

Color Cross Talk Correction for Digital Image Printing System

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Abstract

On color photographic media the image is formed in three different layers of the photographic emulsion. Ideally each layer is only sensitive to a single primary color; Red, Green and Blue, (R, G and B, respectively). However, due to the band structure of the molecular excitation level found in the embedded dyes, there is cross talk between the different light sensitive layers. Red exposure not only creates density in the red sensitive layer, it also creates small but measurable contributions in the green and blue sensitive layers. Similar effects can be seen for green and blue exposures. To achieve the desired density on the final print it is necessary to compensate for the density contribution arising from cross talk. In digital printing equipment this is conventionally accomplished through either a closed loop or iterative calibration process. Both of these are cumbersome and wasteful in time and media usage.

This paper puts forth a novel method that corrects for the cross talk contribution. This method is based on measuring the densities that are printed at different light exposure values. From these measured densities one can obtain the correlation between the printed grayscale densities and the light exposure values over a wide range for each of the complimentary and non-complimentary light. In comparison to the conventional methods, this method provides quick and satisfactory results for cross talk correction. Taking the cross talk contribution into account, a linearization method has been developed to achieve equal perceptual steps of gray. This method enables us to calibrate printers from scratch in a single attempt.

Keywords: cross talk, printed density, digital printing systems, linearization to equal perceptual gray-steps.

Introduction

Color photographic material usually consists of three light sensitive layers plus a blue blocking layer of emulsion. Ideally each layer would only be sensitive to the light of its complementary primary color. The amount of dye produced in a layer would be proportional to the particular exposure level of its complementary color, i.e. red light would create cyan dye, green would produce magenta and blue would create yellow. However, due to the band structure of molecular excitation levels in dye molecules, cross talk between the different layers is becoming an issue, causing each dye layer not only to absorb its complementary color, but also small contributions from the two other non-complementary primary colors. This causes the density of the resulting image to be different from the ideal case, where only the complimentary colors are creating the desired output density. This effect is known as cross talk, and limits the ability of color photographic materials to re-create real-life colors accurately during the printing process if no cross talk correction is applied. To achieve the desired output densities it is necessary to calibrate, or “Gray Balance”, the output device.

Output device calibration can be achieved in various ways; through a closed loop process, an iterative algorithm or the method described in this paper. The first two methods are wasteful in time and material while the third one enables the user to achieve machine calibration in a single attempt.

The cross talk compensation method described herein begins with a calibration image having different printed grayscale densities ranging from “paper-white” to the maximum density the material can support. This is achieved by exposing the media with the three primary colors, RGB. By measuring the printed image densities at the different light exposure values, one can obtain a correlation between the printed grayscale densities and the light exposure level over the entire range of exposure values for all primary colors. Additionally, an analytical density test image made up of cyan, magenta and yellow components is generated and measured. By using the measured correlation between the printed densities and the light exposure values, as well as the measured analytical densities, one can calculate the cross talk effect contribution.

This provides a quick calibration for output devices.

Blue light sensitive, yellow dye forming
Yellow filter layer
Green light sensitive, magenta dye forming
Red light sensitive, cyan dye forming
Media Support

Figure 1. The essential elements of a color photographic medium[1]

Figure 1 shows a simplified cross-section of a color photographic medium. The basic structure from top to bottom is as follows: a blue light sensitive layer, a yellow filter layer, a green light sensitive layer, and a red light sensitive layer, all coated onto a media support. When the medium is exposed to light and chemically processed, yellow, magenta, and cyan dyes are formed in the layers sensitive to blue, green, and red light, respectively.

The light exposure values for color of light (e.g. red, green, and blue) are given by the following equations[1]:

$$R_{exp}=K_r\Sigma_\lambda S(\lambda)T(\lambda)r(\lambda)$$

$$G_{exp}=K_g\Sigma_\lambda S(\lambda)T(\lambda)g(\lambda) \qquad (1)$$

$$B_{exp}=K_b\Sigma_\lambda S(\lambda)T(\lambda)b(\lambda)$$

where R_{exp}, G_{exp} and B_{exp} are the exposure values for red, green, and blue light; $S(\lambda)$ is the spectral power distribution of the printer light source; $T(\lambda)$ is the spectral transmittance of the medium; $r(\lambda)$, $g(\lambda)$, and $b(\lambda)$ are the red, green, and blue spectral sensitivities of the medium; and k_r, k_g, and k_b are normalizing factors. These normalizing factors usually are determined such that R_{exp}, G_{exp}, and B_{exp} = 1.0 for theoretically 100% transmissive negative media.

The printing density values of red, green, and blue light on the exposed medium are defined as [1]:

$$PD_r = -\log_{10}(R_{exp})$$

$$PD_g = -\log_{10}(G_{exp}) \qquad (2)$$

$$PD_b = -\log_{10}(B_{exp})$$

where PD_r , PD_g , and PD_b are red, green, and blue printed density values. These are the parameters that represent the color characteristics of the printed medium.

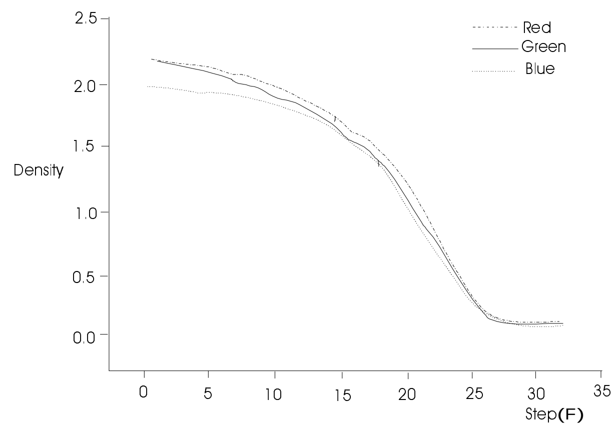

Figure 2. Printed grayscale densities $PD\lambda_{i,j,k}$ as a function of light exposure value (ϕ).

Figure 2 displays the red, green, and blue printing densities to achieve equal RGB on an equal perceptual gray pattern as a function of light exposure value.

In the ideal case, the spectral responsiveness of the photographic emulsion would be very narrow, completely separated from one another, and perfectly aligned with the spectral absorption of the corresponding dyes. As a result, the cyan dye of the negative image uniquely controls the red-light exposure to the printed medium. Therefore, the cyan dye has only red printed density and has no green or blue printed densities. Similarly, the magenta dye of this idealized example uniquely controls the green light exposure, and the yellow dye uniquely controls the blue light exposure. In this case, there would be no cross talk effect.

Figure 3 shows the spectral transmission densities of the cyan, magenta, and yellow dyes for a typical printed medium. Note that the spectral characteristics of these dyes, particularly the cyan dye, are somewhat different from what we expected. The cyan dye absorbs not only red light, but also some green and blue light. Therefore, the cyan dye not only contributes to the red printed density, but also to blue and green printing densities. Similarly, the magenta dye absorbs not only green light, but also small amounts of blue and red light. Thus, it not only contributes to the green printed density, but also to the blue and red printed densities.

The yellow dye not only contributes to the blue printed density, but also to the green printed density. As a result of this unwanted absorption, cross talk is introduced to the printed material.

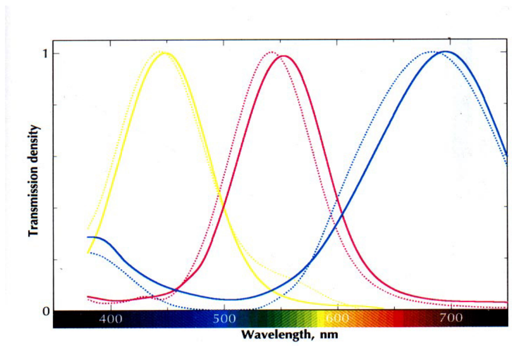

Figure 3. Comparison of spectral transmission densities of cyan, magenta, and yellow dyes. Solid lines represent photographic color negative film and dotted lines represent transparency film[1]

In order to simulate the real-life color as much as possible, the cross talk effect must be corrected for. We have developed a method to calculate the printing density values taking the cross talk effect into account and correcting for it. Based on the corrected printing density values, one can adjust red, green, and blue light exposure values to achieve the desired final density.

Cross talk Effect Correction

For the purposes of this discussion "printed grayscale densities" refer to red, green and blue density values of an image in grayscale. The printed grayscale densities can be measured with a densitometer which introduces no contributing error.

Printed grayscale densities are functions of light exposure values (shown in figure 2) as described below:

$$PD_{\lambda_k}(\phi) = \Psi(\lambda_k, \phi) + \delta\Psi(\lambda_{i,j}, \phi); \quad k \neq i, j \qquad (3)$$

where $PD_{\lambda_k}(\phi)$ is the printed density (either red, green, or blue) measured in grayscale; $\lambda_{i,j,k}$ is the wavelength of light exposure (either red, green, or blue); $\Psi(\lambda_k, \phi)$ is the analytical density contributed only from λ_k (without $\lambda_{i,j}$); $\delta\Psi(\lambda_{i,j}, \phi)$ is the density contributed to $PD_{\lambda_k}(\phi)$ by the exposure light with $\lambda_{i,j}$; and $\delta\Psi(\lambda_{i,j}, \phi)$ is the contribution of cross talk effect.

For example if $\Psi(\lambda_k, \phi)$ is the red printed density, then $PD_{\lambda_k}(\phi)$ is the total red density measured, Ψ is the portion of this total contributed by the red light exposure and $\delta\Psi$ is the portion of this total contributed by green and blue light exposure.

Using the measured printed density values PD_{λ_k} in grayscale and the corresponding analytical $\Psi(\lambda_k, \phi_0)$, the contribution of the cross talk effect can be calculated from the following equation:

$$\delta\Psi(\lambda_{i,j}, \phi) = PD_{\lambda_k}(\phi) \times [1 - \Psi(\lambda_k, \phi_0) / PD_{\lambda_k}(\phi_0)] \qquad (4)$$

where ϕ_0 is the selected light exposure value in the middle region of the density curve (shown in figure 2). It should be noted that in equation 3, both analytical density $\Psi(\lambda_k,\phi)$ and the cross talk effect contribution $\delta\Psi(\lambda_{i,j},\phi)$ are at same light exposure value ϕ. However, in practice, the red, green and blue light ($\lambda = \lambda_i, \lambda_j, \lambda_k$) could be used to expose with different exposure values $\phi_{i,j,k}$, in order to achieve a desired density in grayscale.

These different exposure values produce different cross talk contributions as $\delta\Psi(\lambda_{i,j}, \phi_{i,j})$, because they have different light exposure values. Therefore, in equation 3, in order to keep the printed grayscale density PD_{λ_k} constant with the varying light exposure values $\phi_{i,j}$, the analytical density $\Psi(\lambda_k,\phi)$ must be varied. To vary the analytical density, $\Psi(\lambda_k,\phi+\Delta\phi)$ can be obtained as follows:

$$\Psi(\lambda_k, \phi+\Delta\phi) = PD_{\lambda_k}(\phi) - \Delta\delta\Psi(\lambda_{i,j}) \qquad (5)$$

where

$$\Delta\delta\Psi(\lambda_{i,j}) = \delta\Psi(\lambda_{i,j}, \phi_{i,j}) - \delta\Psi(\lambda_{i,j}, \phi) \qquad (6)$$

The terms of $\delta\Psi(\lambda_{i,j}, \phi)$ and $\delta\Psi(\lambda_{i,j}, \phi_{i,j})$ in equation 6 are calculated using equation 4 in the case where a selected light exposure value (ϕ_0) is used or using equation 7 when measured analytical density values are used:

$$\delta\Psi(\lambda_{i,j}) = PD_{\lambda_k}(\phi) - \Psi(\lambda_k, \phi) \qquad (7)$$

Equation 6 is used to calculate the cross talk effect contributed by the non-complementary light at the same as and at different light exposure values from the complementary light. This value in turn is used to recalculate the analytical density using Equation 5.

The adjusted light exposure value $\phi + \Delta\phi$ is calculated as following and is used to compensate for the cross talk effect:

$$\phi+\Delta\phi = \Psi^{-1}\{\lambda_k, [PD_{\lambda_k} - \Delta\delta\Psi(\lambda_{i,j})]\} \qquad (8)$$

It should be noted that after the cross talk correction is complete, there is a second order cross talk effect when ϕ is changed to $\phi+\Delta\phi$. Therefore the correction procedure can be repeated. However, in practice, the second order cross talk effect is smaller than the densitometer's margin of error, and so the second order correction procedure can be neglected.

Linearization Method

In order to achieve equal perceptual steps in printed images, the correlation between printed densities and light exposure values is often required to be an exponential-like function. This correlation is achieved through a linearization method in which the cross talk correction plays a very important role.

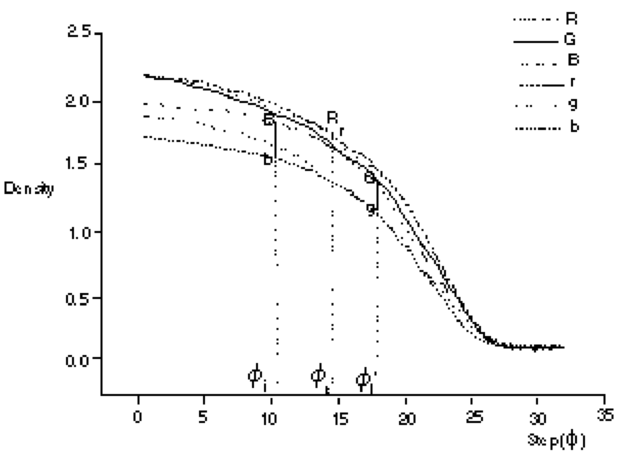

Figure 4. Curves (R, ϕ), (G, ϕ), and (B, ϕ) are functions of printed grayscale density vs light exposure value for red, green, and blue light. Curves (r, ϕ), (g, ϕ), and (b, ϕ) are functions of the analytical density vs light exposure value for RGB light.

To carry out the linearization, the medium is exposed with light in a stepwise fashion with linearly increasing light exposure values to form a strip with printed grayscale densities, referred to as a "step tablet". The increases in the successive light exposure values are in equal steps. The "step tablet" is then used to obtain a correlation between the printed grayscale densities and the light exposure values. The term "printed grayscale density" refers to the red, green and blue density of a grayscale image measured with a densitometer that introduces no contributing error. In the next step the measured printed densities are plotted against light exposure values to obtain a curve for each of the red, green and blue light as shown in Figure 4. Figure 4 shows curves (R, ϕ), (G, ϕ), and (B, ϕ) as functions of printed grayscale density versus light exposure value for red, green, and blue light. The curves (r, ϕ), (g, ϕ), and (b, ϕ) are functions of the analytical density versus light exposure value for RGB light. $\overline{Rr}$ represents the cross talk effect contributed by green and blue light at an exposure value of ϕ_k. $\overline{Gg}$ presents the cross talk effect contributed by red and blue light at an exposure value of ϕ_j. $\overline{Bb}$ presents the cross talk effect contributed by green and red light at an exposure value of ϕ_i. For given targeted printed densities R, G, B in grayscale, one can find the corresponding light exposure values ϕ_k, ϕ_j, ϕ_i from curves (R,ϕ), (G,ϕ), and (B,ϕ) in figure 4. The cross talk effect is corrected by means described above. Once the cross talk effect is corrected, the analytical density values are recalculated using equation 5. Finally the adjusted light exposure values $\phi+\Delta\phi$ are obtained from equation 8.

Due to the fact that cyan dye creates the most significant cross talk contribution compared to that from yellow and magenta dye, it is important to correct for the effect of red printed grayscale density first (k = Red).

Conclusion

A method of cross talk correction for digital printing system has been discussed in detail. This method is conducted based on the measured printed image densities, and provides satisfactory results for cross talk effect correction.

In order to achieve equal perceptual gray steps, a linearization method, in which the cross talk effect correction was taken into account, is discussed. This method can setup printers from scratch to a ready-to use state in one step.

References

1. Edeard. J. Giorgianni and Thomas E. Madden, *Digital Color Management: enconding solution.*
2. Fred Fang Cao, Horst Schaaf and Susan Shuping Zhang, *Crosstalk Correction.* US and worldwide Patent pending.