Method of Printing Images Using Multiple Colorants Having Different Saturation Based on Experiments About Ink Control

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Abstract

Printing using multiple colorants having different saturation can enhance variations of color tones especially in highlight regions. The said multiple colorants include Cyan (C), Magenta (M), Yellow (Y), blacK (K), Light Cyan (LC), and Light Magenta (LM) in this proposed paper. To improve the printing output quality, the implemented kernel technologies involve multi-level halftone, look-up tables of six color transform, 3-D interpolation, and printing algorithm for high resolution rendering. To estimate capability of variations of color tones between amounts of ink drop and different kinds of media, an experiment about ink control is proposed here, and the related data of the experimental analysis can help to determine what amount of ink drop can be absorbed, how to design the proper printing algorithm, and how to design suitable halftoning method based on these printing conditions. Driving tinier and tinier drop size of ink along the development of print head can make the paper absorb more and more amounts of drop, so the printing can render more and more levels of color tones. By the above fact, the multi-color printing technology becomes the major topic of research for these main printer manufactures.

Introduction

The quality of printed images of the ink-jet printer could be improved by increasing the number of color choices for each pixel with various methods. Some of these methods include using multiple droplet sizes, using multiple smaller dots of the same color per pixel, using dots of differing dye loads, and attempts to dynamically vary the droplet size.[4] describes the framework of printing images using multiple colorants having different dye loads and shows the main advantage for this method. In this paper, the invention discloses in terms of an ink-jet printer that can print two dye loads for the colors cyan and magenta, a full or "high" dye load and a reduced or "low" dye load. Thus, the available choices are C, M, Y, Lc, Lm, and K, where Lc is cyan-low and Lm is magenta-low. Yellow is printed only in a full dye load because different levels of yellow are less discernible by the human eye than differing levels of the other primaries. The range of potential colors obtainable with this scheme is greatly increased, and results in better image quality. Here, Lc is also regarded as Light Cyan (LC) and Lm is also regarded as Light Magenta (LM). Parts of Ref. [1] shows the basic ideas of the experiments about ink control for each color channel to get smooth variation of tonal rendering, and this experiment of ink control is used in the proposed paper to help forward to design print algorithm and halftone of each color component to output tonal rendering smoothly.[3] relates to a method for determining usage of diluted versus saturated color inks in an inkjet printer. More particularly, this invention relates to a method for determining the amount of diluted and saturated inks used for each color throughout the color range of a color inkjet printer. The method should provide for a smooth transition in granularity and color lightness from lighter to darker colors. The talked method of color component replacement (CCR) is mixing the saturated ink into the pixel matrix starting at a nominal digital count point below or equal to the diluted ink minimum lightness point and decreasing the diluted ink used in the pixel matrix while maintaining a granularity value of the pixel matrix to be printed to within a predetermined percentage of a granularity value of the color when using a maximum amount of diluted ink to generate the pixel matrix. It also talks the simple structure of six color conversion which can be created easily from adding 1-D look-up tables of CCR to four color transformation.[5] proposes a method and apparatus for color replacement using an extended ink set. It shows a flowchart of six color conversion including RGB to CMY, Gray component replacement (GCR), CCR by the order. In this proposed paper, many experiments like ink control, gray balance, GCR, CCR, color calibration would be needed to get the photo quality images. Before the color conversion, doing the ink control to help designing this print algorithm and halftone to get tonal rendering smoothly. This proposed color calibration will totally consider the color difference produced from all of the procedure of the color conversion including RGB to CMY, GCR, and CCR in finding the minimum average color difference between the target palette and the printed palette, so the quality of the conversion will be under control greatly to make impressive and lifelike printing.

Ink Control

The objective of the ink control is to estimate the amount of ink that media can absorb as how many drops on the testing patches can be absorbed by media for each kind of ink, e.g., cyan, magenta, yellow, black, light cyan, and light magenta, respectively. And the algorithm of ink control for media is designed by finding out the saturation point of color representation when the lightness measured by spectrometer in the CIE Lab space is almost the same, e.g., the ΔL between two color patches is less than a predetermined tolerance. Some useful and important parameters will be got from the experiment as to the print algorithm and halftone design like how many print passes and how many halftone levels, and so on.

Since the resolution that fits the perceptual capability is about 300 dpi, the defined scope for analysis as to the drop combination of ink will be assigned the square of 85 µm. For example, when assuming resolution of printing task on 600dpi × 600dpi, the pattern of the drop combination of ink will be designed as Fig. 1. And the algorithm of determining the maximum amount of drop that media can absorb is described by Eq. 1.

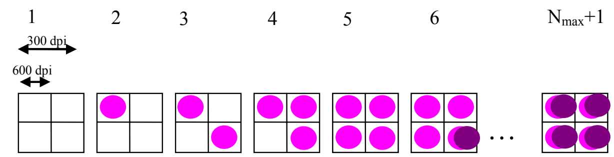

Figure 1. The drop combination of ink assigned in the square of 85μm

Based on the physical capability of this used photometer, it can't measure color values correctly from a circle whose diameter is less than 0.4 cm. Therefore, the area of the square of 85 μm will be duplicated and scaled up to the square of 0.5 cm such that the more correct measurement will be got. Eventually, the lightness on the CIE Lab space of the color patches will be picked up into the Eq. 1's L variable. Each of used ink, e.g., C, M, Y, K, LC, LM, should run this process to determine their maximum amount of drop media can absorb respectively. From these experiments about ink control, the important information will be got and help forward to design this print algorithm and halftone for each color component.

$$N_{max} = \underset{N_i}{Arg}\left\{ L^*(N_i) - L^*(N_i - 1) \cong 0 \right\} \qquad (1)$$

Assume that N_{max} denotes the amount of drop at the saturation point of these test patches assigned in the square of 85 μm; N_i denotes the amount of drop increasing in order on these test patches.

Gray Component Replacement

Gray Component Replacement (GCR) can improve the performance of reducing the consumption of the CMY ink in the ink-reducing technology. The GCR indicates that a ratio of black component will replace some ratios of color components (cyan, magenta, and yellow). In ideal case, the ink coverage is reduced because the equal amount among C, M, and Y ink are replaced with black (K) ink, but in fact one unit of the black ink probably isn't equal to one unit of composite black mixing with C, M, and Y ink. Therefore, the mapping relation between the black ink and composite black must be built with the experiment of gray balance (GB). Based on finding the equal lightness between the black ink and composite black, the look-up table of GB will be made and used for transformation that how much black ink will replace the given amount of composite black. We use the algorithm to get a RGB to CMYK color conversion table. The goal of using Gray Component Replacement (GCR) is to get a 4D Look-Up Table (LUT) from the 3D LUT after the color matching processing. In the paper, the GCR is exploited into black generation and belongs to the GCR of the dynamic ratio which is defined as follows.

$$K = r(C, M, Y) * \min(C, M, Y)$$

$$K' = GB(K)$$

$$C' = C - K$$

$$M' = M - K$$

$$Y' = Y - K \qquad (2)$$

where C, M, and Y are the amount of cyan, magenta and yellow as printing with a RGB to CMY color conversion table, K' is the amount of black replacing CMY, The C', M' and Y' are the respective amount of cyan, magenta and yellow subtracting K from original C, M and Y, r is the replaced ratio of GCR, and GB ( ) shows the LUT of transformation between the black ink and composite black.

In Eq. 2, the minimum among C, M, and Y must be determined firstly, and then the minimum subtracts from the original CMY respectively. The replaced ratio of GCR is dynamically dependent on the different optical density of the minimum among C, M, and Y. In this case, the expected objective is that the higher ratio of black component is used instead of CMY components in darker tones in order to make hues pure, to increase the depth in saturation and to reduce the ink consumption, and otherwise the printing task is processed with a RGB to CMY color conversion table in highlight regions in order to avoid artifact appearing due to high contrast between black and highlights.

Color Component Replacement

Four color printers using CMYK ink can't satisfy with the high quality of photo printing. This main reason is that the high contrast between dark ink and white papers will make the appearance of graininess if the dark tonal ink is used in the highlight region. If the light tonal ink is assumed in the highlight region, the above artifact will be improved because of reducing the contrast between light ink and white papers, so the printing quality will achieve the level of photo output, like the skin tonal region will be more lifelike or the sky tonal region will be smoother. The difference between printing with four color printers and six color printers is shown on Fig. 2.

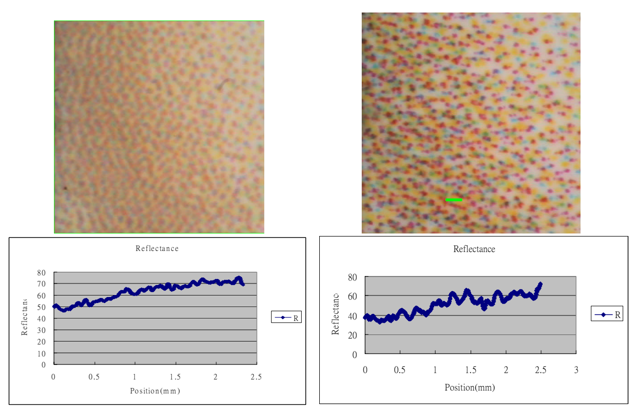

Figure 2. The left part shows printing with six color printers and its reflectance along x axis. The right part shows printing with four color printers.

The objective of the color component replacement (CCR) focuses on preventing the appearance of graininess and reproducing the smooth variation of tone by mixing different ratios of dark and light tonal ink with the same hue. From the result, the best transformation curves between dark and light ink will be got with an algorithm described on Eq. 3.

The basic ideas of the transformation curves are only using the light ink in highlight regions and else using different ratios of dark and light ink in other regions. In the middle tone, after reaching the saturation point of the lightness of the patch only using the light ink, the dark ink will start to be entered into mingling with light ink. From the point to darker tone, the amount of the dark ink will increase while the amount of light ink is decreasing. The expected relation of the color transformation is shown as Fig. 3. Here, the table index at 12 means the saturation point of the lightness of the patch only using the light ink, the number of the vertical axis represents the signal intensity on the print color space, and the number of horizontal axis represents the intensity of the colorant as light ink or dark ink. On the other hand, the other target of the experiment is also to reproduce the smooth variation of the color rendering like the result showing on Fig. 4 or keep the TRC without difference from four color to six color printing.

$$C_{goal,j} = \underset{C_i}{Arg}\left\{\min\left(\Delta L(C_{target,j}, C_i)\right) \& \, Grain(C_i) \le 5\%\right\}$$

$$\Delta L(C_{target,j}, C_i) = \sqrt{(L_{target,j} - L_i)^2} \qquad (3)$$

$$where \quad C_{target,j} = (L_{target,j}, a_{target,j}, b_{target,j}); C_i = (L_i, a_i, b_i)$$

$$L_{target,j} : The \;\; lightness \;\; of \;\; tagert \;\; patch$$

$$Grain(C_i) : The \;\; graininess \;\; of \;\; area \;\; C_i$$

Firstly, design two sheets of palette which have 30x30 patches respectively. One palette shows the mixing appearance between cyan and light cyan, where cyan is sampled as 30 tonal levels and has the equal interval among the horizontal axis and light cyan is also created in the same condition among the vertical axis. And then crisscross the signals among the horizontal axis and the vertical axis, so each palette has 900 tonal patches totally. The other palette replaces cyan and light cyan with magenta and light magenta by the same way. Secondly, print out these palettes and measure them to get lightness with a photometer, and use these measured data to find the optimal replacement relation between dark ink and light ink deepened on these above basic ideas of the transformation curves shown on Fig. 3. Thirdly, there will be 30 points picked up based on fitting the conditions of the transformation described by Eq. 3, and use interpolation to expand these 30 points to 256 points which represent the signal intensity from zero to 255 of the print color space. Eventually, these two transformation tables are made to transform cyan signals to dark cyan ink and light cyan ink and magenta signals to dark magenta ink and light magenta ink.

Experimental Procedure and Results

Before the proposed procedure of the color conversion, decide firstly how many levels halftone is assumed, how many drops of ink should be used according to each level of halftone, and how many passes the printing algorithm will be designed, and then enter the stages of the color conversion. The first stage is to find the suitable GCR's parameters and the look-up table of gray balance depended on the target palette. The second stage is to find the matching curves of CCR according to the TRC of C and M on the target palette. The final stage is to put these GCR, CCR, and RGB to CMY together into color calibration and produces the optimal color transformation of RGB to CMYKLCLM.

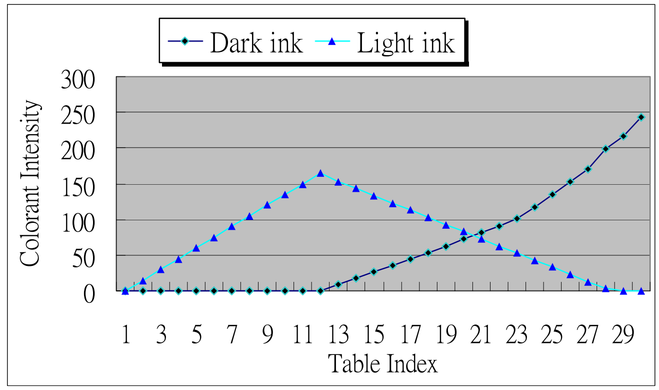

Figure 3. The ideal transformation curves of color component replacement between dark and light ink

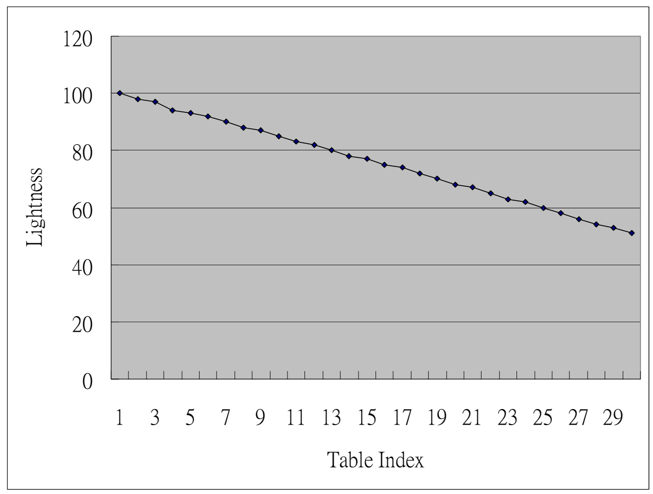

Figure 4. The result of smoothly tonal variation after processing with CCR

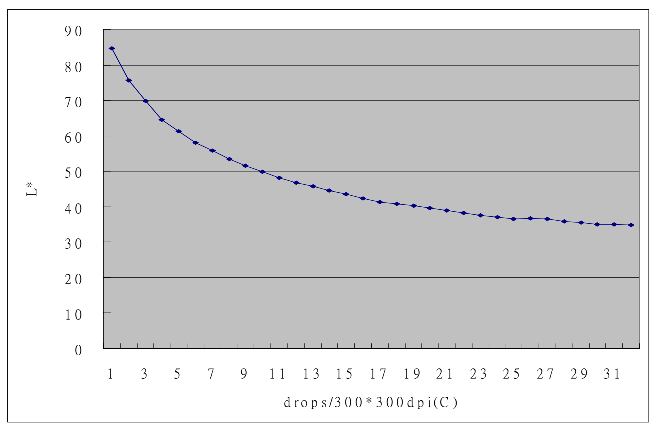

Figure 5. The result of the experiment about ink control of cyan ink

Design Halftone and Print Algorithm Based on Ink Control

Based on the result of the above experiment of ink control like being shown as Fig. 5, the halftone may be recommended to design from 4 to 6 levels, and the assumed drops of each level could be found out from the Fig. 5 depended on keeping each level of halftone to present smoothly tonal variation. After determining the halftone, the most passes of the printing algorithm are got according to the most drops used by the halftone.

Determine Parameters of GCR

Refer to the target palette, the replaced ratio of GCR is chosen as 0.5, and black component starts to replace CMY components from the minimum among C, M, and Y as 108. Finally, the value of the minimum among C, M, and Y multiplied by the replaced ratio of GCR will be as an index to look for the intensity of black ink from the look-up table of GB.

Determine LUTs of CCR

Here, the CCR is expected to keep the TRC without difference from four color to six color printing. By the way, if fitting the above basic ideas of the transformation curves, the appearance of graininess caused by mixing different saturation ink will disappear at ease.

Color Calibration of RGB to CM YKLCLM

After determining the GCR and CCR, the uncertain part of the color conversion for RGB to CMYKLCLM is RGB to CMY .The experimental method and procedure of building a look-up table for RGB to CMY could refer to Ref. [2], but the largest difference is that the proposed printing task uses the six colorants directly instead of only using three primary colorants in this color calibration. The most obvious and excellent advantage of this kind of color calibration is that the color difference produced from all procedure of the color conversion including GCR, CCR, RGB to CMY will be totally involved in finding the minimum average color difference between the target palette and the printed palette. Therefore, the quality of the color conversion will be under control greatly.

Conclusion

The framework of printing images using multiple colorants having different saturation are proposed clearly, and these printing kernel method really can output high photo quality. The ink control method can help forward to design print algorithm and halftone of each color component, and also can be used in the field of ink reduction to estimate ink limitation of media more precisely. The color component replacement can avoid the appearance of graininess obviously and reproduce smooth variation of tone by mixing different ratios of different saturation ink with the same hue. The color difference produced from all of the procedure of the color conversion including GCR, CCR, RGB to CMY will be totally involved in color calibration, so the quality of this conversion will be controlled and improved more easily.

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4. US Patent 5982990
5. US Patent 5982993

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Tung-Lin Wu received the B.S. degree in electrical engineering from Tamkang University, Tamshui, Taiwan, in 1999, and received the M.S. degree in communication engineering from Tatung University, Taipei, Taiwan, in 2001. He is currently working in Opto-Electronics & Systems Laboratories of Industrial Technology Research Institute (OES/ITRI), Hsinchu, Taiwan, as an associate engineer. His current research areas include color signal processing and image processing coding.