Print Quality Analysis as a QC Tool for Manufacturing Inkjet Print Heads

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Abstract

In research and development of inkjet print heads, characterizing ink drops in flight is often done using high-speed video and image analysis techniques. However, such characterization techniques have limited use in production quality control because of limitations in measurement accuracy, reproducibility and speed. Furthermore, the techniques offer no opportunity to observe the interaction of ink and media, well recognized as a determining factor in inkjet print quality. A more practical alternative for inkjet head quality control is to examine print quality using a well-designed test pattern printed on selected media. Print quality measurements typically quantify the accuracy of dot placement, the relative positions of dots projected from multiple nozzles, and dot size and shape. Also quantified are the absence of dots and the presence of satellites, indicators of faulty jetting. If implemented properly, the print quality methodology described can yield critical information not only for final product acceptance, but also for process control and continuous product improvement. Discussed here are the general design requirements for this type of test system, a design methodology for the test targets, data reduction and analysis methods, and system calibration issues. Performance results from a commercial system are also critically examined.

Introduction

The first step in the design of a quality control (QC) system for inkjet print head manufacturing is a clear statement of the requirements. Obviously, at the end of the production line a final inspection must be performed to identify reject print heads. But a useful QC tool must provide much more information: What is wrong with the rejected print head? How should the production process be adjusted to increase yield? How does a given process variable affect quality? In other words, the QC tool must provide useful feedback to the production process.

In this paper, an automated print quality analysis system for QC in inkjet print head manufacturing is discussed. In using the approach described here, the print head being evaluated is used to print a carefully designed test pattern. Measurements on the test pattern are used to determine the critical characteristics of the print head, and to provide diagnostics for adjustments to the production process.

Print Head Characterization

What are the critical characteristics of the print head? The print head, of course, contains many discrete pumping chambers and nozzles, hereinafter referred to as jets. Although there are many technologies and designs for ink jets, they all share the same fundamental requirement: to deliver single drops of ink (i.e. with no satellite drops) of prescribed volume to prescribed locations on the print medium[1]. This fundamental requirement corresponds to two fundamental print quality metrics for each jet: dot size and dot location. Each jet must also be able to re-arm for consistent delivery of drops in rapid succession. This characteristic can be quantified by examining the edge quality of a line printed from a single jet. Finally, the jets must be uniformly arranged in the print head so that images formed from multiple jets do not exhibit geometric distortions and solid fills can be printed without objectionable variations in optical density. The spacing requirement is made especially complicated when jets from multiple print heads or multiple passes are interlaced. Jet

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spacing can be evaluated by measuring the relative locations of lines printed from single jets.

In research and development, drops in flight are commonly viewed using high speed video and stroboscopic, techniques[2-3]. These methods reveal important information about drop formation, size, velocity, and other jetting behavior. However, they are not optimal for production QC.

As ink jet print technologies have continued to develop rapidly, significant advances have been made in ink jet print quality (PQ) analysis techniques for quantifying overall print quality[4-6]. For effective print head QC, however, PQ analyses must be optimized to address the PQ characteristics that specifically relate to the print head (not the paper, ink, ripping, screening, etc…) and to provide useful feedback to the production process.

General Design Requirements of a QC Tool Which Uses Print Quality Analysis

Consumables: Ink and Print Medium

In order to perform print quality analysis, test targets must be printed. This requires both ink and a print medium. The most important requirement in the selection of these materials is uniformity. In the QC system described here, we assume that all variables are fixed except the print head, so that any variation in print quality can be attributed to the print head. If print head quality is stable, but ink viscosity is different from week to week, the line width measurements will change and create the false impression that the print heads are the cause. Similarly, the characteristics of the print medium which affect print quality must be uniform and stable. The print medium must also be dimensionally stable so that variations in line position measurements can be properly attributed to nozzle placement and/or straightness. Finally, the print quality measurements obtained from the selected consumables should be correlated with the print quality obtained with combinations of consumables typically used with the same type of print head in actual practice, so that reasonable acceptance limits can be established.

Printing Device

As a QC tool in production, the printing device used to generate the required test targets must allow for fast and easy changing of print heads. The most important requirement of the printing device is that it have high precision and repeatability, so that variations in print quality can be properly attributed to the print head and not to the printing device. One way to achieve this is to hold the print head stationary while moving the medium in one axis. To eliminate print quality artifacts from the printing device, the velocity of the medium must be constant and the direction of motion must be linear. With proper software control, any combination of jets in the print head can be fired as the medium moves past to produce the required test targets. For example, to print a solid fill, all the jets are simultaneously fired. To print a single pixel width line, an individual jet is fired.

Print Quality Analysis System

Hardware Architecture

Typical hardware for print quality analysis is illustrated in Figure 1[7]. Critically important requirements of the system are accuracy and repeatability of both spatial and optical reflectance measurements, which in turn define many of the specifications for the various hardware subsystems described below.

But accuracy and repeatability are not the only requirements of the PQ analysis system. Flexibility (the ability to measure various test targets, adapt to new test targets, correct for misregistered samples, etc…), ease-of-use, and automation are equally important. Finally, throughput of the system defines its utility as a productivity tool; the system must keep pace with the production of print heads and provide timely feedback so that processes can be corrected with minimum loss.

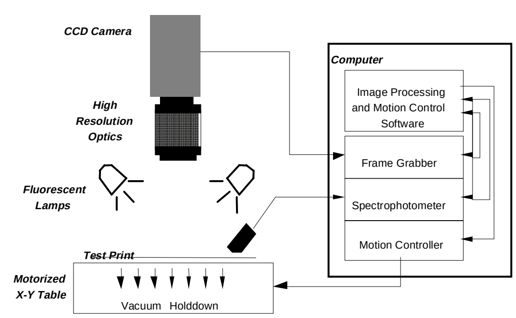

Figure 1. Print Quality Analysis System Hardware Architecture

Image Capture and Digitization

The test target is imaged using either a scanner or a 2-dimensional CCD (charge coupled device) camera with a frame grabber. The primary benefits of scanners are their low cost and their ability to image large areas (e.g., a full A4 page) in a single pass. Scanners are well suited to measuring low spatial frequency print quality characteristics such as print skew and density uniformity. However, scanners are not as well suited to making measurements of fine features, such as small dots and fine width lines. For ink jet head QC, where the width and position of jets must be determined with high precision, 2-D CCD cameras are generally preferred. This choice also facilitates easy changes of magnification using adjustable or interchangeable optics (lenses).

Specifications of the camera relate directly to the accuracy and repeatability of results from the PQ analysis system.

Illumination Source and Diffuse Lighting Environment

Lighting must be consistent over time and uniform across the camera's field of view. If it is not, measurements of certain attributes (e.g., optical density) will not be accurate. Also important is a light-tight measurement enclosure, which eliminates several sources of measurement error including ambient light and shadows cast by the equipment operator.

Motion Control

A limitation of high resolution imaging (e.g. 5–10 µm per pixel, or 5080–2540 dpi) using affordable CCD cameras and frame grabbers is that only a small field can be imaged in a single frame (e.g. 25 mm^2). Since a typical test target may be much larger than this small field, the system must have an x-y motion stage to move the test target relative to the camera in two axes. The motion stage must be flat, fast, and accurate. The accuracy of the motion stage and the spatial resolution of the image define the accuracy of absolute position measurements of features on the test target. This requirement can be relaxed if a test target is designed in which only relative positions of features in a single frame need to be measured. However, for ink jet head QC, the most straightforward approach requires absolute jet position measurements.

Media Handling

A method is required for holding the test sample flat on the x-y table so that the lighting is consistent and the sample is in focus. Although glass plates are commonly used to hold down samples, they are a potential source of error: the glass plate makes contact with the sample, it is easily contaminated, and the sample is viewed through it. The best option appears to be a vacuum system, which provides uniform hold-down over the test print surface.

Image Acquisition, Display and Processing Functions

Basic functions include image capture, image display, histogram computation, profile computation, and contour extraction. These functions are necessary for any automated image analysis system, but for systems dedicated to print quality analysis specifically, additional functions are also needed[8], as listed in Table 1.

Data Reduction, Display, and Storage

An automated computerized PQ analysis system is capable of generating overwhelming quantities of data from a single print target. It is therefore essential to incorporate effective data reduction algorithms to reduce the information to simple indicators and useful statistics. In the system discussed here, data logging facilitates tracking processes over time.

System Performance

There are many issues related to system performance, including calibration, programmability, throughput, accuracy, and repeatability. The system must include methods for easy and reliable calibrations to traceable standards. For maximum utility, it must be easy to program the system to measure new and different print targets. The throughput requirement depends on the specific production line, but generally the system must keep pace with the production line while providing timely feedback for process adjustments. Finally, accuracy and repeatability must be consistent with the print quality goals for the print head.

Table 1. Print Quality Analysis Metrics

Image Element	Quality Attributes
Dot	Dot location Dot gain Dot shape Edge raggedness Satellites
Line	Line location Line width Edge sharpness Edge raggedness Optical density Resolution
Solid Area	Optical density Color (chroma, hue) Noise (graininess, mottle) Gloss

Test Target Design

A well-designed test target is key to successful implementation of the print quality analysis QC system. The critical characteristics of the print head are the position and size of the drops printed from each jet. For acceptable print quality, the drops from all jets must be uniform in size and uniformly spaced. Otherwise, a solid print area will not be uniform in density. Furthermore, the drops from each jet must be of the proper size – large enough so that adjacent lines overlap to produce a complete solid fill, but not so large as to degrade resolution.

Based on these requirements, one might consider a test target consisting of a single solid fill area. Many print head defects will manifest as non-uniformity across a solid fill. The print quality analysis performed on such an area could be very fast and simple, consisting of a single image profile measurement across the solid area. There are many limitations to this technique, however. First, the sensitivity of the measurement to a problem involving a single jet is very poor. For a high resolution print head (i.e. one with close jet spacing), a single missing jet in a solid fill area may be difficult to detect, and slight variations in jet widths are virtually undetectable. The solid fill can also mask many problems. For example, if alternate nozzles are producing both wide and narrow lines, the solid fill may look fine, but text, half-tones or interlaced images produced with the same print head would be poor. The print head ought to be rejected, but the solid fill test would be unlikely to expose its defects. The most severe limitation of the solid fill test target is that it cannot reveal the source of failures. For example, a solid fill with a light streak through it may be due to a missing jet[9], a misdirected jet, a narrow jet, or a combination of problems in adjacent jets. From the solid fill area, there is no way to determine the source of the problem, and therefore no feedback can be provided to correct the production process. For these reasons, the solid fill print target is inadequate.

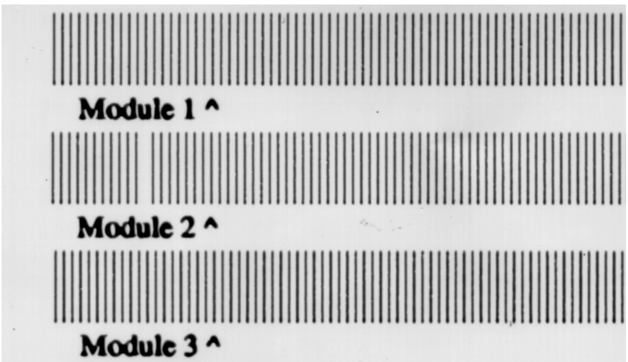

Figure 2. Small portion of a well-designed print head test target.

To overcome these limitations, a test target must be designed to provide measurements of the output of individual jets. A pattern of one pixel wide lines, each printed from a single jet, spaced so that each line is clearly resolved, satisfies the test target design requirements. The width and position of each line are the fundamental print quality metrics for each jet and can be measured directly. This results in a data set that not only detects defects, but also clearly indicates the source and nature of defects in the print head. In addition to revealing any problems with individual jets, this type of data can be processed to predict the print quality of solid areas based on the relative positions and widths of adjacent jets (after interlacing). This type of test target provides useful diagnostic feedback to the production process.

Application and Discussion

To demonstrate the diagnostic utility of this QC system, an inkjet print head with several defects was selected for testing. Figure 2 shows a small portion of the test target printed. This particular print head contains 12 modules; each module has 128 jets nominally spaced 1/50th of an inch (0.51 mm) apart. The 12 modules are offset from each other by 1/600th of an inch (0.042 mm) in the print head, so that the interlaced print head contains 1536 jets evenly spaced at 600 dpi (23.62 dots per mm).

Line position and width measurements were obtained from this test target for all 1536 jets using QEA's IAS-1000 Image Analysis System. In the interest of brevity, only the results from the first 240 jets (20 from each module) are presented here, as they include various examples of jet failure.

The first category of failure is missing jets. Among the first 240 jets, jets number 137 (module 2, jet 12) and 225 (module 9, jet 19) are missing. The former can be observed in Figure 2. It should be emphasized that the PQ analysis methods described here using the test target of individual lines yields a very high degree of confidence in identifying exactly which jets are present and which are missing.

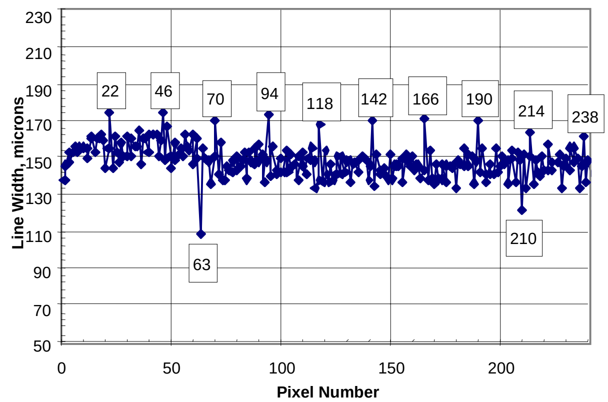

Figure 3. Line widths from first 240 jets with exceptional jets identified

Another failure category is faulty line widths. Figure 3 shows the line width measurements from the first 240 jets of the print head. The absolute acceptance limits for line width must be determined based on the specifications for any given print head, but it is clear from the figure that several jets deviate substantially from the mean width. In particular, jets 22, 46, 70, and so on at 24 jet increments are too wide. This corresponds to all the even numbered jets of module 3 (jets 2, 4, 6, …). In this particular print head, piezo-transducers are bonded to two opposed surfaces, each controlling alternate jets[10]. The data clearly indicate faulty assembly of module 3, providing valuable feedback to the production process.

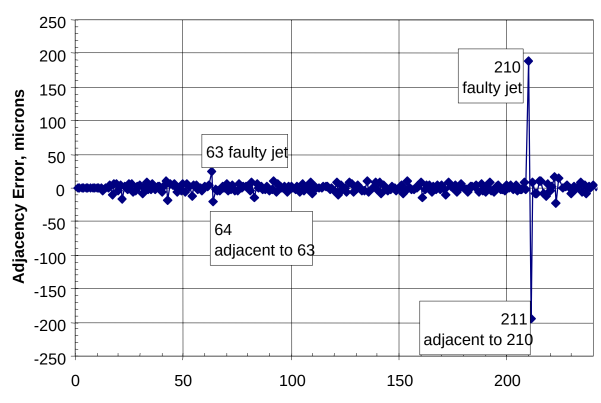

Figure 4. Adjacency errors from first 240 jets with exceptional jets identified.

Figure 3 also reveals several jets which are too narrow, particularly jet 63 (module 4, jet 6), and jet 210 (module 12, jet 18). Accurate measurement of the line widths and identification of the faulty jets is the essential first step to finding and correcting the source of the defects.

Adjacency errors are yet another failure category. Figure 4 shows adjacency errors, here defined as the difference between the actual spacing of adjacent jets and the ideal spacing, computed from the measurements on the first 240 jets of the test target. As with line width, absolute acceptance limits must be established according to the print head specifications, but again the data reveal several exceptional jets. Note that a single misdirected jet produces a pair of errors, since it is too close to one of its neighbors, and too distant from the other. Jets 63 (module 4, jet 6) and 64 (module 10, jet 6) exemplify one such pair. The fault in this case is clearly jet 63, which is misdirected and too narrow (see Figure 3). A similar, but much more severe defect is seen in jets 210 and 211. Once again, the faulty jet (210) is both misdirected and too narrow.

Conclusions

A quality control tool for manufacturing inkjet print heads using print quality analysis has been designed and its utility demonstrated. With careful selection of consumables, printing device, print quality analysis system, and test target, useful diagnostic information is obtained and used to adjust and improve the production process. An effective test target consists of a pattern of resolvable lines, one printed from each jet in the print head. Measurements on the target include the position and width of each line. The resulting data are used not only in making the pass/fail decision for the print head, but also for process control, revealing and pinpointing defects in individual jets, including missing jets and defects due to improper jet spacing.

References

1. Hue P. Le, "Progress and Trends in Ink-jet Printing Technology," *Journal of Imaging Science and Technology*, vol. 42 **No**. 1, pg 49. (1998).
2. Lars Palm and Johan Nilsson, "An Optical Method for Measuring Drop Flight Stability in a Continuous Ink Jet," *Journal of Imaging Science and Technology*, vol. 41 **No**. 1, 48-53. (1997).
3. Christian Rembe et. al., "Realcinematographic Visualization of Droplet Ejection in Thermal Ink Jets," *Journal of Imaging Science and Technology*, vol. 40 **No**. 5, 400-404. (1996).
4. Ludwik Buczynski, "Special Print Quality Problems of Ink Jet Printers," *IS&T's NIP 13*, 1997 International Conference on Digital Printing Technologies, 638 (1997).
5. Rodney Shaw, "Image Quality Considerations for Printing Digital Photographs," *IS&T's NIP 13*, 1997 International Conference on Digital Printing Technologies, 562 (1997).
6. Fredrik Nilsson and Björn Kruse, "Objective Quality Measures of Halftoned Images," *IS&T's NIP 13*, 1997 International Conference on Digital Printing Technologies, 566 (1997).
7. Ming-Kai Tse, David J. Forrest and John C. Briggs, "Automated Print Quality Analysis for Digital Printing Technologies," PPIC/JH '98: The Society of Electrophotography of Japan, Pan-Pacific Imaging Conference/Japan Hardcopy '98, July 15-17, 1998, Tokyo, Japan
8. Draft standard ISO/IEC DIS 13660, "Information Technology—Office equipment—Measurement of image quality attributes for hardcopy output—Binary monochrome text and graphic images." (1998).
9. Robert V. Lorenze and Daniel E. Kuhman, "Correlation of Misdirected Satellite Drops and Resultant Print Quality Defects with Nozzle Face Geometries in thermal Ink Jet Printheads," *IS&T's NIP 10*, 1994 International Congress on Advances in Non-Impact Printing Technologies, , vol. 39 **No**. 6, pg 49.489 (1995).
10. Edward R. Moynihan, "Recent Advances in Niche Printhead Technology," *IS&T's NIP 11*, 1995 International Conference on Advances in Non-Impact Printing, 350 (1995).

Biography

David Forrest is the Vice President of Engineering at QEA, Inc. Mr. Forrest received his B.S. in Mechanical Engineering from the University of Wisconsin in 1990, and his M.S. in Mechanical Engineering from MIT in 1992.