# Robustness of Various Halftoning Methods to Process Variations in a Thermal Ink Jet Printer

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## Abstract

As currently practiced, Thermal Ink Jet is a binary marking process. A printed image is formed by producing relatively well-formed spots at specific locations on the printing substrate. Like many other technologies, however, process variations in a Thermal Ink Jet printer can lead to perceptual variations in the final printed image. Such process variations may include spot-to-spot variations within a printhead array, temperature-induced spot size variations, and spot placement errors. This paper illustrates how some halftoning techniques are more robust than others in minimizing the effects of such process variations on the printed image. The choice of a halftoning algorithm to be used with a printer will depend on the expected nature and magnitudes of the process variations of the printer. Several examples illustrate the importance of this choice in producing consistent and high-quality output.

## Spot-to-Spot Size Variations

Ink jet printers generally produce spots that are nearly circular in shape. The exact shape of the printed spot will depend on the nature of the paper. Thus, for heavily coated silica papers, the spots are almost perfect circles, while the spot shapes may be very distorted on the more rough plain papers. In order to produce fill between adjacent spots on the page, it is desirable to have the spot diameter be approximately equal to the pixel spacing (1/resolution) times the square root of two. In this way, spots printed in neighboring pixel positions either up and down or left and right will overlap, while spots printed on neighboring pixel positions on the diagonal will just touch.

The sizes of the printed spots are determined by many factors including the design of the printhead, temperature of the printhead, formulation of the ink, and type of paper being used. Since variations in spot size will lead to variations in ink coverage and optical density, it is important to control the factors which affect spot size in order to minimize the resultant affect on print quality. The degree to which these factors must be controlled will depend on the variations in print quality deemed acceptable as well as the halftoning method being used.

As an example, consider a print bar made by stitching together several printheads in a line. The sizes of printed spots made by jets within a single printhead will usually be very nearly equal. However, variations in the manufacturing process may cause one printhead to produce a slightly different size spot than another. Thus, when two such printheads are stitched together, there may be a perceived discontinuity in the printed image. If the spot size difference between the adjacent printheads is large, dark and light bands or stripes will be produced in the final image.

A study was performed to determine the acceptable difference in spot sizes between adjacent printheads. A test image consisting of text, graphics, and a pictorial was used in order to determine the affect on various types of images. Prints of the test image were produced over a range of spot size differences between adjacent printheads. In addition, both a conventional dot growth halftoning algorithm and an error diffusion method were used. In this way, the visual impact of the spot size discontinuity could be compared for various magnitudes of the discontinuity as a function of the halftoning method used.

The results indicated that, for a particular difference in spot sizes between adjacent printheads, the visual banding produced in the printed image was much more noticeable when the error diffusion method had been used to process the image. In fact, the banding was noticeable even when the difference in spot diameters was as little as 5 microns. This compared with prints made using the conventional dot growth algorithm which did not show any banding at a spot size difference of 5 microns, and only a slight banding at a difference of 10 microns. By knowing how the various design parameters of the printhead affect the size of the printed spot, these results can be directly related to how well the manufacturing process must be controlled in order to produce

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"matched sets" of printheads. The degree of control will, of course, depend on the type of images which the printer is expected to produce, the type of halftoning algorithm to be used, and the desired quality of the final output.

## Temperature-Induced Spot Size Variations

In a thermal ink jet printer, the size of the drop ejected from a jet will depend not only upon the design of the printhead, but also upon the temperature of the printhead. Thus, as the ambient temperature rises, the printhead will generate larger printed spots. This will result in a darker image being produced. In addition, the printhead itself may heat up while printing at a high duty cycle (i.e., high area coverage). Such heating may be localized to a section of a long array of jets or bar produced by stitching several printheads together. In this latter case, there will usually not be a sharp discontinuity of spot sizes produced in the image (as in the previous section when two printheads producing different spot sizes are stitched together). Rather, since heat will diffuse laterally from the hot sections of the array, the variation in spot size through the section will usually be smooth.

Another study was performed to determine the effect of temperature-induced spot size variations along the array of jets on the perceived print quality. In this study, the same test image as before was used. Again, the image was printed using both a conventional halftoning algorithm and an error diffusion algorithm. Several sections along a long array of jets were artificially heated to produce localized spot size variations within the array. In this way, the variation in spot size across the array of jets was made to be smoothly varying. Sets of print samples were produced by holding the temperature in the middle of each section fixed at various levels. The perceived banding due to the localized heating and resultant variations in spot sizes was then assessed.

The results indicated that, as before, images processed using the error diffusion algorithm showed dramatically more visual banding than did the prints produced using the conventional dot growth algorithm. However, the banding produced by this type of smooth variation in spot sizes across the array of jets was less noticeable than the previously discussed discontinuous variations in spot sizes at comparable differences in minimum and maximum spot diameters. Thus, although the error-diffused prints showed noticeable banding when the difference in minimum and maximum spot sizes across the array was 5 microns, the perceived banding was less than that produced when the spot size difference between adjacent printheads was 5 microns (as in the previously discussed study). The perceived banding in the prints made using the conventional dot growth algorithm was dramatically less than in the previous study. When the variation in spot size was smooth, banding in these print samples was not noticeable at all when the difference between the minimum and maximum spot diameter was as great as 10 microns, and only slightly noticeable when the difference in diameters was as great at 15 microns. Thus, the error diffusion algorithm is again more sensitive to variations in spot size than is the conventional dot growth method. In addition, the perceived banding is greatly reduced when the spot diameter varies smoothly across the array of jets over situations where the variation in spot diameter goes through a sharp discontinuity.

Such results can be used to set specifications for temperature uniformity across an array as a function of the type of image being printed, the halftoning method being used, and the required level of print quality for various types of images.

## Summary and Conclusion

These studies indicate that error diffusion methods are more sensitive to process variations than are conventional halftoning methods in a thermal ink jet printer. Thus, although error diffusion methods may be preferable for this binary marking process in that they can more faithfully render detail and tone variations in some images than can conventional dot growth techniques, the benefits of using such methods must be weighed against the added requirements on controlling other process elements in the printer and or manufacturing process.

The reason for the increased sensitivity of error diffusion methods to spot size is fairly simple. In a dot growth algorithm, many ink drops are placed on neighboring pixel positions in order to create a cluster of spots which comprise the halftone dot. This method of growing the halftone dot tends to produce the maximum overlap of printed pixels. An increase in the size of the printed spots will, thus, increase the total area coverage or optical density on the page. In an error diffusion algorithm, however, no attempt is made to cluster the printed spots. In fact, there is a tendency to print diffuse patterns with little overlap of spots. Using this method then, an increase in the spot diameter will again increase the total area coverage or optical density on the page. Since many of the printed spots overlap using a conventional halftoning algorithm, the net increase in area coverage due to an increase in spot size will not be as great using this method as it would be using an error diffusion method where the spots do not overlap as much. Thus, changes in spot diameter will cause greater changes in optical density when using an error diffusion method than when using a conventional dot growth algorithm. This will cause more noticeable banding when an error diffusion algorithm is used than when a conventional dot growth algorithm is used if there are variations in the printed spot size across an image.