Color Mapping of Continuous Ink Jet Printers Using Non-Linear Masking Equations

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Abstract

In areas of direct-digital color proofing, it is sometimes desirable to remap the color space of the digital color printer to approximate the color space of an analog proof or press sheet. While this color remapping is traditionally performed using three-dimensional tranformations, an alternative approach involves the use of non-linear masking equations.

This paper describes the methods for implementing non-linear equations for digital color proofing. A target proof was generated which contained color patches with various CMYK color amounts. These patches corresponded to specific primary and overprint hue vectors. A second test image was printed on a four-color continuous ink jet printer, and contained color patches which sampled the color space of the ink jet printer. Colorimetric measurements, obtained from each of the color patches, were used to compute the non-linear masking equations. Ink jet prints produced with these equations were then colorimetrically compared to prints made with the target proofing system. Results indicated that the use of non-linear masking equations provided an effective means of mapping the color space of the four-color continuous ink jet printer to the original target.

Presented at *IS&T's 47th Annual Conference: The Physics and Chemistry of Imaging Systems*, May 15-20, 1994 in Rochester, New York.

Introduction

Color Proofing

The printing industry has, until recently, informally standardized on analog proofs to simulate the quality of press output. Analog proofs gain wide acceptance for several reasons. First, analog proofing could be generated faster than on-press proofs and therefore provided higher throughput. Secondly, analog proofs exhibited a higher degree of color consistency than on-press proofs. With the advent of direct digital color proofing systems, the printing industry has begun accepting digital proofs as a replacement for analog proofs. Digital proofs can be produced without generating separation films, thus improving throughput over analog proofs. Some digital proofs, specifically using continuous ink jet technology, have also been found to exhibit color consistency comparable to analog proofs.[1,2] However, many in the industry had standardized on the color appearance of analog proofs to make color judgments before going to press. This meant that if the digital color proof could simulate the color appearance of an analog proof, the printer could utilize the digital proof as the analog proof.

Digital Proofs Using Continuous Ink Jet Technology

One type of digital proofing system used in the printing industry utilizes four color continuous ink jet technology. Four color continuous ink jet technology, such as those developed by IRIS Graphics, can produce a large number of visually distinct colors necessary to simulate the colors produced by an analog proof. However, a method for remapping the color gamut of the continuous ink jet proofer is required to approximate the color gamut of an analog proof.

Gamut Remapping

Several types of transformations can be used to perform gamut mapping. The most common method involves using interpolation with a three dimensional look up tables.[3] While this method can perform the color conversion, the transformation process is generally computationally intensive and usually requires the use of specialized hardware to be used in practical applications. A second method for transforming color involves using one dimensional color lookup tables for cyan, magenta and yellow, and linear-masking equations as

$$C_{out} = a_{11}C_{in} + a_{12}M_{in} + a_{13}Y_{in} + a_{14}K_{in} \quad (1a)$$

$$M_{out} = a_{21}C_{in} + a_{22}M_{in} + a_{23}Y_{in} + a_{24}K_{in} \quad (1b)$$

$$Y_{out} = a_{31}C_{in} + a_{32}M_{in} + a_{33}Y_{in} + a_{34}K_{in} \quad (1c)$$

$$K_{out} = a_{41}C_{in} + a_{42}M_{in} + a_{43}Y_{in} + a_{44}K_{in} \quad (1d)$$

shown in equations 1a-1d. The amount of cyan, magenta and yellow out (C_{out}, M_{out}, Y_{out}, K_{out}) represent the digital values provided to the continuous ink jet proofer, C_{in}, M_{in}, Y_{in}, K_{in} correspond to the digital values of the original analog proof, and a_{11}, a_{12}, a_{13}, etc. represent conversion coefficients. While this type of transformation provides good results for conventional halftone printing, ink jet prints using linear masking typically produces poor gamut mapping as a result of its non-linear printing characteristics.

Another method for performing the color gamut mapping entails using non-linear masking equations. An example of non-linear masking equations would be an abbreviated Taylor series expansion shown in equations 2a-2e.

$$C_{out} = f(C_c) + f(C_m) + f(C_y) + f(C_{my}) + f(C_{cy}) + f(C_{cm}) + f(C_k) + f(C_{cmy}) \quad (2a)$$

$$M_{out} = f(M_c) + f(M_m) + f(M_y) + f(M_{my}) + f(M_{cy}) + f(M_{cm}) + f(M_k) + f(M_{cmy}) \quad (2b)$$

$$Y_{out} = f(Y_c) + f(Y_m) + f(Y_y) + f(Y_{my}) + f(Y_{cy}) + f(Y_{cm}) + f(Y_k) + f(Y_{cmy}) \quad (2c)$$

$$K_{out} = f(K_k) \quad (2d)$$

$$f(C_c) = a_1C_c^3 + a_2C_c^2 + a_3C_c + a_0 \quad (2e)$$

Cout, Mout, Yout, and Kout, which again represent the digital values used by the continuous ink jet proofing device, are a function of the amount of cyan, magenta, yellow, and black ink jet ink needed to match the colors on the analog proof. It was speculated that using this gamut mapping method would provide better color results than linear masking equations and would require fewer computer-intensive instructions than three dimensional matrix interpolation. To determine if non-linear masking equations could be used for gamut mapping, a test was conducted to map the gamut of a continuous ink jet image to an analog proof.

Experimental

Generation of Analog Proof

In order to evaluate the feasibility of the non-linear masking equation concept, an analog proof was generated which contained two test patterns. The first pattern, referred to as Test Pattern A, consisted of step wedge color patches in 10% dot increments for the primary colors (cyan, magenta, yellow, and black), two-color overprints (red, green, and blue), and three color gray. The second pattern (Test Pattern B) was comprised of 512 color patches which had various percentages of cyan, magenta, yellow, and black.

Color Measurement of Proof

After generating the analog proof, CIE L*a*b* (D50, 1931, 2°) measurements were obtained for the various color patches using a color measurement system. The system consisted of a Gretag SPM-100 spectrophotometer, a gantry stage with X, Y, and Z axis motion, and a PC to control measurement timing and stage motion. Calibration and long term drift correction was used to achieve measurements repeatable to 0.1 ΔEab units.

Lookup Table Generation

Using the color measurements from Test Pattern A, computations were performed to determine the percentage of cyan, magenta, yellow, and black ink jet ink required to match each color patch in Test Pattern A. The actual ink percentages were computed using a L*a*b* to CMYK three dimensional matrix interpolation scheme. Lookup tables which represent the functions for the non-linear masking equations (see equation 2e) were determined using the ink percentages and a cubic spline algorithm.

Continuous Ink Jet Prints

After computing the lookup tables, Test Pattern B was printed on the continuous ink jet proofer using the non-linear equations and measured on the color measurement system. Color differences were then computed between the analog proof and the continuous ink jet proof in terms of ΔEab.

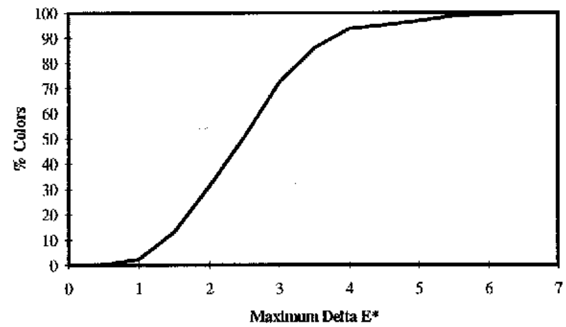

Figure 1. Color differences between 512 colors produced on analog proof and continuous ink jet proof

Discussion

In order to assess the overall color differences between the continuous ink jet proof and the analog proof, a cumulative plot of maximum ΔE* versus the percentage of total colors on Test Pattern B was generated. This plot, seen in Figure 1., shows that the color difference for 95% of the color patches were roughly 4.5 ΔE* units or less. Based on earlier color repeatability studies, these differences are close to the color repeatability of continuous ink jet and analog proofing systems.[1]

Conclusion

Based on the findings presented in this paper, using non-linear masking equations provides an effective means of remapping the color gamut of continuous ink jet devices to simulate the color appearance of analog proofing devices. This approach has been integrated into IRIS' color software applications for simulating proofs, and generating color output for textile design and CAD applications. In addition to continuous ink jet technology, the non-linear masking scheme could also be used with electrophotographic and dye sublimation printing technologies.

References

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