Computer Simulation of Printed Colors on Textile Materials

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Abstract

The printing process of textile materials uses an inks set dependent on the image to be printed and referred as the primary color palette. The colors of the printed textile material depend on the printing sequence of the ink masks and are referred as the secondary color palette. A single primary color palette may conduct to different secondary color palettes, as a function of printing sequence.

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 provides 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.

1. 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 difference are notable:

1. The printing process of textile materials is much less controllable than the paper printing process. The textile materials surface consists of a texture, rather than an uniform surface. The 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 is not deposited like on the paper, on an uniform surface, but is absorbed by the material fibers, or is retained in the wholes of the texture, where it solidified.

2. The material texture affects the printed color appearance. Some materials are loosely sewed, others are tightly sewed. The textile material surface appears, because of the effect of texture, more roughly than the paper. In some cases, the textile fiber has a special reflection, increasing the contrast between the wholes and the nodes of the colored texture.

For some thin 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).

3. 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. The rigidity of the textile material is far unstable and not-uniform than for paper substrate.

4. The ink mask printing sequence influences the color appearance. The order of printing can be changed in order to obtain an optimal set of color combinations, used to represent the original picture.

The textile printing process uses a specific set of inks for each original image to be printed, in order to obtain an improved color gamut. The inks are selectively deposited on the textile substrate, using a mask for each ink to be printed. The ink masks enable overlapping of inks in certain amounts, creating gradation between the colors that overlap. 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 defines 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.

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;
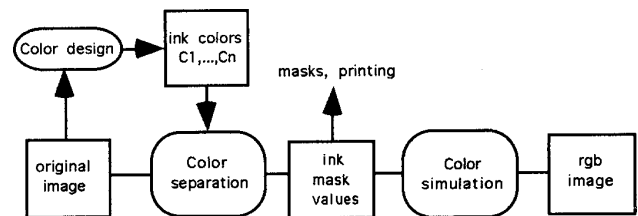b. color separation;
c. color simulation;

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.

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

2. The Ink Set

The color palette to represent the original picture can be derived by a color quantization method. Several methods can be selected.[1,2,3]

The color quantization find the colors required to represent a picture, when the number of these colors is apriori decided. The method does not find the set of inks required to print the picture on textile material. In fact the color palette derived by color quantization method gives an idea about the gamut of colors resulted after combination of the printed inks on textile material.

The problem of finding the set of inks to print a certain picture on textile substrate is more complicated. The ink colors can be selected in the points that defines the maximum convex hull of the color volume which result after color quantization process. Usually the number of these points is greater than the printing technologies constraints admit, so that a truncation of this number is required. Planes or surfaces to bound the color gamut determined by color quantizations can be selected. In this paper we do not concentrate on this subject, which is left for future development.

In some cases, it is considered that the ink colors are imposed by the user. Especially in case of textile printing which simulates traditional painted japanese images, the set of dyestuff were severe imposed and only the ink mask order and ink quantities were allowed to change. This method preserves some tonal constancy of the picture and hides a part of the mysterious secret of color nobility that original traditional japanese textile painting exhibits also today.

The original textile color is usually selected as one of the color in the color set used for printing process for a few reasons:

a. important saving of ink results when the surface corresponding to the color of the original unprinted textile material remains not printed;

b. the unprinted material has a different transparency than the material covered by ink. The full printed textile material is usually not transparent so its color can be easily predicted as the color of the ink. If the unprinted textile material is transparent in a certain ratio, variable color occurs when the material is seen over different color of the background, named under-background color, in order to be distinct from the textile background color.

The color gamut resulted using a certain color ink set can be represented as a volume inside the RGB color space or CIELAB color space. The printed color gamut has some particularities:

• the lighter point of color volume does not correspond obligatory to the absence of dyes on the textile material. Especially in case when the unprinted textile has not highest luminance compared with the inks luminance, the most lighter color results after printing of the most lighter ink.

• the color appearance is influenced by the texture type, nature of material, dyestuff combination chemistry. These effects are included in the color calibration process.

3. Generalized Separation Algorithm for an Arbitrary Ink Set

The set of the color inks forms the primary color palette, denoted by $(C_1, C_2,...., C_n)$, 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 $(\mathbf{Cb_1, Cb_2, ..., Cb_N})$. 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. Figure 2 depicts the relation between primary and secondary color palette.
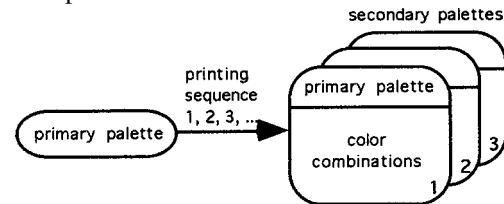

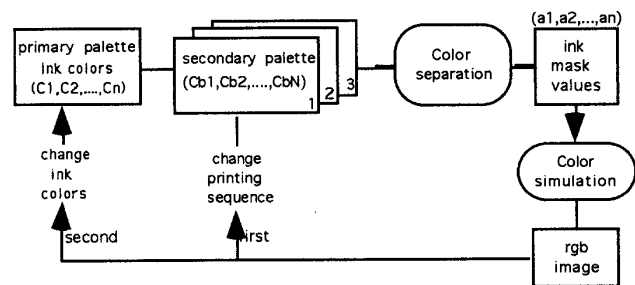*Figure 2. Relation between primary and secondary color palettes*

Figure 3. The interactive process of optimizing the printing sequence based on color simulation

The number of color combinations, N, is determined by the mixture of ink on the textile material. In case when the printing order of ink masks does not significantly affect the appearance of colors on the textile material, the color combination is determined only by the amount of each ink used. The number of color combinations is in this case $N = 2^n$ colors. This number of combinations corresponds also to the case when the order of ink mask printing is prefixed and is not a process parameter. In case when the order of ink mask printing affects the final printed color, the number of combinations is more complicated to be estimated. In this case, it can be observed that not any color combination can result in printing process. For example if the combination determined by the $(1 + 2 + 3)$ order of printing is used, the combination $(2 + 1 + 3)$ is not permitted, since a ink mask is used a single time during the printing process. To solve this problem, the printing order of the ink mask is considered fixed. In this case, the number of color combinations is $N = 2^n$ colors as stated before. The color separation process and the color simulation are performed for a fixed order of ink mask printing. If the computer simulation of the textile printed color is not satisfactory, another sequence of ink mask printing can be selected and all the process is restarted. Additionally, in more severe cases, if all printing sequences are exhausted, the primary color palette can be modified, selecting other set of inks. The interactive process of optimizing the printing sequence based on color simulation is illustrated in figure 3.

The generalized color separation process requires to convert the components of input color, devoted by $\mathbf{C_i}$, of the original image, to the set $(a_1, a_2, ..., a_n)$ specifying the amounts of ink of the primary color palette $(C_1, C_2, ..., C_n)$. By overlapping the $(a_1, a_2, ..., a_n)$ amount of $(C_1, C_2, ..., C_n)$ inks it must result on textile material the same color like the input color, $\mathbf{C_i}$.

The process of color separation is described in the CIELAB color space. Transformation from RGB color space, YMCK color spaces or other color spaces to CIELAB color space are available.[4,5,6]

The block diagram of the generalized color separation process is described in figure 4.
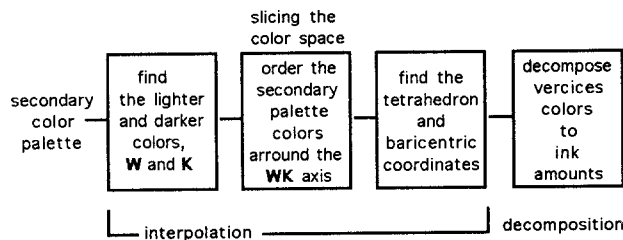

Figure 4. Diagram of the generalized color separation process

The color separation process consists of two main steps:

a. the first step consists of an interpolation process of the input color, based on four vertices selected from the colors of the secondary color palette;

b. the second step consists of decomposition of the four color combinations resulted from first step into the amount of inks that conduct by printing to the input color.

The interpolation process uses baricentric interpolation method[1] which is equivalent to the tetrahedral linear interpolation method.[2] Each color combination of the inks used to print the textile material corresponds to a point in the CIELAB color space. Four colors from the secondary color palette are selected for baricentric interpolation. The four colors can be selected in different ways. For our method, two vertices of the tetrahedron are fixed in most lighter color combination, named $\mathbf{W}$, and mosr Ñarker color combination, named $\mathbf{K}$, of the secondary color palette. In the CIELAB color space, these two points determines a maximum length of the projection segment on the luminance axis. In case when unprinted material color has the maximum lightness from all secondary color palette, the $\mathbf{W}$ point correspond to the color of unprinted textile material. The other two vertices are selected in such way that the two planes determined by these points and the $\mathbf{KW}$ axis determines the tetrahedron that includes the input color and does not contain **inside** other color of secondary color palette. The specification "inside" do not refer to the surface of tetrahedron. Finding a tetrahedron with this method is equivalent to slicing the color space with planes which rotate around the $\mathbf{KW}$ axis (that is not obligatory the luminance axis). A representation of slicing process of the color space based on secondary palette colors is presented in figure 5.

The baricentric interpolation is applied for the four colors of the secondary color palette. The result of baricentric interpolation conducts to the amount of 4 combinations that compose the input color. To find the amount of inks conducting to input color, a decomposition process is performed. Based on the baricentric interpolation, the decomposition process de-

termines the amount of each ink of primary color palette which, by overlapping, conduct to the input color.

Summarizing, the generalized color separation process is performed in the following steps:

a. Select the most lighter and darker colors of the secondary color palette, denoted by $\mathbf{W}$ and respectively $\mathbf{K}$ vertices. In a plane normal to the $\mathbf{WK}$ axis, all N-2 remaining elements of the secondary color palette are ordered by angle value with respect to an arbitrary reference point in that plane. Denoting by $\mathbf{Cb_{j1}, Cb_{j2}, ..., Cb_{jN-2}}$ the ordered colors of secondary palette, then:

$$h(Cb_{j1}) \leq h(Cb_{j2}) \leq ..... \leq h(Cb_{jN-2}),$$

where $\mathbf{h}(*)$ represent the ordered function applied to color *. This function we named generalized hue function. Note that if the $\mathbf{WK}$ axis is identical to the luminance axis, the function $\mathbf{h}(*)$ represents the hue of color *.

b. Find the tetrahedron determined by 4 combinations of the secondary color palette that includes the point corresponding to the input color. One such tetrahedron is determined by the following 4 vertices: two fixed points $\mathbf{W}$ and $\mathbf{K}$ and two points which satisfy the condition:

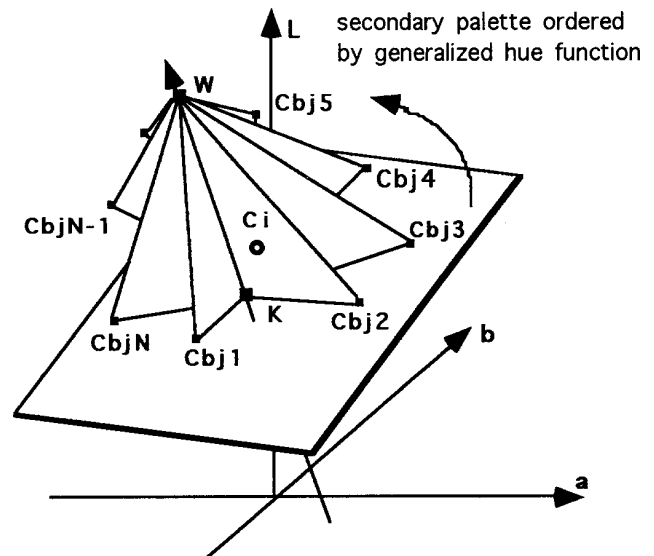$$\mathbf{h(Cb_{jp}) \leq h(C_i) < h(Cb_{j(p+1)}).}$$

Figure 5. Slicing process of the color space based on secondary color palette

The process is illustrated in figure 5. The process of slicing of the color space by planes which has a common edge close to the luminance axis is specific to the generalized separation method that we used. The slicing n≥@the color space is similar to the method proposed by Ostromoukhov,[9] which is equivalent to mode C introduced by Gennetten[7] and with Clark interpolation described by Kasson & al.,[8] with observation that the last two methods refer to the cube space.

c. The unknown baricentric coordinates, (t_1, t_2, t_3, t_4) of input color $\mathbf{C_i}$ are detennined by the following equations[7]:

$$t_1 \bullet \mathbf{W} + t_2 . \mathbf{Cb_{jp}} + t_3 \bullet \mathbf{Cb_{j(p+1)}} + t_4 \bullet \mathbf{K} = \mathbf{C_i},$$

$$t_1 + t_2 + t_3 + t_4 = 1,$$

where the colors $\mathbf{W}$, $\mathbf{Cb}_{jp}$, $\mathbf{Cb}_{j(p+1)}$, $\mathbf{K}$ and $\mathbf{C}_i$ represent tridimensional vectors with the elements the coordinates of these colors in the CIELAB color space (or in other space used for separation process). The coordinates (t_1, t_2, t_3, t_4) result as positively values corresponding to inside position of input color with respect to tetrahedron volume.

d. The decomposition process determines the amount of each ink required to create by overlapping the same printed color like input color. The algorithm of decomposition works in the following way:

d1. the amount vector $(a_1, a_2, ..., a_n)$ of $(C_1, C_2, ..., C_n)$ inks set is initialized with 0 value;

d2. if the color $\mathbf{Cb}_{jp}$ corresponding to the vertex i, i = 1,2,3 or 4, is the result of overlapping of inks $p_1, p_2, ..., p_r$, where $p_1, p_2, ..., p_r$ are numbers in $\{1,2,3,...,n\}$, then the amounts $a_{p1}, a_{p2}, ..., a_{pr}$ are increased with value t_i. For example, if the coordinate t_i correspond to the color $\mathbf{Cb_3}$ resulted by overlapping of inks 1 + 2 + 4, when 6 inks are used (n = 6), then the amount vector $(a_1, a_2, ..., a_n)$ increases with: $(a_1, a_2, a_3, a_4, a_5, a_6) = (a_1, a_2, a_3, a_4, a_5, a_6) + (t_i, t_i, 0, t_i, 0, 0)$. This process is performed for all four tetrahedron vertices.

The fimal amount vector $(a_1, a_2, ..., a_n)$ corresponds to the value of ink masks for the pixels with input color $\mathbf{C}_i$.

4. Color Calibration

As it can be observed, the color separation process depends essentially on the 100% overprinted inks, referred as color $\mathbf{Cb_1, Cb_2, ..., Cb_N}$ of the secondary color palette. These color combinations are represented in the CIELAB color space and are used in color space slicing.

The colors $\mathbf{Cb_1, Cb_1, ..., Cb_N}$ 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 one 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.

Table 1

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

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.

Calibration process associates to the combination $\mathbf{Cb_1, Cb_2, ..., Cb_N}$ the 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 6 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.
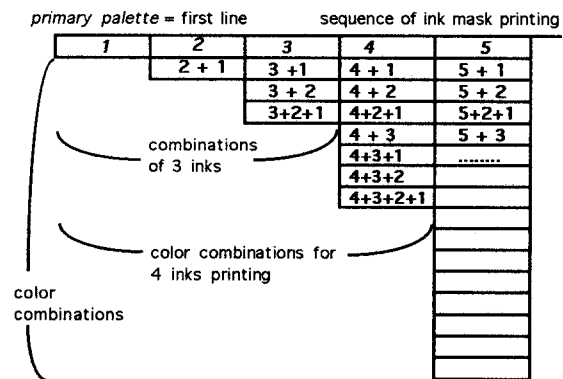

Figure 6. Secondary color palette ordered in a hyerarchy as displayed during color calibration

In case when color calibration is visually checked, the method of modulation of color luminanoe by the luminance of the black and white texture image (described later in this paper) is used. The matching between the textile color samples and the simulated color on the CRT can be checked.

5. 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 under-background 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 oolor; 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:

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

(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:

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

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 model[9] 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:

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

case B:

$$C_{app} = [a_1 \cdot a_2 \cdot Cb_1 + a1 \cdot (1 - a_2) \cdot Cb_2 + (1 - a_1) \cdot a_2 \cdot Cb_2 + [(1 - a_1) \cdot (1 - a_2) \cdot C_{tex} \cdot (1 - t) + t \cdot C_{bk}]. \quad (4)$$

As can be observed, in case A, the relationship (3) includes in the square brackets, the Neugebauer equations for two inks.[9] 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.[5] The tristimulus XYZ are calcu-
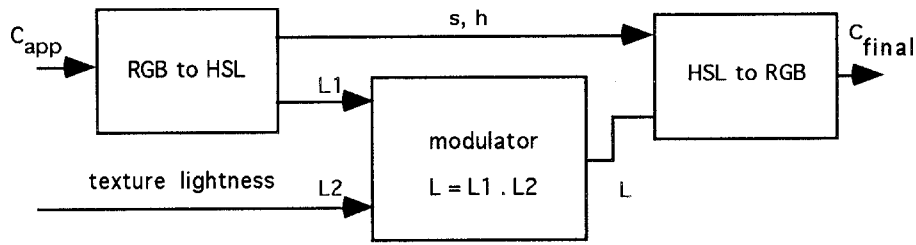
Figure 7. Texture influence in final color appearance simulation

lated 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, only the last terms of Neugebauer equations is affected by the transparency phenomena.

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

case A:

$$\mathbf{C_{app}} = [f_1 \cdot \mathbf{Cb_1} + f_2 \cdot \mathbf{Cb_2} + ... + f_{N-1} \cdot \mathbf{Cb_{N-1}} + f_N \bullet \mathbf{C_{tex}}] \cdot (1 - t) + t \cdot \mathbf{C_{bk}}. \quad (5)$$

case B:

$$\mathbf{C_{app}} = f_1 \cdot Cb_1 + f_2 \cdot \mathbf{Cb_2} + ... + f_{N-1} \cdot \mathbf{Cb_{N-1}} + [f_N \cdot \mathbf{C_{tex}} \cdot (1 - t) + t \cdot \mathbf{C_{bk}}] \quad (6)$$

where the coefficients $f_1, f_2, ..., f_N$ are calculated based on amount vector $(a_1, a_2, ..., a_n)$ and are dependent on the area covered by each color combination $\mathbf{Cb_1}, \mathbf{Cb_2}, ..., \mathbf{Cb_{N-1}}, \mathbf{C_{tex}}$. The coefficients $f_1, f_2, ..., f_N$ are calculated by following formula:

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

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

$p_k =$
$\quad$ 1 - a_i, if color ink i is not involved in combination $\mathbf{Cb_j}$;
$\quad$ a_1, if color ink i is involved in combination $\mathbf{Cb_j}$;

Note that the secondary palette colors, $\mathbf{Cb_1}, \mathbf{Cb_2}, ..., \mathbf{Cb_N}$, are the result of mixture of (primary palette) color inks $(C_1, C_2, ..., C_n)$, and the RGB representation of these color are used during the color calibration process.

6. 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.[10]

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 non-uniformities 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 7 depicts the procedure of texture effect simulation by modulation the simulated color.

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:

$$\mathbf{C_{final}} = \mathbf{C_{app}} \cdot (1 - f(L_{\text{texture}})) + \mathbf{C_{bk}} \cdot f(L_{\text{texture}}),$$

where the function f(L) is a nonlinear function which provides the balance between classic Neugebauer simulated color and background color, as is suggested in figure 8.

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 5.

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.
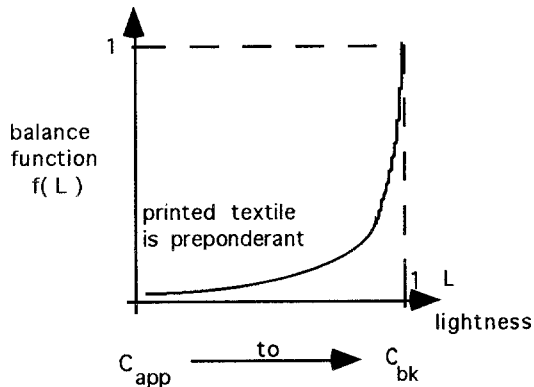

Figure 8. The balance function f(L).

7. Conclusions

This paper discussed some aspects of designing and simulation of the printed colors on textile materials. A color separation method that works for an arbitrary numbers of colors was described. The separation method uses an interpolation process followed by a decomposition process. The influence of sequence of the ink mask printing was discussed.

A color hierarchy was established to select and display the possible printable color combination as a function of the order of the ink mask printing and ink set. The calibration process influences essentially both the result of 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.

The paper emphasizes the difficulties of the designing and prediction of the color printed on textile materials. Many of development conditions of this project were im-posed by practical conditions. Some aspects, like accurate selection of inks according to the image colors, are left for future analysis and developments.

8. References

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