Custom Color Printing With Liquid Toners

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Abstract

Custom Color Printing refers to printing a customer-selected color as a solid area using a single toner or ink, rather than as a halftone of process colors. One example of custom color is the Pantone Color Matching System, containing ~1000 precisely defined colors mixed from a set of 11 primary colors. Electrophotographic custom color printing requires mixing two or more colors from a set of primary toners and requires that the primaries have equal developabilities to prevent differential development and the resulting color shifts over long runs. Liquid toners meet the first of these requirements, but in a long run even very small differences in developability will lead to concentration changes in the toner supply and shifts in printed color. To compensate for those variations, the mixed toner in the developer housing can be replenished in a way that keeps printed color constant. In this paper we outline a differential replenishment method using feedback from various sensors. We describe in detail a simple close feedback loop control scheme that maintains color consistency throughout long print runs and also enables on-the-fly color changes. Applications for this technology include digital printing of black and one or two spot colors which is widely used in offset printing, e.g., packaging, forms, and event flyers.

Introduction

Combinations of the four colorants that form the base of the printer's primary palette cannot adequately represent the color of most of what we see in the world. This becomes important because color is evocative and can modify behavior. Studies of consumer behavior associate color preference with demographics and purchasing decisions. Correct use of color can produce higher response rates to direct mail advertising and even greater on-time payment rates in billing applications. Corporate identity campaigns frequently control color explicitly in an effort to evoke a powerful connection between a visual experience and brand identity. Commercial printing typically uses custom colors to supplement the process color gamut (colors printed by overlapping halftone patterns of cyan, magenta, yellow, and black). As an example of custom colors, the Pantone® system makes about 1000 custom colors by mixing 2-4 primary inks from a set of 18 primaries. About half of these colors are outside the process color gamut. Toyo Ink and several other companies offer similar systems. Because custom colors are printed as a solid, continuous ink layer, even colors within the process color gamut are less subject to problems caused by mis-registration, Moiré, and the stack-up of individual color variations.

Liquid xerographic toners can be combined in the same way that printing inks are combined.[1] Charging of liquid toners is controlled by a chemical reaction between a charge control agent bound to the particle and charge director molecules suspended in the carrier liquid. This makes it possible to adjust the CCA of each component so that all components will have approximately equal charge to mass ratios and mobilities, thereby making all component developabilities approximately the same. However, if a fixed supply of mixed toner is used any differences in component developability will lead to continuous changes in the ratio of components in the toner supply and resulting changes in the printed color. This issue is demonstrated in the work reported by P. E. Materazzi.[2] Here it was shown that precise formulation resulted in toners using different pigments that had essentially identical Q/M's (within 1%). Blends of these toners were shown to develop the desired mixed color, however, with print runs of less than 1000, color variation approached $\Delta E = 1$. In an example where the Q/M's were different by about 5% the ΔE exceeded 3 at 700 prints. Differential replenishment was noted to be a possible solution to enable long print runs.

Therefore, a robust toner supply control system for a mixed liquid xerographic toner must add individual components as they are depleted by development. This control system must allow for some differences in the development rates of the different components (e.g., due to manufacturing variations, changes in temperature and humidity, etc.). Over the last few years our group has developed a variety of *in-situ* color mixing systems, sensing color at different points in the printing process, using a variety of sensors and control algorithms.[3-8] In this paper we describe the simplest of these control systems, one that senses and keeps constant the color of the mixed toner supply using sensors based on light transmission through the toner. In particular, we describe a simple light analyzer sensor that consists of a small number of filtered photodetectors.[5] This system is combined with other controls[7] to keep the final printed color constant. And it can be used to control in-machine mixing of primary colors to make each user-selected custom color.

Color Mixture Control

Liquid toner replenishment systems measure properties of the toner supply, (such as conductivity, volume, or opacity) and add components (such as charge director, carrier, or concentrate) to keep the supply's properties constant in time.[9] Additions are made by opening a valve for a predetermined length of time, thus adding a known volume. Similarly, adjustments to a mixture of colors can be made by adding predetermined volumes of the component concentrates. Since the weight percent solids of each concentrate is known, it is convenient to calculate and to control the weight percent solids, denoted w_i, of each component. The sum of the w_i is typically in the range 1-3%. The control system adds individual components as needed to achieve a target set of ratios, w_2/w_1, w_3/w_1, …, w_N/w_1 while keeping $W = \Sigma w_i$ as close as possible to its target value. The problem becomes one of estimating the changing w_i due to printing and replenishment.

One method[5] of calculating the w_i is to pass white light through the toner and then through a set of filters. The intensity of the light that passes through each filter is measured and the w_i are calculated by matrix multiplication

$$w = A\, s$$

where $\underline{\mathbf{w}}$ is the array of N weights, w_i, $\underline{\mathbf{s}}$ is the array of M signals, s_j, and $\underline{\underline{\mathbf{A}}}$ is an NxM matrix. The matrix elements may be calculated from the transmission spectra of the toner components and of the filters assuming some optical model. An approach is to use Beer's Law as a zero order approximation to describe the transmission properties of the liquid toner dispersion. Alternatively, the matrix elements may be obtained empirically.

Modeling Results

To see how well this method can be used to estimate w_i, we used Beer's Law and estimated the transmission spectra for 70 mixtures of 6 primary colors. The primaries are similar to the Pantone® Yellow, Warm Red, Rubine Red, Reflux Blue, Process Blue, and Green primaries. Each mixture is made from 2-3 primaries and has a total W = 1 wt%. Component concentrations differ from one mixture to another by as little as 0.01 wt%. Filter responses were modeled by ideal Gaussian transmissions. That is, each filter is specified by its wavelength for 100% transmission and its full width at 50% transmission.

a. Filter Set Optimization

We initially used an equally spaced set of 625 nm wide filters to span the range of visible colors. The filters are centered at 425, 475, 525, 575, 625, and 675 nm. We calculated the transmission of each component through each filter and inverted them to obtain **A**. Then we calculated a set of signals, **s**, for each of the 70 mixtures and calculated 70 sets of weights, **w**. This led to some negative w_i and to positive w_i for components that were not in some of the mixtures. Of course, *a priori* knowledge of the components used to make each mixture can be used to set these w_i to zero. With this correction the RMS error was 0.36 wt%. This value is too large to provide the fine control required for custom color.

We then adjusted filter positions and widths and repeated this procedure. After several iterations we found the set shown in Table I that yield a 0.20 wt% RMS error. This may be sufficient for crude color control for some applications but is still too large for fine printing. This procedure yields a filter set that is optimized for the set of primary colors used. For different primaries, or for additional primaries, a different filter set would be optimized.

Table I. Optimized Filter Set

Center (nm)	400	430	510	570	630	700
Width (nm)	25	25	25	25	50	10

b. A_{ij} Optimization

Instead of trying to find the A_{ij} by direct calculation it is possible to determine them empirically. We used the Solver tool in Excel to adjust the A_{ij} for the filter set in Table I until the RMS error for the 70 sets of weights was minimized. This yielded an RMS error of 0.040 wt%. This procedure yields A_{ij} that are optimized for both the primary colors used to make custom colors and the set of filters chosen.

c. A_{ij} Segmentation

Even greater precision can be achieved by using *a priori* knowledge of the components used to make each mixture. It is no longer necessary to use a single 6x6 matrix to calculate all weight sets. Instead, different $\underline{\underline{\mathbf{A}}}$ matrices are used for each set of primary colors. The results shown in Table II are accurate enough to distinguish clearly each custom color in our set from all other colors. This process could in principle be extended to produce a JxM matrix, $\underline{\underline{\mathbf{A}}}$, for each target color, where J is the number of primary colors used to make the target color. Of course, the actual optimization of all the A should be done with data from the real optical system and would be specialized to the light source, etc.

Table II. Performance

Colors	Number of Mixtures	RMS Error
Yellow, Warm Red	13	0.001 wt%
Yellow, Rubine Red	8	0.001 wt%
Warm Red, Rubine Red	6	<0.001 wt%
Yellow, Rubine Red, Process Blue	6	0.006 wt%
Process Blue, Green	7	0.001 wt%

System Performance

System performance simulations were carried out using the system depicted in figure 1.

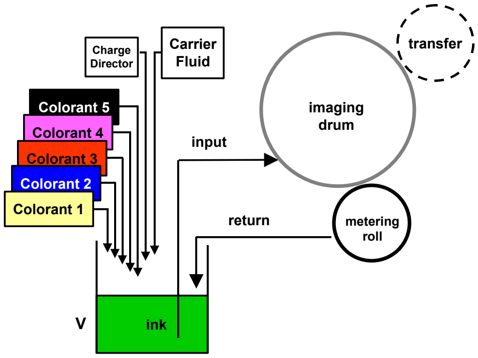

Figure 1. Schematic of the liquid ink delivery system and printing engine.

Figures 2 and 3 show the results of print simulations with and without differential replenishment. These simulations include a close feedback loop controller using the above described sensor, input from two ink primary sources with one component having twice the developability of the other. About 20,000 prints were simulated at 120 ppm and 5 % area coverage.

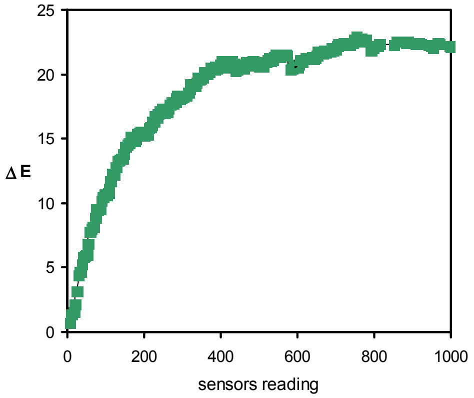

Figure 2. Results of the print simulations for color changes during 20,000 prints without differential replenishment.

Figure 2 shows that the color changes as the higher developability component is depleted from the sump. The system reaches steady state behavior for $\Delta E > 20$. Figure 3 shows both initial ink mixing and printing. Our sensing control scheme enables both accurate sump preparation and long run color stability with $\Delta E < 2$.

In summary we have shown a simple method of accurately sensing and controlling liquid ink supply for custom color printing. These sensing and control scheme solve both issues of precise sump preparation and long run color stability.

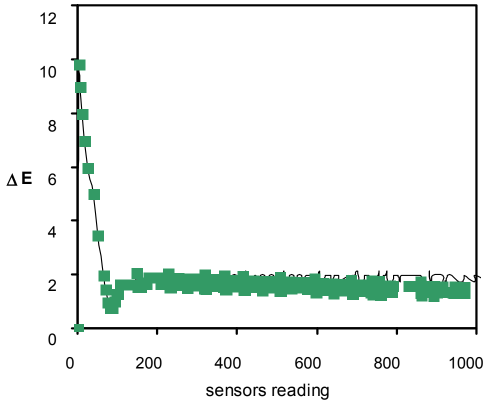

Figure 3. Results of the print simulations for color changes during sump preparation and 20,000 prints with differential replenishment.

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Biographies

Ed Caruthers has a Ph.D. in theoretical Solid State Physics from U. Texas, Austin. He has worked in the area of liquid Electrophoretic printing at DuPont, DX Imaging, AM Graphics, and Xerox. Previous papers for IS&T's 8th, 10th, 14th, and 15th meetings concerned liquid ink formulation, toner charging mechanisms, toner control systems, Electrophoretic development, metering, transfer, and image quality.

R. Enrique Viturro, Ph.D. Technion, Israel, is member of the Wilson Center, Xerox Corporation. Enrique has been actively involved in R&D on liquid electrophotographic printing, including research on electrical transport properties in colloid systems. He has published 60 technical papers and has over 10 patents in areas of color electrophotography, sensor and controls, media sensing, and printing processes. He is a member of the PRIMA Technical Advisor Committee, University of Minnesota, and has served in the Executive Committee of the NYSS APS.

James R. Larson received a Ph.D. in Chemistry from the University of Washington in 1980, and two years later, after a post-doctoral appointment at the University of Chicago, he joined the DuPont Company. In 1984 Jim became part of a small DuPont team working on liquid electrostatic toner technology. By 1987 this effort grew into DX Imaging, a partnership company parented by DuPont and Xerox, of which Jim was a founding member. Jim joined Xerox in 1991 and continued work on liquid toner technology. Jim has 59 issued US patents and authored 33 technical publications.

George A. Gibson holds an M.S. in Chemistry from SUNY at Binghamton and an M.B.A. from the University of Rochester's Simon Graduate School of Business. He has worked in liquid toner since 1981 managing Toner Development for Savin Corporation, Toner Development and Manufacture for AM Graphics and serving as a Technical Manager and Technical Program Manager at Xerox. George has 36 US patents in areas of liquid toner materials and processes, liquid and dry toner control systems as well as ink jet systems and has authored 32 technical publications.