Printing System Optimization via Supplemental Light Colorants

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Abstract

Traditional printing processes usually consist of three basic colorants, i.e., cyan, magenta, and yellow, for their inherent subtractive color nature. Black colorant is sometimes adopted to optimize a printing system between stable neutrality, lower colorant consumption, and achieving higher reflection density. The capability of printing extra color(s) is used in two scenarios: accent colors to precisely matching colors, and light colors, such as light cyan and light magenta, to further enhance image quality. The advantage of adopting light colors to improve print quality such as granularity is its low development cost compared with significantly improving the corresponding complicated fundamental printing process; however, it requires better halftone design, precise supplemental colorant replacement strategies, and imposing an extra cost per page compared with the traditional printing process. We will address this system optimization process by quantifying the overall graininess reduction and its corresponding colorant consumption increase.

Introduction

Traditional printing processes usually consist of three basic colorants, i.e., cyan, magenta, and yellow, for their inherent subtractive color nature. Black colorant is sometimes adopted to optimize a printing system between stable neutrality, achieving higher reflection density, and lower colorant consumption. Because human viewers prefer images with high colorfulness, researchers have been pushing for colorants with high chromaticity. However, achieving larger color gamut is only one objective of a digital printing system. Another facet of the printing system optimization is to reduce imaging artifacts, such as granularity, mottle, and macrononuniformity, which are caused by its intrinsic system noise. Since studies have shown that, the perceived strength of imaging artifacts, such as graininess and mottle, is directly related to the luminance and chromatic contrast of selected colorants [1], a digital printing system needs to strike a balance between the volume of the achievable color gamut and the severity of imaging artifacts.

The approaches to address this optimization problem depend upon the imposed constraints. If the number of available colorants is fixed and a minimal volume of color gamut is required, it becomes essential to improve the printing process; however, if the printing process has the capability of imaging extra colorants, it has been shown that supplementing the current printing process with light colorants will improve the image quality while at least maintaining the existing color gamut volume [2, 3, 4, 5]. Although improving the printing process is fundamental to completely eradicate any imaging artifact issue, the progress has been slow and costly because of its highly complicated and interconnected nature. On the other hand, supplemental light colorants can quickly boost the image quality in terms of lower granularity, mottle, better tonal resolution, less perceivable over-print halftone structures in the targeted color space without modifying existing halftone design, and still benefit from any future improvement in the fundamental printing process; however, they require better halftone design, precise supplemental colorant replacement strategies, and imposing an extra cost per page compared with the traditional printing process. In this paper, we will address the printing system optimization problem via a supplemental light colorant by measuring the color granularity within the color gamut, and the corresponding colorant consumption under various supplemental colorant replacement strategies. Our experiment is conducted on a *Kodak Nexpress S3000* digital printing press equipped with five printing modules, where the fifth module is fitted with light magenta or light black. A normal *ICC* workflow is adopted where a series of five-color substrate *ICC* color profiles were built based on the constraint on the maximal supplemental light color coverage and the relative length of transition between the normal primary color and its corresponding light color.

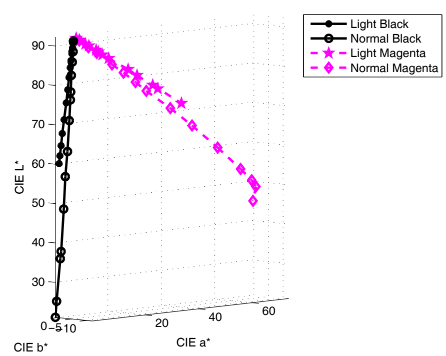

Figure 1. *Light/Normal Black and Light/Normal Magenta color ramp trajectories in the CIELAB color space*

Granularity Constraint

Although it is possible to select light colorants with any color, the light versions of the primary colorants, i.e., cyan, magenta, and black, are usually adopted in the actual practice [6, 7, 8]. As a result, the physical color rendition in the device color space can be easily extended from the existing four-color printing system by replacing one primary color with the combination of the corresponding light and normal colorants [3, 9]. Nonetheless, as shown in Figure 1, the color trajectories in the *CIELAB* color space between the normal and light colorant are usually different. Researchers have suggested to directly construct a substrate *ICC* color profile according to the colorimetric measurement on a multicolor test target [4], which is similar to the approach we adopted in this paper. How to balance between the gray component replacement and the fifth/light color component replacement becomes a critical step to achieve the optimal performance.

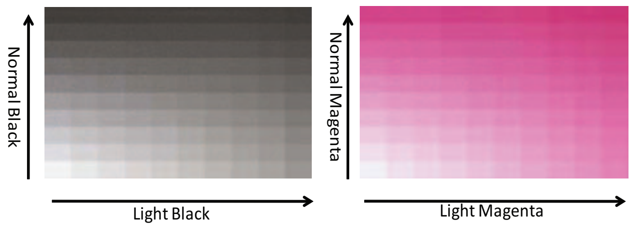

Figure 2. *Light/Normal Black and Light/Normal Magenta Granularity Target*

Besides color matching accuracy, the main objective of adopting the light colorant is to improve image quality, especially in granularity; hence, imposing constraint on granularity is essential to the success of the supplemental light colorant. Two test targets are designed, as shown in Figure 2, to explore the complete granularity performance with $N_r \times N_l$ color patches where N_r is the number of sampling points along the normal colorant and N_l represents the number of sampling points along the light colorant, which are both set to be 10 in Figure 2. Each color patch has to reach the minimal size to reliably estimate color granularity [1].

Our analysis shows that, at each light black or light magenta level, the measured granularity can be approximated by a quadratic functional as shown below:

$$G_{lk}(K) = a_{k2}(lk)K^2 + a_{k1}(lk)K + a_{k0}(lk) \quad (1)$$

$$G_{lm}(M) = a_{m2}(lm)M^2 + a_{m1}(lm)M + a_{m0}(lm). \quad (2)$$

The estimated polynomial coefficients $a_{k2}, a_{k1}, a_{k0}, a_{m2}, a_{m1}$, and a_{m0} are shown in Figure 3, and they can further be modeled by a set of quadratic polynomials, $\Phi_K(lk), \Phi_M(lm)$, of light black and light magenta. The R^2 values of the composite quadratic polynomial models, $G_{lk} \circ \Phi_K$ or $G_{lm} \circ \Phi_M$, for the light black and light magenta are 0.96 and 0.95, respectively. Figure 4 shows the contours of equal-graininess within the light black/normal black and light magenta/normal magenta two-dimensional domains.

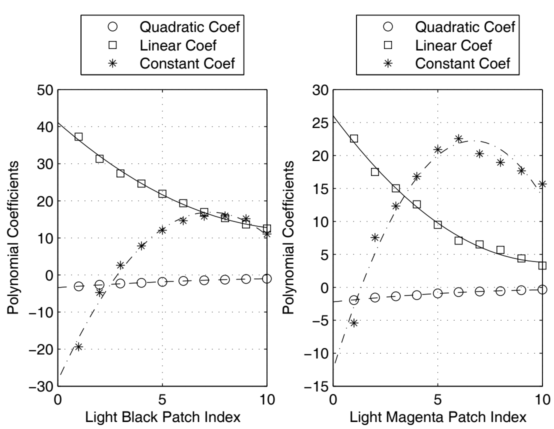

Figure 3. *Quadratic granularity-variation models for Light Black and Light Magenta*

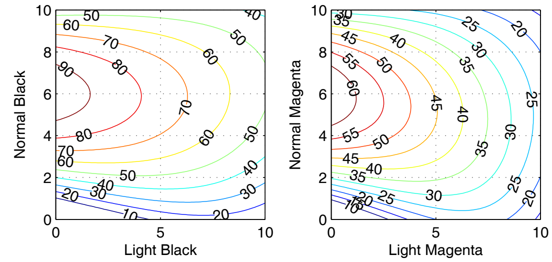

Figure 4. *Estimated granularity contour for Light Black/Normal Black and Light Magenta/Normal Magenta*

Cost/Quality Tradeoff

While the supplemental light colorant provides immediate improvement in image quality, this approach also incurs some disadvantages, such as additional imaging processes needed, increase of cost per page, more difficult color replacement constraints, and potential impact on printing speed and productivity depending upon the architecture of the printing press. The overall length of substrate path on the *Kodak Nexpress S3000* press remains as constant regardless of the number of active printing modules. As a result, there exists no concern in loss of productivity whether a supplemental light color is adopted or not. Furthermore, because *Kodak Nexpress S3000* press is equipped with five imaging modules, our experiment only include one supplemental light color, light black or light magenta. They are chosen based upon the higher luminance contrast of the normal black and magenta colorants than those of cyan and yellow colorants. Consequently, they contribute to more perceivable graininess assuming the actual imaging noise is the same among all imaging modules, and the extra light black and/or light magenta should maximize the improvement on image quality.

Light Magenta

Because the fifth color component replacement using the light magenta is far away from the gray component replacement in the *CIELAB ICC* profile connection space, each color replacement process is controlled independently. While fifth color component replacement always begins at the *media white point*, the starting point of the gray component replacement varies from $L^* = 100, 90, 80, 70$ in the relative colorimetric intent. Since the light magenta colorant mainly replaces the normal magenta colorant, we can expect to observe the granularity improve in magenta, bichrome red, bichrome blue, and multicolor neutral, where Figures 5 and 6 show the estimated graininess along the magenta and black color ramps. Figure 5 indicates that the controlling parameter for the gray component replacement has little impact around the color space of the magenta primary trajectory, but the presence of light magenta colorant further improves the granularity along the neutral axis as shown in Figure 6, where the estimated graininess of the baseline four-color with gray replacement beginning at $L^* = 80$ approximately equals the five-color light magenta configuration with gray replacement beginning at the *media white point*.

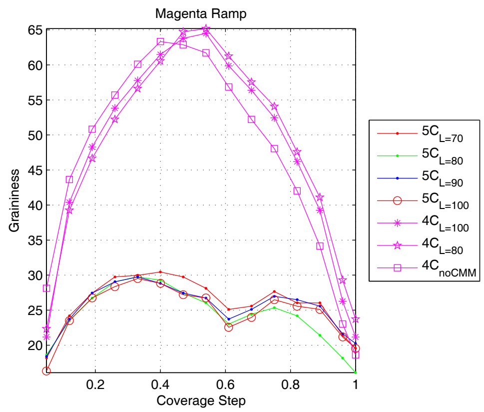

Figure 5. *Estimated graininess along the Magenta ramp in the case of Light Magenta*

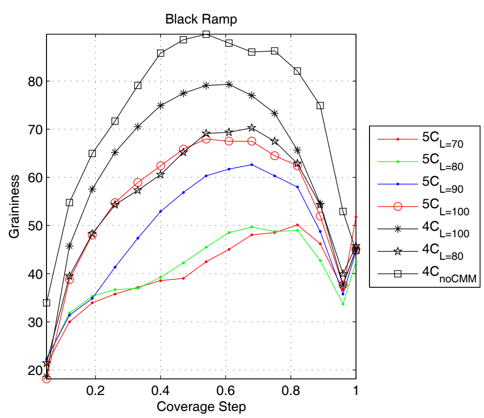

Figure 6. *Estimated graininess along the Black ramp in the case of Light Magenta*

Because of the lack of information regarding the actual color distribution of realistic jobs, a *noninformative uniform prior distribution* is assumed where each point in the *CIELAB ICC* profile connection space is equally likely to be printed. Hence, we uniformly sample the color gamut of an average press within the *CIELAB ICC* profile connection space and simulate the theoretical colorant consumption based upon the set of derived *ICC* substrate profiles. The actual colorant consumption depends upon the dot gain of the printing press. Without focusing on precise colorant consumption of a printing press, we assume a simple power functional to roughly capture the conversion from the theoretical colorant consumption to actual colorant consumption, where *Dot Gain Index* being 1 represents a printing press without dot gain, and *Dot Gain Index* being 2 represents approximately 20% dot gain. Figure 7 shows that, while overall consumption decreases with increasing dot gain, baseline four-color configuration with gray replacement beginning from the *media white point* consumes the least amount of colorant, and all variant color replacement configurations with light magenta consume more colorant than the two baseline four-color configuration.

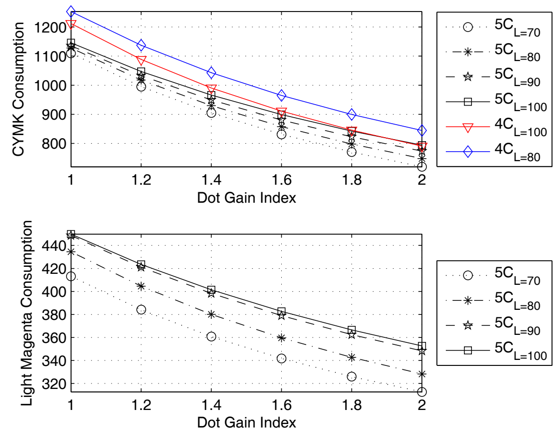

Figure 7. *Estimated toner consumption of Light Magenta in the case of noninformative uniform prior distribution*

Light Black

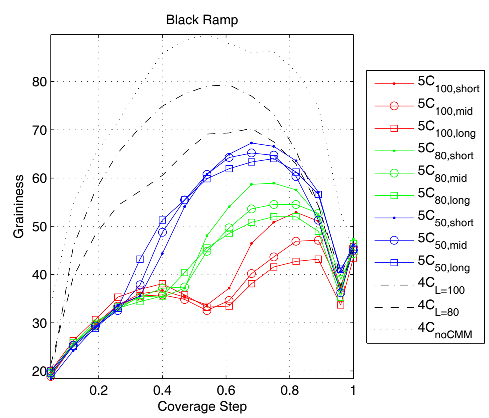

Figure 8. *Estimated graininess along the Black ramp in the case of Light Black*

The color replacement between the light black and normal black becomes a little tricky since the trajectories of gray component replacement and fifth color component replacement almost coincide with each other. Since it makes little sense to perform gray component replacement before the light black replacement, the light black replacement should take precedent over the gray component until reaching to a predefined highest level of light black. The second replacement parameter controls the duration where the light black is approximately maintained at the predefined highest level. Figure 8 shows the measured graininess along the neutral axis under various light black replacement strategies, where three distinct groups of graininess behavior occur affected by the predefined highest level of light black. The duration of maintaining the highest level of light black only exhibits a secondary effect in reducing graininess. Compare Figures 6 and 8, and it shows that light black is more effective in reducing granularity near the neutral axis while light magenta will address the granularity issue in red and blue quadrants within the color gamut of the printing press.

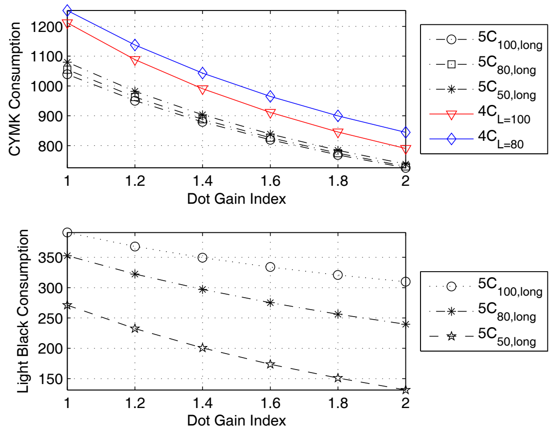

Figure 9. *Estimated toner consumption of Light Black in the case of noninformative uniform prior distribution*

Figure 9 shows the estimated colorant consumption under the same *noninformative uniform prior distribution* assumption. Use the four-color configurations with two different gray replacement strategies as the colorant consumption baselines, and it is obvious that the five-color equipped with light black overall consumes less colorant than that with light magenta even though both five-color configurations consume more colorant than the four-color baseline.

Conclusion

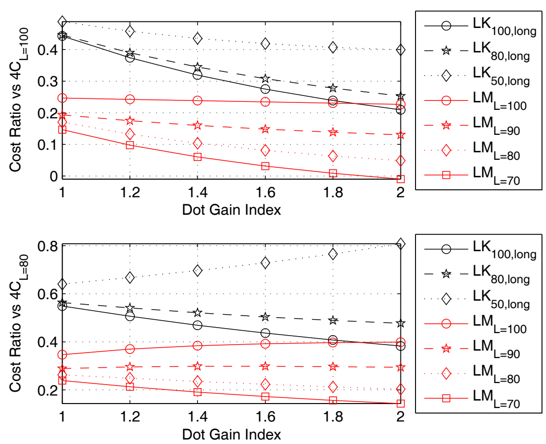

Figure 10. *Estimated cost ratio of Light Black/Light Magenta relative to baseline CMYK 4C (UCR/GCR) total cost in the case of noninformative prior distribution*

Our experiment shows that a supplemental light colorant, such as light magenta and light black, significantly improves granularity in the targeted color space while incurring slight cost increase. However, because light colorant contains less color pigment than does normal colorant, it should be safe to assume that the cost of producing light colorant is lower as well. Assuming all four primary colorants cost the same, Figure 10 indicates the required discount in the light black/light magenta to match the overall cost under the four-color baseline configurations.

References

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