Intelligent Image Rendition

Chunghui Kuo and Horia Neamtu; Print Systems Division, Eastman Kodak Company, 2400 Mt. Read Blvd, Rochester, NY14450, USA

Abstract

The traditional image rendition process assumes an ideal output imaging system where each image pixel will be perfectly reproduced regardless of different image formation processes. In reality, each individual imaging system can be approximated as a linear system with its own unique transfer function characteristics, which could exhibit spatial and/or temporal variations. Consequently, it will produce inconsistent tone scale reproduction curves during the print production run. The objective of this paper is to investigate the tone reproduction curve variations caused primarily by the interaction of neighboring imaging pixels. An intelligent image rendition algorithm is presented to compensate for this macroscopic imaging process deficiency. Experimental results will be demonstrated to show the effectiveness of the proposed algorithm, which has been deployed commercially on a digital printing press.

Introduction

The traditional image rendition process assumes an ideal output imaging system where each image pixel will be perfectly reproduced regardless of different image formation processes. In reality, each individual imaging system can be approximated as a linear system with its own unique transfer function characteristics [1]. Furthermore, the tone scale reproduction of a real imaging system often exhibits its own distinct spatial and/or temporal dependent characteristics. For example, when the tone reproduction curve of a digital printing system exhibits spatial variation across the imaging width, the macro nonuniformity artifact is often noted as streak; conversely, when the tone reproduction curve shows temporal variation, the artifact is often denoted as banding [2]. Different image formation processes will be susceptible to different imaging artifacts [3]. The normal technology development process always intends to identify the root cause of each artifact and hopefully leads to a robust solution. However, the cost of achieving a perfect imaging system often outweighs that benefit. As a result, researchers eventually turn to various robust system compensation algorithms to optimize the overall performance of the entire system. For examples, researchers have demonstrated that it is possible to correct streak and banding artifacts by modifying the output of the digital writing module and/or the input images [4, 5]. Researchers have continuously pushed the technological limit of the digital printing technologies to the field of three-dimensional microstructure manufacturing. Consequently, the requirement for material deposition accuracy has surpassed the limit of the human visual system, which imposes even more stringent precision tolerance on printer component construction and subsystem/system assembly. As a result, intelligent printing system optimization processes using various active devices to fulfill the ever-demanding image quality requirements are essential to unlock the full economic potential of large-format three-dimensional microstructure manufacturing on different receivers.

The objective of this paper is to devise an image correction algorithm for the tone reproduction curve variations caused primarily by the interaction of neighboring imaging pixels. Different from the streak and banding artifacts noted previously, this local tone scale variation is mostly independent from the hardware composition of a printing system provided that all imaging components and subsystems are positioned within the production tolerance. Therefore, a precomputed compensation scheme based on the relative physical location similar to the streak correction process is not applicable. Furthermore, different image formation processes, such as electrophotography, inkjet and dye-sublimation, have their own distinct local pixel interaction properties. Consequently, it often degrades the final output quality by modifying an image for one local pixel interaction characteristic and producing it on a different imaging device. The optimal solution is to devise an intelligent image rendition process on the intended digital print engine to compensate for this microscopic imaging process deficiency during runtime.

More specifically, we would like to address the *Fringe Field effect* in the electrophotographic imaging process [6, 7], which can be described as the electric field variation at the intersection of high and low charged regions where image edges occur. The effect is illustrated in Figure 1. At two boundary conditions, where code values are 0 and 255 in an 8-bit imaging system, the image rendition within the fringe field returns back to normal behavior of 0 percent and 100 percent ink coverage respectively; however, in the mid tone region, the Fringe Field results in less colorant deposited on the intended substrate locations than that of other unaffected areas. An intelligent image rendition algorithm is presented to compensate for this macroscopic imaging process deficiency. Experimental results will be demonstrated to show the effectiveness of the proposed algorithm, which has been deployed commercially on a digital printing press.

Image-Dependent Tone Scale Variation

The root causes of image formation artifacts in a digital printing system can be attributed to two categories: the first is the imperfection in the imaging component manufacturing and/or system assembly, and the other is the physical and material properties of the selected imaging process. Although it might not be economically viable, it is possible to tighten the manufacturing tolerance to minimize any system imperfection, such as irregularity of imaging cylinder circumference and inkjet printhead defects. Furthermore, the image artifacts caused by hardware defects usually appear in predictable locations with fixed reoccurrence frequencies. Therefore, various print quality enhancement algorithms have been devised to actively cancelling out these deterministic image artifacts [8]. Conversely, the image artifacts attributed to the physical and material properties of the corresponding imaging process are usually related to the percent coverage of each colorant, which depends upon the code values of input image pixels [9, 10]. In general, a process control algorithm is implemented to ensure the corresponding digital printing system operating within the specified environment, but it is often very difficult to minimize the associated imaging artifacts with an active signal cancellation algorithm.

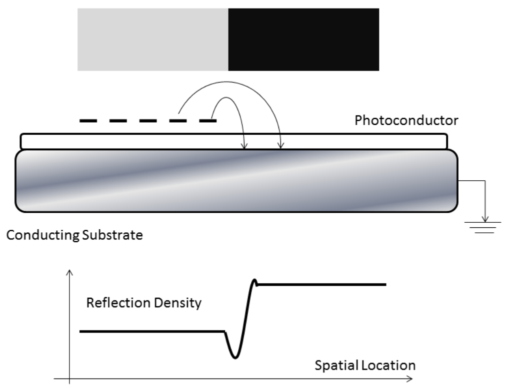

Figure 1. *Fringe Field effect in the electrophotographic process*

The image artifacts affected primarily by the colorant coverage combination at the corresponding pixel locations can be denoted as *Degree 0* (D_0) artifacts such as granularity and mottle. There also exist imaging artifacts that are caused by the interaction of imaging pixels within a neighborhood, which can be classified as *Degree 1* (D_1) artifacts. The halo artifact created by the *Fringe Field effect* in the electrophotographic imaging process belongs to a D_1 artifact. This artifact only occurs along the image edges with significant pixel code value differences, where the image edges on the side with lower toner coverage appear lighter than their neighboring pixels with the same toner coverage as shown in Figure 1. Different from the well-known contrast effect of the human visual system, the halo artifact can be detected by a color measurement equipment [11]. Consequently, the images reproduced by the electrophotographic printing process appear to be higher contrast, or *sharper*, than those produced by other digital imaging processes such as inkjet and dye sublimation. While it might sometimes be beneficial for text and graphics, the high pass filter characteristics of the electrophotographic imaging process will amplify the inherent image noise and increase the overall graininess of the reproduced output. As a result, it is necessary to optimize the sharpness performance while minimizing the adverse effect of granularity for the dry electrophotography imaging process to expand into photo applications with the most stringent demand in image quality.

Unlike many D_0 artifacts, the pixel locations of the halo artifact induced by the *Fringe Field effect* is image dependent and can be precisely predicted by an image analysis algorithm. Furthermore, the effect on the image quality degradation can be described as a local tone reproduction curve variation where the immediate edge pixels neighboring the image areas with higher toner coverage exhibit lighter mid-tone reflection density as illustrated in Figure 2. The deviated tone reproduction curve can be experimentally determined. As noted previously, the modification of the tone reproduction curve needs to satisfy two boundary conditions where the normal tone reproduction curve, TRC_n, and deviated tone reproduction curve, TRC_d, converge at two end points with code values being 0 and 255 in an 8-bit digital imaging system.

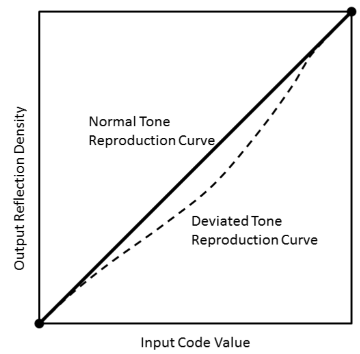

Figure 2. *Fringe Field effect on Tone Scale*

Proposed Algorithm

While realizing that the *Fringe Field effect* is a physical phenomenon that varies continuously, we will first make two simplifications about its impact on the local tone reproduction curve variations to achieve an efficient correction algorithm implementation:

1. All image pixels $I(i, j)$ are classified into two categories, where x_n is the normal pixel and x_d is the pixel affected by the *Fringe Field effect*.
2. Only one TRC_d is required to describe the reduction in the reflection density on $x_d(i, j)$.

Consequently, we can formulate this image-based tone scale variation correction as a simple hypothesis testing between the null hypothesis x_n and the alternative x_d [12]. Let x be a independent random variable drawn from an image that is described as a random field, χ, with probability distribution $P(x \in \chi)$, and y is the class label of $Y = \{x_n, x_d\}$ with the the probability distribution $P(y|x)$. The objective is to find an optimal prediction function $h : \chi \to Y$ that minimizes the overall loss $L(y, \hat{y} = h(x))$. Assuming the null hypothesis is x_n,

$$L(y,\hat{y}) = \lambda_1 R_I(\hat{y} = x_d | x = x_n) + \lambda_2 R_{II}(\hat{y} = x_n | x = x_d). \quad (1)$$

R_I and R_{II} are the *Type 1* and *Type 2* error while λ_1 and λ_2 are the corresponding costs. Perceptually, R_I represents overcorrection and it might create darker outline along the image edges, increase image noise, broaden the line thickness, etc. Conversely, R_{II} means that no correction is performed by the algorithm. The proposed intelligent image rendition algorithm needs to operate on all input files with no user interference; hence, the cost λ_1 associated with R_I should be much larger than λ_2. It has been shown that the simple hypothesis testing can be solved optimally with a thresholding operation while the threshold C is controlled by the ratio $\lambda = \lambda_1/\lambda_2$ [12]. We propose to adopt the magnitude of the local gradient of the image data, $\nabla I(i,j)$, as the measurement for the *Fringe Field effect* with an experimentally determined threshold C.

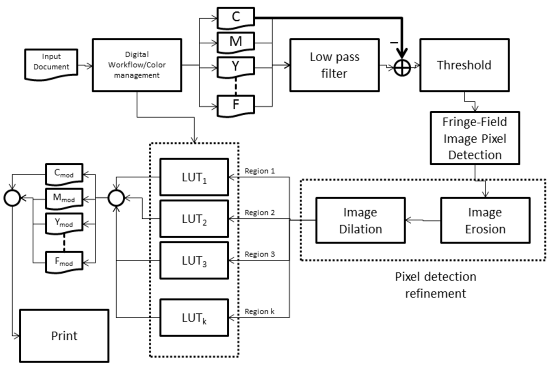

Figure 3. *Intelligent Image Rendition Flowchart*

The intelligent image rendition algorithm is described in Figure 3:

1. The input image first completes the digital workflow and obtains the image data for each primary color separation, $I_c(i,j)$.
2. $\nabla I_c(i,j)$ is derived by subtracting the low pass filter output image from $I_c(i,j)$.
3. Apply a thresholding operation on $\nabla I_c(i,j)$ where the image $I_c(i,j)$ is classified into one of four regions:

   κ_1: $\{(i,j)|\nabla I_c(i,j) > \delta_1\}$
   κ_2: $\{(i,j)|\nabla I_c(i,j) < -\delta_2\}$
   κ_3: $\{(i,j)|0 \le \nabla I_c(i,j) \le \delta_1\}$
   κ_4: $\{(i,j)| -\delta_2 \le \nabla I_c(i,j) \le 0\}$
4. Only the pixels in κ_2 are considered as possible locations impacted by the *Fringe Field effect*. Other regions will play active roles in the following image dilation operation to prevent possible false detection of x_d and increase of R_I.
5. Because of the high cost λ_1 in terms of the image quality degradation, binary erosion operation is adopted to remove isolated pixels in κ_2 to minimize $R_I(\hat{y} = x_d|x = x_n)$.
6. Progressive image dilation is applied to recover the immediate neighboring pixels of $(i,j) \in \kappa_2$. Pixels belonging to κ_1 and κ_3 are excluded in this operation. The number of operations is controlled to reflect the range of the *Fringe Field effect*, which can be affected by the printing speed, halftone selection, etc.
7. The code value of every pixel $(i,j) \in \kappa_2$ is modified to compensate for the deviated tone reproduction curve on that image location.
8. The modified image $\hat{I}_c(i,j)$ for each primary color channel is sent to the digital printing press.

The image erosion and progressive dilation operations in step 5 and 6 can also be accomplished by the level set method with appropriate speed vectors [13, 14].

Experiment Results

The lefthand image in Figure 4 shows the original input image and the righthand image is the result of the proposed intelligent image rendition algorithm. The pixel code values along the border of the font b with lower cyan toner coverage are increased slightly while the pixels inside the font remain the same. The increment of the code value is controlled by the LUTs from each primary color channel as shown in Figure 3. Figure 5 shows the comparison of the final printed output between the standard and corrected input images. The halo artifact around the printed font b is perceivable when printed under the standard process; however, it disappears when the corrected image is printed, which demonstrates the effectiveness of the proposed intelligent image rendition algorithm. We can also notice that the perceived font size and stroke width remain the same.

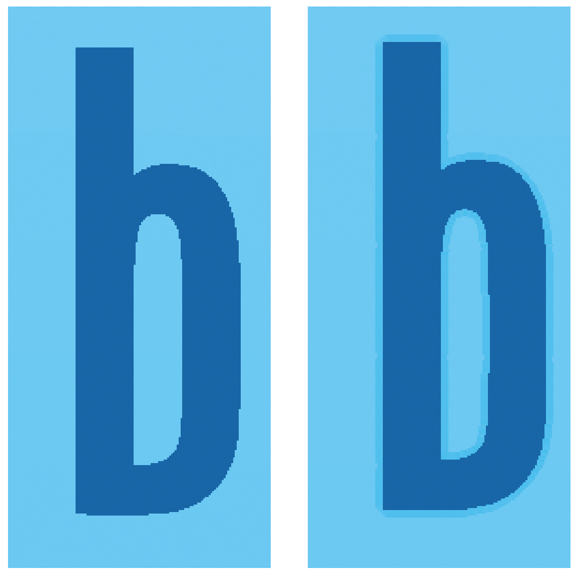

Figure 4. *The input image before and after correction*

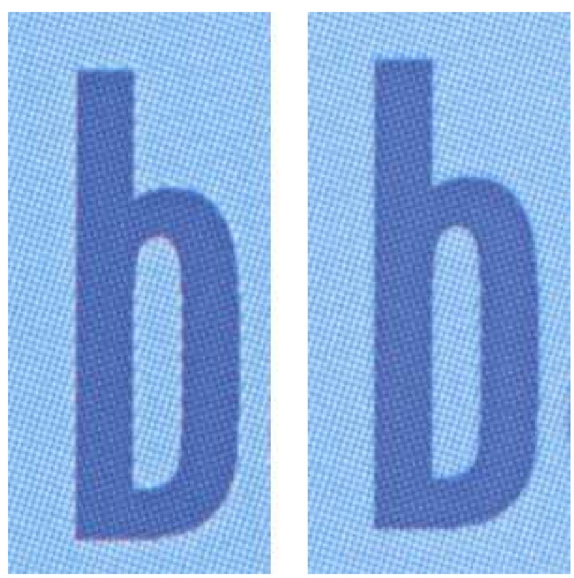

Figure 5. *The output image before and after correction*

In order to illustrate numerically if the proposed algorithm successfully minimizes the halo artifact, a test target with two edge transitions, as shown in Figure 6, is printed where a dark-to-light transition is at the front and the light-to-dark transition is in the rear section. The measured edge profiles of the scanned images is shown in Figure 7. While the reflection density on the lighter side of flat field reduces under the standard printing mode, Figure 7 clearly demonstrates the minimization of the halo artifact by applying the proposed correction algorithm.

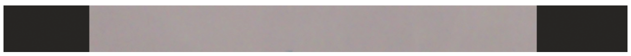

Figure 6. *The input bi-level flat field*

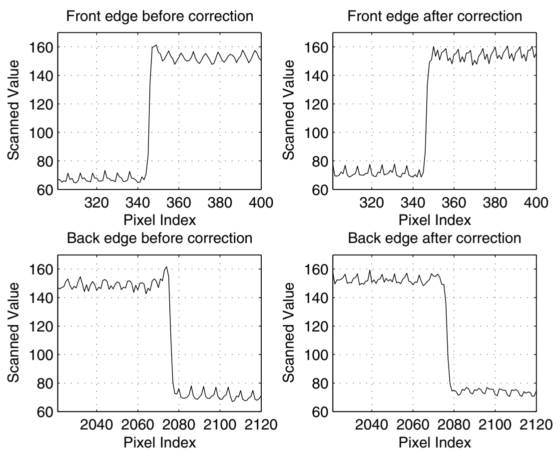

Figure 7. *The output profile before and after correction*

Conclusion and Future Work

A robust intelligent image rendition algorithm is proposed to address the halo artifact created in the electrophotographic imaging process with no operator interference while satisfying other constraints, such as computational efficiency, consistent line thickness, font sizes, and image structure. Examples are shown to demonstrate the effectiveness of the proposed algorithm in addressing the halo artifact and it has recently been deployed in a commercial printing press as a job ticket option. Because this process is applied on each image separation after the color workflow, it can be easily extended to a digital printing process with more than standard CMYK process.

References

[1] Woonyounf Jang and Jan Allenbach, Characterization of Printer MTF, J. Imaging. Sci. and Technol., Vol 50, No 3, pg.264-275, (2006).

[2] T. Iwamatsu, H. Hirakawa, H. Nakaya, and T. Yamanaka, Banding Machanism Caused by Self-Excited Vibration in a Contact Development System, J. Imaging. Sci. and Technol., Vol 50, No 3, pg.276-281, (2006).

[3] Lalit K. Mestha and Sohail A. Dianat, Control of Color Imaging Systems, Analysis and Design, CRC Press, 2009.

[4] Chunghui Kuo, Adaptive digital press optimization via intelligent calibration system, IS&T NIP27,pg. 590-593, (2011).

[5] Howard Mizes, et. al., Automatica density control for increased print uniformity and printer reliability with inline linear array sensing, IS&T NIP24, pg. 206-210, (2008).

[6] R.M. Schaffert, Electrophotography, Focal Press, second edition, (1975).

[7] L.B. Schein, Electrophotography and Development Physics, Laplacian Press, second edition, (1996).

[8] Yongtai Zhang, Shihong Deng, Zhihong Liu, and Minhui Wu, Printing Quality Enhancement of Printhead Defects in Single-pass Inkjet Printing, IS&T NIP30, pg.104-107, (2014).

[9] Chiseki Yamaguchi and Manabu Takeuchi, Influence of Toner Shape and Size on Electrophotographic Image Quality, J. Imaging. Sci. and Technol., Vol 5, No 5, pg.436-440, (1996).

[10] Shu Chang and Peter Paul, Effect of Ink Drop Coalescence on Print Quality in Solid Ink Printing, IS&T NIP20, pg. 429-434, (2004).

[11] Stephen Palmer, Vision Science, Photons to Phonomenology, The MIT Press, (1999).

[12] George G. Roussas, A Course in Mathematical Statistics, Academic Press, (1997).

[13] James A. Sethian, Level Set Methods and Fast Marching Methods: Evolving Interfaces in Computational Geometry, Fluid Mechanics, Computer Vision, and Material Science, Combridge University Press, (1999).

[14] Chung-Hui Kuo and Ahmed Tewfik, Multiscale sigma filter and active contour for image segmentation, IEEE ICIP99, Vol 1, pg.353-357, (1999).

Author Biography

Chunghui Kuo is a senior scientist at Eastman Kodak Company. He received his Ph.D. in Electrical and Computer Engineering from the University of Minnesota and joined Kodak in 2001. His research interest is in image processing, image quality, blind signal separation and classification, and neural network applied in signal processing. He is a distinguished inventor of Eastman Kodak Company, a senior member of the IEEE Signal Processing Society and a member of IS&T.

Horia Neamtu is a 1988 graduate of Purdue University with a BS degree in Electrical Engineering. He joined Kodak, working on image processing software for MIMD computers with 100+ CPUs and earning a US Patent for efficient image data distribution in ring connected multi-processors. Later in his career, he transitioned to working on software for Digital Front Ends for various classes of printers at both Xerox and Eastman Kodak Company. His interests include distributed computing and variable data printing.