Parameterized Printer Model for Rendered Gray Level Images

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Abstract

Xerography consists of a number of complex individual processes which in concert define the image quality of the output print. This paper describes a model which bypasses the complex individual processes and attempts to empirically model the output by use of a few key parameters, motivated by physical insight. Building on a prior modeling approach, a model is defined to empirically fit the microscopic toner mass distribution of halftone patches to measured luminosity (L) across the Tone Reproduction Curve. The simplified model proposed here accommodates the microscopic toner mass of the patch, the Yule-Nielsen effect on paper, and certain key luminosity measurements. Comparisons are made between the simulated and experimental L* values and the optimization procedure used to fit the parameters is described.*

Introduction

Xerographic printers are devices that transform a digital image into a printed hardcopy image through several underlying complex processes. These are commonly referred to as charging, exposure, development, transfer, and fusing, among others. Each one of these processes affects the output print quality and a first principles printer model would contain a first principles model of each sub-process. While researchers have made some progress in this direction, the complexity of the processes motivates more simplified models that are more practically useable.

The manner in which a printer model is to be used is fundamental in defining a simplified printer model. One wishes to retain characteristics required for use of the printer model, while eliminating unnecessary detail. In this work, we propose a printer model for use in exploring print non-uniformity. Thus, the objective of the printer model is to accurately predict the output uniformity characteristics of a printed image. We do not seek the underlying sub-system which is the root cause of the print non-uniformity. Simplified printer models have been developed for use in developing halftone designs and dot sizes to improve image quality. Clearly, the appearance of the printed image highly depends highly on the subsystem parameters, see Mizes.[1] He alludes to the role of the imager in creating some of the print defects such as banding in an image. He developed a partially empirical printer model encompassing sub-system parameters to quantify the tradeoffs between the sub-system parameters, halftone design, and print quality. This paper attempts to further parameterize and simplify the printer model proposed by Mizes, excluding the individual subsystems.

Toyoshima et al,[2] attempt to model the image profile transforming properties, including the laser beam energy distribution, latent image profile and profile of developed toner. Their approach incorporates many subsystems parameters.

There have been other similar printer models that have been developed in the past. Allebach et al[3] have used image analysis to develop and parameterize printer models that form the basis for modifications to the print mechanism or rendering algorithm that could reduce artifacts caused by electro photographic and inkjet print processes. The importance of examining halftone structures to relate them to print quality has been stressed by Pappas et al.[4] They have discussed a printer model to design halftone dot structures that produce images of higher visual quality.

Crounse[5] has proposed a measurement based printer model with a reduced number of parameters. He has focused on applications that require estimation of the tone-reproduction curve. He also investigated the use of a reduced system model for good halftone design, thereby incorporating it to halftoning algorithms.

Studies relating to physical models that have focused on estimating measurable quantities such as reflectance have been conducted to account for complex interactions between dots. One such physical model has been developed by Yi,[6] where the relation between gray value and mass/toner was studied.

The work described here models reflectance measurements based on some key parameters using physical insight. In addition to the free parameters described here, the halftone structure and radius of the ROS spot play important roles in the estimation of Tone Reproduction Curve. This work incorporates an empirical model of the physical process involved in scattering of light in the paper and its effect on the Tone Reproduction Curve as made evident by Yang et al,[7] by including a Yule-Nielsen factor in the simplified printer model. The following sections describe the printer model and show a comparison between the simulated and experimental Tone Reproduction Curves.

Printer Model

The model described here converts the input digital image to a simulated output printed image without modeling the complex underlying subsystem processes of the printing device. Instead, the proposed model attempts to capture the essential characteristics of the printer device using a simplified model, motivated by physical insight, which contains only a few key parameters. A high-level flow diagram for the simplified printer model presented in this paper is shown in Figure (1).

In the proposed model, the input digital image is first halftoned using a clustered dot screen. For the work presented in this paper, an 8x8 clustered dot halftone screen is used and the input digital image is 600 dpi.

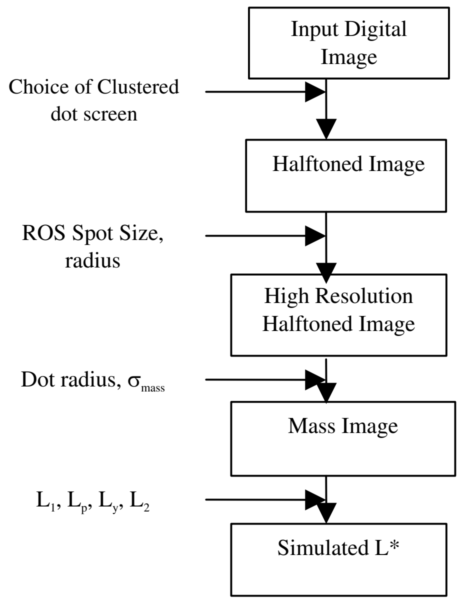

Figure 1. High- level flow diagram for the proposed simplified printer model

The resulting halftoned image is then interpolated to a higher resolution (3600 dpi) such that each pixel in the simulated image that would be exposed by the raster optical scanner (ROS) can be replaced with a round dot. This rounded dot better approximates the true nature of the microscopic ROS pixels than the original square pixels in the output from the first step of the model. The choice of the radius of these rounded dots is a parameter in the printer model that should be chosen according to the spot size of the ROS and the modulation transfer function (MTF) for the printer device being modeled (many subsystems other than exposure may affect the diameter of the dots: e.g. development, transfer, and fusing). In this paper, the radius was chosen to be in the range of 25-50 μm.

The next step in the model is to convert the high resolution halftoned image into a simulated mass image. In this step, the mass distribution of an individual ROS pixel is modeled using a standard 2-dimensional Gaussian function:

$$f(x,y) = \frac{1}{2\pi\sigma^2}\exp\left(-\frac{(x^2+y^2)}{2\sigma^2}\right) \tag{1}$$

Here the choice of the standard deviation for the normal distribution is based on the effective width of the mass distribution for an exposed ROS pixel on the page. The overlap between neighboring ROS dots in this step of the model is handled through simple addition of the overlapping mass values (the overlapping Gaussian functions). This simple model for the mass distribution does not take into account the complexities of the underlying processes (charge, expose, develop), but rather is meant to capture the essential aspects of the mass distribution in a simple manner such that the macroscopic behavior of the simulated print matches that obtained experimentally.

Once the simulated mass image is obtained, it is necessary to convert this to output luminance for comparison with actual experimental data. Following a simplified version of the approach presented by Mizes,[1] the following direct conversion to an L* image, and finally to a single output L* value, is made using the following equations:

$$L_0 = L_p + L_y\overline{m} \tag{2}$$

$$L(x,y) = L_0 + (L_1 - L_0)\left[1 - \exp\left(-m_b(x,y)\big/L_2\right)\right] \tag{3}$$

$$L_{patch} = \frac{1}{N^2}\sum_x\sum_y L(x,y) \tag{4}$$

where L_{patch} is the L* measurement for the patch being simulated, N is the number of high resolution pixels in both the x and y dimensions of the simulated image (assuming the patch is square), L(x,y) is the microscopic luminance value at location (x,y), m_b(x,y) is the microscopic mass at location (x,y), L_p is the measured L* of the bare paper, L_1 is the L* value of a solid toned region of the paper, L_0 is the L* value of the paper with linear darkening due to additional toner mass in the neighborhood of the measurement point (Yule-Nielson effect), $\overline{m}$ is the average toner mass in the patch being simulated, L_y determines the rate at which the bare paper darkens with increased area coverage, and L_2 is the rate at which added mass darkens the toned areas of the page. Note that some liberty has been taken in defining a microscopic L* value at location (x,y) in (3) since luminance is as a macroscopic phenomenon. However, the goal of the present modeling approach is to match the *macroscopic* behavior (in particular the luminance measurements) of the simulated and experimental prints. Thus, the intention is not to suggest that (3) actually represents a physical, measurable quantity. Instead, it is merely a convenient intermediate output for use in the present modeling approach.

It can be easily seen that the proposed model in (2)-(4) attempts to represent the complexities of the underlying printer device using only a small number of adjustable parameters. Sample images indicating typical intermediate output results from each step of this simulation model are presented in Figure 2 for reference.

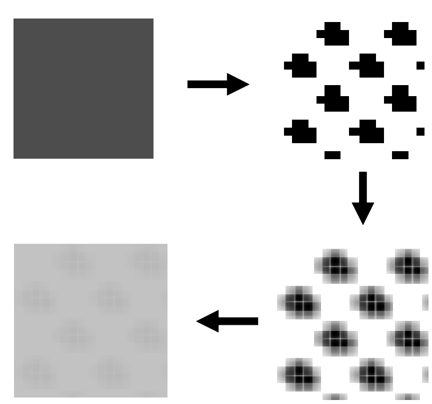

Figure 2. Steps in the conversion of the input grayscale image to a simulated output print (in L)*

Matching Simulated and Experimental L* Measurements

Several parameters in the proposed model, in particular L_p and L_1, can be directly measured from experimental samples. There are, however, several parameters in the proposed simulation model (L_y and L_2) that must be adjusted in order to achieve satisfactory agreement between simulated and experimental luminance values. In order to empirically fit these parameters, a series of halftone patches, representing sample points along the tone reproduction curve (TRC) of the printer device being modeled, were simulated. In this case, 15 patches ranging from 0% area coverage (i.e. from paper with no toner) to 100% area coverage (solid patch) were used (see Figure 3). The resultant simulated L* values for these patches were then compared to experimental data samples from actual prints. The experimental L* values were obtained using a hand-held spectrophotometer.

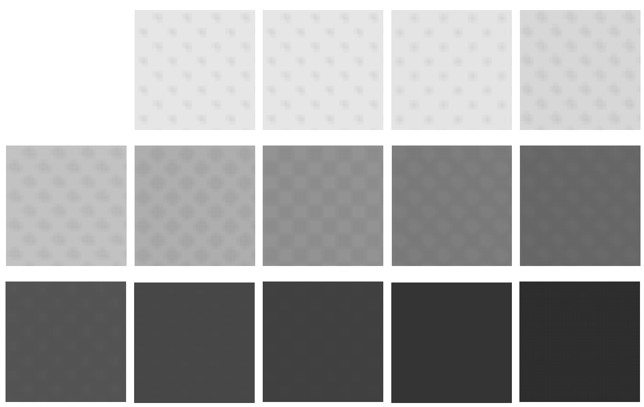

Figure 3. Simulated TRC patches.

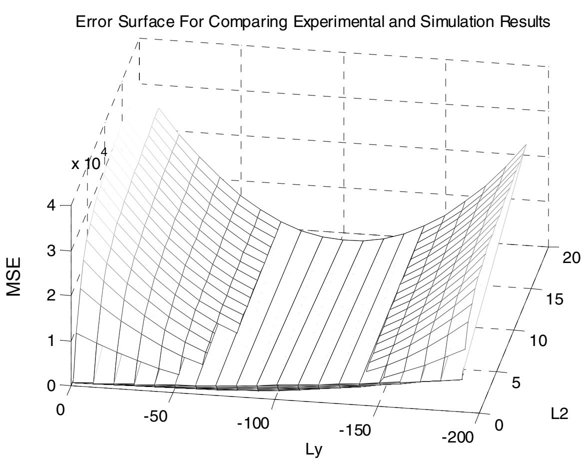

Figure 4. Error surface for a sweep of model parameters

In order to fit the two model parameters, L_y and L_2, an iterative search method was used to select values of these parameters that would minimize the error between the simulated and experimental L* measurements. A plot of the mean squared error (MSE) surface for a sweep of the two model parameters is shown in Figure 4. From this figure, it is clear that the model is more sensitive to the L_y parameter than to the L_2 parameter.

Using the parameter values resulting from the iterative search, a comparison plot showing close agreement between the experimental and simulated results for the 15 patches along the TRC curve of the printer is shown in Figure 5.

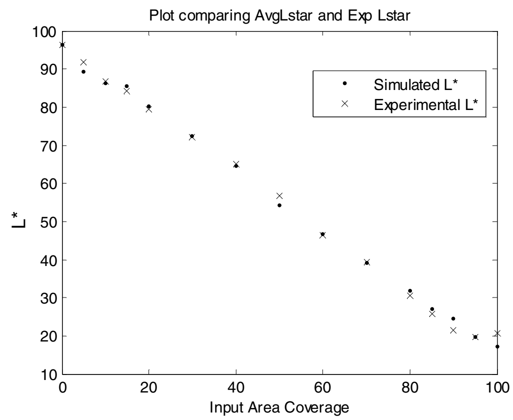

Figure 5. Comparison between experimental and simulated L values*

Conclusion

A simplified printer model has been presented which does not require detailed models for the complex individual subsystem processes in a Xerographic printer. Instead, this approach, motivated by physical insight, generates a simulated output print using only two key parameters: L_y and L_2. The ability of this model to capture sufficient information about the printer device to reproduce macroscopic printer effects was demonstrated by comparing simulated and experimental TRC data.

The simplified printer model presented in this paper can be extended slightly by enabling modulation of the halftone dot diameters. This technique could enable a simple method for reproducing macroscopic print defects such as mottle and streaks.

Acknowledgement

This project has been funded by CEIS, a NYSTAR designated center for advanced technology and Xerox Corporation.

References

1. H. Mizes, "Empirically Based Printer Model of Halftone Structure", IS&T's NIP20 Conference on Digital Printing Technologies (2004).
2. J. P. Allebach, G.Y. Lin, C.-L. Chen, F. A. Baqai, J,H. Lee and G.T.C. Chiu, "Image Analysis as a tool for Printer Characterization and Halftoning Algorithm Development", 5th IEEE Southwest Symposium on Image Analysis and Interpretation (SSIAI'02).
3. T.N. Pappas, J. P. Allebach, and D.L. Neuhoff, "Model Based Digital Halftoning", IEEE Signal Processing Magazine, 20 pp. 14-27 (2003).
4. C.K. Dong, T.N. Pappas, and D.L. Neuhoff, "Measurement of printer parameters for model-based halftoning", Proc. SPIE Int. Soc. Opt. Eng. 1913, 355 (1993).
5. Kenneth R. Crounse, "Measurement-Based Printer Models with Reduced Number of Parameters", Proceedings of SPIE Volume 4663;2001; p. 121-129.

6. J. Yi, A Xerographic Simulation Model, MS Thesis, University of Idaho, 1999.
7. L. Yang, B. Kruse and R. Lenz, "Light Scattering and Ink Penetration Effects on Tone Reproduction", proceedings IS&T's PICS Conference (March 2000).
8. J. S. Arney and S. Yamaguchi, "The Physics Behind the Yule-Nielsen Equation", proceedings IS&T's PICS Conference, pp. 381-385, (1999).

Author Biography

Vivek Jaganathan received his Bachelor of Engineering Degree in Electronics and Instrumentation from the University of Madras at Chennai, India in 2002 and his MS degree in Electrical Engineering from Rochester Institute of Technology in 2005. He worked at RIT as a research assistant in the area of simulating macro and micro level print defects, low cost full width array sensors and developing parameterized printer model. Recently he joined Xerox Corporation in the Production Systems Group.