Automatic Density Control for Increased Print Uniformity and Printer Reliability with Inline Linear Array Sensing

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Abstract

Color electrophotographic printing requires consistent and uniform color within a single page. One approach to increase and maintain uniform color is to measure any residual nonuniformity and then adjust the image to compensate for it. To make this measurement, we develop a test pattern consisting of a series of different density strips with fiducials to identify the position along the strip. The strip can be printed on a surface in the machine such as a photoreceptor belt. An image of the test pattern strip is captured as the strip passes under a linear array detector. The test pattern is cleaned from the belt and thus requires no user intervention to monitor. The density of toner as a function of position is extracted from the linear array response. From the toner density profile and the engine response curve, the gray level needed to compensate for any nonuniformity can be calculated. The change in the gray level is injected into the image path, so that the digital image is modified in a way to exactly compensate for the varying engine response. Control techniques maintain the uniformity throughout long prints runs.

Introduction

Producing uniform color prints require the performance of the marking engine to not vary across the page. However, streaks are inherent in most printing processes. The spot size of the exposure device may vary slightly as it sweeps across the photoreceptor. The efficiency of charging, development, and transfer might have local variations as the surfaces and materials involved change their properties. As the parts age, more streaks may occur which must be resolved with operator intervention or a service call.

The iGen4 contains an auto density control feature to obviate streaks which leads to more uniform prints and reduced press maintenance. Auto density control is enabled by the use of an inline full width array (FWA) sensor which monitors the presence of streaks while the press is running. Streaks are monitored by printing a series of patches of different densities and colors that span the length of the photoconductor. If a streak or a density variation is detected, a correction is made to the image path by changing the digital gray level in the vicinity of the streak. The resulting size of each halftone dot is chosen to exactly compensate the decreased local dot gain which is the cause of the streak.

Figure 1 illustrates the concept. Suppose the printer not functioning optimally such that when an image is printed it results in streaks parallel to the process direction. The streaks can be eliminated if the digital image is first modified so that locations where light streaks occur are made darker just enough so that when the image is printed, the desired print density is made. In general, for any streak profile (density variations from one side of the page

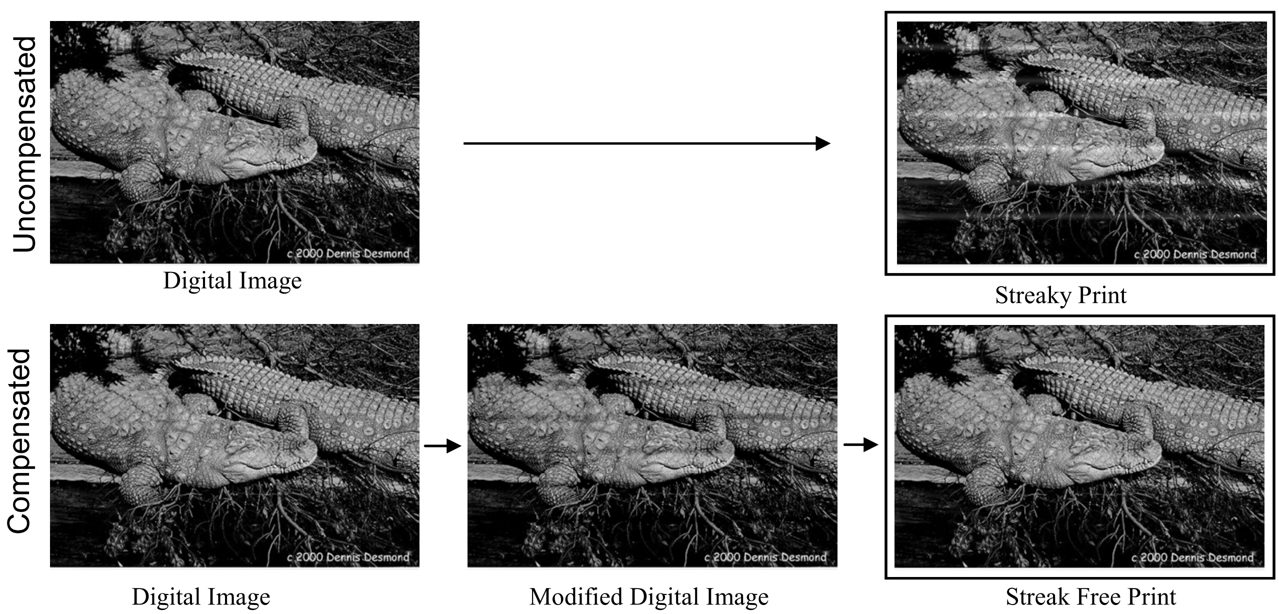

Figure 1 – Top: illustration of perfect digital image resulting in streaky print. Bottom: Illustration of modification of original digital image to produce streak free prints. Auto Density Control determines the correction automatically without making prints.

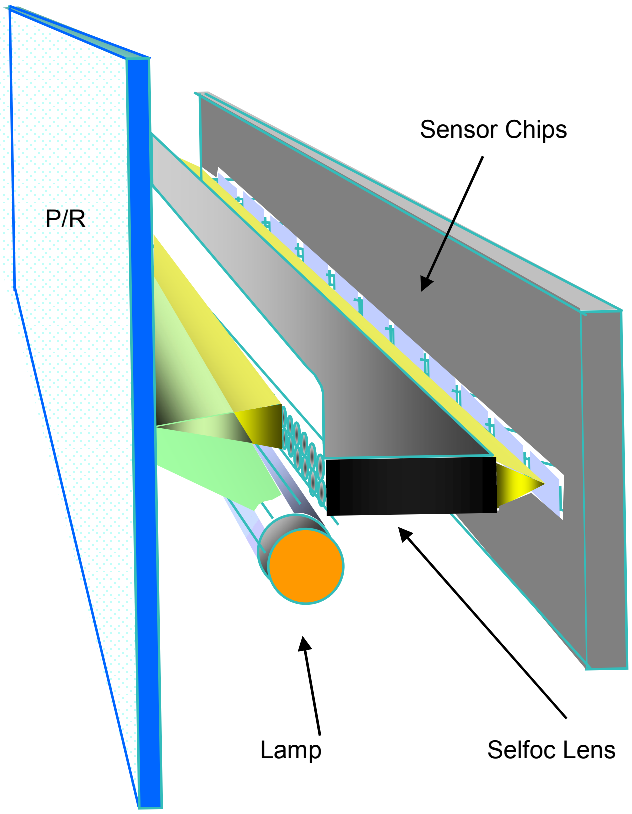

Figure 2 – Inline full width array imager

to the other, random noise), the digital image can be modified in a way to balance these variations and give a streak free print. If these density variations can be detected automatically with test patches, then printed images will remain streak free.

In this paper, we describe the technical challenges and solutions that enable auto density control. These technical challenges occur in the sensing of the uniformity on the photoreceptor, the control algorithms which calculate the compensating gray levels, and the way the image path is modified to change the gray levels across the process. We show that the use of auto density control leads to improved uniformity across the page and an increase in productivity because of extended part life.

Inline Sensing

Auto Density Control prints uniformity patches as the press cycles up and throughout the run of the press in the space between the sheets of paper. The patches pass under the inline FWA for measurement and then removed by the cleaner so that they are never printed.

The FWA consists of a series of photosensitive elements at a spacing of 600 spots per inch. A typical application of a FWA is as the sensing element in a scanner, where it operates in diffuse mode. In diffuse mode, the media is illuminated at an angle and the sensing elements are normal to the media. However, the photoreceptor surface is smooth and does not diffusely scatter light. Therefore, the FWA is used in specular mode, where the illumination angle and the detection angle are equal, as illustrated in figure 2. When there is no toner on the surface, the incident light is reflected into the sensors giving a high signal. The presence of toner on the surface scatters light away from the sensors and the signal decreases. The sensed light decreases monotonically with toner density and this provides a measure of the toner density on the photoreceptor surface.

Four major technical challenges must be solved in order to sensor variations of toner density with sufficient accuracy. These challenges include compensating for photoreceptor structure, spatial nonuniformity in the FWA and the image, skew of the FWA, and halftone descreening.

Unlike paper, the photoreceptor does not necessarily have to have an optically uniform surface. Figure 3 shows a contrast enhanced image of a bare photoreceptor surface and the same surface with the uniformity patch. One can observe local variations in surface reflectivity which is likely due to surface topography. These reflectivity variations are removed by measuring the patch in two steps: a calibration step and a normalization step (figure 4). In the calibration step, a bare area of the belt is first measured to determine the gain and offset of each pixel in the FWA. Following that, the entire bare photoreceptor is imaged and stored. Each time a uniformity patch is measured, it is normalized by taking the ratio of the profile of the patch to the profile of the bare belt. Structure on the order of 2 gray levels is observed. The center plot shows the same region of the belt when a 12.5% area coverage halftone patch has been imaged. The same structure is reproduced along with true density variations. The ratio of these two profiles is plotted in the lower plot. The belt structure is eliminated, leaving the true patch density variations.

Compensation of streaks requires its location to accurately be measured. However, slight spatial variations and nonlinearities in the FWA and the printing process may lead to slight errors in determining the streak's location. These problems are solved by the use of fiducials. Test patch fiducials are the dark series of squares at the top of the patch in figure 3. In processing the patch, the profile of a cross section through all the fiducials is calculated and the center of each fiducial is identified. With the center locations, the density profile can be mapped from FWA space to digital image space, thus giving the location of any streak to the nearest pixel.

Sensor skew occurs if the inboard side of the FWA is not aligned with the outboard side. The consequence of skew is that the captured image is skewed. Image processing can make sensing the profile robust to image skew. A periodic pattern at the fiducial frequency is searched for line by line. If the image is skewed, this periodic pattern will first be detected on one side of the image and

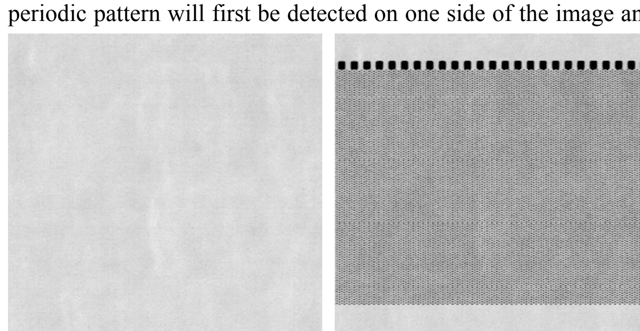

Figure 3 – Same area of photoreceptor surface with and without uniformity patch. Size of image is .7x.7 inches.

then the other. The profile is accumulated relative to the top of each fiducial. This technique also makes the image processing robust to variations in the trigger which starts the image capture and isolated structure on the photoreceptor that might be misidentified as a fiducial.

The patch is halftoned in the same way as an image. The halftone must be low passed filtered so that the space between the dots is not identified as a very narrow streak. The filter is optimized to give the best performance between halftone descreening and the ability to eliminate narrow streaks.

Control

The FWA can sense relative changes in toner density across a uniformity patch. The goal of the control algorithm is to determine how much the gray level must be changed locally in order to compensate the presence of a streak. The response of the printer is described by a spatial Engine Response Curve (sERC) and the gray levels to compensate for streaks are given by a spatial Tone Response Curve (sTRC).

Figure 5 gives the response of the FWA to 8 different patches measured at 8 different gray levels between 32 (area coverage=12.5%) and 255 (area coverage=100%). These profiles show an increase in print density (decrease in sensor reflectance) at the right side of the print. At each position in the cross process direction, the response of the FWA as a function of gray level is defined as the local ERC.

The physics of the xerographic process dictates that variations in the sERC will be highly correlated as a function of gray level. However noise in the measurements of the density of each patch might produce some slight uncorrelated variations. These variations are eliminated by performing singular value decomposition (SVD) of the matrix where the rows are spatial location, the columns are the gray level, and the elements are the SVD response. The first few principle components of the SVD are extracted and the smoothed ERCs is reproduced for a more accurate measurement.

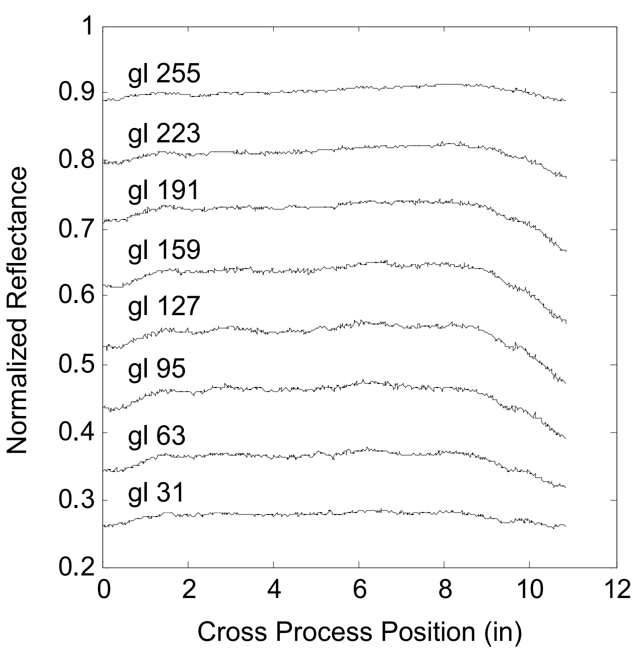

Figure 5 – Normalized uniformity profiles at different gray levels.

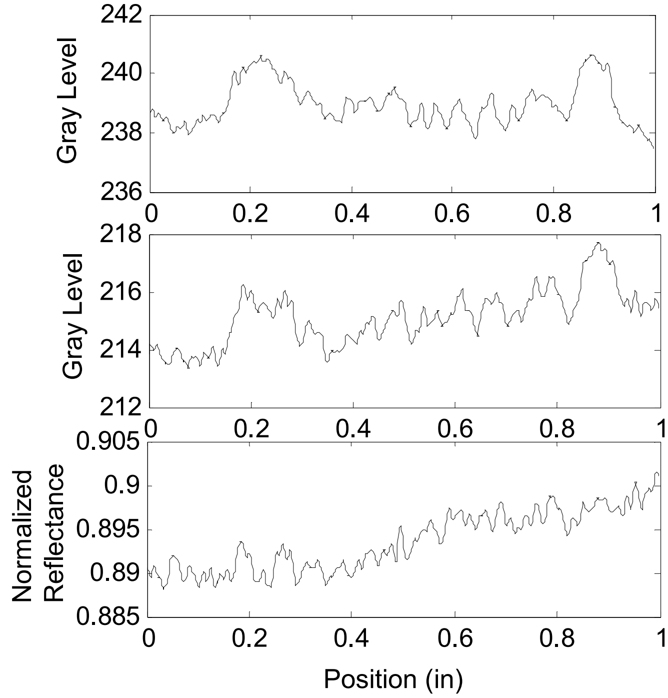

Figure 4 – Section of patch profiles: Top – Bare photoreceptor calibrate profile, Middle – 12.5% area coverage halftone calibrated profile, Bottom – 12.5% area coverage halftone normalized profile.

Throughout long runs the sERC may change which if left uncompensated would lead to streaks and maintenance of the press. In auto density control, patches of different densities and colors are continually printed and monitored. When a new patch is printed, it replaces the earlier patch and the calculation of the sERC is updated.

Actuation

In printers, the number of pixels turned on in the digital pattern is not proportional to the developed density. This observation is remedied by choosing a set of digital area coverages for each input gray level that corresponds to the desired printed density. In auto density control, this change is made locally. If the FWA detected a light streak at a particular location, the gray level at this location is made darker so that the resulting print is free of streaks.

This concept is illustrated in figure 6. Suppose the solid dark line is the desired engine response curve, and the thin line is the engine response curve at one particular location in the cross process direction. A pixel at gray level 150 should cause enough development to give a FWA sensor response of 0.7, but at that particular location, the response is only 0.55. From these measured curves, one can determine that increasing the gray level from 150 to 205 will bring the reflectance back up to 0.7, and there will be no perceptible streak.

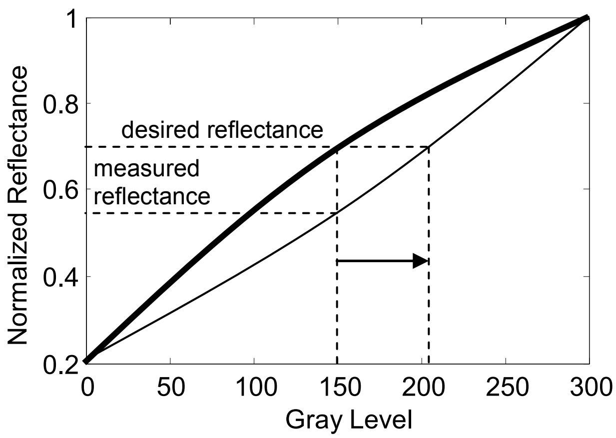

Figure 6 – Schematic illustration of streak compensation.

The sTRC is described by a matrix of 256 by N points, where N is the number of locations where the sTRC is described. For each gray level in an image, this gives a lookup table on how the gray level should be changed. This matrix can be quite large. For a 14 inch wide process with the ability to correct streaks a narrow as 1/100 inch requires 1400x256 points.

However, there is a high correlation between the elements of the sTRC. SVD is used to reduce the amount of information. The largest principle components of the sTRC are calculated in the same way as for the ERC. To implement the sTRC, only the few dominant sTRCs (the basis vectors) and the multiplier of this sTRC at each point in the cross process direction (the weights) need to be passed to the image path. Each pixel in the image is modified real time in the image path according to the appropriate basis vectors and weights before it is halftoned.

There is a potential for the application of s-TRCs to introduce contouring artifacts in uniform colors if changing the gray level by 1 gives a perceptible transition at the boundary. This transition may be more objectionable than the streak. To mitigate this issue, the desired gray level is calculated at a higher resolution than the capability of the printer. At each position in the cross process direction, the printed gray level is either rounded up or rounded down, with the probability of rounding up proportional to the fraction part of the gray level. For example, a gray level of 10.2 will round up with a 20% probability and round down with an 80% probability. This procedure has the effect of smoothing out the transition between gray levels and eliminating any potential for contouring.

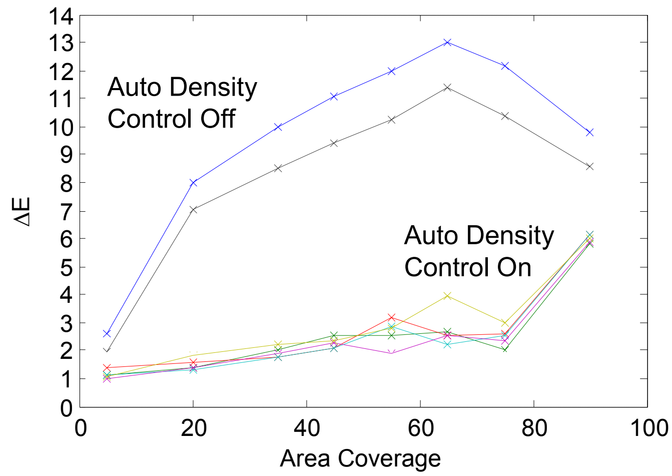

Figure 8 – Maintenance of uniformity over long runs.

Results

We demonstrate the effectiveness of auto density control with some example measurements. These measurements were performed on an experimental press where the various subsystems were intentionally moved away from their best operating range to demonstrate how auto density control can restore their functioning.

Figure 7 shows one example of the application of auto density control. The parameters of one of the subsystems were intentionally changed to introduce low frequency streaks with a period of approximately 2 inches. This streaking is seen in a measurement of the CIELAB L* coordinate measured with a flatbed scanner plotted as a function of position. When auto density control was turned on, the streaks were eliminated and a uniform profile was again achieved.

Figure 8 plots another example of how auto density control can restore uniformity across all area coverages. Again, many subsystems were intentionally put into a failed state to produce a poor uniformity. Here, we plot the CIELAB ΔE, where ΔE represents the maximum change in color from a measurement across the process direction. The measurement was made at different times during a long run of the press. Two measurements were also made at the beginning of the run and the end of the run with auto density control off. One observes that auto density control can maintain good stable uniformity across long runs.

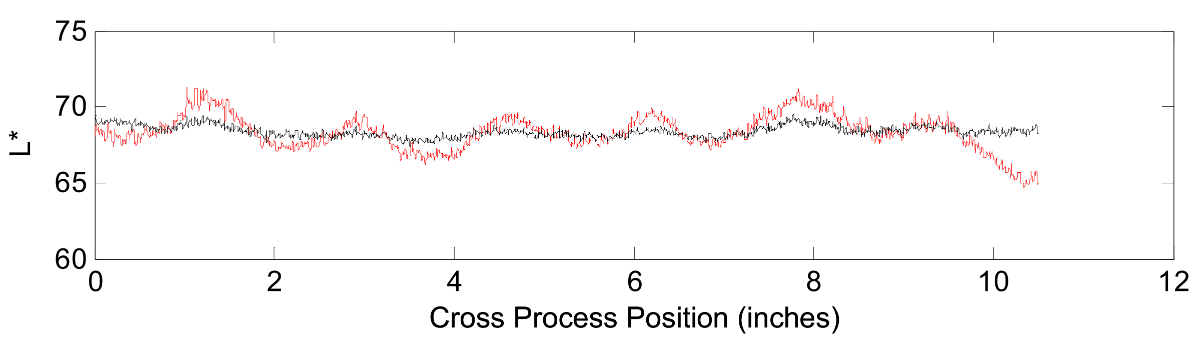

Figure 7 – Experimental demonstration of the elimination of streaks by the application of auto density control.

Conclusions

Maintaining high quality uniform images over long runs is an important requirement for production printing. Auto density control is a technique that incorporates inline sensing, control and actuation to learn that streaks might be occurring and to obviate them without the necessity to stop printing. Incorporating a full width array sensor in the marking engine allows the entire image to be monitored and not just isolated patches. Because of this capability, parts and subsystems that would normally be replaced because they were degrading image quality can continue to be used.

Author Biography

Howard Mizes received his BS degree in Physics from the University of California at Los Angeles in 1983 and his Ph.D. degree in Applied Physics from Stanford University in 1988. Since 1988, he has been with Research and Technology at Xerox Corporation, where he is a Principal Scientist. Dr. Mizes' research has been primarily focused on understanding and controlling the process physics of xerographic printing, and quantifying and improving the resulting image quality. He has worked in the areas of charge transport and contact charging, particle adhesion measurements and modeling, and experimental probes of the xerographic development process. His image quality work has focused on improving the spatial uniformity of the printed page. e-mail: howard.mizes@xerox.com.