Efficient Grayscale Rendering of Large Images Using a Signal Processing Model and the Arctangent Function

Jang Yi
University of Idaho, Moscow, Idaho

Richard B. Wells
University of Idaho, Moscow, Idaho

George Kerby
Hewlett Packard Company

Abstract

An accurate printer model that is efficient enough to be used in halftoning applications is proposed. The printer model utilizes a physical model to train Adaptive Linear Combiners (ALCs), after which the average exposure of each pixel for any input pattern can be calculated using the optimized weight vector. The average exposure is then converted to the corresponding potential, which is rendered as an 8-bit grayscale image using the arctangent function. Scanned printouts and model outputs of various test images are presented.

This grayscale rendering method can be used to model pulse width modulation for template-based applications. Grayscale images from the model using laser pulse width modulated input images with different sets of templates are presented with measurements. Grayscale images from the model very closely resemble scanned images.

Introduction

The purpose of a printer model is to accurately predict the gray level of a binary image produced by a printer. Printer models are widely used in various digital halftoning algorithms to efficiently improve the print quality of laser printers.[1-4] Typical printer models assume a constant gray level for a pixel. Although the eye responds only to the average gray level over the site, a physical development quantity such as toner mass and reflectance must be examined in the continuous spatial domain in order to account for the complex interactions among dots. Yi presented one such physical model for predicting PC surface exposure energy[5] and extended his model to predict gray level and developed toner mass.[6] Such physical printer models are computationally expensive since the physical equations, first of all, are fairly complex, and obtaining a reasonable average gray level for a pixel requires numerous calculation points per pixel; thus, it is not efficient to use a physical model directly in digital halftoning algorithms. To overcome this inherent disadvantage of physical models, Wells et al. introduced an approach to printer modeling based upon signal processing techniques.[7] They used Yi's physical model[5] to train an adaptive signal processing model (SPM) offline. Once trained, the SPM can be used to accurately predict the average exposure over each pixel in a finite window for a given laser pulse width (Figure 1). Isolated exposure profiles are then linearly superimposed as the SPM window moves across the bitmap. In this paper, we present an empirical procedure for estimating output grayscales from the SPM's average exposure values and validate our approach with scanned images from two test devices.

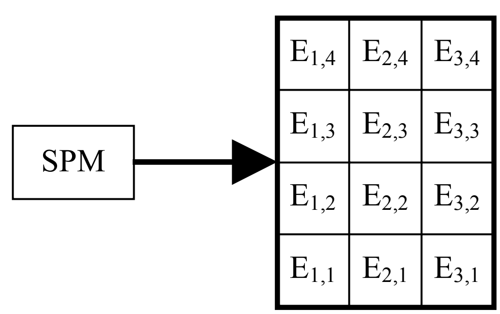

Figure 1. SPM window

Templates

The two test printers, Printer A and Printer B, used in this work achieve their output resolution of 1200 dpi by a patented resolution enhancement technique,[8-10] where every other 1200 dpi laser scan line is skipped (requiring a laser scan resolution of 600 dpi in the vertical direction) and 1200 dpi dots between two 600 dpi scan lines are produced by laser pulse width modulation (PWM), as illustrated in Figure 2. In Figure 2(a), the scanning position of laser beam is at the center of the pixels in the second row. In this case, the size of one pixel represents the printer resolution (about 42 μm for a 600 dpi printer). To increase this optical resolution by a factor of two, one must be able to place two vertically adjacent pixels between two scan lines, as illustrated in Figure 2(b). The pixels between the scan lines are created by appropriately interleaving isolated exposure profiles.[8-10]

A set of 4x3 templates completely determines the laser pulse width at the center of each sliding 4x3 window, as illustrated in Figure 3, via the standard lookup table method. An example template set developed at the MRC institute is shown in Figure 4. Desired 1200 dpi dots are indicated with black pixels; white pixels represent no development; gray pixels are don't cares. The hexadecimal digit under each template represents the matching 6-bit pulse width. The templates in Figure 4 determine the pulse width based solely on the desired output bits of each window's center column.

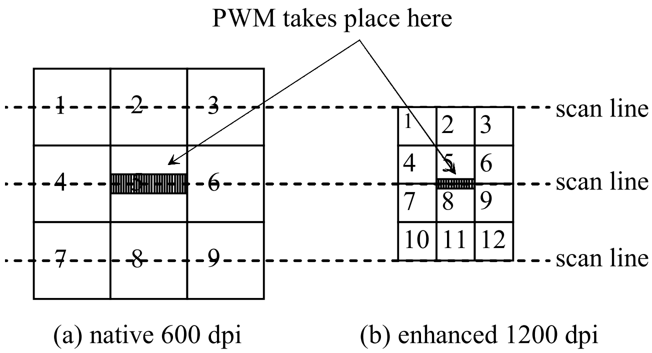

Figure 2. Resolution enhancement

Gray Level vs. Potential

Once exposure is obtained from the SPM, knowledge of how exposure and voltage interact with each other can be utilized in obtaining the photoreceptor surface potential. The relationship between exposure and voltage is called the Photo Induced Discharge Characteristics (PIDC). The PIDC of a printer family is obtained from physical measurements. A curve fit method using the simplex algorithm is employed to approximate the voltage at an arbitrary exposure level.[5] A typical PIDC curve is shown in Figure 5.

In our experiment on Printer A, a 1/3 inch × 1/3 inch image consisting of one constant gray level was converted into a halftoned bitmap. The halftoned binary bitmap no longer consists of one gray level, and its darkness can only be expressed in terms of %-coverage, which is the ratio of the area occupied by the black pixels to the total image area. Note that gray level-% and %-coverage are equivalent measures (the former represents the darkness of a grayscale image and the latter the darkness of a halftoned bitmap). The converted bitmap was printed and then scanned using a high resolution scanner. Each of the digitized image pixels has a gray value ranging from 0 to 255. Calibration curve data were obtained by calculating the average gray level of the scanned image and the average potential from the SPM and PIDC. This process was repeated for various gray levels and the collected data are shown in Figure 6 (diamond markers). The measured gray level variation, in Figure 6, as a function of average potential resembles an arctangent transition. Average potential values were fitted to the measured average gray levels using the following equation

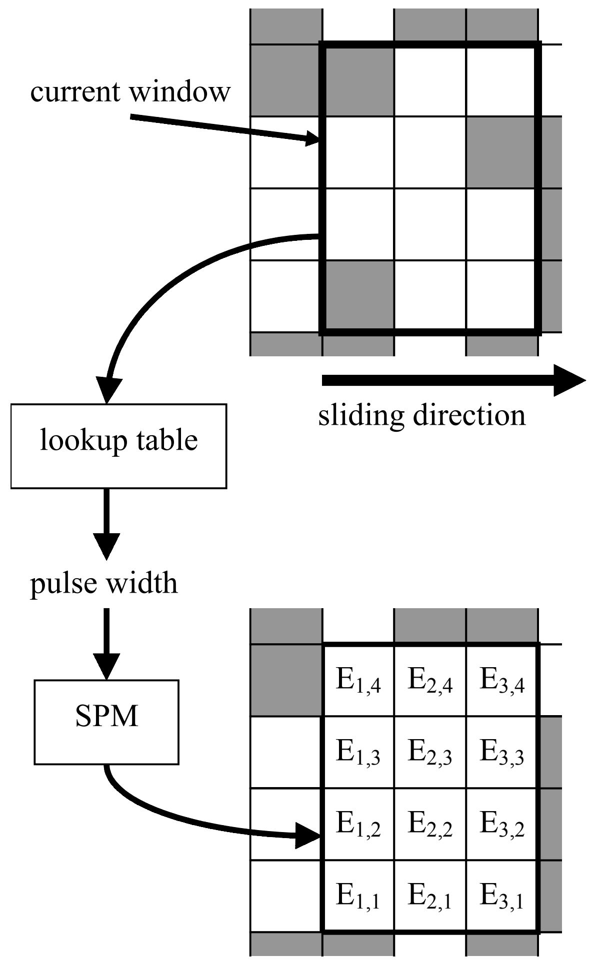

Figure 3. Pulse width and exposure calculation

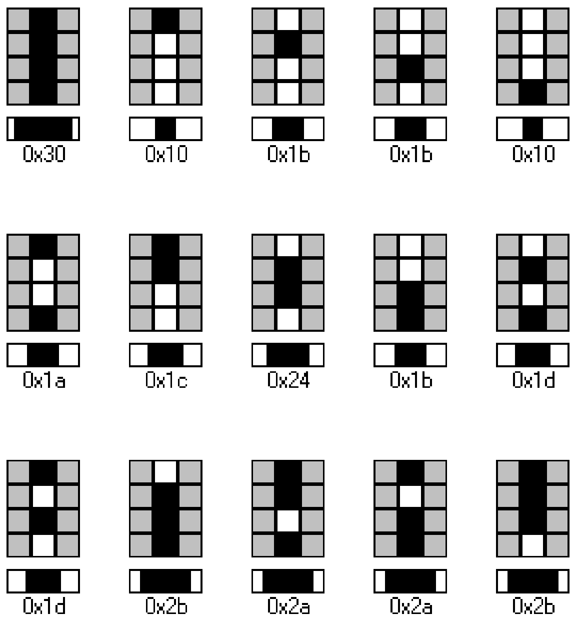

Figure 4. Example templates

$$g(V) = g_{\min} + \frac{g_{\max} - g_{\min}}{2}\left[1 - \frac{2}{\pi}\arctan\left[a(V - V_{shift})\right]\right], \quad (1)$$

where a and V_{shift} are the image contrast and brightness parameters, respectively, and $g_{\max}$ and $g_{\min}$ are the maximum and minimum gray levels (that $g(V)$ can reach), respectively. The resulting gray level calibration curve for Printer A is shown in Figure 6 (solid line). Using this calibration curve, the average gray level of each of the test patterns used in our experiment was obtained by calculating

1. potentials using the SPM and PIDC,
2. gray levels from (1), and
3. the average of the gray levels obtained in 2.

The predicted average gray levels for the test patterns are shown in Figure 6 (x markers). The average estimation error between the measured and predicted average gray levels is ±4.38 in gray level. Our experiment on Printer B was conducted in the same manner and yielded an average estimation error of ±4.37 in gray level.

Images from Printer A

Two sets of templates, Template Set A and B, were tested on Printer A. Template Set A is shown in Figure 4. Template Set B contains the optimized 1200 dpi templates for Printer A. Consider the bitmap shown in Figure 7. The size of this 1200 dpi image is about 1.5 inch × 1.8 inch. Using Template Set A, the generated pulse widths are shown in Figure 8. Note that the horizontal and vertical resolutions of the pulse width plot are 1200 and 600 dpi, respectively. Predicted grayscales from our model and a scanned image printed from the bitmap in Figure 7 are shown in Figures 9 and 10, respectively. The dark oval center region in Figure 10 is not apparent in either the original bitmap or the pulse width image, but it is accurately predicted in the simulated grayscale image.

Figures 11 and 12 show predicted and scanned grayscales of Lena, respectively, using Template Set B. The optimized templates in Template Set B seem to accurately depict this complex 1200 dpi image. The modeled grayscales closely resemble the scanned image. However, the predicted grayscale image seems to show more contrast (resulting in a sharper image). We suspect that this is mainly due to calibration error and unmodeled factors such as toner scattering, which can make images look blurred.

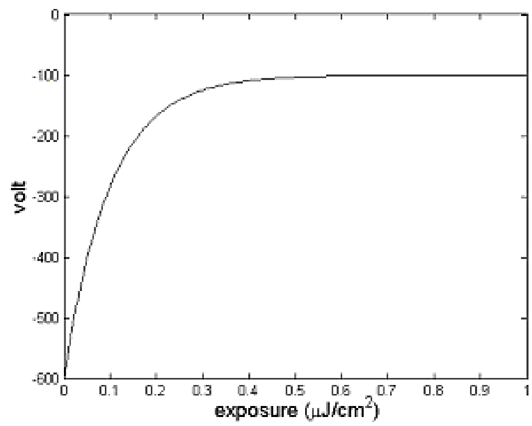

Figure 5. A typical PIDC curve

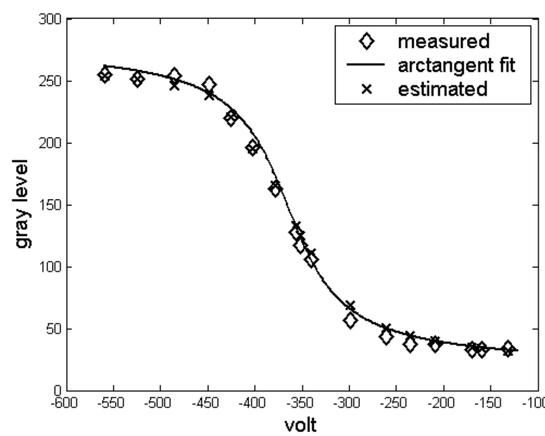

Figure 6. Calibration curve for Printer A

Images from Printer B

Two sets of templates, Template Set C and D, were tested on Printer B. Template Set C contains the optimized 1200 dpi templates for Printer B. Template Set D employs reduced pulse widths for lighter printouts. Figures 13 and 14 show predicted and scanned grayscales of halftone strips using Template Set C, respectively. The printed gray ramp at each halftone frequency is rendered smoothly without noticeable halftone artifacts and the modeled counterpart shows much the same halftone result.

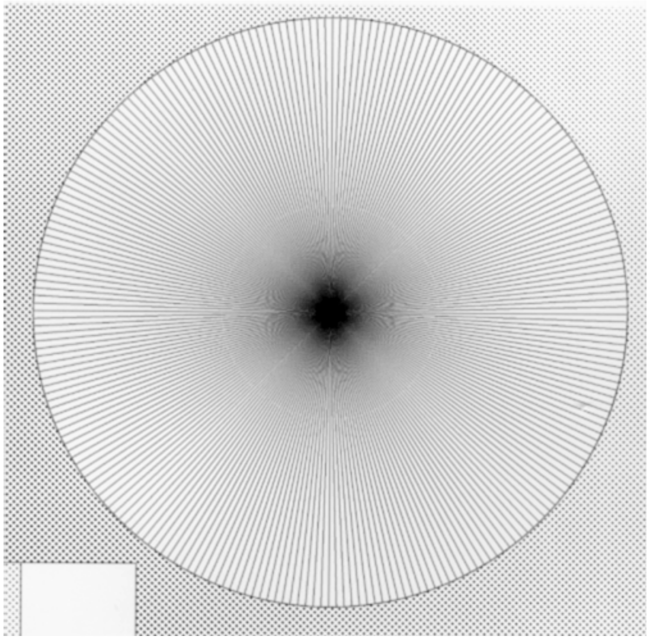

Figure 7. 1200 dpi bitmap (Image used by permission of Spencer & Associates Publishing, Ltd.)

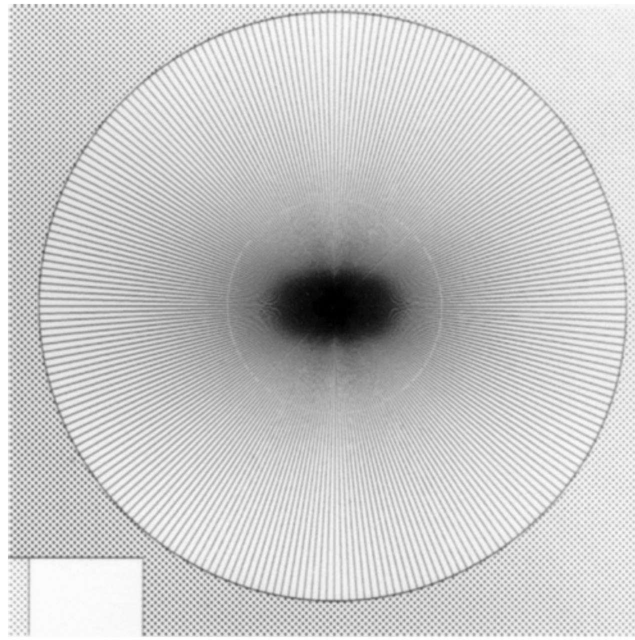

Figure 9. Predicted grayscale image using Template Set A

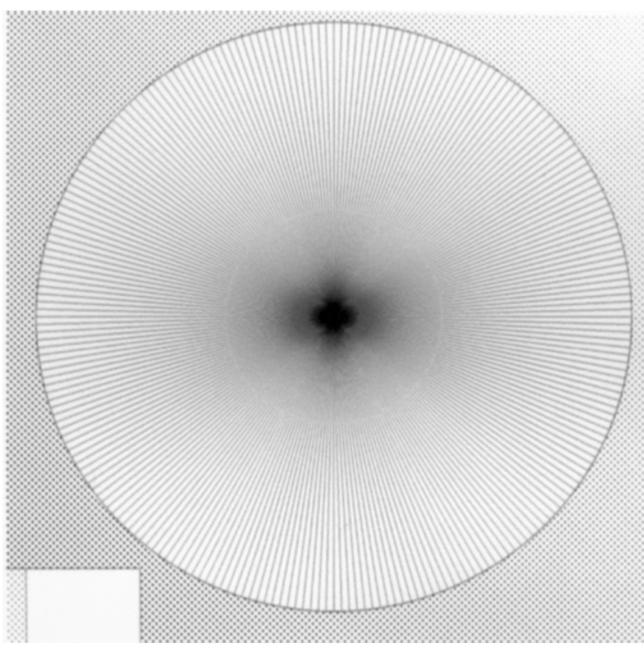

Figure 8. Grayscale rendition of generated pulse widths using Template Set A

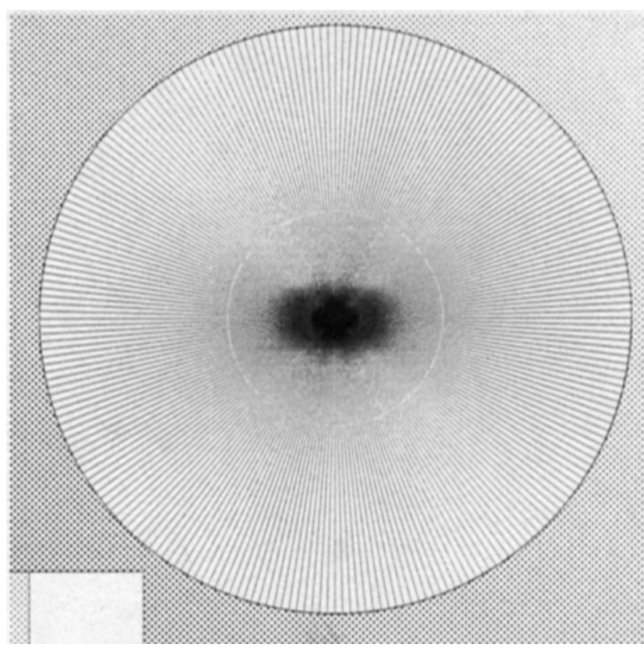

Figure 10. Scanned grayscale image using Template Set A

Figure 11. Predicted grayscale image using Template Set B

Figure 12. Scanned grayscale image using Template Set B

Figures 15 and 16 show predicted and scanned grayscales of the bitmap in Figure 7, respectively. The darkest center region in both images is rendered with a gray mid tone. This is an artifact arising from the templates used to create lighter prints.

Concluding Remarks

An accurate and efficient printer model for template-based applications and an empirical calibration method were presented. To validate our approach, scanned printouts and model outputs of various test images and using two test printers and four template sets were presented. We verified that grayscale images from the model very closely resemble scanned images. However, we found that there are small discrepancies between predicted scanned grayscales. We suspect that this is mainly due to calibration error and toner scattering.

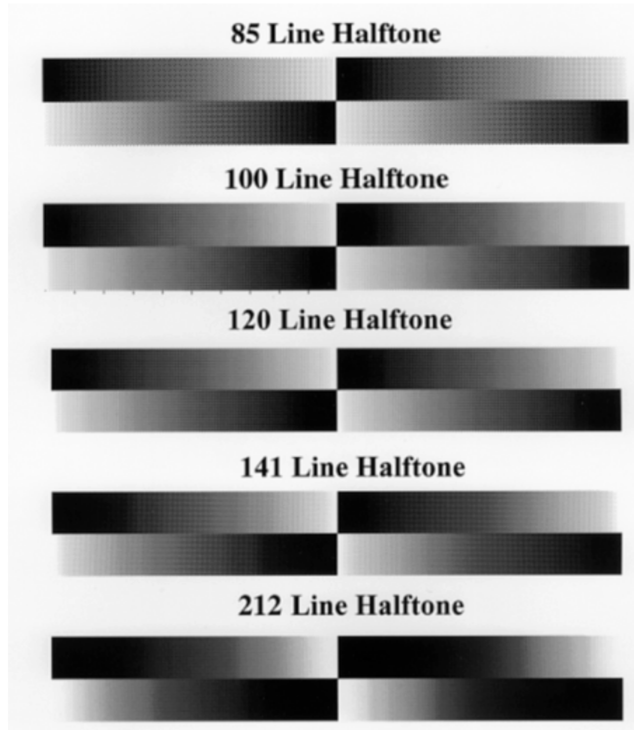

Figure 13. Predicted grayscales using Template Set C

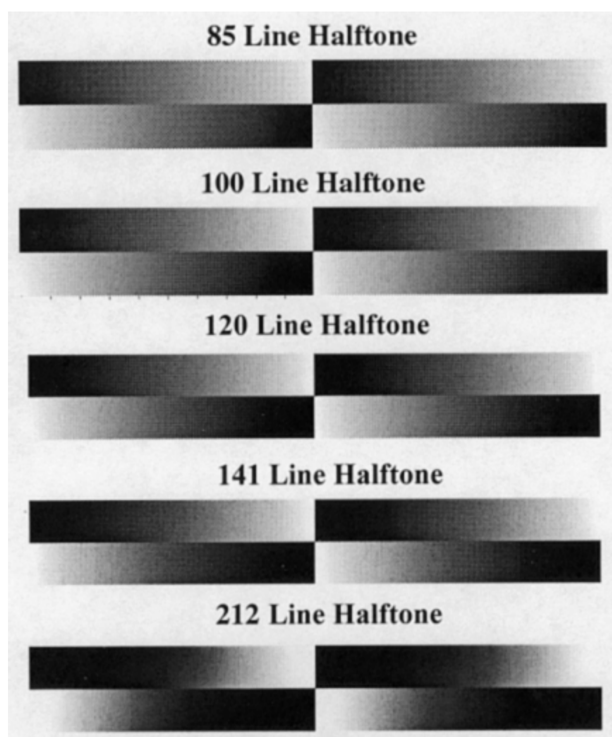

Figure 14. Scanned grayscales using Template Set C

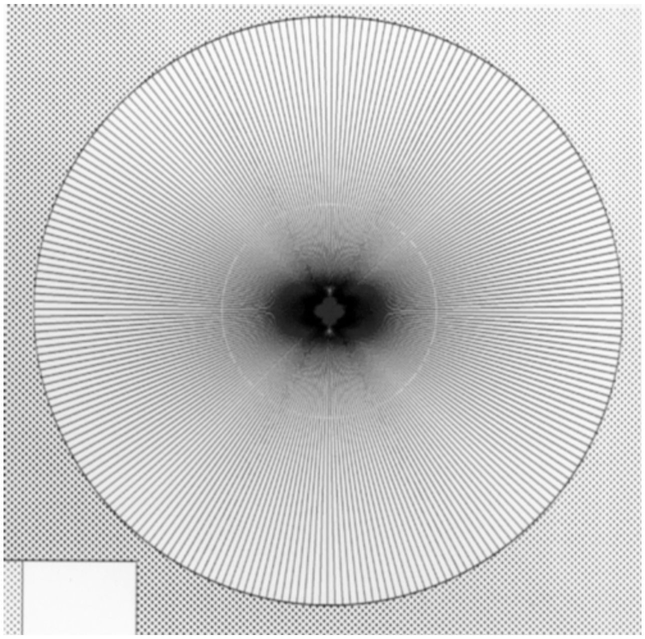

Figure 15. Predicted grayscales using Template Set D

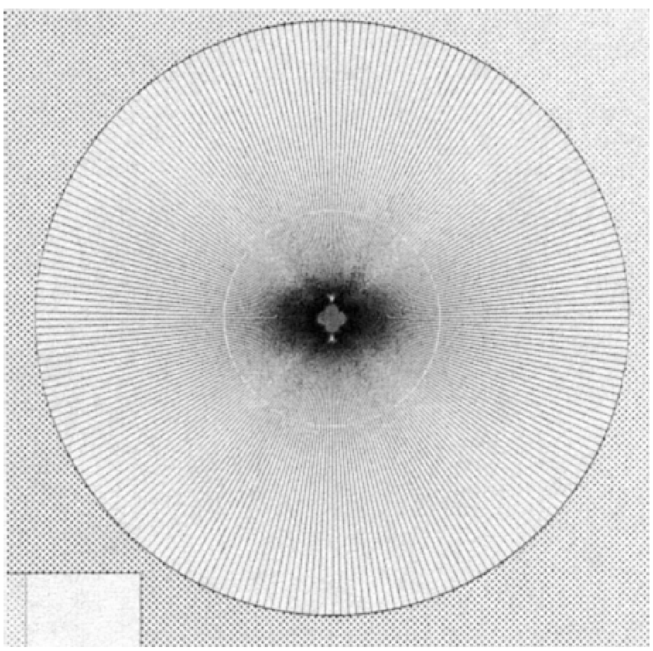

Figure 16. Scanned grayscales using Template Set D

Acknowledgement

This research was supported by a grant from Hewlett-Packard Company.

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Biography

Jang Yi received the B.S. degree in computer engineering in 1997, the M.S. degree in electrical engineering in 1999, and the Ph.D. in electrical engineering in 2002 from the University of Idaho, Moscow, ID. He's currently a research engineer at the same institute. His dissertation was on modeling electrophotographic development physics. His current research area is the development process.