

A Color Consistency Algorithm Between Different Printers

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Abstract

Color consistency between different color peripherals such as printers, scanners and digital cameras is a well-known problem. In this paper, a color consistency algorithm between different printers is proposed.

Each printer has its own characteristics. The color behavior of a printer can be modeled by a nonlinear characteristic function. We approximate the characteristic function by a three-dimensional look-up table. Then, a transfer function between two printers can be constructed based on their characteristic functions. The transfer function is to compensate one's color behavior and simulate another's color behavior. After applying the transfer function, the color difference (ΔE) and hue difference can be reduced to two to three times smaller.

Introduction

The production of color images has grown rapidly in recent years. Access and equipment affordability is now bringing a new generation of color products into the marketplace. Color consistency between different color peripherals such as printers, scanners, and digital cameras is a well-known problem. In this paper, a color consistent technique is proposed between different color printers.

As mentioned earlier, it has been important that the color consistency and high fidelity of color image reproduction among different color devices. However, printing a color image, different printers give different printouts since each of them has its own characteristics (different inks, paper, dot sizes, resolutions, ... etc) and, of course, generate different color characteristics. It is very challenging to develop an algorithm to correct effectively the color differences in order to maintain color consistency between different printers. In this paper, we are going to present an algorithm which will allow a printer to generate the same color image of another printer.

The algorithm involves determining the first and second characteristic functions which respectively define the relationship between an input image and a corresponding output image of the first and second printers.

Moreover, the characteristic functions are preferably determined by performing a color space transformation from RGB color space to CIELAB color space using a three-dimensional look-up table and tetrahedral interpolation. Then, a transfer function is constructed from the determined first and second characteristic functions. The transfer function, when applied to the second printer, operates on the characteristic function of the first printer. This enables the second printer to simulate the output of the first printer in response to the same input signal.

The described technique has been used to simulate different color printers to achieve same printed colors. In this paper, we will present the results of two Ink-jet printers (HP Photo Smart Printers and Epson Stylus-photo printers). We use HP PhotoSmart Ink-jet printer to simulate the behavior of Epson Stylus-photo printer.

Characteristic Functions of Printers

A color image is usually stored as RGB format. When sending a color image to a color printer, the color signal RGB will be transformed to the subtractive CMYK color signal and then color halftoning bi-level signal. Different color printers generate different color halftoning signals due to their own characteristics, giving different printouts when printing the same color image. For example, we print 125 color patches which are randomly sampled in the 24 bits RGB color space ([0-255] x [0-255] x [0-255]) using Photo-smart and Stylus-photo printers. Figure 1 shows the CIELAB ΔE between the printouts.

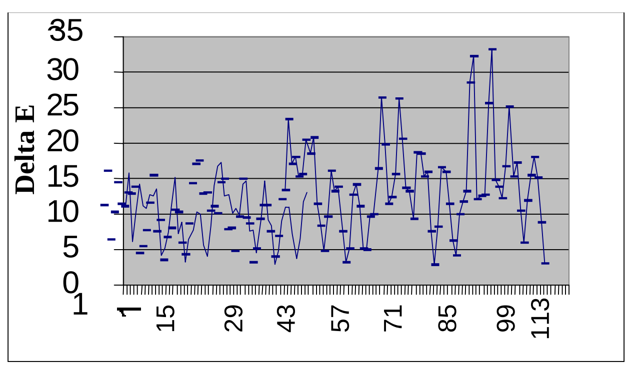

Figure 1. ΔE of 125 colors which are randomly chosen from the RGB color space.

The average of ΔE is 11.83 with the standard deviation of 6.02. The block diagram of a color printer to produce color printouts is presented in Figure 2. We treat the whole procedure that a color printer to generate color halftone signal as a black box. The black box can be modeled by a *nonlinear characteristic function* ***f (.).*** Therefore, the color behavior of a color printer can be described by the following simple equation:

$$O = f(x),$$

where O represents the printout color signal in CIELAB space and x is the input signal from the 24 bits RGB color space. Of course, the output color space can be defined as a device-depend color space (like a scanner RGB space). For color printer B to generate consistent color outputs as printer A, a ***transfer function*** needs applying to the input signal which is sent to both printer A and printer B. Figure 3 shows the block diagram. ***F*** and ***G*** denote the nonlinear characteristic functions of printer A and B respectively. Without applying the transfer function**,** the printouts have different colors. The purpose of the transfer function H is to compensate the color behavior of printer B and then simulated the color behavior of printer A. The transfer function H is defined as

$$H = F \circ G^{-1}$$

where G-1 is the inverse characteristic function of printer B.

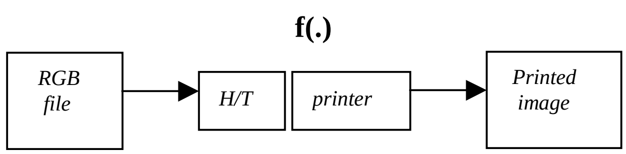

Figure 2. A color image in 24 bits RGB space is sent to a printer. Each printer has its own color conversion, dot size, resolution, ink and sorts of paper. The overall process is modeled by the characteristics function f(.). In this paper, we choose the CIELAB as the output space.

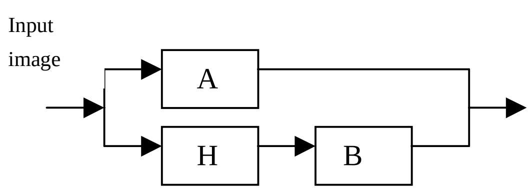

Figure 3. The procedure to make Printer B produce consistent color outputs with printer A. H denotes the transfer function. The transfer function H makes printer B to simulate the color behavior of printer A.

Constructing the Transfer Function

The flow chart to determine the transfer function H is shown in Figure 4. Color behavior of printer A and printer B needs determining first. In the following sections, we will describe a technique of constructing a 3 dimensional look-up table to approximate the transfer function based on tetrahedral interpolation.

Determining the Characteristic Function of a Printer

The characteristic function of a printer is defined as a mapping from a device-dependent color space (printer-RGB space) to another device-independent color space (CIELAB space). For a given color printer, different resolutions and sorts of paper will result in different characteristic functions. We approximate the characteristic function by a 3-D look-up table. The printer RGB color cube is sampled uniformly along the R, G, and B axes. In [1], a non-uniform sampling scheme is also discussed. The uniformly sampled RGB coordinates represent the nodes of a uniform 3D lattice in the RGB cube. The nodes form a set of non-overlapping cube cells. There will be (n-1)^3 cubes and n^3 sampled points where ***n*** is the number of sampling rate. Each cell can be partitioned as a set of prisms, pyramids, or tetrahedrons. Among them, tetrahedral interpolation [2, 3] is the most popular technique.

The printed patches are then measured by the Gretag spectrophotometer to get the CIELAB information. The color information is stored in each entry of the 3-D table. The LAB information of unmeasured RGB points can be calculated based on the tetrahedral interpolation. Tetrahedral interpolation using the four vertices of the encompassing tetrahedron determines a set of weights to interpolate any point in the interior or boundary of the tetrahedron. The weights are positive and sum to unity. The weights are then used to compute the weighted sum of the LAB values which are stored at the corresponding vertices.

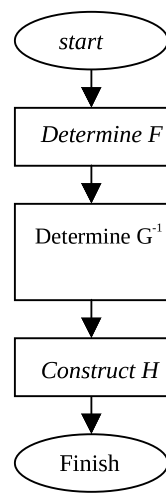

Figure 4. The flow chart of constructing the transfer function H.

The accuracy of the interpolation depends on the non-linearity of the characteristic function, the sampling rate in the RGB space and the tetrahedral partition. A high sampling rate in the RGB space will have small inter-polation error, this, however, needs to print a lot of patches. In [4], a nonlinear resample technique based on B-splines to increase the sampling rate and reduce the interpolation error has been proposed.

Constructing the Inverse Function

The inverse function of a printer is a mapping from a device-independent color space (CIELAB space) to another device-dependent color space (printer RGB space). The input domain can be predefined as [0-100] x [-120, 120] x

[-120, 120] in CIELAB space. Each entry in the 3-D table contains the corresponding printer RGB. The procedure for determining the appropriate printer RGB coordinate for a given CIELAB color can be described by the following two mapping strategies based on that the colors are inside-gamut or outside-gamut.

Inside-Gamut Mapping

The measured CIELAB information of the printed patches forms a set of non-overlapping tetrahedrons. For a given color, being outside or inside of a tetrahedron can be determined by a set of weights. If the weights are all positive and sum to unity, the color is inside the tetrahedron. If any weight is negative or greater than one, the color is outside the tetrahedron. The corresponding printer RGB of that color can be computed by a weighted sum of the printer-color values stored at the corresponding vertices.

Outside-Gamut Mapping

If a color is outside the set of tetrahedrons, then the color is outside the gamut of the printer. There are different color mapping algorithms of transforming input colors to the surface or inside gamut: clipping, linear compression, and nonlinear compression [5]. For the results presented in this paper, out of gamut colors are mapped to the gamut boundary. The method projects an out-of-gamut color along lines of constant hue while mapping to constant luminance.

Cascading Two Tables to Form the Transfer Function

The final step to construct the transfer function H is to cascade the two tables, which can reduce the memory requirement and increase overall performance. The dimension of H can be different from that of F and G^-1. The dimension of F is equal to the number of sampling rate in the RGB space. In order to preserve enough color information of inside gamut, the dimension of the inverse characteristic should be high enough. A simple pseudo code is presented to describe the cascading procedure:

```
For (R =0; R<= 255; R+= 255/Dim)
   For ( G = 0; G <= 255; G += 255/Dim)
       For (B = 0; B <= 255; B+= 255/Dim) {
          InterpolateRGBtoLab(F,R,G, B, L,a,b);
          InterpolatedLabtoRGB(G-1, L, a,b,R1,G1,B1);
          Assign(H,R,G,B,R1,G1,B1);
      }
```

where Dim is the dimension of the final table size. After cascading two tables together, the transfer function H defines a mapping from printer A RGB color space to printer B RGB color space. The accuracy of the function depends on the non-linearity of both functions, the sampling rate of each function, and the final dimension of the transfer function.

Experimental Results

We apply the above technique to the HP Photosmart printer and EPSON stylus photo printer. To measure the characteristic function of both printers, we print 13 x 13 x 13 patches which are sampled uniformly in the RGB space. The dimension of inverse characteristic function and the transfer function is chosen as 33 in order to preserve the color information. After applying the transfer function to the image which then is sent to HP photo smart printer, the average ΔE is reduced substantially to 6.6 from 11.8. If we compare the hue accuracy, which is defined as the arctan(B/A), the average hue difference is reduced to 0.105 from 0.287.

Conclusion

In this paper, we present a technique to have different color printers produce consistent color outputs by cascading the characteristic function of printer A and the inverse characteristic function of printer B, and then the transfer function can make printer B simulate the color behavior of printer A.

When the technique is practically applied to two photo ink jet printers in the market (EPSON stylus photo and HP Photosmart) in our experiment, the result shows the color differences can be reduced to two to three times small after applying the transfer function. The experimental results demonstrate the effectiveness of the algorithm.

References

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