

A Model of Color Appearance of Printed Textile Materials

Gabriel Marcu and Kansei Iwata
Graphica Computer Corporation, Tokyo, Japan

Abstract

This paper provides an analysis of the mechanism of color appearance on the printed textile materials. The analysis conducts to a model to simulate on the computer display the appearance of the textile printed colors as a function of few parameters: ink color, ink mask size, original textile color, transparency of the not-printed textile material, background color under the textile material is observed and printing sequence of individual ink mask. The influence of material texture is included.

The simulation includes a generalized Neugebauer model. A hierarchical structure is introduced for the colors of the secondary palette in order to provide the coefficients of the Neugebauer model. For a certain textile material, the color hierarchy is dependent on the ink set and the printing sequence. The color hierarchy is established as result of color calibration process. Printed samples are used for calibration procedure.

Printing on Textile Materials

The majority paper printing technologies use the four ink (yellow, magenta, cyan and black) printing process. The printing process for textile materials is different from the paper printing process. Few factors characterize the printing process on textile materials, as mentioned below.

1. The textile printing process uses a specific set of inks and ink masks for each original image to be printed, in order to obtain an improved color gamut and to minimize the errors caused by misalignment of the ink masks. If a set of inks is selected, named primary color palette, the colors resulted by combinations of inks that overlap can be derived and form the secondary color palette. A calibration process enables to define the secondary color palette. The secondary color palette acts like a color profile which characterizes the printing process for a certain type of material and a certain type of dyestuffs, in the same manner like an ink printer is characterized by the paper (type and color) and the set of inks.

2. The inks have a certain opacity and fluidity. The inks opacity influences the color appearance of overlapped ink layers. The sequence of ink mask printing determines the color combinations of the solid printed inks (100 % ink mask printed inks), which are referred as secondary color palette. The same primary color palette may conduct to different secondary color palette, as a function of ink mask printing.

3. The textile material is not rigid and not uniform. The rigidity of the textile material is far unstable and not-

uniform than for paper substrate, and is affected by the amount of ink deposited on the substrate. The masks are more difficult to be exactly positioned with respect to the textile material, even if the mask markers are correctly positioned. Usually, the textile surface to be printed are very large and ink masks misalignment errors occur more frequently.

4. The material texture affects the printed color appearance. Some materials are loosely sewed, others are tightly sewed. For thin and loosely sewed textile materials, the transparency is another factor that must be taken into account. The transparency of thin textile materials modifies the printed color appearance (in many cases this is a desired effect).

5. The ink/material properties affect the final printed color appearance. The material texture, determined by the sewing technology and the fiber features, influences the appearance of the textile printed color. The textile fiber is not uniform and consequently, absorb a non uniform amount of ink. The ink can be absorbed by the material fibers, or can be retained in the texture wholes, where it solidified. The both cases are analyzed in the paper and a model of color appearance is derived in each case.

The global process of textile **material printing** designing, as it is presented in figure 1, involves the following steps:

- a. selection of the ink set colors;
- b. color separation;
- c. color simulation;

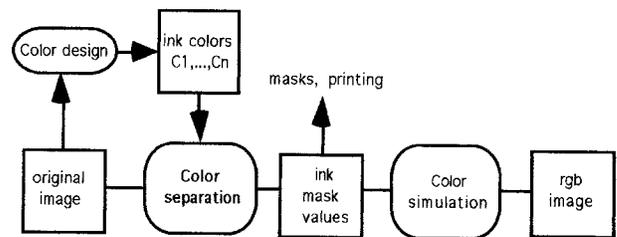


Figure 1. The diagram of designing and simulation process of textile materials printing.

The color separation process enables to find the ink mask values and the sequence of ink masks printing. A generalized color separation algorithm is proposed in order to represent an input image using an arbitrary set of ink.

A color calibration process enables to determine the RGB representation of the secondary color palette. The secondary color palette is organized as a hierarchy and is used during the color simulation.

The color simulation process enables to see on the computer display the color of the final, printed picture, when the ink masks and the printing sequence are specified.

This paper describes the a model that enable to simulate the color appearance as a function of previously introduced parameters: ink color, ink mask size, original textile color, transparency of the not-printed textile material, background color under the textile material is observed and printing sequence of individual ink mask. The influence of material texture is included.

The ink set, the printing sequence and the ink mask values are decided prior to color simulation. A color separation method for arbitrary set of inks can be used in order to obtain the data required by color simulation process^{1,2}.

Color Calibration

The set of the color inks forms the primary color palette, denoted by (C_1, C_2, \dots, C_n) , where n specifies the number of inks (equal to the numbers of ink layers) used in the textile printing process. All color combinations resulted by overlapping the ink layers, printed with 100% mask value, form the secondary color palette, denoted by $(Cb_1, Cb_2, \dots, Cb_N)$.

All the elements of primary color palette are included in the secondary color palette as combinations of a single ink color. The secondary color palette includes additionally all combinations of two or more ink colors of primary color palette.

The colors Cb_1, Cb_2, \dots, Cb_N of the secondary color palette are dependent on the sequence of ink mask printing. A single primary color palette may conduct after printing process to a number of different secondary color palettes. The secondary color palette which corresponds to a defined printing sequence is a subset of all possible combinations set. Each secondary color palette contains only the possible printable colors by a determined ink mask sequence (same ink cannot be printed two or more times in printing process). The total number of color combinations forms a color data base for the program of designing and simulation of textile materials printing and results as a union of secondary palettes that results from all permutation of inks in a printing sequence. The maximum number of elements of color data base, $N_t(n)$, is dependent on the number of inks, n , used in printing process. This number is given by the following formula:

$$N_t(n+1) = N_t(n) \cdot (n+1) + 1,$$

where $N_t(1)=1$. Table 1 shows a dependence of the number of colors in the secondary color palette, N , and total number of combinations, N_t , as a function of the number of ink masks.

Even for small number of ink colors, the total number of combinations is very large for a manual calibration. The calibration process is performed only for few sequences of ink mask printing. As a new sequence of ink mask printing is calibrated, the color data base is enlarged with a new set of color combinations.

In general, the textile printing process obtain great contrast effect is the printing process follows a luminance ordered ink mask printing. If the original material is lighter, the printing process starts with lighter color inks and ends

with darker color inks. If the original textile material is dark, the printing process uses the reverse order of the ink mask. This printing rule is not obligatory.

Table 1.

Inks no.	N	Nt
1	2	2
2	4	14
3	8	17
4	16	86
5	32	517
6	64	3103
7	128	21722

Calibration process associates to the combination Cb_1, Cb_2, \dots, Cb_N the RGB colors components that are measured from the textile printed samples. The samples are obtained by overprinting the 100% ink masks in the same sequence as real printing process. Few subsets of color combinations can be measured to enable optimal selection of the printing sequence.

The color combinations are organized to be displayed on CRT in a hierarchy corresponding to the sequence of printing that determines the specific secondary color palette.

Figure 2 presents the secondary palette colors ordered in a color hierarchy. The first line of the hierarchy represents the ink colors arranged in the order of printing, from left to right. One column represents the color resulted by combination of the head column ink with the already printed inks and their combinations, which are positioned on the left side of current ink column. The colors under the first line represent only combinations of the colors of the first line in the order determined by the position of colors in first line. First column has a single element, first ink color. The second column has ink 2 and combination 2+1, that is 100% ink mask 2 printed over 100% ink mask 1. And so on.

Changing the sequence of ink mask printing conducts to permutations of first line of the color hierarchy, and this requests a new set of secondary color palette to be calibrated or loaded from the color data base.

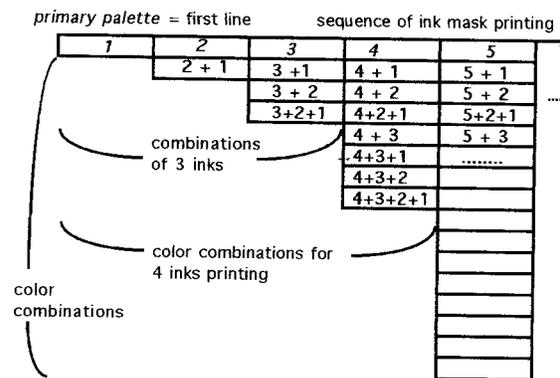


Figure 2. Secondary color palette ordered in a hierarchy as displayed during color calibration.

Simulation of Printed Colors on Textile Material

The color simulation enables to represent on the CRT the printed colors of the textile material, independently of the real printing process. Usually, before printing process, the simulation enables to check for correctness of color separation method, to select the optimal sequence of the ink mask printing, and to modify the set of inks.

In order to introduce the general simulation model of printed colors on textile material, we start with the case of a single color printed on substrate with certain transparency.

The following notation were used in order to describe the color appearance of the printed textile when is seen over different under-background colors:

C_{tex} : original (unprinted) textile color, considered as the color of textile fiber; this color is specified by textile material manufacturer;

C_{bk} : background color describes the color of the background under the textile material is observed; the background color influences the appearance of the printed textile color when the original textile material has a certain transparency;

C_{app} : apparent color is the perceived color when the printed textile material covers an object with the underbackground color;

t : the transparency factor describes how much of background color is seen through the original textile material; the textile material is assumed to be placed near the background, to avoid focus errors which strongly affects the perception of the apparent color; the theoretical range of transparency factor is between 0 and 1; Value 0 corresponds to not-transparent material;

a : the ink mask value describes the percentage area covered by the ink C_{bk} , and represents the component of the amount vector, which in case of a single printed color, has one element; the range of the ink mask value is between 0 and 1; Value 1 corresponds to the total transfer of the ink through the mask;

C_{ink} : ink color corresponding to ink mask value 1 (100% ink mask) as it appears printed on material fiber, not affected by transparency effect. Note that this color is a calibration color, and does not represent the final printed color on material which can be transparent, or has some texture and its color is subject of simulation;

The color appearance results as two kind of color mixtures:

a. the mixture of ink color, C_{ink} with the original textile color C_{tex} , due to the variable ink mask value; this process is controlled by the hole size of the ink mask, a ; the resulted color is the printed textile fiber color;

b. the mixture of printed textile fiber color with the background color C_{bk} ; this process is more difficult to control but approximately is described by the transparency factor, t ;

The appearance of the textile printed color is therefore considered in two cases:

A. in case when printed material is transparent, that is the ink is completely absorbed by textile fiber and the holes of the texture remains empty, the following equation is used:

$$C_{app} = [a \cdot C_{ink} + (1 - a) C_{tex}] (1 - t) + t \cdot C_{bk} \quad (1)$$

B. in case when printed material is completely opaque, that is the dry ink is stops and obstructs the texture holes, the following equation is used:

$$C_{app} = a \cdot C_{ink} + (1 - a) \cdot [(1 - t) C_{tex} + t \cdot C_{bk}] \quad (2)$$

Between these two cases there are combination of them but, in principally, for the simplicity, only the two cases are considered.

This equation shows that full printed ink color (corresponding to $a=1$) transforms the textile material into a not transparent surface with the color of ink (color of ink printed on fiber):

$$C_{app} = C_{ink} \cdot (1-t) + t \cdot C_{bk}, \text{ in case A,}$$

and

$$C_{app} = C_{ink}, \text{ in case B.}$$

The not printed textile material (corresponding to $a=0$) has the color determined by the original material color and background color:

$$C_{app} = (1-t) \cdot C_{tex} + t \cdot C_{bk}.$$

The case of nontransparent textile material, corresponding to the transparency factor $t=0$, has the color appearance more easy to predict as follows:

$$C_{app} = a \cdot C_{ink} + (1 - a) \cdot C_{tex},$$

and corresponds to the Neugebauer model³ for a single ink mask.

For two ink masks, that is a primary color palette with two elements, will result 4 color combinations Cb_1, Cb_2, Cb_3, Cb_4 , as elements of secondary palette and an amount vector (a_1, a_2) that describes the ink mask values. The last color combination Cb_4 , is assumed to be the original textile color, and remains with the same notation C_{tex} . The color appearance of the textile printed material results as follows:

Case A:

$$C_{app} = [a_1 \cdot a_2 \cdot Cb_1 + a_1 \cdot (1 - a_2) \cdot Cb_2 + (1 - a_1) \cdot a_2 \cdot Cb_3 + (1 - a_1) \cdot (1 - a_2) \cdot C_{tex}] \cdot (1 - t) + t \cdot C_{bk} \quad (3)$$

Case B:

$$C_{app} = [a_1 \cdot a_2 \cdot Cb_1 + a_1 \cdot (1 - a_2) \cdot Cb_2 + (1 - a_1) \cdot a_2 \cdot Cb_3 + [(1 - a_1) \cdot (1 - a_2) \cdot C_{tex} (1 - t) + t \cdot C_{bk}]] \quad (4)$$

As can be observed, in case A, the relationship (3) includes in the square brackets, the Neugebauer equations for two inks³, and this reflects the fact that the Neugebauer model is preserved in case when the inks are uniformly absorbed by the textile fiber. The color combinations can be

understood as XYZ tristimulus vectors, or RGB tri-component vectors, more convenient for computer display representation. The RGB color is equivalent, using a linear transformation, to the tristimulus XYZ. The tristimulus XYZ are calculated as an additive mixture of colors of the secondary color palette. The colors of the secondary palette gives the coefficients of the Neugebauer equations. In case B, when the ink is obstructed in the texture holes and the texture structure is perturbed, the Neugebauer model is strongly affected by transparency changes.

These equations can be easily generalized in order to obtain the model of color appearance for arbitrary number of inks printed on the textile material. In general case, the color simulation takes advantage of the color combination hierarchy and of the generalized version of Neugebauer model. The model is summarized below.

The amount vector (a_1, a_2, \dots, a_n) specifies the areas covered by the colors (C_1, C_2, \dots, C_n) of the inks set. The color appearance of the textile printed material results as follows:

Case A:

$$\mathbf{C}_{app} = [f_1 \cdot \mathbf{Cb}_1 + f_2 \cdot \mathbf{Cb}_2 + \dots + f_{N-1} \cdot \mathbf{Cb}_{N-1} + f_N \cdot \mathbf{C}_{tex}] \cdot (1-t) + t \cdot \mathbf{C}_{bk} \quad (5)$$

Case B:

$$\mathbf{C}_{app} = f_1 \cdot \mathbf{Cb}_1 + f_2 \cdot \mathbf{Cb}_2 + \dots + f_{N-1} \cdot \mathbf{Cb}_{N-1} + [f_N \cdot \mathbf{C}_{tex} \cdot (1-t) + t \cdot \mathbf{C}_{bk}] \quad (6)$$

where the coefficients f_1, f_2, \dots, f_N are calculated based on amount vector (a_1, a_2, \dots, a_n) and are dependent on the area covered by each color combination $\mathbf{Cb}_1, \mathbf{Cb}_2, \dots, \mathbf{Cb}_N, \mathbf{C}_{tex}$. The coefficients f_1, f_2, \dots, f_N are calculated by following formula:

$$f_j = p_1 \cdot p_2 \cdot \dots \cdot p_n,$$

where n is the number of inks and p_k is defined as:

$$p_k = \begin{cases} 1 - a_i, & \text{if ink } i \text{ is not involved in } \mathbf{Cb}_j; \\ a_i, & \text{if ink } i \text{ is involved in } \mathbf{Cb}_j; \end{cases}$$

Note that the secondary palette colors, $\mathbf{Cb}_1, \mathbf{Cb}_2, \dots, \mathbf{Cb}_N$ are the result of mixture of (primary palette) color inks (C_1, C_2, \dots, C_n) , and the RGB representation of these color are used during the color calibration process.

Simulation of Texture Effect

When the printed material is observed from small distance, the color appearance is affected by the material texture. In this case, the texture influence must be simulated on the screen.

The texture influence can be simulated by modulating the lightness of the simulated color, \mathbf{C}_{app} , with the lightness value of a monochrome texture pattern which is similar to the material texture. The following transformation are used:

1. Extract the lightness component from simulated color: $L_{app} = L(\mathbf{C}_{app})$, where $L(*)$ is the lightness of *. The hue and saturation are also extracted.

2. Modulate the lightness of simulated color with the lightness of texture pattern, as follows:

$$L = L(\mathbf{C}_{app}) \cdot L(\text{texture pattern});$$

3. Recover the RGB color components of the new color based on hue and saturation computed in the first step and with the new lightness value computed in the second step.

The monochrome texture pattern can be derived using the following methods:

1. synthesizing the texture using a mathematical model. Several method of simulation of different types of texture have been proposed.⁴

2. recording the image of original unprinted material texture. In this case, the image of the unprinted textile material is transformed to black and white image, keeping only the luminance information from the RGB pixel components. The luminance information describes with enough accuracy the texture features, including the nonuniformities of sewing and fibers, as well as any particularities of the original textile material. Especially these non-uniformities are more difficult to express in mathematical model.

Figure 3 depicts the procedure of texture effect simulation by modulation the simulated color.

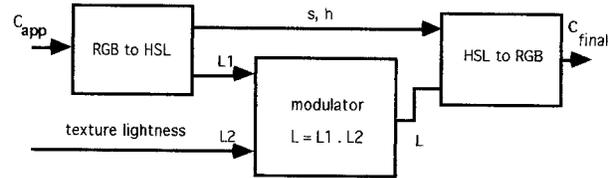


Figure 3. Texture influence in final color appearance simulation

It can be observed that the texture pattern can be used to simulate the transparency effect. The monochrome texture pattern modulates the mixture between the classic Neugebauer simulated color and the background color. When the lightness value of texture pattern is low, corresponding to holes of texture, the final simulated color is preponderant the background color. When the lightness value of texture pattern is high, corresponding to textile fiber, the final simulated color is the classic Neugebauer simulated color. The mixture function is given by the following relationship:

$$\mathbf{C}_{final} = \mathbf{C}_{app} (1 - f(L_{texture})) + \mathbf{C}_{bk} f(L_{texture}),$$

where the function $f(L)$ is a nonlinear function which provides the balance between classic Neugebauer simulated color and background color. The method works only when the screen resolution is high enough to represent accurately the texture pattern. Usually, the surface to be simulated on screen is large, and the texture to be represented is under the display resolution capability. In this case the influence of texture can be neglected but the influence of material transparency remain and is simulated by the method presented in paragraph 3. The effect of transparency is more realistic simulated by the method presented in this paragraph in case when displayed area is small enough to enable accurate representation of material texture.

Conclusions

This paper discussed some aspects of simulation of the printed colors on textile materials and emphasizes the difficulties of

the designing and prediction of the color printed on textile materials. The calibration process influences essentially the color separation process and of color simulation process. The color simulation uses the generalized version of Neugebauer model with coefficients the components of the color combinations resulted after calibration process. The transparency and texture of material are included in the simulation model.

References

1. K. Iwata, G. Marcu, Computer Simulation of Printed Colors on Textile Materials, *Proceedings of the "Color Hard Copy and Graphic Art III Conference*, SPIE/IS&T symposium: Electronic Imaging Science and Technology, 6-10 February 1994, San Jose, California; (see page 223 this publication).
2. G. Marcu, K. Iwata, Designing the Color Palette for Textile Materials Printing Process, *Proceedings of the "International Conference on Acoustics, Speech and Signal Processing"*, ICASSP '94, 19-21 April 1994, Adelaide, Australia.
3. V. Ostromoukhov, Chromaticity gamut enhancement by heptatone multi-color printing, *Proceedings of the "Device-Independent Color Imaging and Imaging Systems Integration" Conference*, 1-3 February 1993, San Jose, California, *SPIE Vol. 1909*, p.139.
4. T. Chang, C. C. J. Kuo, Texture Analysis and Classification with Tree-Structured Wavelet Transform, *IEEE Trans. on Image Processing*, Vol. 2, No. 4, October 1993, p. 429.

published previously in the IS&T 1994 Annual Conference Proceedings, page 743

