Active Alignment of Print Heads

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Abstract

This paper describes an automated approach to maintain the alignment of modular direct marking print heads. An inline full width array sensor monitors the print head alignment and drop position within a print head by capturing and analyzing test patterns written to an intermediate drum. Unique steps are taken in illumination and calibration to ensure the structured drum media does not degrade the alignment measurement. The image is processed to identify the position of each mark. Interpolation and statistical averaging increase the accuracy beyond the resolution of the linear array. Both digital manipulation of the image and physical movement of the heads are used to maintain alignment.

Introduction

Scalable modular print heads provide a way to increase the width and process speed of office and production printers. Multiple print heads are placed in series to increase print width, and along the print path to increase speed and resolution.

The modular head for the Xerox ColorQube is shown in figure 1. The print width is just approximately 3 inches. The design of the print head was optimized in part to achieve high jetting frequencies and small drop masses[1]. The head contains 220 jets each of cyan, magenta, yellow, and black arranged in a grid over the surface. Specifically, the jets are arranged staggered grid of 16 rows and 55 columns to give a spacing of 75 dpi per color.

Figure 2 shows four modular print heads to provide color printing at 50 pages per minute. The four individual heads are

Figure 1 – Modular Solid Ink Print head

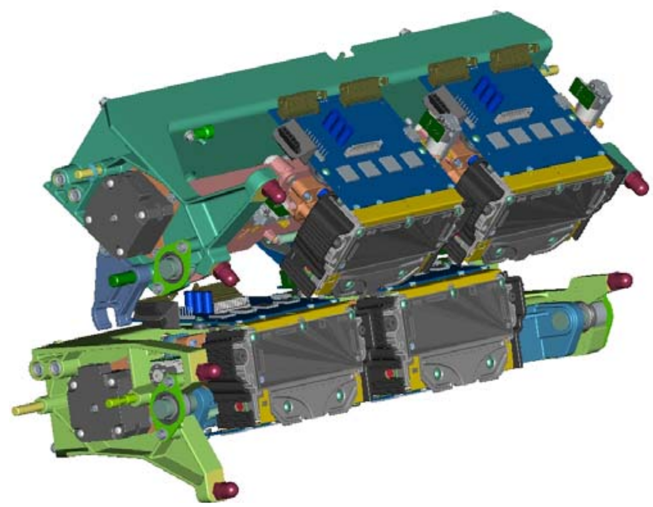

Figure 2 – Staggered array of Modular Print Heads.

arranged around an intermediate drum upon which an image is built in multiple passes of the drum. The heads are translated laterally after each pass to create a high resolution color image. After the image is formed on the drum, it is transferred to paper.

Challenges of Alignment

The heads must be aligned to an accuracy greater than the print resolution to maintain seamless images. Individual print heads are mounted in a module and there is typically some mechanism to adjust the head position to maintain alignment[2]. The ColorQube uses stepper motors to move the heads laterally. Throughout the life of the printer, the motor is continually adjusting the position of the head to ensure the spacing between the adjacent end jets on each head have the same spacing as the jet to jet spacing within a head.

Alignment in the process direction is also an important factor. The process direction alignment depends not only on the physical position of the heads, but also on the head to drum spacing and the flight time of the drop across the nip. Any change will result in an alignment error and a process direction shift in an image printed across print heads. Alignment of the heads in the process direction can be achieved by delaying the firing of drops between print heads. This delay results in a process direction translation of the drops ejected by that head.

Even within a print head the drop position many vary. Variations in the shape of the drop and how it ejects from the nozzle will affects its flight time and thus the position it will ultimately land on the paper compared to the drop's neighbors. This variation in drop position will result in ragged horizontal lines. The alignment of drops within a head can be performed digitally, by shifting each pixel column of the image for drops (essentially changing the time the drop is ejected) to cause land on the media at their desired position. Figure 3 shows a cartoon of a horizontal line before and after this correction.

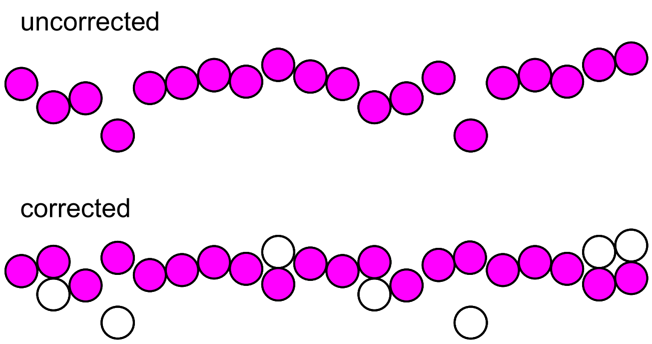

Figure 3 – Cartoon of line noise due to drop flight time variation and digital correction.

Ink on Drum Detector

Active alignment requires accurate sensing the location of the print head. One approach is to measure the hue of secondary colors[3]. If each primary color is printed from a different head, and the test pattern is designed so that the secondary color depends on alignment, then the alignment can be inferred from the color of the patch as measured with a spectrophotometer. Another approach is to print a registration mark and detect its position with a sensor using the reflectivity difference between the mark and the substrate. This is typically done with a point sensor and monitoring the marks as they pass under the sensor. The ColorQube measures printed marks. However, in order to simultaneously monitor all the print heads and jets in the printer, a linear array sensor or an Ink on Drum (IOD) detector is employed.

Figure 4 shows a cartoon of the IOD detector monitoring a test pattern on the drum. The detector is 8.5 inches in length and has a resolution of 600 dots per inch. The drum is approximately 12 inches wide. The IOD detector monitors the full width of the process by shuttling between both sides of the drum. The illumination source is a light pipe running across the length of the IOD and can be illuminated with any linear combination of red, green, and blue illumination.

A more common use of a linear array in printing is in an input scanner. For that application the media is illuminated at an angle

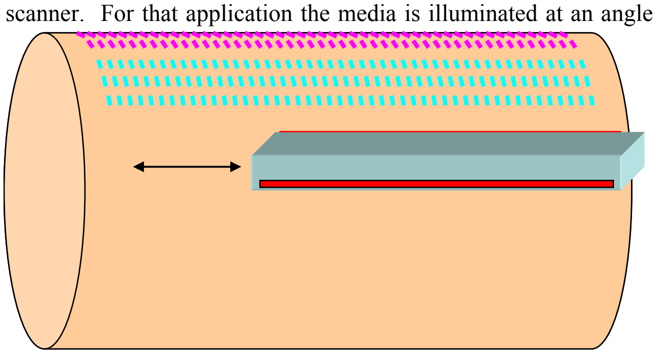

Figure 4 – Cartoon of IOD detector monitoring test pattern on intermediate drum.

to the paper and each sensing element is normal to the paper. Maximum reflection occurs from scattered light over bare areas. Ink on the paper decreases the diffuse reflection by absorbing the light.

However, the internal drum surface is optically smooth to facilitate rather than rough like a paper surface. If diffuse illumination was used, there would be almost no signal over bare areas of the drum. The response over inked areas would depend less on the mass of ink and more on the deposited drop geometry and front surface reflection. Therefore a different illumination strategy is required.

When the IOD is oriented specularly, so both the sensing element and illuminator are at an equal but opposite angle with respect to the normal, a mass dependent signal can be obtained [4]. The maximum signal occurs when the drum surface reflects light into the detectors. Any ink on the surface attenuates this reflection in a way that depends more on mass than drop geometry. The illumination color for any particular ink is chosen so that color ink mostly absorbs the light and appears “black”. For example, red illumination is chosen to monitor cyan and blue illumination is chosen to monitor yellow.

Capturing a test pattern is performed in the following way: First, the drum is slowed and an image of the bare drum is captured as one full revolution of the drum passes under the IOD. The captured image depends on the product of the gain of each sensing element and the local reflection from each area on the drum surface. A test pattern is then printed onto the drum but not transferred to paper at the nominal print speed. The drum is then slowed to the same velocity as calibration and another image is captured. The ratio of the two images removes the variation in the gain and offset of each sensing element and surface reflectivity variations due to drum structure. What is left is a map of the mass of ink on the surface. The reason the drum is slowed during image capture is to achieve the desired process direction resolution for a successful image analysis.

Test Patterns

Figure 5 shows a captured image of the head alignment test pattern. Each dash is printed from a different jet on the print head. The first three rows are printed from the even indexed jets and the next three rows are printed from the odd indexed jets. This staggering strategy leaves enough bare drum between dashes to accurately determine the center location of the dash. The image is written in a single pass or rotation of the drum. Different colors from the same head are printed on different sections of the drum.

Figure 6 shows a captured image of the test pattern for the drop alignment test pattern. Each jet writes a single drop each time the drum rotates under that nozzle. The print head is translated each pass, resulting in a series of short horizontal line. When the drops are aligned, the segments will be aligned in the lateral direction and equally spaced in the process direction. Three techniques are used to increase measurement accuracy. Comparisons are only made between nozzles that are closely spaced. Symmetric patterns are used to mitigate against drum velocity variations. The pattern is repeated many times so statistical averaging decreases noise.

The head alignment test pattern is printed and monitored regularly to maintain head alignment to maintain alignment throughout the life of the printer. The ink is removed from the drum by the drum maintenance unit and does not affect the printer productivity. The drop position test pattern is printed infrequently and ensures consistent drop alignment throughout the life of the product.

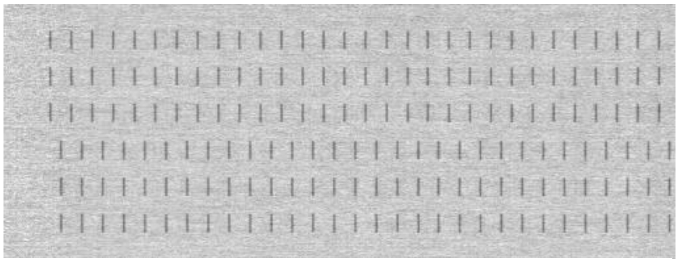

Figure 5 – Head alignment test pattern.

Test Pattern Analysis

The accuracy of alignment depends on determining the center of each dash. The pattern analysis starts with determining an illumination profile. An illumination profile results in an average reflectance as a function of lateral position, shown in figure 7. Each point in the profile corresponds to a response of an IOD pixel averaged from the top of the dash to the bottom of the dash.

For high measurement accuracy, the dash center must be detected at a higher resolution that the pixel spacing. There are two approaches to perform this analysis. In the first approach, the locus of local minimums along a dash profile is identified. A quadratic is fit to the local minimum and its two nearest neighbors. The minimum of the quadratic approximates the dash center. This fit is also illustrated in figure 7. In an alternative approach, the profile is convolved with an edge detecting kernel. The zero crossing of the convolved signal corresponds to the center of the dash.

The process direction position of each nozzle for the head alignment test pattern is determined by first finding a profile through the center of the three dash repeats. From this profile the top edge and the bottom edge of the dash can be identified.

The alignment of the heads at each interface is determined by inferring the head boundary. This inference is performed by fitting a line to a plot of the dash position (either in x or y) vs. dash index. This fit is performed for the last few jets for one head and the first few jets of the adjacent neighboring head. If the curves intersect at the head boundary then the heads are well aligned. The more these lines diverge, the more misaligned the heads are. By monitoring the test pattern regularly and adjusting the head position, alignment can be held over long time periods.

Results

We report here not the full control system capability but instead the accuracy of the IOD sensing. An experiment was performed where the spacing between two heads was intentionally changed and the spacing measured multiple times with the IOD detector. The results of this experiment are presented in figure 8.

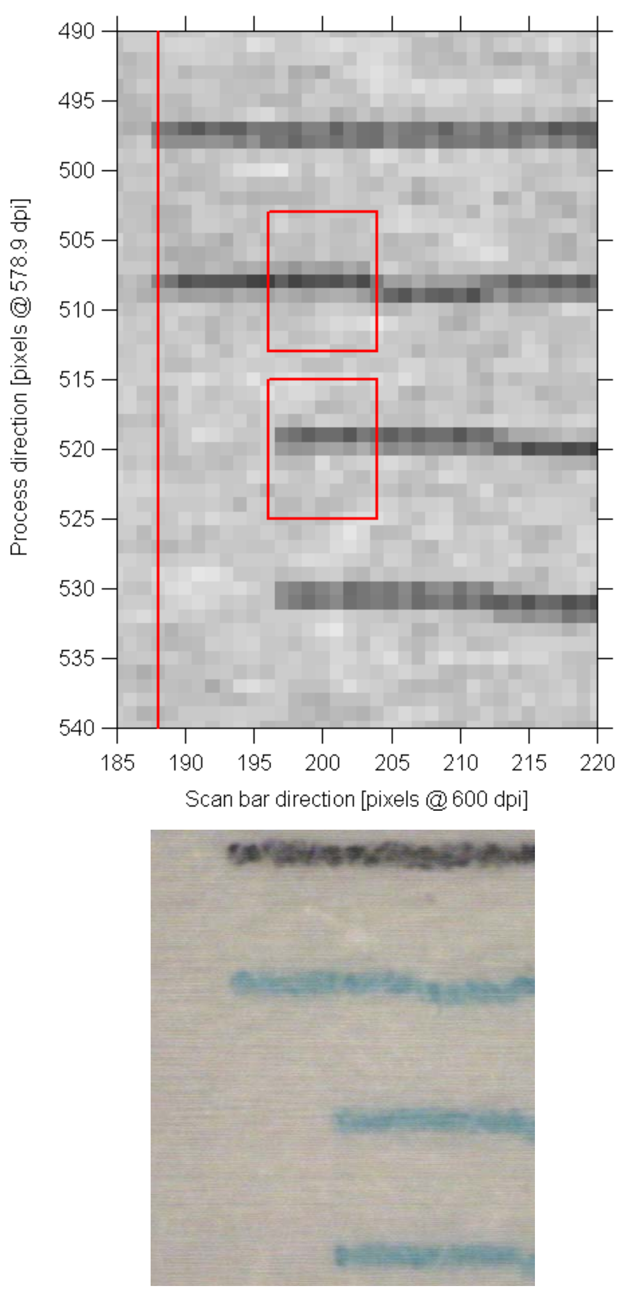

Figure 6 – Captured section of drop alignment test pattern and corresponding print.

The head spacing was set as various values between -50 μm and 50 μm. Each curve is a histogram of repeated spacing measurements at that spacing. The accuracy of the measurement technique is sufficient to be able to place two heads with a spacing error much less than the imaging resolution in the lateral direction.

To assess the accuracy of the drop placement measurement, 33 pairs of IOD images which correspond to 100,000 jets taken sequentially in time were compared. This measurement includes system variation and time variation. The measurements include those taken before and after the correction in drop position was applied. Figure 9 plots the difference in the position of the drop from sequential images. The measurement error is excellent with a 6σ error of 4.8 μm. The measurement system is well below the acuity error of a human observer.

Conclusions

In summary, inline linear array sensing enables an accurate measurement of the drop and print head positions. Specular illumination of the smooth drum surface provides a way to monitor the mass of ink on the drum. Two-dimension calibration removes artifacts introduced by the drum structure. Using the gray level information to interpolate between pixels and averaging over repeats of the test pattern provide a way to increase the measurement accuracy beyond the resolution of the sensor. These techniques provide a way to sense drop and print head alignment with high precision and thus the means to maintain alignment and increase reliability.

References

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[3] S. Puigardeu, J. Sender, and R. Vega, "A Method To Perform Printhead Alignment By Means of Colorimetric Patches", Proc. NIP24, pg. 199 (2008).

[4] H. Mizes et al, "Automatic Density Control for Increased Print Uniformity and Printer Reliability with Inline Linear Array Sensing", Proc. NIP24 pg. 206 (2008).

Author Biography

Howard Mizes received his BS degree in Physics from the University of California at Los Angeles in 1983, and his Ph.D. degree in Applied Physics from Stanford University in 1988. Since 1988, he has been with Research and Technology at Xerox Corporation, where he is a Principal Scientist. Dr. Mizes' research has been primarily focused on understanding and controlling the process physics of xerographic printing, and quantifying and improving the resulting image quality. He has worked in the areas of charge transport and contact charging, particle adhesion measurements and modeling, and experimental probes of the xerographic development process. His image quality work has focused on improving the spatial uniformity of the printed page. e-mail: howard.mizes@xerox.com.

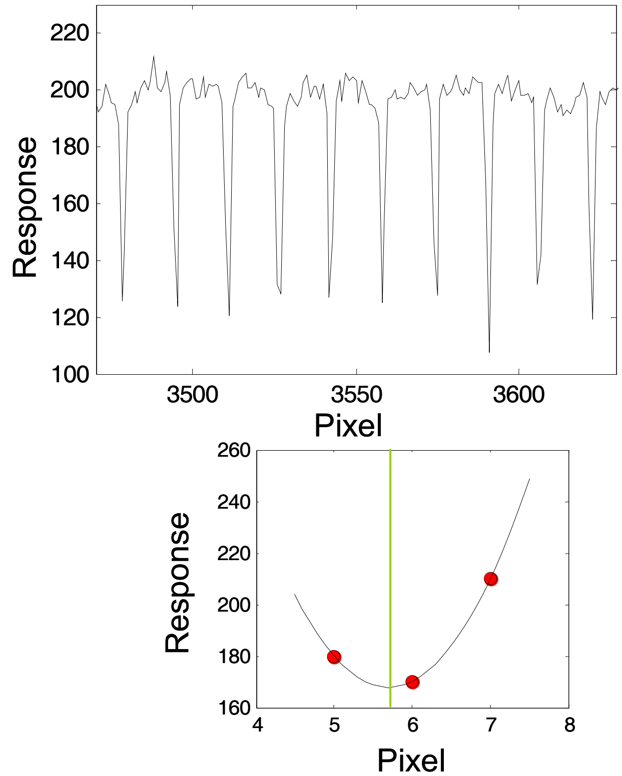

Figure 7 – Dash profiles and interpolation of the dash centers.

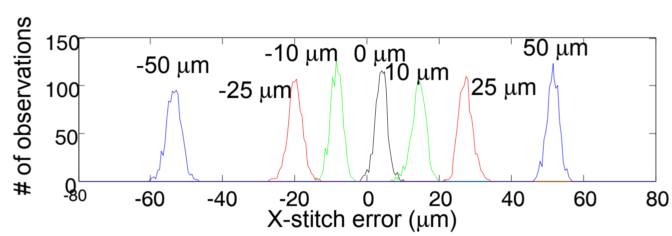

Figure 8 – Stitch measurement accuracy.

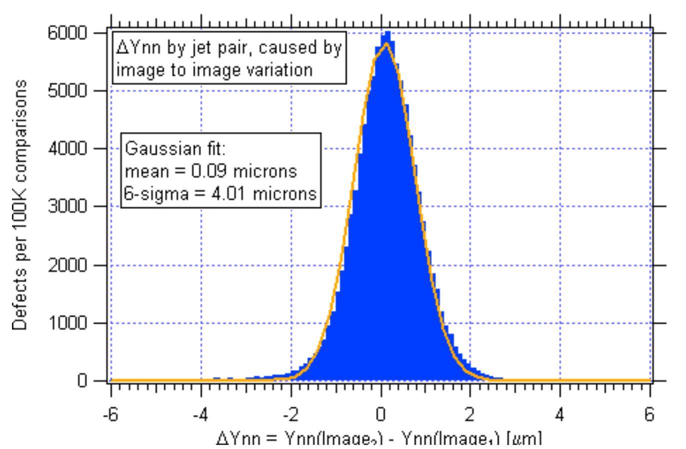

Figure 9 – Drop position measurement accuracy.