Automating Jet Quality Analysis Using a Scanner-Based System

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Abstract

Evaluation of jet performance and jet failure analysis is an ongoing and critical task during the product development phase of all inkjet systems.

While jet quality is often assessed via visual inspection, these inspections return results that are subjective and difficult to quantify.

During the development of a wide format inkjet printer aimed at the print shop market, jet quality analysis was being analyzed by a completely visual, laborious, and time-consuming process that resulted in failure counts and a rudimentary categorization of failure modes.

The decision to move from subjective assessment to the use of an automated alternative was motivated by a desire to track the performance of a wider variety of jet quality measures on continuous quality scales rather than with the current manual process that only yields attribute classification and pass/fail counts.

A scanner-based image quality system was identified based on proven prior experience and an open architecture that allowed for measurement method customization. The application was developed, tested, and put to use measuring not only the jet quality attributes that had been evaluated via visual assessment, but it also broadened the scope of the analytical process to include attributes and variables that were of great interest that could not be tracked using the previous process.

This paper details the use of a commercially available scanner-based image quality measurement system in the automation of jet quality analysis. Application details and the results from system verification and qualification will be presented.

Introduction

Nozzle failure data was traditionally evaluated by counting individual nozzle failures while printing images. Unfortunately, the distributions of this type of data are binomial and Poisson, and they typically require large numbers of failures to produce reasonably small confidence intervals. Continuous variables (those that can actually be measured) are always more desirable for testing, especially if DOEs are being considered.

Eastman Kodak Company personnel working on this project had previous experience with a low-cost, scanner-based image quality measurement system called ImageXaminer,[1] created by ImageXpert Inc. (IX), which could be used to provide numerous metrics for evaluating inkjet print performance. If this measurement system could be shown to provide highly repeatable metrics, small nozzle performance changes could be reliably detected without requiring a nozzle failure to occur. Using the system would allow DOEs to be designed to quickly determine key process parameters that impact print performance, based on quantitative data and by using smaller sample sizes. It was also hoped that the use of this system would reduce the support necessary to conduct tests, when compared to the time and effort required to get test results using traditional evaluation methods.

The project required a thorough assessment of the measurement system to determine its suitability for use in this project.

In order to evaluate the system, a set of printed samples were provided to the vendor for initial set-up and testing, and the data was assessed in-house for repeatability using the methods of a Gage R&R (Repeatability and Reproducibility) Study.

The four metrics to be assessed for each jet included:

- Line width
- Line roughness (top and bottom)
- Number of segments
- Dot placement (X–Y)

Jet patterns for cyan, magenta, yellow, and black were included in the test samples, and data was reported for all of them. However, only the data from the magenta patterns were used in this study.

Jet Quality Test Target

Jet quality is often assessed using stepped-ladder charts printed by one jet that is fired for a period of time in a manner that isolates it spatially from other jets. In order to make a pattern that has the most efficient use of space, several jets are fired in the same column of the ladder pattern leaving sufficient space between jets to enable visual assessment and/or automated measurement.

Jet tests are performed for each colorant and can be used to assess the print quality impact of a variety of system-level variables such as voltage, printhead-to-paper spacing, and nozzle geometry.

Figure 1 shows a portion of a typical jet test pattern.

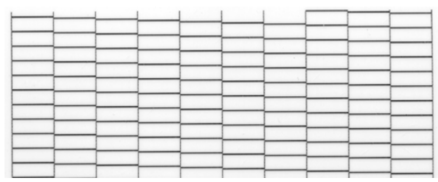

Figure 1. Example of jet test ladder pattern

The jet pattern provides information about jet integrity but does not provide complete information about relative jet position. For the analysis of our print engines, we included several other pattern features to allow for a more complete assessment of jet quality. Along with the typical jet ladder target, we also included a dot pattern for dot placement analysis and 1-on-1-off patterns for Y-location measurement for banding (although the banding analysis is not covered in this paper).

Figure 2 shows a portion of the target used in this analysis and identifies regions used in each specific measurement type.

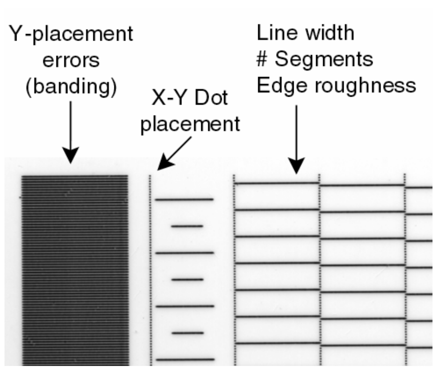

Figure 2. Test target with identified measurement regions

Measurement System

The ImageXaminer system uses an Epson 1640XL flatbed scanner with an optical resolution of 1600dpi for image capture. A document feeder enables full automation of jet analysis by allowing an operator to put a stack of printouts in the document feeder and to run the analysis automatically without the need to intervene for sample handling or test actuation.

IX software runs the scanner automatically and performs the image quality analysis and data reporting. Data is reported in tab-delimited text files for maximum portability.

At full resolution (1600dpi, 15.8 μm per pixel), the scanner provides adequate detail for comparative analysis of the attributes that were of interest for this product. Using the scanner, a large area can be imaged and measured at high resolution within a time frame that was comparable to visual analysis while providing more detailed and useful information to development engineers. Images were scanned in color to maximize the contrast of each colorant and to improve the quality of the analysis.

In order to perform the required analysis on the samples, a method was employed within the software to accommodate for sample position difference (all samples were hand cut) and to allow for individual jet quality analysis for all metrics of interest with the most efficient approach possible. The method is called a "moving ROI" where a small region of interest (ROI) is moved over each location where a jet should be located. The presence or absence of the jet is determined, and a jet that is present is measured for all of the attributes required. For this study, these attributes included line width, line roughness, and segmentation. When everything is correctly aligned this is a straightforward process. The addition of translation and skew require the software to identify the position of the pattern and to accommodate for the offset and skew by dynamically changing the locations for the ROI to align the locations with the actual jet positions on a particular sample.

Measurements

Line Width

Some skew is inherent in the sample preparation and in sample placement, therefore, a line width measurement method that minimizes the impact of skew on width results was chosen for this application.

Edge points were identified via a scanning direction (top to bottom or bottom to top), a polarity (light to dark), and a gradient. Once the edge points were identified, a best-fit line was calculated per edge using a least squares fit. The normal distance from the center point of the best-fit line for one of the edges to the best-fit line through the other edge was reported as the line width.

Figure 3 shows this method schematically.

This method also has a low sensitivity to noise near the edges and segmented lines.

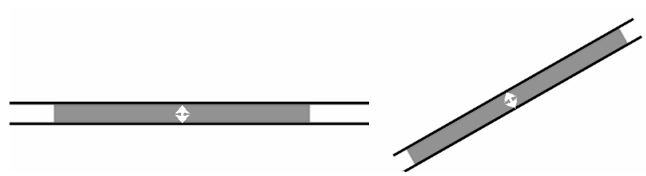

Figure 3. Line width measurement

Line Roughness

Line roughness was measured separately for each edge using a metric called mean deviation. Once the edge points are identified and a best-fit line is calculated, the mean of the distances from the edge points to the best-fit line is reported as a measure of roughness. Figure 4 shows a conceptual drawing of the distances between edge points and a best-fit line.

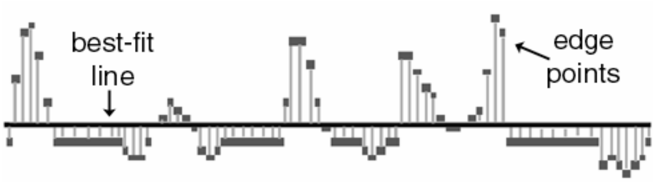

Figure 4. Mean deviation calculation for line roughness

Top and bottom line roughness values were almost perfectly correlated (Pearson Correlation Coefficient = +0.99), so top and bottom mean deviations were averaged for each nozzle and treated as a single response: mean line roughness.

Number of Segments

A perfect inkjet line with no discernible breakage has a segment count of 1. If the printed line is broken up, the number of segments for the line increases and the number of segments can be used as a quality indicator. The target requires 75 firings from each jet; therefore, counts can range from 0 (indicating a nozzle out) to 75 or more (individual dots plus satellites or other image noise).

Figure 5 shows two lines: one with no breakage and one with considerable breakage (segmentation).

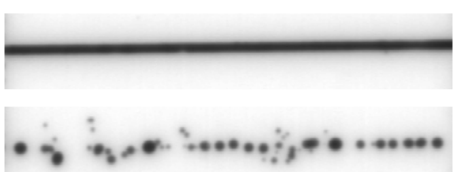

Figure 5. The top line shows no segmentation, while the bottom line shows a significant amount of segmentation.

The software identifies segments by looking at the number of parts that fall within a specific size range, polarity (dark on light), and threshold value. A diagram illustrating the concept of segmentation identification within the broken line from Figure 5 is shown in Figure 6.

Notice how some adjacent dots could be counted as individual segments, or they can be counted as a single segment depending on the software settings, particularly threshold.

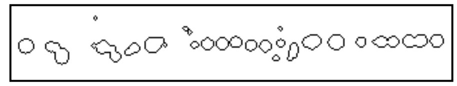

Figure 6. Outline of line segments identified using threshold and size range. Small particles could be included or excluded in the count as desired.

Threshold

A threshold value calculation was used to automate the collection of quantitative data without the subjective interference of the on-the-fly threshold setting.

To decrease the effect of noise, the threshold was automatically calculated by measuring 85% of the average of the dark and light modes in the histogram, as shown in Figure 7 and Eq. 1.

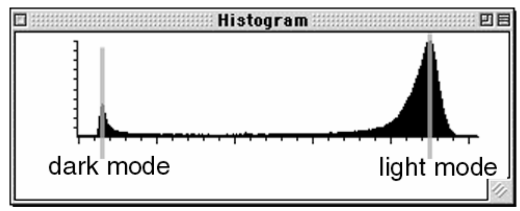

Figure 7. Threshold setting using histogram analysis

$$\text{Threshold} = 0.85*((\text{light mode} + \text{dark mode})/2) \qquad (1)$$

This threshold value was automatically applied for all of the threshold-dependent measurements including line segmentation and dot position.

Dot Placement

Dot placement was measured by identifying each dot using a threshold value (as discussed in the previous section), a polarity (dark on light), and a size range limited to exclude image noise and satellites. Once each dot was located, the geometric center was calculated, and X and Y coordinates were reported. The scanning sampling rate was sufficient to preserve dot-to-dot differentiation spatially, allowing for enough pixels per dot to enable an adequate calculation of centroid location.

Figure 8. Dots for dot placement analysis

Raw dot positions are reported relative to the image buffer, so a skew correction would need to be put in place to accommodate for sample-cropping errors and the minimal amount of skew induced by the document feeder.

Measurement System Repeatability

Six sample targets were sent to IX, with a request to read the entire series four times. We specifically requested that the samples be reordered randomly and re-fed through the document feeder for each of the trials.

Line Width

We elected to use the mean line width (taking the average for all of the line widths for each nozzle row) in each sample.

In the samples provided to IX, there were some jets that were clearly outside of the expected operating range. We opted to keep those data in the samples to see how IX would handle the extreme data. With well over one hundred line widths in each average, the leverage exerted by individual dots tended to be minimal.

For the R&R study, all that was important was the repeatability when the same target and nozzle row were read multiple times. The repeatability was excellent. After correcting for any variation as a result of the samples and nozzle row differences within each sample, only 0.3% of the total variation came from the basic repeatability of ImageXaminer.

Line Roughness

Top and bottom edge roughness were almost perfectly correlated (+0.99), therefore, the two values were averaged for each nozzle, and the mean edge roughness was used as a single response for each line.

In order to assess measurement system repeatability, line roughness means were averaged for lines printed by all of the nozzles and considered as a single measure for the nozzle row.

Analysis was performed on data from all of the nozzles as well as from a reduced data set where data collected from clearly errant jets were excluded.

The analysis showed that only 0.8% of total variation comes from ImageXaminer. For the reduced data set 7.6% of total variation comes from ImageXaminer. This increase in percentage makes sense because the range of values was reduced.

Although it is too early to predict the usefulness of this particular metric, it looks like it will be better suited to detecting major excursions, rather than subtle shifts in mean levels.

Number of Segments

Targets provided to IX contained a variety of printed lines at differing levels of quality. The goal of this portion of the study was to assess the ability of the ImageXaminer system to count segments in a repeatable fashion. To accomplish this, line counts were summarized for all nozzles and considered as a single measure for the nozzle row. If all nozzles fired properly, the count would be equal to the number of nozzles. If any nozzles produced segmented lines, their counts would be greater than 1 and the nozzle row count would therefore be greater than the number of nozzles.

With all of the nozzles included in the analysis, the R&R analysis shows that the number segments is a repeatable metric. The percent of the total measurement variation, which is due to the ImageXaminer repeatability, was just 0.04%.

When the analysis was repeated with a limited data set, with the clearly errant nozzles excluded, the variation caused by the measurement system was 0.1%, which, again is expected, given the range of the reduced input data.

It was determined that the number of segments can be useful in evaluating printhead performance and may be especially powerful when simultaneously evaluated with other metrics, such as line width and dot position.

Dot Placement

The final metric to be considered in this repeatability study is dot placement (X–Y). This is the metric with which we were most concerned.

Dot positions are reported relative to the image buffer, so any sample translation and skew will be reflected in the raw data. Figure 9 shows two different dot position graphs. The overall skew of the sample is reflected in the skew of the data on the graph.

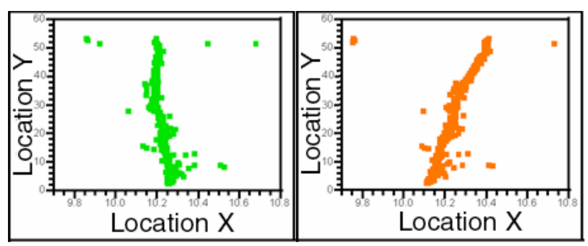

Figure 9. Dot positions for two samples differing primarily by amount of skew induced by cropping. Direction and magnitude of skew is evident in plotted results.

After the initial position results were analyzed, it became clear that X locations were more sensitive to variation than Y locations. The amount of the total variation for X locations that was due to the measurement system was 2.9%, while the amount of variation created by the ImageXaminer system for the Y location measurements was only 0.1%.

Targets were fed to the ImageXaminer system scanner via an automatic document feeder. From a production standpoint, this automatic feeding feature has many advantages. In order for dot position measurements to be repeatable in µm, the positioning of the target on the platen must be consistent. This analysis characterized how well this positioning occurred and predicted what the measurement repeatability might have been if scan-to-scan positioning differences were minimized.

In the plot shown in Figure 10, X location data is plotted on the vertical axis for each individual nozzle, with all four replicates overlaid. Think of it as the printed line lying on its side. There is no doubt that the scanner is looking at the same printed line of dots each time. The plots differ only in offset. If standard deviation were calculated using these data, it would appear greatly inflated from the system capability, if the effect of offset were corrected. For this particular sample, the standard deviation for location would be reported to be 18.2 µm.

In Figure 11, the run average was subtracted from each individual X location within that run to make all runs vary around an average value of zero. This plot more accurately represents how repeatable the measurement system would be if run-to-run sample positioning offset were negligible. With this correction, the standard deviation for X-location would be 4.4 µm.

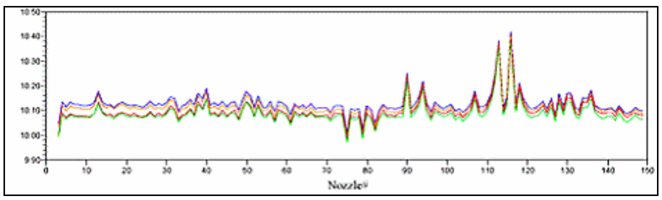

Figure 10. Offset in X position between four runs

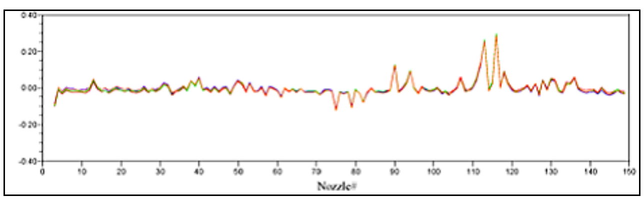

Figure 11. Offset corrected: residual X position error negligible

Clearly, a next step could be to automatically subtract the impact of scan-to-scan variation - perhaps by reporting centroid locations relative to a fiducial and accommodating for sample skew, both being certainly possible for this system.

Alternatively, a different method could be performed using the same data. A best-fit line could be calculated through each of the dot centroids. The X component of the distances from each centroid to the best-fit line could be determined. If the standard deviation of those distances for each sample and each run were computed, it could be treated as a univariate response representing the "goodness" of the line of dots. Individual dots that are excessively out of position might still influence the standard deviation calculation, but the leverage of a few dots would be limited because of the larger, total number of dots. If a line of dots is nearly perfect, the standard deviation of the X distances with reference to the best-fit line will be small. Conversely, if the line of dots is particularly poor, the standard deviation should increase. The advantage of this method is that it is not dependent on absolutely precise positioning of the sample.

Conclusion

The scanner-based image quality measurement system was determined to be well suited for use in the jet quality testing for our product. The results of this analysis led to a decision to purchase the equipment.

Once the system was integrated into the workflow, the sample-to-sample processing time is about the same as with visual assessment, but now we have continuous responses rather than count data. Therefore, instead of classifying a nozzle's performance as simply "good" or "bad,", we have variable data that produce continuous distributions for the significant quality features discussed in this paper: line width, line roughness, segmentation, and dot position. With continuous variables rather than class variables, sample sizes can be greatly reduced while simultaneously increasing the information gleaned from an experiment. For example, it might have required 20–40 print samples per experimental treatment using simple visual count data to know, with confidence, the proportion of nozzles that were failing for each failure classification. With continuous measures of nozzle performance (using ImageXaminer) in the same experiment, a single test print could reveal the distribution of line widths, dot placement, and line roughness for every nozzle in the printhead. Therefore data from a single test print using continuous, objective measures results in more informative data than the simple classification and count data that was achieved visually from 20–40 test prints.

References

1. Yair Kipman, Sam Reele and Randy Dumas, Image Quality Testing on the Production Line, *Proc. PICS*, pg. 114–116 (2000).

Biography

Dana Aultman is a technical associate at Eastman Kodak Company where he has worked for 26 years. He holds a BS degree in Electrical Engineering and an MS in Math and Applied Statistics from Rochester Institute of Technology, as well as an MS degree in Biological Sciences from SUNY College at Brockport. He specializes in design and analysis of experiments for product and process development, with a keen interest in metrology issues.