (K_1 - C_1) \quad (1)$$

Similarly, E_2 is the distance of the cyan line to the trailing black line compared with the distance of the black line that is nominally adjacent to the cyan line to the trailing black line.

$$E_2 = (C_1 - K_2) - (K_3 - K_2) \quad (2)$$

The positional error that was reported was the average of these two errors,

$$E_{AVG} = average(E_1, E_2) \quad (3)$$

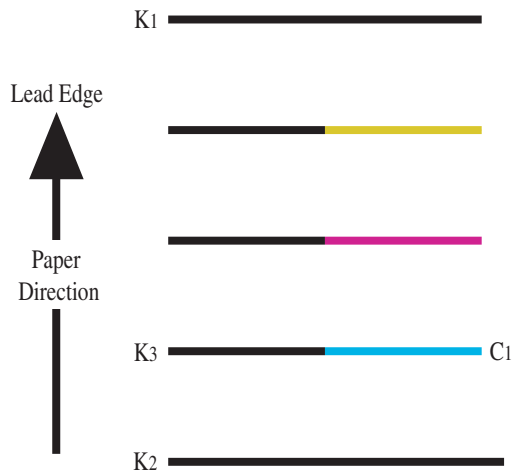


Figure 1. The pattern used to study engine registration.

The Camera Setup

Monochrome (black and white) CCD cameras record color features (especially yellow features), with very low contrast and are not usable for robust color registration testing. Since a black and white camera was not appropriate, a 3-CCD RGB camera was used to capture the images that were analyzed for this test. The use of 3 CCDs minimizes errors due to chromatic aberration and the interpolation that is associated with mosaic color CCD cameras. The red channel was used to capture the images used for measurement of cyan lines for the cyan registration measurements, the green channel was used for measurement of the magenta lines, and the blue channel was used for the yellow lines.

The Sony XC-003 RGB camera was set up with two 25 mm extension tubes for its 75 mm lens. The resultant field of view for the 480 x 640 pixel buffer was 5.8 x 7.8 mm. The camera aperture was f/11.

Distance Calibration

A calibration process using a specially designed ceramic calibration plaque (fabricated by Applied Image) was used to provide the translation between captured pixels and the real-world length units measured on the target. The calibration target was provided by ImageXpert to be used in the system calibration and verification process. The calibration process is quite robust and includes automatic internal correction for any potential distortions due to camera mis-alignment with respect to the image plane.

White Point Calibration

A light intensity calibration sequence was developed to verify illumination level and to permit adjustment so the sample's paper-white would generate an intensity value between 225 and 235 on a 0-255 scale. If needed, the user can initiate a Run Timed Cycle measurement method that provides both numerical and graphical feedback in real-time so the lens f-number can be adjusted by the operator until a "Pass" is indicated in the on-screen report.

Image Capture and Analysis

Using an X-Y-Theta stage controlled by ImageXpert software, each page was positioned such that images were captured at a 3 degree (plus or minus 30 minutes) angle with respect to a horizontal reference. All measurements were performed automatically via a task list (a macro) that moved the X-Y stage to the desired location, selected the correct camera and channel for image capture, applied image analysis, and saved the data to a report. At each location, the measurements and errors were calculated using ImageXpert and the resulting data was saved into an Excel file for post-processing and display using Matlab.

The 3-degree rotated angle applied before image capture reduced errors that could occur from non-exact alignment between the line patterns and the CCD sensor array or those that might be introduced by rotating the images digitally.

The first step in data collection was to create a matrix of X-Y stage positions that would allow image capture of each of the registration patterns on each sample. Measurement sequences were created to change camera channels, measure line center locations, and to calculate the distances between the centers. Lines were identified by a combination of a polarity (dark line in light background), a scanning direction (up to down, left to right), and a threshold value. The threshold value for each line color was determined empirically to result in robust edge point selection. Once the edge points were identified for the top and bottom or left and right, the averages of each edge point pair were calculated. Next, a least squares fit was applied to that set of averages to determine the best-fit line through the line itself. The center point of each line is defined by the

intersection of the horizontal or vertical mid-line of the ROI (region of interest) and the best-fit line. Distances between lines were calculated by measuring the perpendicular distance between the center point of one line to the best-fit line through the other. The error between the color line placement and the black line placement was calculated using a simple difference measurement in ImageXpert, and the average of the two error types was calculated and reported automatically.

The print engine digital signature (yellow dot pattern identifying the engine) implemented with some of the printers did not add to the yellow measurement error.

The measurement of all of the registration patches on a single sample took approximately 16 minutes when it was optimized for maximum throughput.

One of the largest challenges was to determine appropriate measurement order and data reporting structure for the combination of long edge feed and short edge feed prints. Excel was used to re-arrange data as necessary after it was collected.

Analysis of Data

Figure 2 shows a scatter plot of all the process and lateral direction registration errors in microns for the 432 target positions within a page for all six printers. Note that the magnitude of the lateral direction misregistration is usually less than the process direction and that the yellow color plane generally has the largest variation. The two tandem printers measured for this study had larger registration errors as did the low-cost 4-pass printer.

Figures 3 and 4 show 3-D plots of the location of registration errors on a page. In Figure 3 note that the yellow printer has one area, at position 8, in which the process-direction registration error is most severe. The registration characteristics shown in Figure 4 for one of the tandem engines shows more overall variation, as might be expected. All printers exhibited such variations within a page, some being more randomized and most following a particular pattern (repeated print to print). For long-edge feed printers that imaged two pages simultaneously on one drum revolution, the lead page on the drum and the trail page had quite different registration characteristics, and this difference was consistent among consecutive pairs of pages.

Potential Complication

A complication could occur when evaluating printers that do not print single colors. For example, if the black lines are printed as some composite -- some process color (C, M, and/or Y) in addition to pure black -- then the registration measurements relative to black will not be accurate. In this case, an alternative would be to measure the resulting line width variation and would require a different target design and different measurement and analysis approach.

Summary and Conclusions

A simple, effective methodology of quantifying within-page registration has been demonstrated using the ImageXpert system and Matlab analysis tools. The results of this study of six printers showed that sampling color registration at a few points within a page could overlook quite significant localized registration problems of a print engine, and this was demonstrated by both four-cycle and tandem color printers.

References

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Biography

William Kress received his BS and MS in electrical engineering and has spent the last 30 years working in the fields of analog and digital imaging. His vocational interests include digital image capture systems, image processing algorithms, color optimization, and development and use of preference-, attribute- and metric-based image quality assessment techniques.

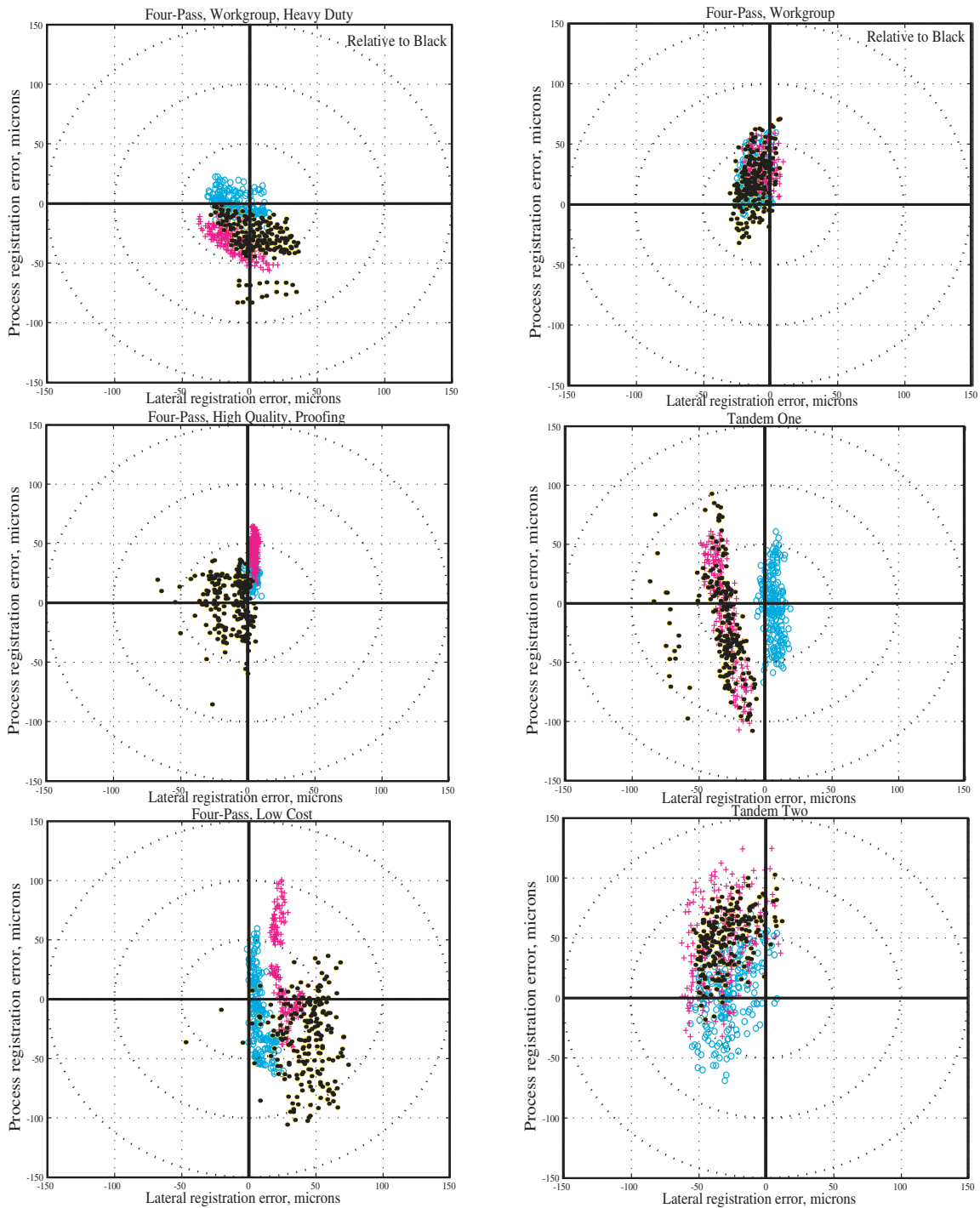


Figure 2. Distribution of process and lateral direction mis-registration for six different printers. The cyan (circles), magenta (+), yellow (black-center asterisk) registration errors are relative to the black printer

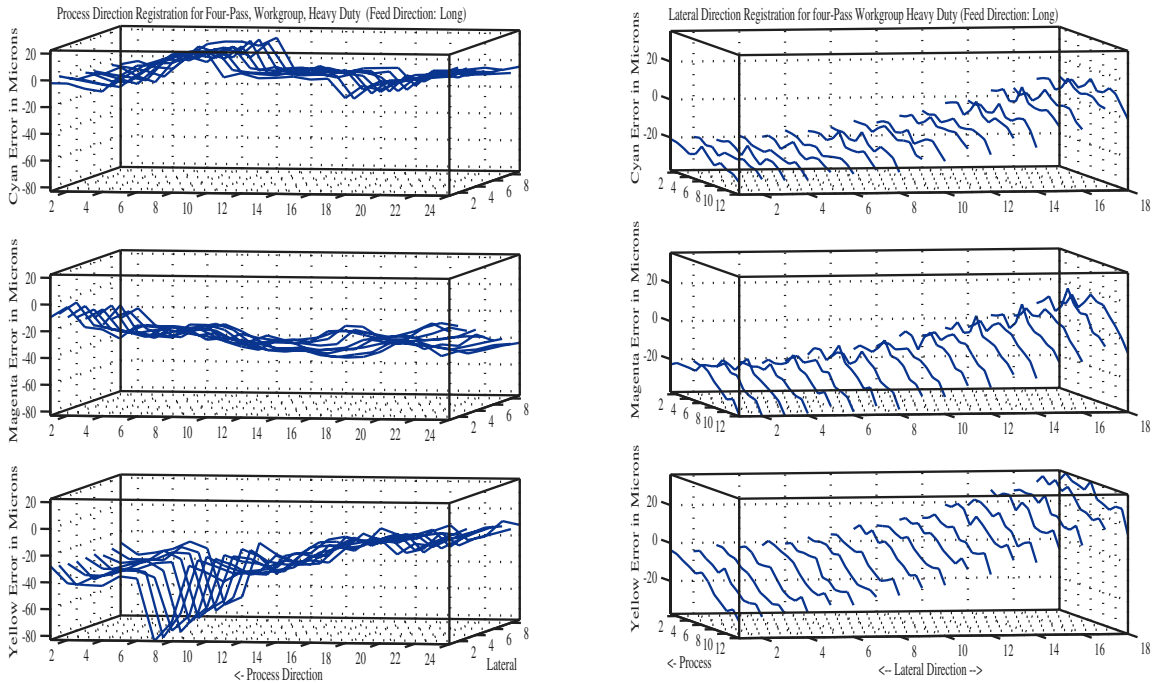


Figure 3. Process (left) and lateral (right) direction color registration page profile for a four-pass, workgroup, heavy duty color printer.

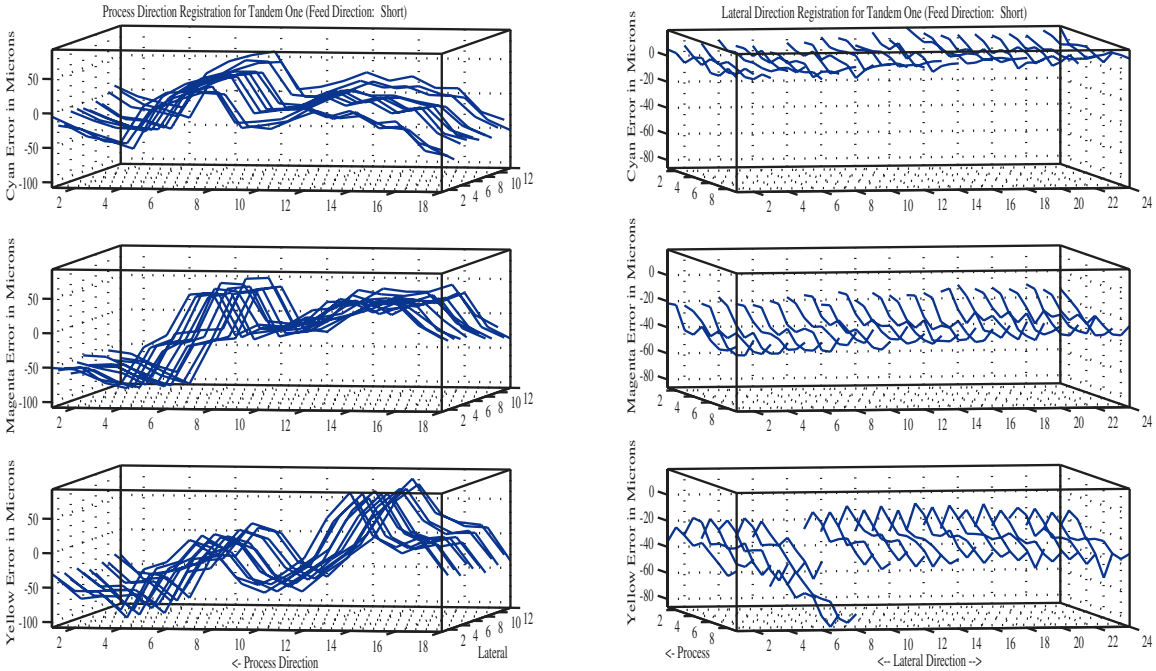


Figure 4. Process (left) and lateral (right) direction color registration page profile for a tandem color printer