Photo-Realistic Ink Jet Printing Through Dynamic Spot Size Control

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Abstract

A method has been developed for dynamically modulating the drop volume created by an array piezoelectric drop-on-demand ink jet printhead. A 4:1 range of volume modulation has been achieved to date, resulting in an approximately 4:1 range in printed spot area. The modulation is continuous (i.e., not discrete) over a significant part of the total range, and is achieved with a minimal decrease in throughput. Optical densities for modulated spots have been measured at 300 and 600 dpi for several printhead configurations. Algorithms have been designed to use a combination of continuous modulation and halftoning (using modulated drops) to produce photo-realistic images.

Introduction

In the past five years, drop-on-demand ink jet printers have come to dominate the low end printer market. The transition of ink jet printers to color has both accelerated this trend and created new markets. With the emergence of color, image quality has assumed a new importance. The principle factor limiting image quality in most office printers, including ink jet, is fixed spot size. Users can look at a wide dynamic range of spot intensities on their CRT, but cannot easily and inexpensively print them.

Thermal ink jet printers do not readily lend themselves to drop volume modulation because of the almost binary nature of their droplet formation process. Concepts for multiple heating elements have been proposed, but have not been demonstrated and would lead to a significant increase in complexity. Most piezoelectric ink jet printers can easily modulate drop volume, but drop velocity is coupled with drop volume. This causes placement errors. Also, the easiest way to modulate drop volume, via voltage modulation, causes the drive electronics to be expensive. Finally, both thermal and piezoelectric printers can modulate spot volume by using multiple drops per spot. However, either the throughput must decrease from what could be achieved using a single drop per spot, or the number of orifices must increase.

Through a combination of printhead design and drive waveform modulation, Compaq Computer Corporation's[1,2] array piezoelectric drop-on-demand ink jet printhead technology can achieve drop volume modulation with a minimal decrease in throughput. In addition, unlike using only multiple drops per spot, the modulation is continuous (i.e., not discrete) over a significant part of the total range.

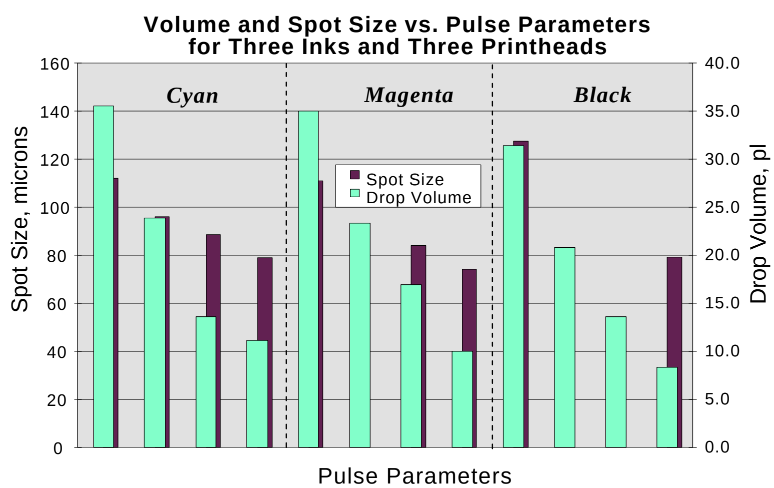

Figure 1*: Example of drop volume and spot size modulation results obtained with three ink / printhead combinations.*

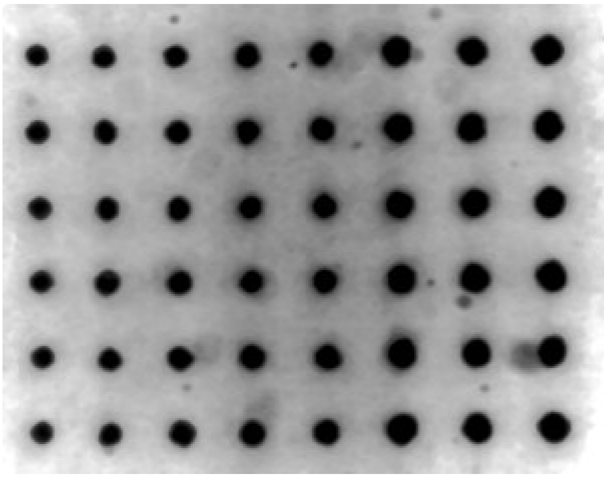

***Figure 2**: Photomicrograph of 4:1 real-time spot area modulation: 300 dpi with every fourth pixel printed; 3,000 lines/second.*

Results

Drop Volume Modulation

Using the print head design described in References 1 and 2, drop volume modulation results as shown in Figure 1 have been obtained. For each of the three ink / printhead combinations shown, the drop volume could be continuously modulated between the largest two volumes and the smallest two volumes. Spot size data was obtained by printing onto coated paper with a solvent based ink.

Spot Size Modulation

To demonstrate both the spot size modulation range and real-time nature of the methods employed, an image was generated in which every fourth pixel of a 300 dpi image was a different grey level, each corresponding to a different drop volume / spot size. This image was printed at a line rate of 3,000 per second, and is shown in the photomicrograph in Figure 2.

Image Generation

To assess the impact of drop volume modulation on image quality, images were printed at both 300 and 600 dpi. Both monochrome and color images were generated, but only the monochrome results are presented in this paper.

First, solid areas were printed, both at 300 and 600 dpi. Each solid area was printed with a different spot size. Different printheads were used for the 300 and 600 dpi cases in order to properly match the spot size range with the print density. Optical densities were then measured. To assign drop volume levels to values of a 256 level grey-scale image, the optical densities were converted to reflectances, the largest drop volume was assigned to level 0, and the was paper (no drop) assigned to level 255. The entire range of drop volumes producible by the printhead were assigned grey-scale levels by linearly interpolating the reflectances. Figure 3 illustrates a typical optical density and grey-scale level result.

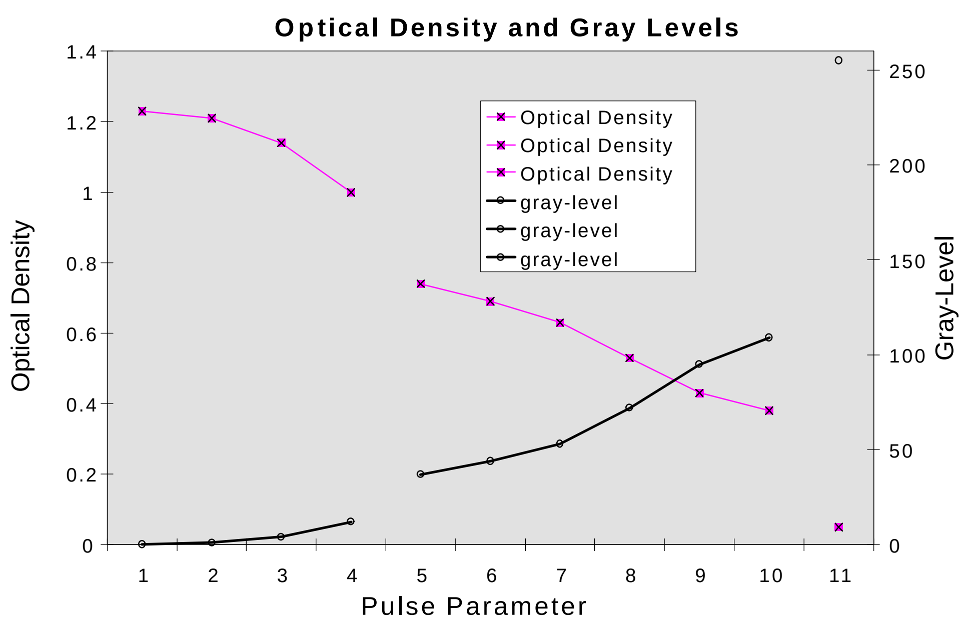

***Figure 3**: Optical density range and grey-level assignment resulting from drop volume modulation.*

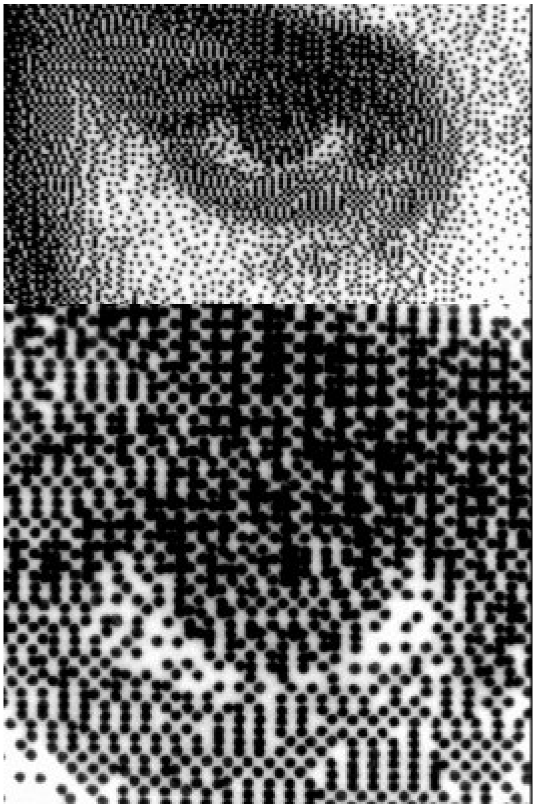

***Figure 4**: Photomicrograph of fixed spot printing using the same printhead and original image as was used in Figure 5.*

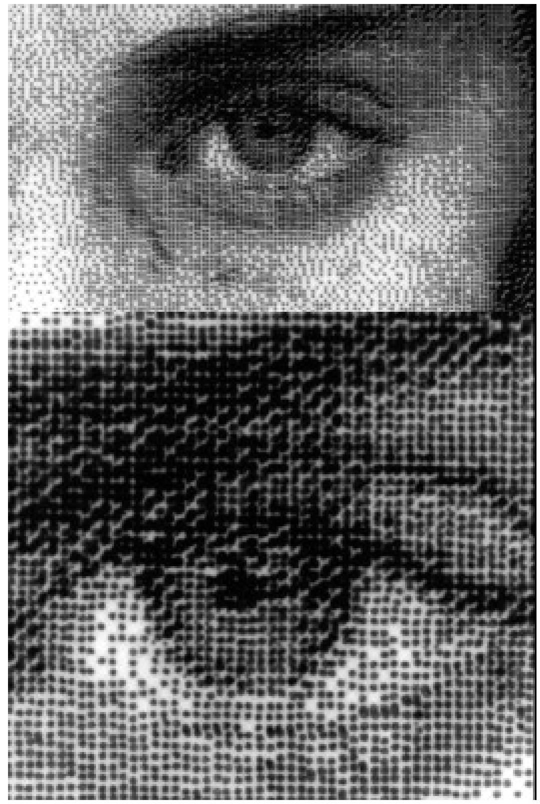

***Figure 5**: Photomicrograph of image printed using spot volume modulation.*

Because the grey-scale levels corresponding to the drop volumes produced do not cover the entire range of 255 levels, those levels that have no corresponding drop volume were created using error diffusion halftoning of the image to be printed. In each image, the highlight levels with no corresponding drop volumes were created by halftoning (error diffusion) with the smallest volume drop and no drop as the two levels. The shadows levels with no corresponding drop volumes were created by halftoning (error diffusion) with the two drops bounding the region. Although straightforward in concept, use of commercial image processes software requires a tedious set of image splitting, mapping, halftoning, remapping, and recombining to accomplish this.

An example of a monochrome image printed using the volume module method and image processing described above is shown the photomicrograph in Figure 4.

For comparison, the same original 256 gray-level image was printed using the same printhead with a fixed spot size and conventional error diffusion halftoning. The resulting image is shown in the photomicrograph in Figure 5.

Acknowledgements

Carol Scalf, Jim Stortz, and Todd Podhaisky of Compaq Computer Corporation were instrumental in the development of the printhead, electronics, and software utilized for the work described in this paper.

References

1. J. Pies, D. Wallace, and D. Hayes, Sidewall Actuator for a High Density Ink Jet Printhead, U.S. Patent 5,227,813, July 13, 1993.

2. J. Pies, D. Wallace, and D. Hayes, High Density Ink Jet Printhead, U.S. Patent 5,235,352, August 10, 1993.