Hue preservation aspects of CMYK - CMYKcm color transformations

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Abstract

Printing images with additional light inks is one of the most effective methods helping to reduce graininess in highlights and shadows regions. Usually, original RGB files are converted into six separations on the RIP stage, so that all the printing workflow is handled by six channel printer device profile. Then, the last minute decision to add light separation data to original CMYK data either consumes additional RIP time or becomes impossible if the original file is unavailable. In this paper we present algorithm of low computational complexity, which allows to perform fast hue preserving CMYK – CMYKcm color conversions, without sending job to the RIP again.

Introduction

Recently, more and more printing houses working with digital presses start taking an active part in photo and photo speciality markets. The photo – oriented markets have a number of new requirements from offset – like digital presses. These requirements originate from the silver halide technology market origin: the photo production has to have so – called ”photographic look and feel”, which results in special substrate choice, usage of special ICC profiles and so on. One of the most important issues, which printing house has to struggle with is graininess of screened images in different color regions. Such graininess results from the fact that the digital presses technology, unlike silver halide technology uses screening method to halftone the images. Large contrast between ink dots and paper in highlights, between screen clusters and voids in shadows and midtones is the main reason of it.

The most of printing devices use standard method, which allows to reduce substantially graininess of images by using light version of cyan and magenta inks. When printing photos (see fig.1), the press uses only light version of ink in the highlights region. In the shadows, the original ink dark clusters are printed over the solid light ink layer, reducing thereby visual graininess of printed image.

As it can be seen from fig. 1, such CMYK – CMYKcm transformation is single dimensional, i. e. can be applied to each one of the image separation independently: $C \rightarrow (\tilde{C}, \tilde{c})$, $M \rightarrow (\tilde{M}, \tilde{m})$, $Y \rightarrow \tilde{Y}$ and $K \rightarrow \tilde{K}$. This has the great advantage over the multi–dimensional RGB – CMYKcm or CMYK – CMYKcm conversions in the context of last minute decision to print CMYK file with light separations. However, such single dimensional transformation results in undesirable hue shifts, relatively to an original image. This happens because of the fact that the ink spectrum is changed after separations has been split. For instance, measured spectrum of yellow ink layer printed under cyan ink is changed if it is printed under two layers cyan and light cyan inks (see fig. 2) producing $\Delta E_{ab} \approx 3.6$.

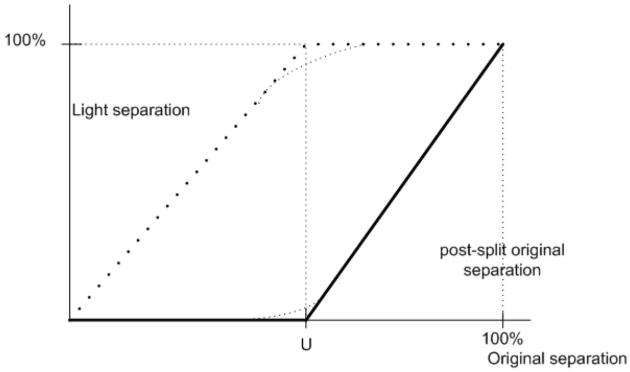

Figure 1. *Splitting the original separation into two separations at stitching point U.*

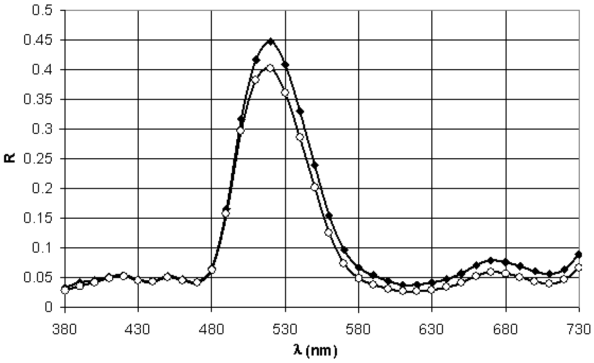

Figure 2. *Spectrum curves of yellow solid layer printed under cyan solid (rhombs) and under cyan and light cyan solid layers (void circles) correspondingly.*

Hue shift problems emerge in the RGB color space as well, as a result of the application of different image enhancement algorithms, such as contrast stretching, slicing and histogram equalization. Recently, many successful hue preserving algorithms in RGB color space have been developed (see reference [1] for review). Since most of those techniques use device independent color spaces for hue calculations, they are not applicable in the CMYK color space, where, in most cases, corresponding information is lost. In this paper, we use printing device property gray balance in order to reduce undesirable hue shifts, which appear after single dimensional color conversions in CMYK color space.

Gray balance method

As discussed above, single dimensional color transformations cannot preserve hues due to various effects like ink trapping, ink - paper optical interactions and others. However, it appears that preservation of some general constraints, such as press gray balance, helps to enhance significantly the color similarity between original and modified images.

Consider the gray balance curve

$$\begin{cases} F_1(a^*,L^*)=0 \\ F_2(b^*,L^*)=0 \end{cases} . \tag{1}$$

in CIE L^*,a^*,b^* color space. The above equation represents the general expression for the curve in three dimensional space. As a rule, this curve is defined as a straight line passing through black and white points. A black point might be defined as the maximum ink coverage color coordinates L_b^*,a_b^*,b_b^* and a white point as paper color coordinates L_w^*,a_w^*,b_w^*. Then, functions F_1 and F_2 in the above equation (1) can be written down explicitly as

$$\begin{array}{l} F_1(a^*,L^*) \equiv \frac{a^*-a_w^*}{a_b^*-a_w^*} - \frac{L^*-L_w^*}{L_b^*-L_w^*} \\ F_2(a^*,L^*) \equiv \frac{b^*-b_w^*}{b_b^*-b_w^*} - \frac{L^*-L_w^*}{L_b^*-L_w^*} \end{array} . \tag{2}$$

We assume neutrality of the black ink, which is relevant for many black ink processes. Then, measuring press gray balance is reduced to finding triples of cyan, magenta and yellow dot area (DA) coverage values C_j,M_j,Y_j such that while printing, their color measurement will give L_j^*,a_j^*,b_j^* belonging to the line (2). Thus, gray balance measurement maps line (1,2) in color space to another empirical curve

$$\begin{array}{l} I_1(C,M)=0 \\ I_2(C,Y)=0 \end{array} \tag{3}$$

in press CMY ink space. This mapping is defined by press gray balance look up tables

$$\begin{aligned} C &= G_C(L^*,a^*,b^*) \\ M &= G_M(L^*,a^*,b^*), \\ Y &= G_Y(L^*,a^*,b^*) \end{aligned} \tag{4}$$

where triples L^*,a^* and b^* belong to the gray balance curve (2) (see figure 3). Apparently, the above curves are ink, substrate and process dependent. Their measurement can be performed using some iterative procedure.

In this section we show how the look up tables (4) can be used to reduce hue shifts in the gray balance region resulting from application of such single dimensional transformations as contrast and brightness. Consider an arbitrary single dimensional transformation in CMY ink space, identical for all inks

$$\tilde{S} = T(S), \tag{5}$$

where S is one of the process ink separations. For most known inks, the mapping functions (4) are different, which implies $G_C(L^*,a^*,b^*) \neq G_M(L^*,a^*,b^*) \neq G_Y(L^*,a^*,b^*)$. Then the above transformation (5) may map point C_j,M_j,Y_j originally belonging to the gray balance curve (3) to another point $\tilde{C}_j,\tilde{M}_j,\tilde{Y}_j$ outside the gray balance curve. This conclusion is true, of course for any other point of press gamut space.

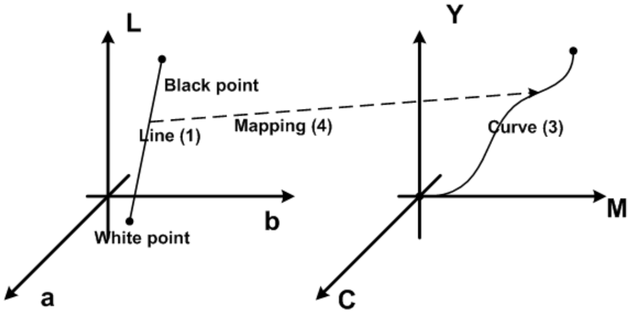

Figure 3. *Gray balance. The gray balance is defined as a straight line (eq. (2)) in $L^*a^*b^*$ device independent color space (see left-hand plot). The mapping (gray balance) function (4) transforms the gray balanced point in $L^*a^*b^*$ to the corresponding point in press CMY ink space (see right-hand plot)*

The main idea is as follows. *Any single dimensional ink coverage transformation (5) aiming to preserve image hue should be constructed in such way that any point in three dimensional ink space, lying on the gray balance curve (3) will be transformed to a point, which belongs to the same curve. Then, any gray hue will be transformed to a gray hue of different brightness.*

As was shown empirically, such gray conserving transformations substantially reduce hue shifts, even in regions which are far away from the gray balance curve (1). This can be explained as follows. Applying transformation (5) on CMY ink space maps the original space to the same one, but distorted. This means that the point $\{C_j,M_j,Y_j\}$, which corresponds to the hue value H_j is transformed to a point with a different hue. Constructing transformations (5) as described above, we can fully repair distortion of the gray balance curve and partially repair the rest of the space. The degree of repair decreases with distance from the gray balance curve.

Preservation of gray balance is not a new concept. Many years ago, before computers came into the publishing industry, SWOP densities were established based on the same idea - keeping shadows gray balanced on SWOP media. Later, Cusdin [2] proposed an algorithm, which varied ink solid optical densities in order to achieve shadow gray balance consistency between different press media. However, applying this to the present problem, this methodology has at least two main disadvantages: It does not control all gray levels, and it changes the appearance of solids.

Gray balance and light inks printing

Splitting the original image separation into two separations, the original one and its light version, is a common method to reduce image graininess and printing artifacts and, as a result, achieve photo quality. Usually the good candidates for such modification are cyan and magenta separations, due to their high contrast with paper. Corresponding transformations can be mathematically described as

$$\begin{cases} \tilde{S} = T(S) \\ \tilde{s} = t(S) \end{cases}, \tag{6}$$

where $\tilde{S}$ and $\tilde{s}$ are transformed and light color components of parent color (cyan or magenta) separation S. The corresponding look-up tables $T(S)$(solid line) and $t(S)$(dotted line) are schematically shown in figure 1. Apparantly, the transformations of the type (6) applied on cyan and magenta separations, splitting them into two new components will not preserve image hues. Then, we try to construct the final transformations by conserving press gray balance when going from CMY to CMYcm ink space. In order to achieve this goal, we need to have, in addition to (4), a gray balance look up table in CMYcm space. We can simplify the problem by measuring this table for some "reduced" ink space $(C^{(r)}, M^{(r)}, Y^{(r)})$. "Reduced" means that if point $\{C_j^{(r)}, M_j^{(r)}, Y_j^{(r)}\}$ belongs to the gray balance curve in "reduced" ink space, then when split, it will give a point in CMYcm space, which belongs to the corresponding gray balance curve. Suppose, these transformations are given by the following mapping functions:

$$\begin{aligned} C^{(r)} &= G_C^{(r)}(L^*, a^*, b^*) \\ M^{(r)} &= G_M^{(r)}(L^*, a^*, b^*) \\ Y^{(r)} &= G_Y^{(r)}(L^*, a^*, b^*) \end{aligned}, \tag{7}$$

which should correspond to the same gray balance curve in $L^*a^*b^*$ color space (2) with a different black point $\{L_b^*, a_b^*, b_b^*\}$ suitable for new CMYcm ink space. Having 1D transformations (2) and gray balance tables (4,7) we can construct new transformations in such a way that gray balance will be conserved in the new CMYcm space. This can be provided by mapping of a point, which has to be split, to "reduced" ink space as if it is a gray one. Such a mapping may not preserve lightness, since it has different ranges in both ink spaces because different black points are defined. To overcome this difficulty we use a lightness transfer function $L^{*(r)} = f(L^*)$ which can be of relative or absolute colorimetric intent depending on its implementation. These options each have their own advantages and disadvantages. The final transformations are then as follows:

$$\begin{cases} \tilde{C} = T_C\left(G_C^{(r)}\left(f\left(G_C^{-1}(C)\right)\right)\right) \\ \tilde{c} = t_C\left(G_C^{(r)}\left(f\left(G_C^{-1}(C)\right)\right)\right) \\ \tilde{M} = T_M\left(G_M^{(r)}\left(f\left(G_M^{-1}(M)\right)\right)\right) \\ \tilde{m} = t_M\left(G_M^{(r)}\left(f\left(G_M^{-1}(M)\right)\right)\right) \\ \tilde{Y} = G_Y^{(r)}\left(f\left(G_Y^{-1}(Y)\right)\right) \\ \tilde{K} = K \end{cases} \tag{8}$$

Color accuracy analysis

The main idea of the construction (8) is gray balance preservations while going from one type of CMYK color space to another type of the same space. However, such single dimensional transformations can not guarantee preservation of all color hues. For instance, pure yellow color of 40% coverage will not preserve its hue under (8), if printed on bluish paper. On the contrary, original transformations (6) remain yellow separation unchanged. On the other hand, our transformations convert point on CMYK color space to another CMYK - like color space, which is substantially the same, which is ensured by the way the light inks are produced. Then the following questions should be asked: a) What is improvement rate of the algorithm? b) Which color regions does algorithm improve and where does it work bad? In order to understand the influence of proposed 1D transformations (8), we have printed IT8.7/3 and ECI 2002 Visual Layout targets in three configurations: reference CMYK, CMYKcm using original transformations (6) and CMYKcm with grays preserving transformations (8). All the targets were measured by GretagMacbeth Spectroscan device and output values $L^*a^*b^*$ were analyzed.

Improvement rate

For the each one of the color bars on the above targets we calculated two values: ΔE_{ab}^j and $\Delta \tilde{E}_{ab}^j$. These values give color difference between the original CMYK color strip and that of converted by 1D transformation (6) and that of converted by construction (8) correspondingly. The unified histogram of the both targets is shown in the figure 4. As it can be seen from this figure, 67% of all patches give $\Delta\tilde{E}_{ab} \approx 2.2$ using gray balance preserving transformations (8), while transformation (6) gives $\Delta E_{ab} \approx 3.3$. The 95% limit gives $\Delta\tilde{E}_{ab} \approx 4.3$ and $\Delta E_{ab} \approx 6.0$ for (8) and (6) correspondingly.

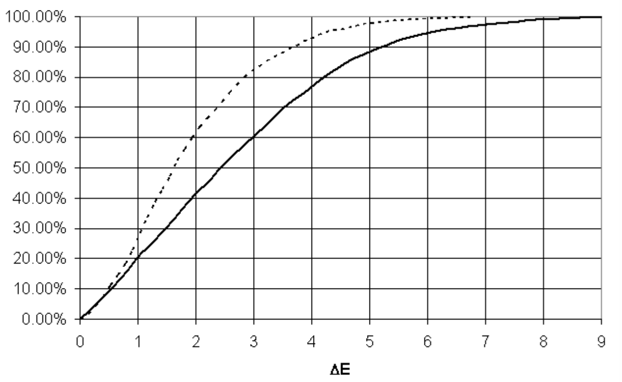

Figure 4. Statistics of hue accuracy of standard transformation (6) (solid line) and gray balance preserving transformation (8)(dotted line)

Hue accuracy in different color regions

In order to understand which colors can the algorithm improve, we have put all the measured points on a - b diagram on fig. 4. The blue circles correspond to the colors for which improvement in ΔE_{ab} is larger than 1, the red circles correspond to the colors for which degradation is larger than 1. The rest of the colors are presented by the green circles. As it can be observed from this diagram, the region of grays is improved by transformations (8) as expected. The yellow region experiences a little degradation, due to the reasons mentioned above. The same degradation can be seen in pure magenta and saturated cyan and green regions. However, statistics of improvement rates and visual images comparison show clear advantage of the gray balance preservation method (8) over the standard one (6).

Summary

Single dimensional transformations in press ink space have their advantages and disadvantages. On the one hand, they allow performance of certain classes of image corrections relatively fast, using separate look-up tables for each image separation. However, on the other hand, these transformations lead to undesirable hue shifts. As shown in this paper, these hue shifts can be substantially reduced by building separation transformations in such way that gray balance is conserved. This constraint does not increase dimensionality of image conversions and therefore does not require additional CPU and memory resources.

References

[1] Sarif Kumar Naik and C. A. Murthy, ”Hue-Preserving Color Image Enhancement Without Gamut Problem”, *IEEE Trans. Image Processing*, vol. 12, pp. 1591-1598, December 2003.

[2] George Cusdin, ”Gray Balance Control: The Color Management Link Between Press and Prepress”, *Flexo Magazine*, May 2000.

Author Biography

Gregory Braverman received his PhD in theoretical physics of condensed matter from Ben – Gurion University of the Negev in Beer – Sheva, Israel (1998). After that, he worked in Max – Plank Institut für Kernphysik in Heidelberg, Germany (1998 – 2000). Currently, Gregory Braverman is working in the Indigo division of the Hewlett Packard company in Rehovot, Israel. His work has focused on the development of color control algorithms and color conversions for HP digital presses.

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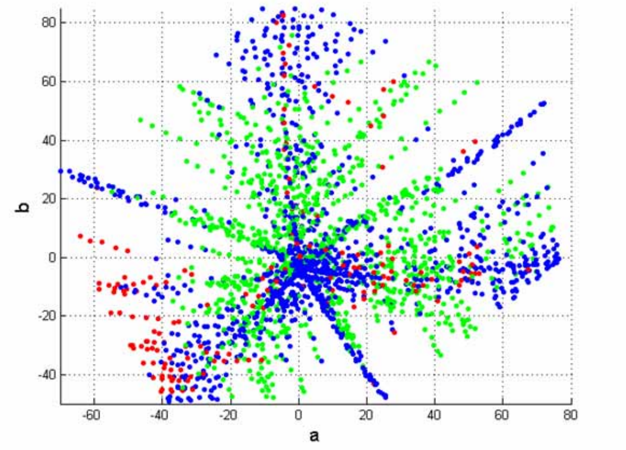

Figure 5. *Gray balance preserving transformation improvement rate a-b diagram. Blue, green and red circles mean improvement, the same and degradation regions)*

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