# The Influence of Paper Properties on Color Reproduction and Color Management

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## Abstract

The characterization of the transfer function of a printing device is a complex procedure involving not only the device itself but also the paper and its properties. The work reported here is an ongoing development of building a library of characterization procedures. These procedures can be applied to printing situations with different combinations of printing engines and paper grades. An example of a building block is color separation with respect to halftoning techniques and available inks or toners. Another is the characterization of the physical properties of the paper substrate. The most common characterization procedure is through the ICC-profile. Device ICC-profiles contain the data needed for a color management system (CMS) to do color separation and the color mapping. In this study special emphasis is put on the influence of the paper properties and on how they affect the profile. Gloss, surface roughness, whiteness and light scattering are all measurable paper properties that certainly will affect the color reproduction. Ink and paper interaction and especially ink penetration is also a phenomena that affect the color reproduction and thus the ICC profile.

## Introduction

Today, ICC color management is supported by almost all color imaging software and used for most printing applications, both in the Graphic Arts industry and also introduced in some home and office applications. The ICC committee standardizes the ICC profile structure[1,2] but the creation and use of the profile is specific for each supplier of Color Management software. Within the home and office area, the printer supplier distributes general profiles with little consideration taken to the influence of different papers.

The accuracy of a color reproduction system depends on the imaging processing and on the stability of the printing process. The quality of the imaging processing, including color transformations, color separations, rendering intent, halftoning etc., depends up on the information in the ICC profile and the calculations carried out by the Color Management Module (CMM).[3] Therefore, proper information in the profile is crucial. The process of creating ICC profiles is time consuming and expensive. Knowledge about components that affect the profile are important in order to understand when a new ICC profile is needed. One example is the white point of the paper. The paper whiteness included in the ICC profile is measured in D50 luminance. The use of FWA (Fluorescent Whitening Agent) in paper production affects the white point and it might be under estimated due to the low UV content of the illumination used in the spectrophotometer.

## Theory

In ICC color management the ICC profiles are central components of the workflow. The profiles characterize each device and are used by the Color Management Module (CMM) to link colors between device dependent and device independent colors spaces. Color reproduction characteristics of an output device is affected by the halftoning method,[4-11] the process colors characteristics[11,12] and the properties of the paper. The interaction between paper and ink, or toner, together with paper properties like whiteness, light scattering, amount of FWA and gloss must be considered in the creation of ICC profiles. To get highly saturated colors the colorants must be bound close to the paper surface. If the colorants penetrate in to the paper structure the result will be weak and dull colors.[13-22] The whiteness of the paper is supposed to mainly affect the color reproductions of high-key colors while the gloss level should effect all colors in the gamut but most noticeable on high-saturated colors. The FWA is active when there is UV content in the illumination. UV light is absorbed and reemitted in the visual region, thus contributing to a higher reflectance in blue part of the visual spectra.

The formula of CIE whiteness (Eq. 1) includes not only the lightness but also a contribution of the tone value.[23] Whiteness is a subjectively perceived property and most people consider an increase in whiteness when the paper has a slightly blue tone. The whiteness measurement is done with D65 illumination and 10° observer.

$$
\begin{aligned}
&W = Y_{10} + 800(x_{n.10} - x_{10}) + 1700(y_{n.10} - y_{10}) \\
&Y_{10} = Y - value \\
&x_{10}, y_{10} = Chromaticity\_co-ordinates \\
&x_{n.10}, y_{n.10} = Chromaticity\_co-ordinates\_D65-illu\min ant
\end{aligned}
\quad (1)
$$

In the paper industry most spectrophotometers are using xenon lamps as light source. The spectral distribution of a xenon lamp is close to the CIE D65 standard illuminant.[24] The UV content is adjusted with UV filter in order to get a good match of the UV content of CIE D65 standard illumination. In the Graphic Arts industry spectro-photometers are often equipped with tungsten lamp wit a low UV content  and spectral distribution close to CIE A standard illumination. The spectral distribution is recalculated by a mathematical weighting function. This mathematical adjustment has no effect on the activation of FWA in the paper.

Another attribute is how different printing technologies change the appearance of the printed surface. Electrophotographic prints gives differential gloss depending on the amount of toner applied to the paper surface and the combination of temperature and pressure in the fusing process.[25,26] In inkjet printing, the effect some times is the opposite, high amount of ink gives a decrease in gloss level.

## Method

In this study a selection of different paper grades with different physical and optical properties have been used. The selection of paper includes both coated and uncoated grades with different light scattering properties, whiteness level, shade, gloss level and amount of FWA. The differences between the paper samples are representative to commercial products. The idea was that these variations of parameters should give clear and understandable response on the color reproduction and the data in the ICC profile. These selections of papers were printed in three electrophotographical printers and two Inkjet printers. The printing trials included calibration of each device for each paper grade. The printed samples were visually inspected to secure that no artifacts or unevenness would affect the color measurements. All test forms were created as PostScript files[27] or TIFF images in order to be sent directly to the printer or RIP to avoid all interfering with settings in software applications.

ICC profiles were generated for all combinations of paper grade and printer. The IT8/7.3 color chart was used as reference file and the profiles were calculated with the Gretag Macbeth ProfileMaker software. A color target of 950 color patches intended to represent colors on the gamut surface was used for gamut visualization and for calculations of the color gamut volume. The profiles were used for color separation of images, the Gretag TC 2.88 RGB color target, *figure 1*, and designed color charts with color patches representing different color distributions in the CIELab color space. The Adobe Photoshop software and the Adobe ACE CMM were used for the color separations. In order to study the effect of the paper whiteness the absolute colorimetric rendering intent was selected. Color gamut and generated profiles were analyzed in Matworks Matlab software.

The printed samples were measured in a spectrophotometer with an optical geometry of 45°/0° and an observation angle of 2° and a measurement aperture of 4,5 mm in diameter. Measurements were done with D50 illuminant and with neutral filter (No). To show the influence of FWA additional measurements with D65 illumination, 2° observer and D65 filter was done.

A printing trial in a MANRoland DicoPress was performed with different temperatures in the Gloss Enhancement Module (GEM) in order to get printed samples with the same properties except for the gloss level. The roll temperature was changed between 40°C and 120°C.


*Figure 1. Color chart containing 288 patches, used for evaluating the effect of the ICC profile. The file format is TIFF RGB.*

## Results

The physical properties differ widely between the paper grades included in this study. Differences in coating color composition and coating layer composition results in large differences in the interaction between ink/toner and paper and also in the optical properties of the paper. The whiteness, light scattering, FWA content and gloss level are all parameters showing large differences between the paper grades. The analysis of the ICC profiles shows that even a moderate changes of these parameters gives response to the data included in the profile.

**Whiteness**

The use of FWA in paper paper production makes the UV content of the illumination crucial. If the UV content is to low, as might be the case for many spectrophotometers used in the Graphic Arts industry, the effect of FWA may not fully be captured by the ICC profile.

The difference in whiteness effects the color reproduction and the ICC profile. The color gamuts of two papers that are similar except for the whiteness level are shown in *figure 2*. Paper A (solid gray) got a lower whiteness level and a yellowish tone compared to paper B (line plot) with higher CIE whiteness and a bluish tone. The color difference between the two white points, the two peaks in the figure, is about 5ΔE.

Figure 3 illustrates the resulting color error of prints if both papers would have been printed with the same ICC profile. The circles size represents the color error. The average color difference of 288 colors, distributed allover the gamut, is 1.8ΔE but in the upper part of the gamut, around the white point, the color difference is around 4.5ΔE. Inside the gamut and for dark colors the color difference is close to zero.

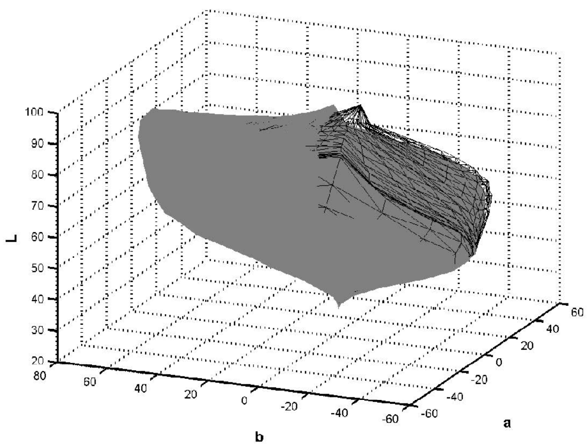

*Figure 2. Two papers with different whiteness levels. Paper A (solid gray) with lower whiteness and yellowish tone value and paper B (line plot) with higher whiteness and bluish tone value.*

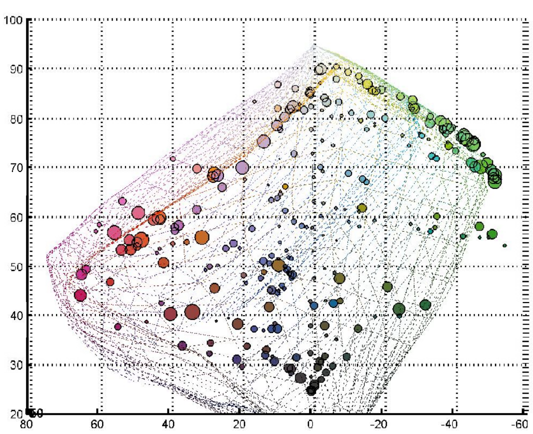

*Figure 3. The color error between the two papers in figure 2 if printed with the same profile. The largest color errors are noticed for high-key colors.*

**Gloss**

In *figure 4*, the effect of gloss level is showed. The two papers H and L have the same properties except for the gloss level. Paper H (line plot) has a higher gloss level as compared to paper L (solid). The higher gloss paper has a larger color gamut and the difference is largest for high-saturated colors and dark.

By comparing the color separation of the TC 2.88 RGB color target the color error of prints on the two papers with the same ICC profile can be estimated, *figure 5*. The largest color difference is noticed for high saturated and dark colors with differences of 5 to 7ΔE.

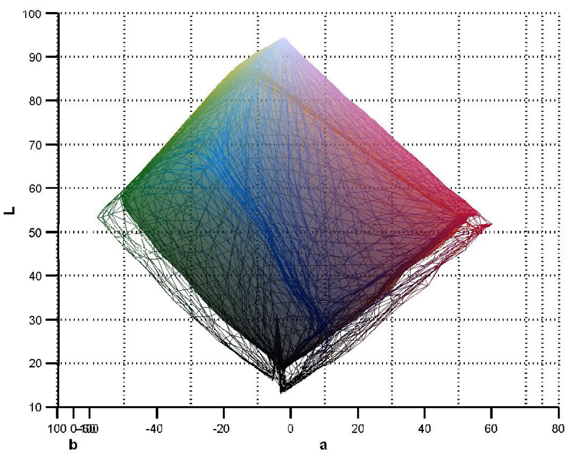

*Figure 4. Two papers with different gloss levels. Paper H (line plot) has a higher gloss level as compared to paper L ( solid).*

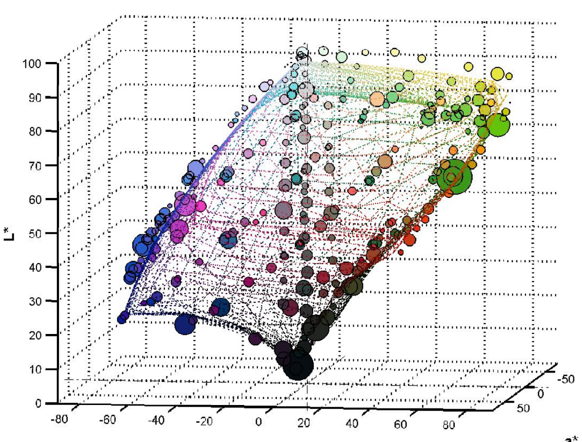

*Figure 5. The color error between the two papers in figure 4 when the same ICC profile has been used. The size of the circles corresponds to the color difference. The largest difference, about 7ΔE, is noticed for high-saturated colors.*

## Ink and Paper Interaction

Two illustrate the importance of the ink and paper interaction two papers with the same optical properties but with large differences in interaction with the ink was selected. The two papers were printed in and desktop Ink-jet printer with dye based inks. Paper T (line plot) in *figure 6* has been surface treated to keep the colorant close to the paper surface.

In the interaction between ink and paper U (solid) most of the colorant is absorbed into the paper structure.

The ink and paper interaction mainly affect the reproduction of highly saturated colors. In *figure 7*, a color chart with colors intended to be on the gamut surface has been treated by the two ICC profiles for the papers in *figure 6*. The color difference between the two papers is illustrated with circles, the size of the circle corresponds to the color error. The largest color difference, about 17ΔE, is noticed for high-saturated colors.

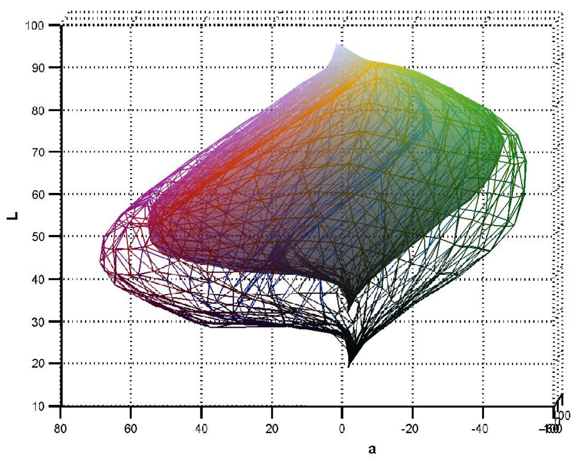


*Figure 6. Two papers with differences in ink interaction. Paper T (line plot) bounds the colorant at the paper surface while it penetrates in to the paper structure for paper U (solid).*

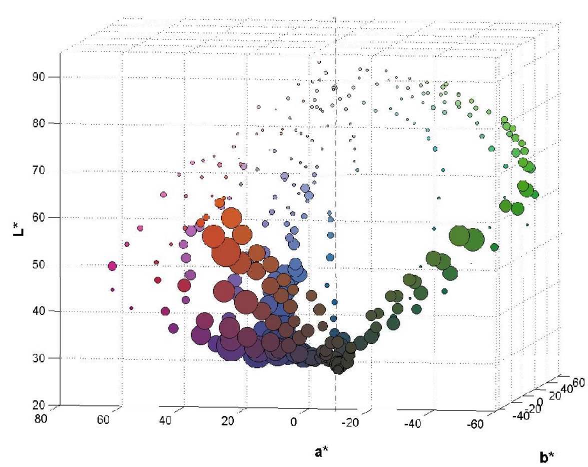


*Figure 7. Color difference between the two papers of figure 6. Largest difference, up to 17ΔE, is noticed for highly saturated colors.*

## Fluorescent Whitening Agent (FWA)

Papers with different amount of FWA but in other respect similar were measured with both D50 and D65 illumination. This effect will appear if the prints are studied both in indoor and outdoors environments. The color gamut in *figure 8* represent the two papers with different FWA content. Paper F (solid gray) does not include any FWA while paper G (line plot) has an FWA content representative for ordinary office paper. In *figure 8*, both paper are measured with D50 illumination with low amount of UV light. The gamut of the paper with the higher whiteness level is slightly larger, especially in the blue-high luminance region (negative b-values).

The same samples as in *figure 8* have been measured with D65 illumination. They are shown in *figure 9*. The difference between the two papers is larger and the major change is in the blue-high luminance region. Also notice how the two peaks has been tilted away from each other.

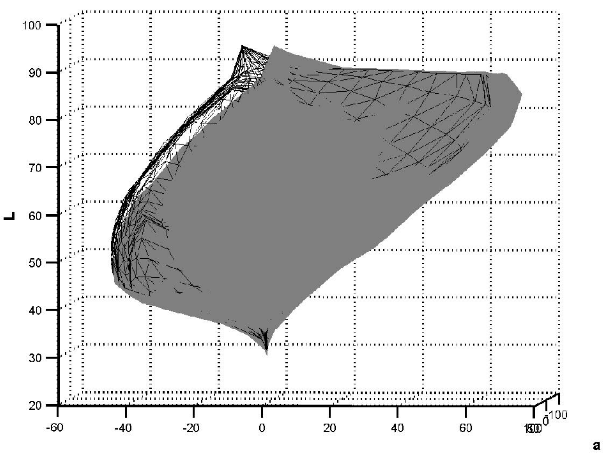


*Figure 8. Two papers with different levels of FWA content. Paper G has a FWA content representative for standard office paper while paper F has no FWA content at all.*

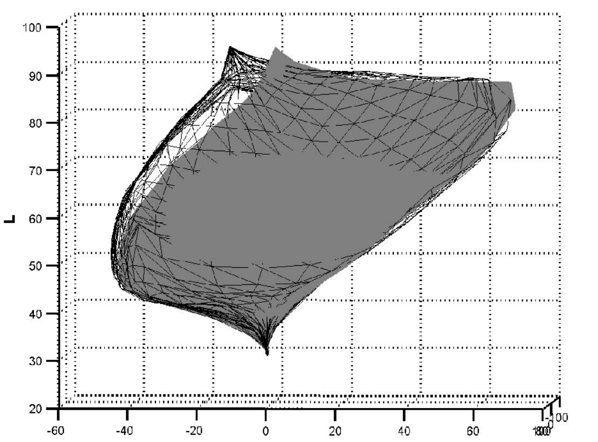


*Figure 9. The same paper as in figure 8 but now measured with D65 illumination. The difference between the two papers is larger compared to the D50 measurement. The difference is most noticeable in blue-high luminance region.*

## Conclusion

This study shows the importance of including the influence of the paper in the ICC profile. Properties like whiteness and gloss significantly effect the color reproduction and together with the ink and paper interaction these differences can be as large as 20ΔE. The amount of fluorescent whitening agent will also influence the color reproduction, especially with illuminations containing UV light. One problem with the FWA is the differences in standards for the graphical art industry and the paper industry. The amount of UV light in the measurements differ significantly, the D50 light used in the graphical art industry has a very low UV content.

This study shows that the different paper properties give an effect on the ICC profile. The whiteness of the paper mainly affects the light colors, around the white point. The effect of gloss level is largest for dark and highly saturated colors. The largest effect on the color reproduction has the interaction between paper and ink with color difference up to 20ΔE.

Visual perception tests of printed samples must be performed to fully determine if this effect is correctly captured in the profile. Especially the effect of whiteness differences expects to be under estimated.

An interesting aspect on the result of this study is to investigate the possibility of design a paper specific module to apply to the ICC device output profile in order to adjust for different paper properties. This should be of special interest for home and office user with applications with higher quality demands then can be achieved with the general predefined settings.

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