Color Image Processing in Fujifilm's Digital Imaging Services

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Abstract

The color image processing architecture on Fujifilm's digital imaging services is designed to achieve high print quality and color compatibility in various types of digital printers and displays, which are connected to digital photo systems in photo finishing lab. In order to produce a desirable photo print on various devices, which have different color gamut from each other, we define the reference color reproduction device on which the desirable color of an image data is achieved, and then the color of it is reproduced with high fidelity on any other devices. The auto color correction technology is introduced to achieve optimal contrast and brightness on the reference color reproduction device. In addition, consistent color reproduction is obtained on all printers through a color matching technology based on the accurately calibrated colorimetric method that eliminate measurement errors caused by a fluorescent whitening effect. The reference color reproduction is designed based on the color reproduction characteristics of the Frontier350 digital minilab.

The color image processing software that integrates these technologies is incorporated in all Fujifilm's digital imaging services.

Introduction

The Fujifilm's digital imaging services (FDi services), which started in 1997 as digital imaging services in photo finishing laboratories, have allowed flexible photo printing services connected with a variety of I/O devices.[1] These services include printing image data captured by digital still cameras (DSC), printing image data processed by the PC and copying prints using reflection scanners, as well as the service to write images captured on silver halide film to a dedicated CD-R and the service to print image data recorded on CD-R (Fig. 1). Captured data, such as data scanners read from silver halide film and data the DSC captures, needs to be converted into data capable of providing gradients and color reproductions suitable for prints. At this point, a process is needed to set the brightness and color balance appropriate to each scene, considering a difference in the observation environment between viewing captured scenes and viewing prints, as well as the gradient range that can be reproduced on the print.

In order to faithfully reproduce the data optimized for prints at any location, the following color management needs to be accurately performed not just within one system but also between multiple laboratories:

1. Matching colors between the monitor and printer
2. Matching colors among different print devices
3. Matching colors between reflecting originals and print copies

In order for different laboratories to produce uniform color reproductions, print reproduction needs to be stipulated to serve as an image design reference. In addition, accurate measurement of print colors is essential in order to match colors on different devices.

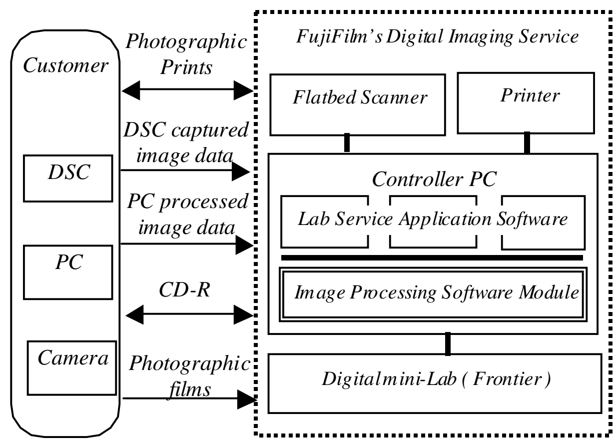

Figure 1. Fujifilm's digital imaging services

The authors have incorporated into the image processing terminals in the laboratories a color management system that can answer all the requirements addressed above. The overall color management configuration and each technical requirement are described next.

Color Transform Between Devices

Basic Concept

The color management system in the Fujifilm laboratory service can be represented as shown in Fig. 2. Colors on image capturing devices, such as negative scanners and DSC, display devices, printers, and print scanners are associated as f0-f3 respectively with reference printer colors serving as common color representations.

A reference printer, which constitutes the core of color management and is also a print reproduction design target, must have a color reproduction range sufficient for photographic representations and must be able to reproduce target photo images. As the reference for color management, reproduction characteristics need to be precisely defined using values. In order to successfully exchange image data in open environment, compliance with international standards is also essential. From the above point of view, a print model is used as a reference print. This model is defined with color reproduction characteristics using CIE colorimetric values based on color reproduction when printed on a silver halide laser printer (Frontier350). In addition, 1-to-1 associations with sRGB that has become a common default color space[2], have been determined.

Input data from image-capturing devices, such as the DSC and film scanners, goes through conversion f0 to reproduce a favorable appearance of the subject on the print and becomes data that provides an optimal image on the reference print. Conversion f1 is implemented on the appearance on the reference print and on the standard monitor stipulated with sRGB in order to produce nearly the same impressions, before creating data for the CD-R write service. Print data is created via conversion f2, which maps reference print colors in the printer's color reproduction range. This conversion f2 is designed considering accurate gray balance and hue reproducibility as well as gradient reproducibility for the reference print. The data input from reflection scanners goes through conversion f1 in order to reproduce original print colors accurately on the reference print.

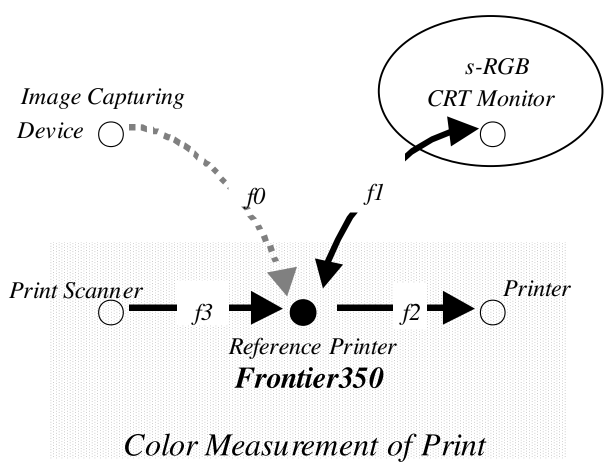

Figure 2. Color transform between devices

Color Print Colorimetric

Reproduction of reference print colors is defined with CIE colorimetric values that determine color values. The colorimetric values of prints can be found with a colorimeter. However, these values frequently do not correspond to visual evaluations due to the influence of fluorescent brightener contained in a majority of color print media.

Fig. 3 shows the plotting, on the planes a*-b* of the CIE L*a*b* color specification system, of the actual colorimetric measurement values for three different types of color print media (samples A, B, and C) varying in the amount of fluorescent brightener. Sample A appeared to match sample B when these three print medium samples were visually evaluated under a fluorescent lamp with a color temperature of 5,000K normally used for evaluation of colors. However, the measurement results by a standard colorimeter (the hollow symbols) indicate that sample A matches sample C. This discrepancy is due to the difference in the fluorescent brightener effect caused by different relative ultraviolet spectral distributions of two different light sources, the fluorescent lamp used for visual color evaluation and the colorimeter's light source. Such difference significantly affects highlighting important in photo reproduction. For example, when color conversion is performed based on this colorimetric measurement value, sample C results in a print with yellowish highlighted areas.

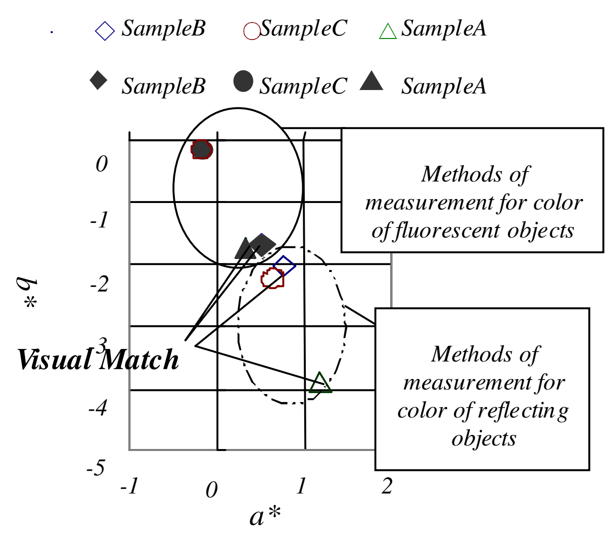

Figure 3. Plots of colorimetric values of photographic color paper by two different measurement methods, Sample A and B match visually

The authors employed a correction method of estimating the influence of fluorescent components under the observation light source from the values measured by eliminating the fluorescent components by a filter and from the standard colorimetric values.

The result of using this correction method (the solid color symbols in Fig. 3) indicates that the value of sample A approximates to that of sample B, confirming that these two visually matched samples are also in agreement in terms of numeric values. This colorimetric value calculation method considering fluorescent effect is used for all color designs in this digital photo system.

Conversion of Capturing Device Data

Prints from Digital Still Cameras

The DSC encodes actual scenes having a wide range of brightness and color reproduction to be captured in signal format in compliance with ITU-R BT.709 (hereafter BT.709). When printing this signal, the following points needs to be taken into account:

1. Enhancement of contrast since brightness when observing the print is lower than when observing the scene.
2. Need to contain within the print's darkness range and to contain the principal part of the photograph accurately in a narrow gradient reproduction range.
3. Requirement for independent control of regenerative colors, such as human skin colors, the green colors of plants, and sky colors.
4. Optimization of white balance
5. Correction of characteristics differences among devices

Gradient Conversion

From the DSC image data encoded with BT.709, the brightness of scene is calculated and then gradient conversion is performed on the darkness value that has been converted into a logarithm (Fig. 4).

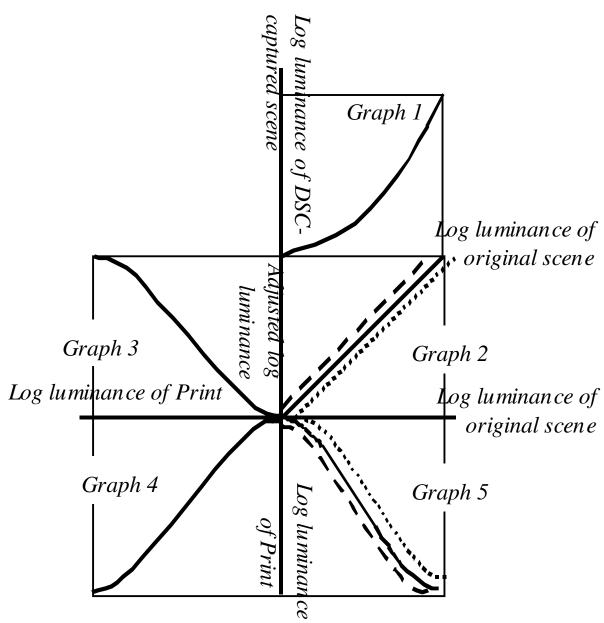

Figure 4. Tone Reproduction Characteristics of DSC Print System

First, color gradient characteristics are accommodated for each equipment model in Graph 1 and then the exposure and light source are corrected by automatic exposure and white balance adjustment technology for prints in Graph 2. At this point, based on various image analysis data, the photographed environment is estimated to find darkness and white balance correction values. As to the analysis data, a variety of information is gathered, ranging from primary characteristic quantities, such as the darkness value on the highlighted side of a cumulative histogram, to high-order characteristic quantities, such as the average darkness value of an area where a human face is extracted.

Next, gradients are contrasted in Graph 3. Since the optimum gradient characteristics are dependent on the image scene, gradient selection is made possible for scenes against the light and under a clouded sky as well as for stroboscopic scenes. These gradients are set separate from standard scenes.

In Graph 4, in order to utilize the narrow reproduction darkness area of the print to its fullest extent, contrast is projected based on the image's analysis information, and the gradient highlighting and shadow areas are nonlinearized. This conversion allows desirable prints to be reproduced without sacrificing gradients of snow scenes, clouds, etc. while enhancing the contrast of the entire image. However, since this gradient nonlinearization adversely affects skin colors, it needs to be used in combination with color correction described next.

Graph 5 shows an overall characteristic between the logarithm luminance of original scene and the logarithm luminance of print.

Color Correction

After gradient conversion the image data is converted into CIE lab signals. The degree of brightness, saturation, and hue modifications for each color is controled independently according to a weighted function using the distance from the center as its variable for each of nine principal colors: skin colors, the green colors of plants, sky blue, R, G, B, C, M and Y. In addition, this color correction section limits the change in skin color saturation and hue depending on the extent of gradient nonlinearization.

Color Gamut Mapping

Chromatic Adaptation

The authors set the display observation environment to 6,500K in compliance with sRGB and selected a 5,000K high color-rendering fluorescent bulb as the light source for print observation. In the process of conversion f0 from sRGB into reference print reproduction colors, color adaptation is corrected using a Von Kries-type adaptation conversion. Furthermore, the color gamut significantly varies between the print and a standard sRGB monitor.

Color Mapping Methods

Various methods are known to accommodate color reproduction area differences.[3] Emphasis on the accuracy of colors in shared reproduction areas among different devices each having a different color reproduction area undermines gradient reproducibility. The authors made an attempt to apply the following two mapping methods in order to match photographic impressions while utilizing the color reproduction area of each device to its fullest extent:

A. Method of optimizing the mapping quantity and direction in order to maintain hues and to preserve color gradients.
B. Method of mapping colors in order to preserve color consistency and gradients as possible.

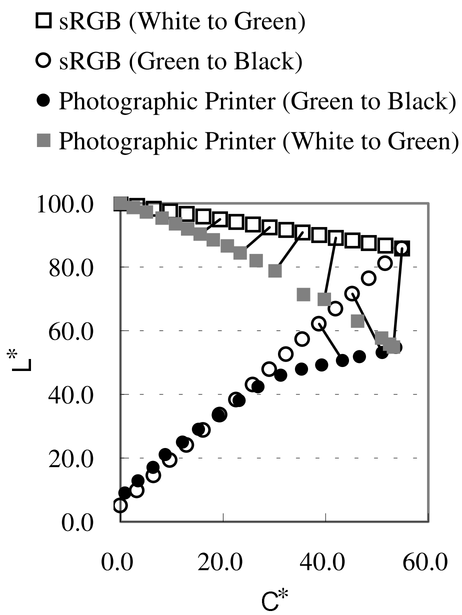

Figure 5. Result of gamut mapping (method A) between sRGB and laser photographic printer plotted in L-C* plane at Hab=180*

The graph in Fig.5 shows the results of the former method applied to the mapping of green hue colors between the sRGB monitor and a laser photo printer. However the lightness of high saturated colors are considerably changed, both series of colors from white to green and colors from green to black are mapped preserving direction of gradients in lightness and chroma. It is important to express the slightest nuances of shading desired by photographers.

The graph in Fig. 6 shows the results of the later method. The smaller lightness change ensures closer appearance between two images. Even though Fig.6 shows the case of mapping between sRGB and laser photographic printer, this type of mapping is suited to the mapping between printers in which closer appearance is strongly required. Both mapping methods utilizing the color gamut of each device to its fullest extent cause no detectable loss of colors in successive transforms.

By selecting a mapping method according to the device and application, the digital print service utilizes the color reproduction characteristics of that device to its fullest extent and also keeps the better reproductions of color gradations.

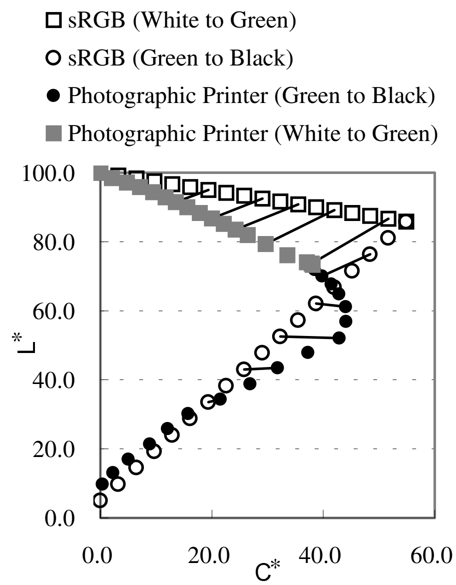

Figure 6. Result of gamut mapping (method B) between sRGB and laser photographic printer plotted in L-C* plane at Hab=180*

Conclusion

Accurate quantitative management of reproduction print colors has been achieved through an error-free, color-print colorimetric method. Correction of color gradients based on scene analysis has made it possible to produce prints with good contrast and desirable reproductions of stored colors from data captured by digital cameras. Furthermore, colors and gradients are matched among different devices by applying color-gamut mapping optimized to utilize the color gamut of each device. Incorporation of such a color image quality assurance system into every image processing terminals in photo-finishing laboratories made it possible to offer a high-quality service that is consistent among different laboratories.

References

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Biography

Akira Yoda received his ME degree in applied physics from Tohoku University. In 1982, he joined Miyanodai Technology Development Center of Fuji Photo Film Co., Ltd. He has worked in digital pre-press system development. He is currently focusing on color image processing in digital photo systems.