Doubling the Color Gamut Volume of Ink Jet Prints using Simple Post-Processing

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Abstract

We describe a novel coating process for preserving and enhancing color images from ink jet prints. It involves stabilizing the printed image, followed by selective chemical interaction with the inks. The coating provides liquid, gas and UV light protection. It also changes the way light interacts with the original colorants. Untrained viewers (e.g. ordinary consumers) report the coated images appear more photographic than the original ink jet image. They prefer these images to the originals by a wide margin and report that they would pay up to \$1.00 *per print for them*[1]. *They describe the colors as more luminous and vibrant. To better understand the reaction of these people we have conducted a small study of the spectral properties of the treated images using standard color calibration prints as test samples. Measurements of the treated samples and their comparisons with untreated samples show the method's ability to enlarge the gamut's volume up to at least the double size of the initial color gamut volume.*

Introduction

Ink jet printing is widely used for creating low cost, photo-like or photo-realistic prints. Enormous improvements in the quality of these printers have been achieved in nearly every new generation of ink jet printers. In general, these improvements require use of specialized inks, a wider variety of inks and the use of specialized substrates [1, 2, 3, 4, a.o.].

Our approach is somewhat different. It derives from several years of informal, private studies and experimentation to improve the quality of ink jet prints. We have focused on using the lowest cost and simplest inks and substrates available[2]. We believe our studies apply to a broad range of printing processes, beyond Ink Jet.

The concept generally relates to a novel coating process intended to enhance the lifetime and color image properties of printed images. Our process involves stabilizing the printed image, followed by a selective chemical interaction with the inks. The coating provides liquid, gas and UV light protection. The structure of the coating results in enhanced illumination of the printed image and a resulting change in the appearance of the image.

Treatment Process

Although a variety of methods can be used [5], the fundamental approach is to transfer some or all of the colorants embedded in the substrate of the printed image into a transparent *structured* coating.

[1]Informal reactions from VC bankers and patent agents.

[2]Our** exploration began in 1996 with the purchase of a low cost, older HP Ink Jet printer. To maintain continuity and stability within these studies, it served as the print engine for all subsequent work.

The treatment process described is performed after the image has been printed. A transparent structural polymer layer is applied to the print. It serves a variety of purposes. It is semi-permeable, porous and sponge like. Its structure is used as a conduit through which a second polymeric material is applied to the print. The two are selected so that they do not chemically interact. The second polymer (reflow agent) interacts with the inks in the printed image. The objective is to transfer some or all of the image into the transparent structured covering layers. The first (matrix) layer provides structure to the coating, limiting the transport of inks. This confines the spread of ink. Another objective is to facilitate Gaussian diffusion of colorant to both soften the defined edge of ink pixels and to allow some limited mixing of ink. The objective is to create colorant clouds within the transparent over layer.

The intertwined dual-polymer structure solidifies resulting in a coating that imparts protective properties to and extends the lifetime of the image. The porosity of the first coating provides reservoirs into which colorants diffuse and mix. Doing so changes the optical properties of the image resulting in a dramatic enlargement of the color gamut.

Moving the colorants into the transparent layer modifies the illumination of the inks used to create the image. Those colorants that are transferred into the structured over-layer interact with light via reflection (as is normal for a printed image) and via translucence: light reflected from the substrate passes multiple times through the colorant clouds increasing its luminosity (like a stain-glass window).

The images analyzed in this paper use selective ink interaction. This formulation uses a reflow agent that interacts and transports only the CMY colorants (not black ink). We choose to do so to retain sharp, highly detailed image. In a sense we are merely mimicking methods used for encoding television images.

Television images are encoded and broadcast such that the luminance of the image is more highly sampled and has a higher transmission bandwidth than does the color portion of the image. Separation of color and luminance in broadcast television reflects both historical and psycho-visual factors. The different sampling rates reflect variations in the retinal mosaic and the various roles played by the rods and cones. Our approach merely incorporates these insights into a process for treating printed subject matter.

Experimental and Gamut Volume Comparisons

In order to evaluate the gamut expansion performance of the introduced treatment, three samples of the ECI 2002 target [6] were printed using a HP670C printer in its *draft quality*, economical ink consuming mode. Our choice of printer was predicated on this printers relatively low resolution (300 dpi) and the simplicity of its inks. The ECI targets were printed on A4 sheets

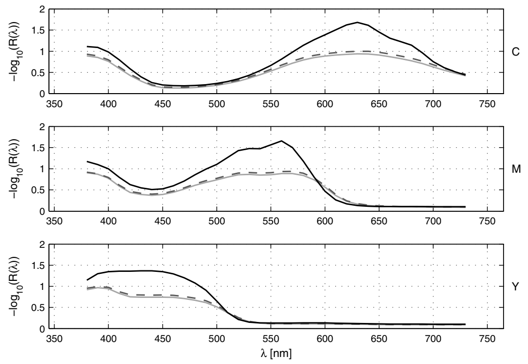

Figure 1. Spectral reflectance density comparisons of the primary (CMY) colors of HP670C prints on plain paper. The untreated colors are depicted by the lowest gray solid lines. The dashed gray lines refer to the samples coated solely by the matrix layer. The solid lines display the density augmentation achieved by the proposed treatment.

of an ordinary office copy type of paper [7]. For evaluations, one of the print samples was coated solely with the matrix layer. A

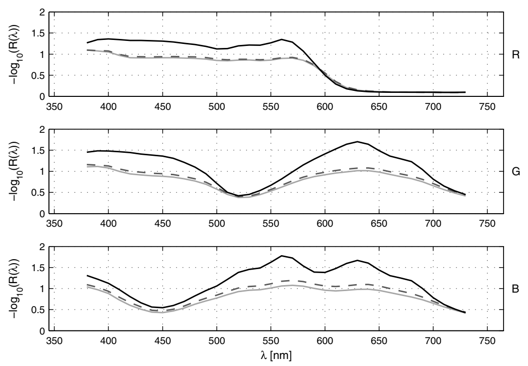

Figure 2. Spectral reflectance density comparisons of the secondary (RGB) colors of HP670C prints on plain paper. The untreated colors are depicted by the lowest gray solid lines. The dashed gray lines refer to the samples coated solely by the matrix layer. The solid lines display the density augmentation achieved by the proposed treatment.

second sample was fully treated with both layers, i.e. matrix layer and reflow agent. The remaining sample was kept unchanged as comparison reference target.

The reflectance spectra of all patches of each sample were measured by using the commercially available spectrophotometer SpectroScan. Fig. 1 and 2 depict the obtained density augmentation achieved by the proposed treatment. On average, the treatment increased the densities by a factor of 1.7. Analyzed on primary color wedges, the effect is almost uniformly observable across the different coverage levels of the halftoned patches as shown in Fig. 3. Hence the whole color gamut of the printer is affected by the proposed process.

According comparisons of the color gamut before and after treatment are illustrated in the *CIE-Lab** space in Fig. 4. For improved visualization, the gamut are projected on the *ab** plane in Fig. 5 as well as on the *La** plane in Fig. 6. These gamut estimations were obtained by using the `quickhull` algorithm [8] implemented in MATLAB, which also returns the volume of the determined convex hull. Table 1 summarizes the obtained results for the three samples described above as well as for an ECI 2002 sample, that was printed as benchmark with the same printer on

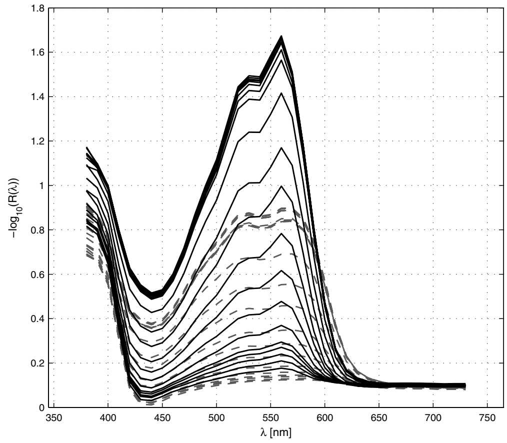

Figure 3. Spectral reflectance density comparisons of a magenta halftone wedge measured before treatment (dashed lines) and after treatment (solid lines).

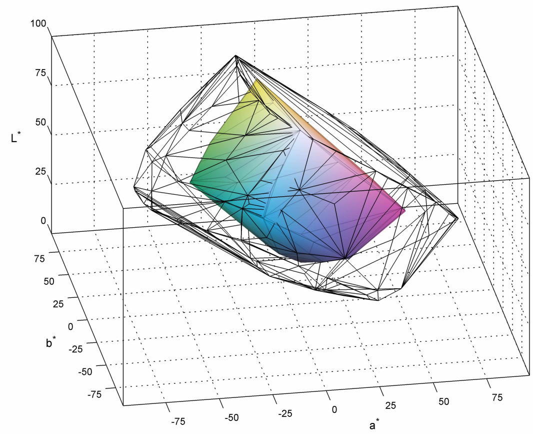

Figure 4. Comparison of the convex hulls surrounding the color loci of the ECI 2002 targets displayed in the Lab* color space. The colored gamut in the center of the graph depicts the measurement of the untreated sample. The measured color gamut of the treated sample is depicted by the enclosing skeleton.

a glossy, photo-quality paper in the best available printing mode. This benchmark sample is listed in the last row of Table 1. The columns of the table list the obtained gamut volumes as well as the colorimetric deviations between the measured data of the respective samples and the data measured from the untreated reference sample.

Conclusion

The print treatment process described is somewhat unusual. Non-expert viewers appear to prefer images treated with this process over untreated images. The colors in the image appear brighter, more vibrant, more luminous than before. The process smoothes out the colorant eliminating any appearance of ink pixels. The resulting image is encapsulated in a protective coating that provides resistance to abrasion, color fading and damage by fluid and UV interaction with its inks.

From a scientific perspective, the ideas explored in this study and the spectral changes measured are provocative and in-

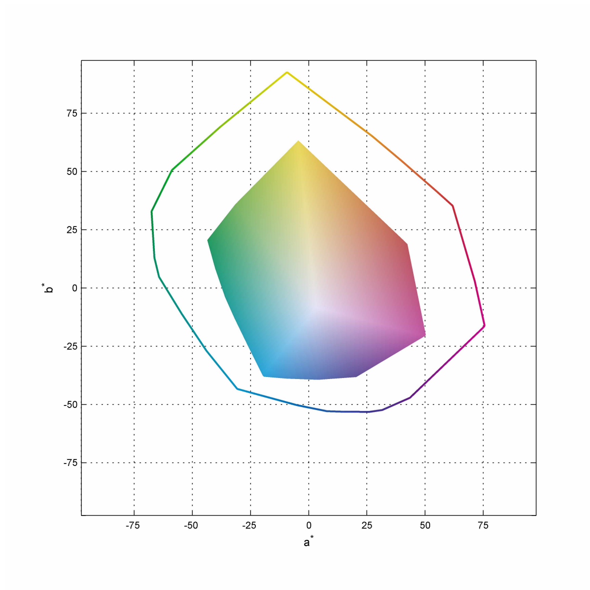

Figure 5. Projection of the data of Fig. 4 on the ab plane.*

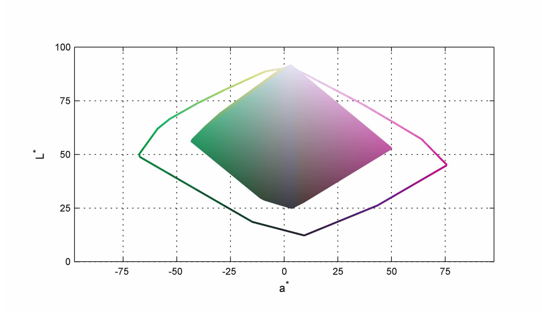

Figure 6. Projection of the data of Fig. 4 on the La plane.*

Sample	$V_{\texttt{qhull}}$	ΔE_{mean}	ΔE_{max}
untreated	$1.6e5$	—	—
matrix coated	$1.8e5$	2.6	8.7
matrix & reflow	**$4.4e5$**	**20.4**	**47.4**
glossy, best-mode	$2.8e5$	15.5	40.8

Summary of the obtained results in terms of the Lab* volume of the convex hull as well as in terms of colorimetric ΔE values. The maximum and average ΔE values corresponds to the colorimetric deviations measured between the patches of the untreated, plain paper samples and the other tabulated samples.

triguing. Clearly a great deal of additional work is required to optimize and tightly control the process. The properties of each polymer and the interactions between them need be optimized. The treatment could be tailored uniquely for different application domains (e.g. newsprint versus high end art books). The process described in this paper uses ink jet prints as an example. Clearly these methods could also be applied to other printing methods. They could result in substantial cost savings. Theoretically, much less ink/colorant would be required to produce excellent color images. Printing time and drying time for prints could be shortened. The uniformity of print images could be enhanced. These issues will require additional study and a thorough analysis of all factors involved in the printing process.

Author Biography

Safer Mourad received the MS degree in electrical engineering in 1993 from the ETH, Swiss Federal Institute of Technology, Zurich and his PhD in computer science from the EPFL, Swiss Federal Institute of Technology, Lausanne. From 1993 to 1997, he developed algorithms for real-time video tracking and high-end surveying instruments at Leica Geosystems. In 1998 he joined the Media Technology Department at the EMPA, St. Gallen. His research interests include colorimetry, mathematical modeling, image processing and real-time control applications. E-mail address: safer.mourad@empa.ch

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