A Table-based Color Matching Approach to Improve Color Calibration for Color Output Devices

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Abstract

The color transformation module is important in Color Hard Copy system. The objective of the module is to get the minimum of the color difference between the color signals represented in input devices and output devices. In the proposed method, the color transformation module is implemented in order to reduce the developing time and has the flexibility to modify the module's components. The module performs gamma correction and color matching algorithm whose data is fed and outputted with look-up tables. The table-based color matching approach is to decrease complexity and cost in hardware implementation. In fact, Most of color devices are given linear input signals, but the output color signals are not linear corresponding to the input, even they are centered on some regions within the gamut of the output device. The relationship between the input and output color signals is approximately a gamma curve in the proposed experiments, so the problem can be resolved roughly by the one-dimension gamma correction. The three-dimension color matching algorithm is performed in the uniform color spaces (CIE Lab, CIE Luv) whose color difference is more closely correlated with the perceptual difference. In general, color calibration must be run in such color spaces that the color difference can be quantized to referable values corresponding to the perceptual difference. The Gray Component Replacement theory will be used in processing color separation. The proposed color transformation module can efficiently improve color calibration from the average color difference about 58 down to about 4 for color output devices in the proposed experiments.

Introduction

Printers typically render outputs in four colors, such as the C, M, Y, K printer. In particular, the usual CMYK toner colors are uniquely selected due to their ability to produce a broad gamut of vibrant ***color*** combinations. Many such ***color*** printers operate by the addition of multiple layers of these inks or toner colorants in layers or halftone dots to a page according to non-linear responses. Ref. [1] represents that RGB are first converted to CMY; the CMY data are converted to CMYK, and each of the four color signals are halftoned separately to establish amounts of the corresponding four inks to print for each pixel. Thus, while a printer receives information in a first color space which has values defined device independent color values, it must convert that information to print in a second *color* space which is dependent of device characteristics. Ref. [2] represents a procedure for forming color look-up tables, and it says that the formation of lookup tables enables the operation of a printing machine and method to select ink drop or other colorant combinations quickly, efficiently and ideally here.

The GCR process includes determining how much CMY ink to remove after a specified amount of black (K) ink has been added to the same color. The concept of GCR involves the replacement of some of the CMY toner or ink with black ink, which may also be described as C, M, and Y minimization. This replacement of some of the CMY toner or ink with black ink can permit extension of the color gamut of a printer, which aids in the production of sharper, clearer looking, and otherwise enhanced output images. At the same time, GCR can be used to reduce the total amount of toner or ink on the page. Ref. [3] describes a method of undercolor removal in cyan, magenta, yellow and black printing. Color reduction is done in the "gray area" and "chromatic areas" of a master. In the chromatic area of the master, color reduction is matched to the respective maximum mean and minimum value of the three chromatic printing signals (cyan, magenta and yellow). Ref. [4] describes a system for tuning off a fraction of pixels to avoid excess toner coverage levels according to a system of selectively turning off pixels in relevant regions and Ref. [5] discloses a printer which uses cyan, magenta, yellow and black toners to create images. A black addition process is used to perform under color removal; calibrated gray balancing, color correction transformation using a tailored look-up table are accomplished to render four color outputs.

However, the GCR procedure limits the maximum area as a function of the sum of cyan, magenta, yellow, and black. And also the GCR ratio cannot be adjusted in the image processing. The undesirable darker dots may be appeared into the lighter background. Ref. [6] describes that the minimum K-amount is used and the total amount of ink is increased. However, the gradation properties are improved because noises are cancelled when the number of colors to be used is increased. Ref. [7] describes a method of reducing granularity in highlights and yellow fields by plane-dependent tables, in device-state error diffusion.

In the proposed method, we use a color estimation method to establish a 3D color conversion table which converts input RGB values to output CMY values. We also introduce the advanced GCR method to add the black colorant by using dynamic adjusted the GCR ratio.

The Color estimation in output device is significantly based on the perception of human eyes; color calibration must be run in the uniform color spaces that the color difference can be quantized to referable values directly corresponding to the perceptual difference. Ref. [8] emphasizes performance of such characterization in a perceptual space as for instance through conversion of initial color data from RGB to the familiar CIELAB coordinates. The proposed 3D color matching algorithm is also performed in CIE-Lab color space because of the color difference between test and target patches are more closely matched with the perceptual difference. Hence the experiment can get reasonable results by the measured values in the uniform color space.

Table-Based Color Matching Method

During the color matching processing, the objective of this proposed method is to find out the optimal matching color patches satisfied with the condition that the minimum color difference values between the test and the target patches. In the proposed method, the color difference values of the test and target patches has been quantified minimum by using the CIELAB color difference formula.

Here, the target color patch denotes C_{target}, the searched sample of all test color patches printed by the experimental printing platform denotes C_i, the optimal matching color patch with from C_i denotes C_{goal}, and the basic estimating criterion is illustrated as the following Eq. (1) and (2).

$$C_{goal} = \underset{C_i}{Arg}\{\min(\Delta E(C_{target}, C_i))\} \tag{1}$$

$$\Delta E(C_{target}, C_i) = \sqrt{(L_{target} - L_i)^2 + (a_{target} - a_i)^2 + (b_{target} - b_i)^2} \tag{2}$$
$$where \quad C_{target} = (L_{target}, a_{target}, b_{target}); C_i = (L_i, a_i, b_i)$$

In the proposed method, we also use the Gray Component Replacement (GCR) Algorithm to get a RGB to CMYK color conversion table. Before applying the GCR, the RGB to CMY color conversion table must be done. The objective of using Gray Component Replacement (GCR) is to get a 4D Look-Up Table (LUT) from the 3D LUT after the color matching processing, i.e., a ratio of black component will be substituted by some ratios of color components (cyan, magenta, and yellow).

Here, GCR is introduced into black generation and is classified to GCR of the constant ratio and GCR of the dynamic ratio which are defined respectively as follows:

GCR of the constant ratio:

$$K' = r * min(C, M, Y),\ C' = C - K',\ M' = M - K',\ Y' = Y - K' \tag{3}$$

GCR of the dynamic ratio:

$$K' = r(C, M, Y) * min(C, M, Y),\ C' = C - K',\ M' = M - K',\ Y' = Y - K' \tag{4}$$

where C, M, and Y are the amount of cyan as printing with a RGB to CMY color conversion table, K' is the amount of black instead of CMY, The C', M' and Y' are the respective amount of cyan, magenta and yellow subtracting K' from original C, M and Y, and r is the replaced ratio of GCR.

In Eq. (3), the minimum among C, M, and Y must be got firstly, and then the minimum subtracts from the original CMY respectively. In general, the case called Full GCR (r=1) is used in ink-saving system because the performance of reducing the consumption of the CMY inks. But it may cause the result of hue shift and dimmed tone except when the color has more equal ratios of CMY. In Eq. (4), 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 negative effect on Eq. (3) was resolved here, and the expected objective is that the higher ratio of black component is instead of CMY components in darker tones in order to make hues pure, increase the depth in saturation and 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 being visible due to high contrast between black and highlights.

Building Color Calibration Environment

The target color palette is printed by a HP 990 Cxi Inkjet Printer with the normal mode and photo paper setting as the target of the matching processing, and the expected objective is to get a 3D color LUT to make the test color palette printed with the LUT approximate to the target color palette optimally. The top view of the experiment is represented as Fig. 1.

In order to use the proposed method, we self-developed a printer device driver for OES/ITRI Printer. The printer driver specification and setting environments are illustrated in Table 1.

In order to test and verify the color reproduction by the designed method, the testing color conversion table will be integrated into our Printer Driver. As regards the colorimeter, Gretag Spectrolino is used as the platform of measuring color values here. In measuring color values, the white base of Gretag Spectrolino isn't adopted here, so the device independent CIE XYZ is assumed indirectly instead of the CIE LAB output of the colorimeter. Afterward the CIEXYZ output is transformed into the CIE Lab space

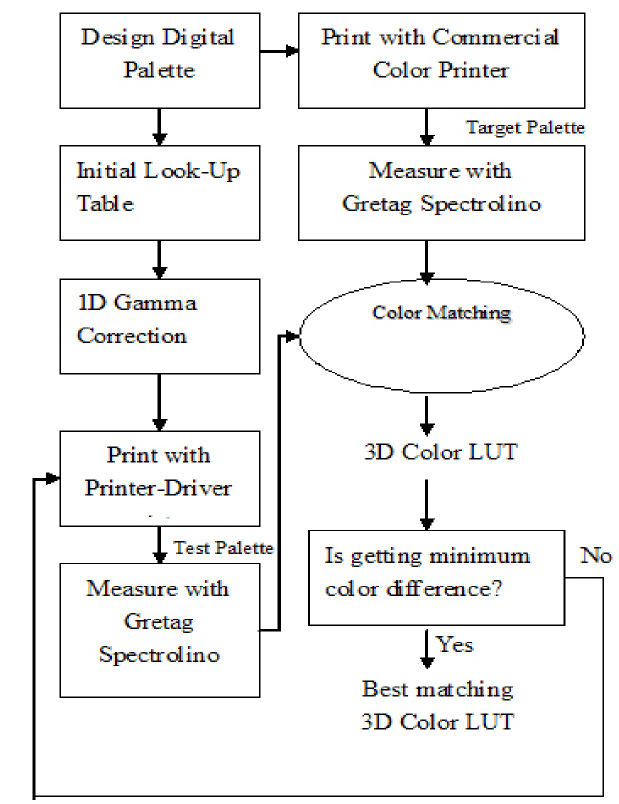

Figure 1. The flowchart of the experiment for generating the color conversion table

Table 1. Color Calibration Printer Driver Setting

Halftone	2~3 bits Multi-level Half toning Algorithm
LUT	4, 6 and 8-points Color Conversion Interpolation
PCL	Hewlett-Packard Printer Control Language 3 Compatible

Experimental Procedure

The experimental digital color palette is designed to have 9x9x9 color patches which have the equal interval between Red(R), Green(G), and Blue(B) respectively and six color bars which also have the equal interval between Cyan, Blue, Magenta, Red, Yellow, Green, and Black respectively. And each of the color bars has 34 tonal levels, so the color palette has 891(9x9x9+27x6) patches totally

In the design of the initial RGB to CMY color conversion table, the input R, G, and B values are just the values having the equal interval in the digital color palette. Afterward the values having the equal interval must be processed by gamma correction respectively in order to enlarge the interval in darker tones to avoid the phenomenon that the saturation occurs easily here, and reduce the interval in highlight regions to increase variations in color tones otherwise. The gamma correcting equations are showed as Eq. (5)

$$R_{out} = (R_{in}/255.0)^{\gamma} \times 255.0$$
$$G_{out} = (G_{in}/255.0)^{\gamma} \times 255.0 \quad (5)$$
$$B_{out} = (B_{in}/255.0)^{\gamma} \times 255.0$$

where R_{in}, G_{in}, and B_{in} are the values having the equal interval in the experimental color palette; R_{out}, G_{out}, and B_{out} are generated by R_{in}, G_{in}, and B_{in}.We have tested the 1D gamma values for the 1.0, 1.8, 2.0, 2.2, and 2.4, and found the tone reproduction is the most uniform at gamma value equals to 2.0 by observing the tonal variations in the printed palette.

The more uniform tonal variations of the printed color palette will help the color matching experiment to have more useful samples. The gamma corrected color conversion table will be integrated into OES Printer-Driver, and the digital palette is printed by the OES printer as the test palette. Afterward the test palette and the target palette are measured by Gretag Spectrolino to get the CIE XYZ values, and transformed into the CIE Lab space. The CIE Lab values of the target palette and the test palette are the input of the color matching processing based on Eq. (1).

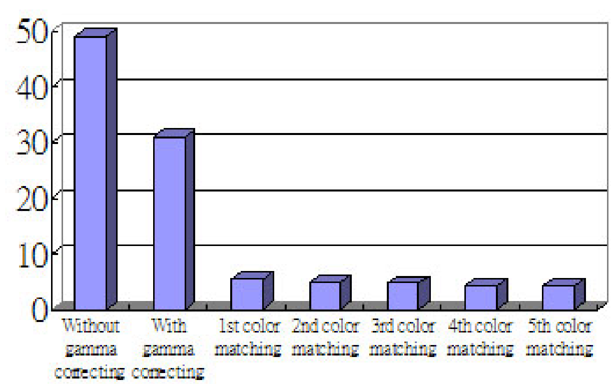

Figure 2. The color matching experiment results of RGB to CMY color conversion

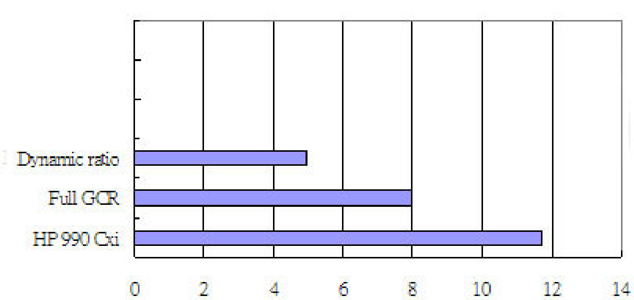

Figure 3. The color matching experiment results of RGB to CMYK color conversion

In the color matching processing, the best matching is to find the minimum color difference between the test and target patches. Some patches with the partially smaller color difference are directly outputted as the part of the new mapping values, and some with the middle color difference are generated by the average of the few test patches which have the small color difference with according target patches. In the proposed method, the excepted objective is to get more patches with the smaller color difference in the next time. The remainder with the larger color differnece will not be processed.

Finally, the output is a new RGB to CMY color conversion table which gets the minimum average color difference between the target palette and the printed result.

The process must run iteratively until the distribution of average color difference approximates the same minimum values in the last few experiences, and the printed patches generated on each time are the reference as the part of the input in next time.

The experiment for generating a color conversion table (4D table) which converts input RGB to CMYK values is based on the results of the experiment for generating the RGB to CMY color conversion table (3D table) which converts the RGB to CMY values. In the other words, a 4D table is derived from the 3D table after the color matching by using the GCR algorithm. Some of the black component will be instead of some CMY components in order to save the ink consumption, speed up the printing task, avoid color bleeding, and increase the depth of the saturated regions.

Experiment Results

Figure 2 shows the measurement results of the color conversion experience. In bar 1 and 2, the color difference values decrease effectively for using the gamma correction method. In the next 5 bars, the color difference values decrease smoothly from 5.58 to 4.19. As seen in the last 2 bars, the color difference values are close with the interval 0.02. It means the iterative color calibration can stop. The point of the minimum average color difference approximating the saturation occurs in the 4th color matching or the 5th color matching according to Fig. 2.

The experimental results of RGB to CMYK color conversion are compared with the color patches printed by the CMYK color printing mode of the HP 990Cxi inkjet printer, and Fig. 3 shows the experimental results about the color difference between the target palette and the test palette. The result represents that the method of the dynamic ratio of GCR make the color difference reduce more than others.

In the experiment for generating the RGB to CMYK color conversion table, the assessment of the results can't be solely judged by the color difference. It is also important to observe the distribution of the ink drops within each color patch by a microscope in addition to observing the average color difference. The experimental result of GCR shows that the higher ratio of black component, instead of CMY components, in the darker tones results in more pure hues, increases the depth in saturation, and reduces the ink consumption. However, the grainy images due to high contrast between black and highlights are created by printing with 4 colors in highlight regions. So printing with 3 colors is recommended in highlight regions.

Based on the above GCR experience, the improved GCR method using dynamic ratio to control the output black ink volume shows better printing quality in comparison with GCR of the constant ratio. In visually comparable image quality, this method is also better than and HP Inkjet-Plain mode in the ink reduction.

Conclusion

To increase the accuracy of these experiments, some elements should be considered, such as the gamut outside of monitors and printer, the influence on medium and ink, etc.

In the future work, the study of gamut mapping and ink limitation depended on different medium will be included to improve color calibration for color output devices further

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Biography

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.

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