Automated Print Quality Assessment of Inkjet Nozzle Plates

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Abstract

We developed a low-cost, highly-automated print quality tool to measure inkjet nozzle misdirection for quality control in the manufacturing process. To minimize cost and improve support, this system needed to utilize off-the-shelf hardware. In this paper we present an approach for measuring inkjet nozzle print misdirection from a reel of inkjet nozzles, prior to final assembly. We define this spatial misdirection as the distance between the ideal and actual printed locations of the nozzles under test. To pass inspection a given nozzle plate cannot have more than a certain number of nozzles that exceed a specified amount of misdirection (e.g., 40 microns). By reducing nozzle misdirection we can significantly improve print quality. We also measured additional print quality primitives, including dot area and print swath height expansion and contraction. This tool has allowed for further refinement in manufacturing processes, which has led to continual improvement in misdirection and other low-level primitives, as well as a further decrease in the nozzle misdirection tolerances used to determine whether a given nozzle plate passes or fails. This has led to reduced manufacturing costs, as an entire reel of nozzle plates can be rejected prior to final cartridge assembly if it is determined to be out of specification.

Introduction

The ability to verify nozzle plate reels after laser ablation is essential to improve print quality and provide process feedback. This can lead to significant cost savings by identifying defective reels prior to final assembly. Previous work has shown that plates with defective nozzles are directly correlated with reduced print quality and can produce images with significant banding artifacts [1, 2]. Our goal was to develop a low-cost, highly-automated tool to quantify low-level print quality primitives such as spatial misdirection, dot area, and swath height expansion and contraction. We also needed a system that could withstand the rigors of a manufacturing environment without the need for specialized training to operate. Therefore, we chose to develop our method using a high-resolution feed-to-flatbed scanner and other off-the-shelf hardware to reduce cost and improve ease of use.

Prior methods have typically used a camera-based system [3, 4], which generally tends to be slower and more expensive. A camera-based system can also be difficult to maintain and may require special training to operate and calibrate. The camera system can also require the captured images be stitched together, which is time-consuming and potentially error-prone. By using a scanner-based approach we were able to process an entire set of redundant nozzle patterns in just a single scan. Gage R&R (Repeatability and Reproducibility) studies were performed prior to adopting our system on the manufacturing line, in addition to making comparisons to an existing camera-based system. The scanner-based system allows us to collect more data per sample, as the 2-D camera system was limited to measuring only one to two droplets per nozzle (due to increased processing time). With the scanner we currently measure 12 to 24 droplets per nozzle depending on the target printed. The larger amount of data has helped to improve accuracy by eliminating problems associated with missing nozzles in a smaller set of droplet patterns.

System Setup

The system includes a printer, test target, scanner, and computer, as shown in Figure 1. Each measured nozzle plate is assembled into an inkjet cartridge, which is installed into the printer. Using this nozzle plate and cartridge, the printer produces a target containing multiple droplets from each nozzle in various patterns across the width of the page. Each pattern, while different, contains exactly one droplet from each nozzle. These prints are then loaded into an automatic belt-fed (ADF) scanner connected to a computer workstation. We chose to use an Epson 10000XL scanner because of its high optical resolution and feed-to-flatbed document feeder. The analysis is performed using an internally-developed library of region-of-interest-based (ROI) image processing routines. These routines allow the application to quickly perform common image processing operations such as connected-component analysis and edge detection, simplifying the analysis of the printed ink droplets.

Figure 1. *The system setup includes a printer, test target, feed-to-flatbed scanner, and computer workstation.*

Process

Print Target and Acquire Image

As mentioned above, the nozzle plates are assembled into cartridges, installed into the printer and the test targets printed. These are printed on glossy photo paper to obtain consistent results by minimizing ink spread and wicking [5]. The printed pattern contains redundant data which helps average out carrier motion artifacts as well as offering protection against occasionally missing inkjet drops. These patterns are enclosed by large fiducials to enable accurate ROI placement. The printed samples are loaded into the ADF and scanned at 2400 DPI. To improve performance, we designed the print sample patterns to minimize the total scanned area.

Image Analysis

Once the image is loaded into memory, the ROI-based image processing software is used to quickly locate our primary fiducial. We typically apply either connected-component ("blob") analysis or edge detection. Based on the location of this initial fiducial, we next read the sample identification (SID) code using custom optical character recognition (OCR). Figure 2 shows an example of the OCR ROI.

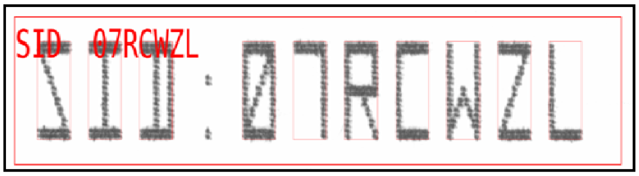

Figure 2. *Custom optical character recognition extracts the character string (red text in upper-left corner) from the scanned image.*

Once identified, this SID is added to the metadata associated with this sample. Other fiducials on the page determine the global skew of the page. This global skew results from scan-to-scan variation or deviation in the printer paper path. We can more accurately place subsequent ROIs by adjusting them for this global page skew. The drop centroids are also skew-corrected before comparison to an ideal grid. The ideal grid is created using a priori knowledge of the nozzle plate specifications and the nozzle pattern printed. Other researchers have employed a similar approach but chose not to remove this scan-to-scan variation [6].

To further reduce scan-to-scan variation, adaptive thresholding segments the ROI into distinct components or "blobs." Figure 3 shows a section of an annotated image. The edge detection ROI is used to locate fiducials for determining the global page skew, and blob detection is used for nozzle statistics. The individual nozzles are labeled with their respective nozzle numbers in Figure 3 to aid in debugging.

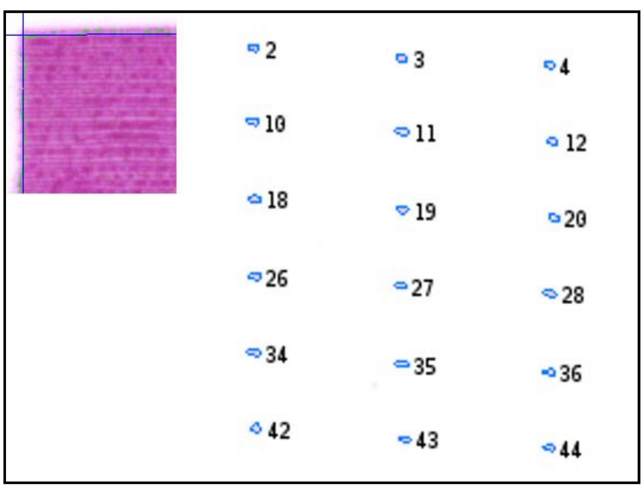

Figure 3. *Left: Locating the fiducial, using edge detection. Right: Partial results from connected-component analysis, with nozzle numbers added for debugging purposes.*

Similarly, each group of redundant nozzle patterns on the target is segmented. Once located, the centroids of the inkjet drops are skew-corrected to remove any global skew introduced by the scanner or printer. The blobs are then sorted into a grid (matrix) based on a priori knowledge about the nozzle pattern printed. For each group, we perform a least-squares regression to fit a line to each centroid in the column of nozzles and average the slope of the fitted lines. This gives us the local skew of the nozzle group, which is used to correct for any skew associated with inaccurate placement of the printhead in the carrier or misalignment of the nozzle plate during assembly [6]. Figure 4 shows a section of a scanned image, annotated with these best-fit lines overlaid on the columns of inkjet drops.

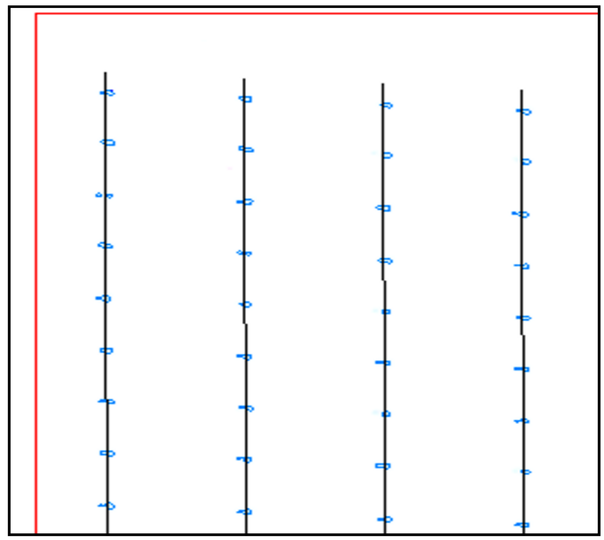

Figure 4. *A best-fit line identifies the local skew for each column of a given nozzle group (thin, nearly-vertical lines). The local skew for the nozzle group averages together the slopes of these lines. The blob centroids are corrected for this local skew before fitting them to an ideal grid.*

After correcting the nozzle centroids for local skew, we superimpose an ideal grid over the measured grid, aligned with respect to the upper left nozzle and look for missing nozzles in the measured pattern. We iterate the ideal grid in both x and y directions from $x = y = -2.0$ to $x = y = 2.0$ in steps of two pixels to obtain an initial correlation between the (skew-corrected) scanned image and the ideal dot pattern. This reduces the iterations required for a fine (sub-pixel) fit. We look to see if our best fit (in a least-squared error sense) occurs on a boundary, i.e., the best fit in either the x or y direction is equal to ± 2.0. If this is the case, we increase the size of our neighborhood by two pixels and re-compute the correlation. After determining this initial correlation, we then search in sub-pixel (e.g., quarter-pixel) increments and re-compute the correlation between the ideal dot pattern and the measured, skew-corrected centroids [7]. Finally, we calculate the physical displacement between each measured location and its corresponding ideal location, averaged across each particular nozzle. We also calculate the average area per droplet and the height of the printed swath, as well as the standard deviation.

Data Handling

We store the measured data and associated metadata in a database which allows access via web-based queries. From this web-based interface the user can view or download reports in various formats, as well as sort the data based on its metadata. Figure 5 shows an overview of the measurement process.

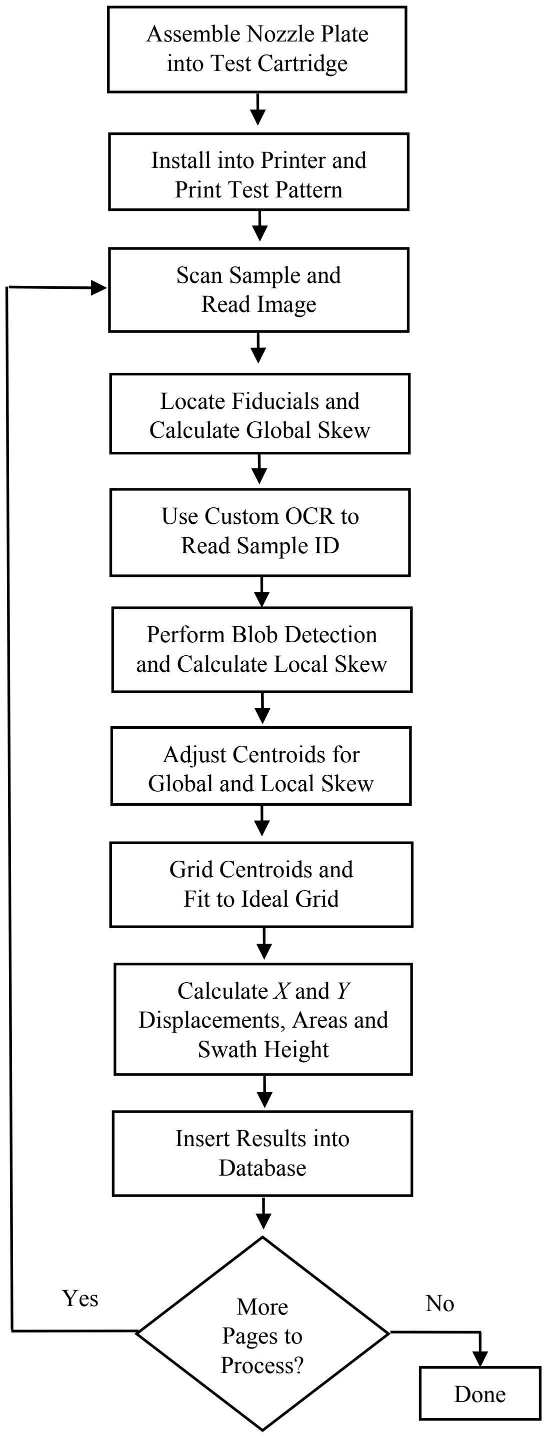

***Figure 5.** Flow chart for measuring inkjet nozzle print quality statistics.*

Results

The ability to view and save annotated results, either upon successful completion or when an error occurs, makes it easier for the technician to diagnose potential problems. Figure 6 shows a magnified portion of a processed image, featuring the detection of cyan inkjet drops. The contours of the drops ("blobs") are outlined in blue, with a portion of the ideal grid drawn with a green *O* and the skew-corrected centroid locations shown as a red *X*. This *X* should overlap the green grid if all the locations are perfectly aligned, as is the case for the upper left blob. In this image the other skew-corrected centroids are each shifted by one pixel.

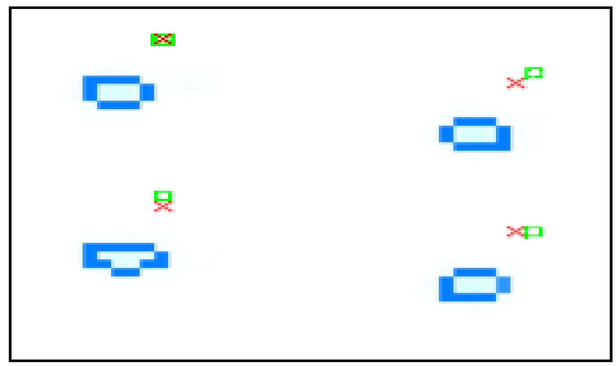

***Figure 6.** Processed image showing four cyan ink drops ("blobs"), along with the ideal grid coordinates (green 'O') and skew-corrected coordinates of the blob centroids (red 'X'). The blob contours are shown in blue.*

This automated inspection tool has enabled manufacturing improvements that have significantly reduced the spatial misdirection of manufactured inkjet nozzles. Specific improvements include better laser control (tighter clustering) and changes to the adhesive tape used to seal the nozzle plate after assembly (reduction in outliers). Figures 7 and 8 show scatter plots of processing results for a 'good' nozzle plate and 'bad' nozzle plate, respectively.

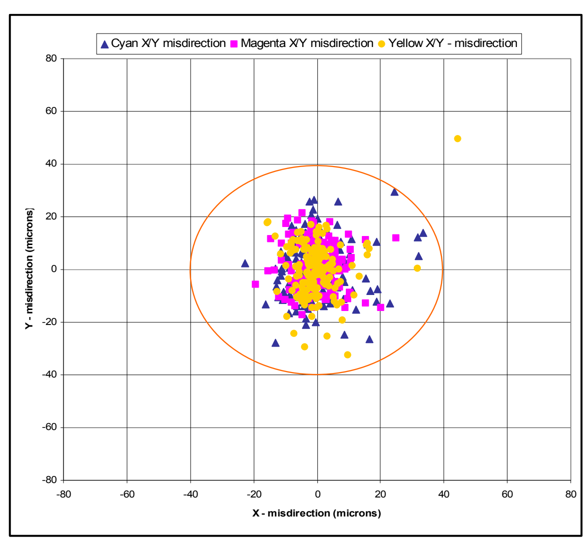

***Figure 7.** Scatter plot of desirable nozzle plate results for cyan, magenta and yellow planes.*

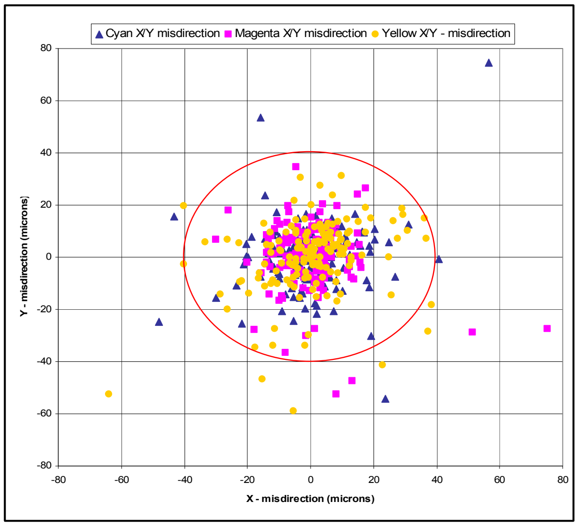

Figure 8. *Scatter plot of undesirable nozzle plate results for cyan, magenta and yellow. Notice the significantly increased spread as well as a greater number of outliers.*

Conclusions

This application demonstrates the practicality of using a conventional scanner to make accurate and repeatable measurements of inkjet droplets. This provides an important advantage in a manufacturing environment where an expensive 2-D camera system may be too sensitive or may require significant training to operate and maintain. Because the system components are commonly available and relatively inexpensive, we have more easily deployed multiple instances of such a system across various manufacturing sites. By tracking changes in manufacturing processes, this tool has enabled significant improvements in print quality. In addition, this system reduces manufacturing costs by eliminating substandard nozzle plate reels prior to final assembly.

References

[1] H. P. Le, "Progress and Trends in Ink-Jet Printing Technology", Journal of Imaging Science and Technology, Vol. 42, No. 1, (1998).
[2] http://www.imaging.org/resources/web_tutorials/inkjet_files/inkjet.cfm
[3] D. J. Forrest, J. C. Briggs, M. K. Tse, and S. H. Barss, "Print Quality Analysis as a QC Tool for Manufacturing Inkjet Print Heads", IS&Ts NIP 14, 1998 International Conference on Digital Printing Technologies, (1998).
[4] Y. Kipman, "A Non-Contact High-Speed Inspection System for Ink Jet Print Head Nozzles", IS&Ts NIP 15, 1999 International Conference on Digital Printing Technologies, 217-219, (1999).
[5] M. Klino, "Automated Inkjet Print-head Quality Analysis", IS&Ts NIP 16, 2000 International Conference on Digital Printing Technologies, 400-402, (2000).
[6] D. C. Aultman, R. Dumas, and T. Salomon, "Automating Jet Quality Analysis Using a Scanner-Based System", IS&Ts NIP 20, 2004 International Conference on Digital Printing Technologies, 378-382, (2004).
[7] Y. Kipman and K. Johnson, "Dot Placement Analysis Using a Line Scan Camera and Rigid Body Rotation", IS&Ts 2001 PICS Conference Proceedings, 68-71, (2001).

Author Biography

Edward Rippetoe received his BS in Electrical Engineering from the University of Kentucky in 2004. Since then he has worked in color science and image quality at Lexmark International, Inc. His work has focused on automated print quality analysis algorithms and tools for use with inkjet and electrophotographic printing. His research interests include image processing and segmentation.