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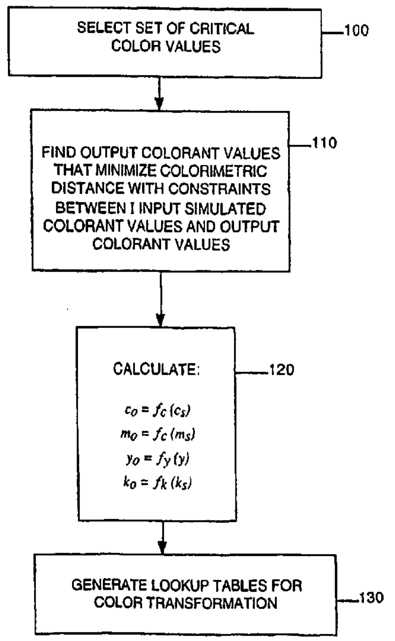
(54) Title: METHOD AND APPARATUS FOR AUTOMATICALLY GENERATING SINGLE-CHANNEL CRITICAL COLOR TRANSFORMATIONS

(57) Abstract

The invention described herein uses minimization techniques to find a good single–channel transformation that preserves the accuracy of critical colors. The invention takes as inputs a set of critical colors and from these colors determines a set of constraints on the output device and simulated device colorants that is used for the minimization. The constraints are selected to allow the minimization step to determine a consistent single–channel transformation. Then, the color characteristics of a simulated and an output printer are used to find a tranformation that minimizes color distance, given the constraints. The invention takes into account certain critical colors during the generation of the single–channel transformation. The invention consists first selecting a set of colorant values in the simulated device color space that are critical to render accurately. The requirements of the critical colors are that they lie on a set of curves in space with the following properties: each curve is smooth and non–intersecting; eeach curve has at least one coordinate that goes from no ink to full ink; and the set of all curves has the property that for each colorant c_s, m_s, y_s, and k_s, there is a curve that has no ink at one endpoint and full ink at the other endpoint. Once the selection of the set of critical colors is made, the functions f_c, f_m, f_y, and f_k are calculated by finding the output colorant values that minimize a colorimetric distance (i.e. CIE L*a*b ΔE) between the input simulated colorant values and the output colorant values.



METHOD AND APPARATUS FOR AUTOMATICALLY GENERATING SINGLE-CHANNEL CRITICAL COLOR TRANSFORMATIONS

BACKGROUND OF THE INVENTION

TECHNICAL FIELD

The invention relates to color printing. More particularly, the invention relates to the automatic generation of single-channel color transformations from one printing device to another that allow output from one printer to closely resemble, or simulate, the output from another printer.

DESCRIPTION OF THE PRIOR ART

In most cases, the primary colorants of a simulated printer differ from the primary colorants of an output printer in both hue and density. The most general approach to simulating a printer using a color transformation from one printing device to another, *i.e.* the approach that is thought to provide the best color fidelity, involves the transformation

$$\begin{aligned} c_o &= f_c(c_s, m_s, y_s, k_s), \\ m_o &= f_m(c_s, m_s, y_s, k_s), \\ y_o &= f_y(c_s, m_s, y_s, k_s), \\ k_o &= f_k(c_s, m_s, y_s, k_s), \end{aligned} \tag{1}$$

where c_o represents cyan of the output printer for cyan; c_s, m_s, y_s, and k_s represent the colorants of the simulated printer; and f_c represents a function that generates the output printer cyan colorant from the input colorants of the simulated printer.

A similar notation is used for the other colorants.

This transformation has c_s, m_s, y_s, and k_s values as inputs from an image separated for the simulated device (*e.g.* DIC inks) and performs the transformations f_c, f_m, f_y, and f_k, respectively, to output device colorant values for each of the output c_o, m_o, y_o, and k_o values.

A shorthand description of the foregoing transformation is

$$v_o = f(v_s), \tag{2}$$

where v_o is the four-dimensional vector with components c_o, m_o, y_o, and k_o; and v_s is the four-dimensional vector with components c_s, m_s, y_s, and k_s.

The function f represents the vector function with component functions f_c, f_m, f_y, and f_k.

For purposes of the foregoing, it is assumed that the transformation t_s from colorant v_s to device-independent coordinates T_s (*e.g.* CIE L*a*b D50 two-degree observer) for the simulated device is available and is given by

$$T_s = t_s(v_s). \tag{3}$$

The transformation t_o from output device colorant v_o to device-independent coordinates T_o is governed by

$$T_o = t_o(v_o). \tag{4}$$

If the function f of Equation 2 above is used for the device simulation, the following tristimulus values are obtained on the output device

$$\hat{T}_s = t_o(f(v_s)). \tag{5}$$

Minimizing over possible functions f,

$$\hat{f} = \arg_f \min d(T_s, \hat{T}_s), \tag{6}$$

an optimal solution $\hat{f}$ is obtained. In Equation 6, d is a distance function, such as CIE L*a*b ΔE. In the ideal situation, where $T_s = \hat{T}_s$ for all colors,

$$t_s(v_s) = t_o(f(v_s)). \tag{7}$$

In this case, the optimal solution is

$$\hat{f}(v_s) = t_o^{\dagger}(t_s(v_s)). \tag{8}$$

This equation reflects in an abstract manner the commonly used approach to simulation that first transforms from the colorant of the simulated printer to device independent coordinates, and that then transforms from device independent coordinates to the output printer colorants. The function $t_o^{\dagger}$ represents the conversion from device independent coordinates to the output colorant, and (in a loose sense) inverts the function t_o, even though the function t_o is not invertible in the strict, mathematical sense (because it is a continuous mapping from four input dimensions to three output dimensions).

An additional complication is the mismatch of gamuts between the simulated device and the output device. Further details of gamut mapping are found in H. Kang, Color Technology For Electronic Imaging Systems, SPIE press, Bellingham, WA (1997).

Even though the approach of Equation 2 above gives the most accurate color fidelity, the class of single-channel color transformations given by

$$\begin{aligned} c_o &= f_c(c_s) \\ m_o &= f_m(m_s) \\ y_o &= f_y(y_s) \\ k_o &= f_k(k_s) \end{aligned} \tag{9}$$

is also very useful.

Given the limitations of the single-channel transformations of Equation 9 above, it is impossible to simulate devices without errors unless all the single colorant hues and the color mixing properties are the same on both the output and the simulated device. For example, if the hue of the magenta colorant of the simulated device differs from the hue of the magenta colorant of the output device, then the single-channel transformation is not able to match the magenta colors precisely.

Nevertheless, in practice, a single-channel transformation often performs well enough in terms of color fidelity and, in addition, offers several advantages. First, a practical implementation of this approach involves a lookup table having only 256 elements for the cyan transformation, and involves similar transformations for the other colorants. These lookup tables are simple, small and fast, both in hardware and in software implementations.

There are, in addition, potential image quality advantages to the single-channel transformations. For example, it is often desired to map the yellow colorant of the simulated device to the yellow colorant of the output device. Even though this mapping may not be as accurate colorimetrically, it can be a subjectively preferred mapping because it minimizes printing engine artifacts that are seen when yellow and magenta toners are mixed on electrophotographic printers; or it minimizes the visibility of halftone dots on inkjet printers.

For the black channel of the simulated device, it is often also preferred to map only to the black channel of the output device. This approach has the advantage of minimizing sensitivity to shifts in gray balance, as well as advantages in situations where the cost of black only printing is lower than mixed colorant printing due to accounting, *e.g.* the number of black only prints counted vs.. the number of color prints counted.

One standard practice that is used to generate single-channel transformations involves measuring single ink densities on the simulated device and, from this, generating targets that consist of (x, d_s) pairs of input ink percent, x, and densities, d_s. This target, (x, d_s), is then used on the output device, together with measurements of single toner density response on the output device of (x, d_o) pairs that describe the current behavior of the output device. These two quantities are combined to generate lookup tables for each of the four color channels that compensate for the density differences.

This approach has certain disadvantages, among which is a metamerism problem in that a densitometer may give the same readings even though the colors are different when observed by a viewer and, conversely, the densitometer may give different readings even though the colors are the same when observed by a viewer. This metamerism problem is due to the differences in the spectral response of the densitometer and the spectral response of the average human eye, and the differences in the spectral properties of the inks and the toners. Another disadvantage of this approach is that it does not accurately simulate critical colors, such as flesh tones, that might be more important than the single ink colors.

A second common practice is to start from a given (x, d_S) target and tune the target by iterative printing of pages that consist of images and patches separated to the simulated device, thereby improving the target by trial and error. This approach is time consuming, requires experienced operators, and can be sensitive to the images chosen for the iterations. In other words, one might overlook problems in the targets if certain colorant values are not contained in the images used during the iterations.

A third approach that is used to generate single-channel transformations involves measuring colorimetric data for single inks for the simulated device and matching these measurements to measurements for the output device. This is a very simple approach that is easy to implement but that, in practice, does not provide good simulations because the ways colors mix on the two different devices may differ. Thus, even though the single inks have a close colorimetric match, other colors that are composed of inputs with mixed inks do not have an accurate colorimetric rendition as a result of this simulation. Also, such simulation does not take into account the fact that certain colors, *i.e.* critical colors, may be more important than other colors with regard to color fidelity in the simulation.

The discussion of the background to the invention herein is included to explain the context of the invention. This is not to be taken as an admission that any of the material referred to was published, known or part of the common general knowledge in Australia as at the priority date of any of the claims.

It would be advantageous to provide a simple approach for generating critical color transformations.

SUMMARY OF THE INVENTION

According to one aspect of the present invention there is provided a method for generating single-channel color transformations, including the steps of:

selecting a set of colorant values in a simulated device color space that are critical to render accurately;

calculating the f_c, f_m, f_y, and f_k by finding output colorant values that minimize a colorimetric distance between input simulated colorant values and output colorant values, where said functions f_c, f_m, f_y, and f_k are single-channel color transformations given by

$c_0 = f_C(c_s)$

$m_0 = f_m(m_s)$

$y_0 = f_y(y_S)$

$k_0 = f_k(k_S)$;

and populating lookup tables with values determined as a result of said calculating step.

According to a further aspect of the present invention there is provided a method for generating single-channel color transformations for the gray colors, including steps of:

selecting a set of colors $(c_S, m_S, y_S, 0)$ that correspond to a definition of gray for an input simulation space;

searching an output colorant space for values $(c_0, m_0, y_0, 0)$ that minimize a ΔE distance;

wherein the values of c_0, m_0 and y_0 define functions f_c, f_m, and f_y of simulated colorants c_S, m_S and y_S; and populating lookup tables with values identified as a result of said searching step.

According to a still further aspect of the present invention there is provided a method for generating single-channel color transformations for flesh tones, including the steps of:

considering values of c_S, m_S, y_S and k_S for flesh tone regions of an image;

generating by incorporating predetermined assumptions made on said values from said regions a single-channel color transformation that accurately renders flesh tones; and

populating a look up table with values identified as a result of generating said transformation.

According to a still further aspect of the present invention there is provided an apparatus for generating single-channel color transformations, including:

means for selecting a set of colorant values in the simulated device color space that are critical to render accurately;

means for calculating the functions f_C, f_m, f_y, and f_k by finding output colorant values that minimize a colorimetric distance between input simulated colorant values and output colorant values, where said functions f_C, f_m, f_y, and f_k are single-channel color transformations given by

$c_0 = f_C(c_s)$

$m_0 = f_m(m_s)$

$y_0 = f_y(y_S)$

$k_0 = f_k(k_S)$;

and means for populating lookup tables with values determined as a result of said calculating step.

According to a still further aspect of the present invention there is provided an apparatus for generating single-channel color transformations for the gray colors, including:

means for selecting a set of colors $(c_S, m_S, y_S, 0)$ that correspond to a definition of gray for an input simulation space;

searching an output colorant space for values c_0, m_0, y_0, 0 that minimize a ΔE distance;

wherein the values of c_0, m_0, and y_0 define functions f_C, f_m, and f_y of simulated colorants c_S, m_S, and y_S; and

populating at least one lookup table with values identified as a result of said searching step.

According to a still further aspect of the present invention there is provided an apparatus for generating single-channel color transformations for flesh tones, including:

means for considering values of c_S, m_S, y_S, and k_S for flesh tone regions of an image;

means for generating by incorporating predetermined assumptions made on said values from said regions a single-channel color transformation that accurately renders flesh tones; and

means for populating a lookup table with values identified as a result of generating said transformation.

According to a still further aspect of the present invention there is provided a method for generating single-channel color transformation including the steps of:

selecting a set of colorant values in at least two planes of a simulated device color space that are critical to render accurately and their corresponding L*a*b values;

jointly searching a corresponding number of output colorant space planes for output colorset values that minimize a colorimetric distance between input simulated colorant L*a*b values and output colorant L*a*b values; and

populating lookup tables with values determined as a result of said searching step;

wherein critical colors lying on separate curves jointly determine an optimal single-channel transformation.

According to a still further aspect of the present invention there is provided an apparatus for generating single-channel color transformations, including:

means for selecting a set of colorant values in at least two planes of a simulated device color space that are critical to render accurately and their corresponding L*a*b values;

means for jointly searching a corresponding number of output colorant space planes for output colorant values that minimize a colorimetric distance between input simulated L*a*b values and output colorant L*a*b values; and

at least two lookup tables that are populated with values determined by said searching means;

wherein critical colors lying on separate curves jointly determine an optimal single-channel transformation.

The invention described herein may use minimization techniques to find a good single-channel transformation that preserves the accuracy of critical colors. The invention may take as inputs a set of critical colors and from these colors determine a set of constraints on the output device and simulated device colorants that is used for the minimization. The constraints may be selected to allow the minimization step to determine a consistent single-channel transformation. Then, the color characteristics of a simulated and an output printer may be used to find a transformation that minimizes color distance, given the constraints. The invention may take into account certain critical colors during the generation of the single-channel transformation. For example, the invention can be used to simulate the Japanese Dai-Nippon Ink standard (simulated printer) on a digital electrophotographic printer (output printer) with good accuracy in flesh tones.

The invention may provide a method that consists of first selecting a set of colorant values in the simulated device color space that are critical to render accurately. A requirement of the critical colors is that they lie on a set of curves in the simulated device colorant space. Define each curve in the set to be a smooth, parametric curve given by:

$$s_i(t) = (c_i(t), m_i(t), y_i(t), k_i(t)) \qquad (10)$$

where the curve $s_i(t)$ is a vector function of parameter t with individual components c_i, m_i, y_i and k_i each a scalar function of parameter t in the range [0,1]. The set of curves, S, consists of N curves s_i where the index i = 1, ..., N.

A requirement of the set of curves is that, for each colorant of the simulated device, there is a curve in S that has the corresponding component function be a bijection (one-to-one, onto mapping) to [0,1].

An example that meets the conditions given above for S is the set of curves with the following properties:

1. Each curve is smooth and non-intersecting.
2. Each curve has at least one component that increases from no ink to full ink.
3. The set of all of the curves has the property that for each colorant c_S, m_S, y_S and k_S there is a curve where that component increases from one endpoint, with no ink, to the other endpoint, with full ink.

Recall that the invention applies to the class of single-channel color transformation given by

$$c_0 = f_C(c_s)$$
$$m_0 = f_m(m_s)$$
$$y_0 = f_y(y_S)$$
$$k_0 = f_k(k_S).$$

Once the selection of the set of critical colors is made, the functions f_C, f_m, f_y, and f_k of Equation 11 are calculated by finding the output colorant values that minimize a colorimetric distance *(i.e.* CIE L*a*b ΔE) between the input simulated colorant values and the output colorant values. It is important that the search space is constrained to an appropriate set of output colorant values before this minimization takes places so that the appropriate functions may be generated. These constraints are built into the minimization process and differ depending on the goals of the user.

BRIEF DESCRIPTION OF THE DRAW1NGS

A preferred embodiment of the present invention will now be described with reference to the accompanying drawings wherein:

Fig. 1 is a flow diagram showing a technique for generating single-channel color transformations according to the invention;

Fig. 2 is a block diagram of a system for generating single-channel color transformations according to the invention;

FIG. 3 is a flow diagram showing the technique for generating single-channel color transformations;

Fig. 4 is a flow diagram showing the generation of a single-channel color transformation, where gray colors are the critical colors, according to the invention;

Fig. 5 is a flow diagram showing the generation of single-channel color transformations, where flesh tones are the critical colors, according to the invention; and

Fig. 6 is a flow diagram showing the use of joint optimization to find a single-channel transformation according to the invention.

DETAILED DESCRIPTION OF THE INVENTION

The invention described herein uses minimization techniques to find a good single-channel transformation that preserves the accuracy of critical colors. The invention takes as inputs a set of critical colors and from these colors determines a set of constraints for the minimization. The constraints are selected to allow the minimization step to determine a consistent single-channel transformation. Then, the color characteristics of a simulated and an output printer are used to find a transformation that minimizes color distance, given the constraints. The invention takes into account certain critical colors during the generation of the single-channel transformation. For example, the invention can be used to simulate the Japanese Dai-Nippon Ink standard (simulated printer) on a digital electrophotographic printer (output printer) with good accuracy in flesh tones.

Fig. 1 is a flow diagram showing a technique for generating single-channel color transformations according to the invention. The invention consists of first selecting a set of colorant values in the simulated device color space that are critical to render accurately (100). A requirement of the critical colors is that they lie on a set of curves in the simulated device colorant space. Define each curve in the set to be a smooth, parametric curve given by:

$$s_i(t) = (c_i(t), m_i(t), y_i(t), k_i(t)) \qquad (12)$$

where the curve $s_i(t)$ is a vector function of parameter t with individual components c_i, m_i, y_i and k_i, each a scalar function of parameter t in the range [0,1]. The set of curves, S, consists of N curves s_i where the index $i = 1, ..., N$.

A requirement of the set of curves is that, for each colorant of the simulated device, there is a curve in S that has the corresponding component function be a bijection (one-to-one, onto mapping) to [0,1].

An example that meets the conditions given above for S is the set of curves with the following properties:

1. Each curve is smooth and non-intersecting.

2. Each curve has at least one component that increases from no ink to full ink.

3. The set of all of the curves has the property that for each colorant c_s, m_s, y_s and k_s there is a curve where that component increases from one endpoint, with no ink, to the other endpoint, with full ink.

Recall that the invention applies to the class of single-channel color transformation given by

$$\begin{aligned} c_o &= f_c(c_s), \\ m_o &= f_m(m_s), \\ y_o &= f_y(y_s), \\ k_o &= f_k(k_s). \end{aligned} \qquad (13)$$

Once the selection of the set of critical colors is made, the functions f_c, f_m, f_y, and f_k of Equation 13 are calculated (120) by finding the output colorant values that minimize a colorimetric distance (*i.e.* CIE L*a*b ΔE) between the input simulated colorant values and the output colorant values (110). This is done by using numerical minimization methods, where

$$\Delta E = \sqrt{(L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2}.$$

The search space is constrained to an appropriate set of output printer and simulated printer colorant values before this minimization takes places so that the appropriate functions may be generated. These constraints are built into the minimization process and differ depending on the goals of the user. The values generated by the transformation function are used to populate lookup tables (130) by which conversion from the simulated color space to the output color space is accomplished.

Fig. 2 is a block diagram of a system for generating single-channel color transformations according to the invention. In the example shown in Fig. 2, input file 28 provides an image separated to a simulated color space. Under control of a processor 22, the system applies the colorants in these files to lookup tables 24 which contain values for single-channel transforms, where the values were determined for critical colors in accordance with the invention as described herein. The transforms applied to the input colorant information result in files 26 having output colorants that most nearly match the output color to the input color for the critical colors. These files are sent to a print engine 30. In this way, the invention produces highly accurate results for certain critical colors, while perhaps sacrificing somewhat color accuracy for other colors.

Example 1

Fig. 3 is a flow diagram showing the technique for generating single-channel color transformations according to the invention. This technique subsumes the simple technique, used in the prior art, of optimizing each individual channel. For example, one may consider the set of critical colors to be given by the four curves

$(c_s, 0, 0, 0)$,
$(0, m_s, 0, 0)$,
$(0, 0, y_s, 0)$, *and*
$(0, 0, 0, y_k)$,

where $c_s \in [0.0, 1.0]$ means the cyan colorant goes from no ink (0.0) to full ink (1.0).

The same conditions hold for m_s, y_s, and k_s.

This technique optimizes the transformation for single ink input colors. To create the simulation, L*a*b values are generated for the input colorants for the single ink curves (300). L*a*b values are also generated for the output colorants (310). ΔE is then minimized to generate the corresponding single ink output colorant for each single ink simulated colorant (320). This provides functions for each channel that minimize the errors for single ink input colors.

Example 2

Fig. 4 is a flow diagram showing the generation of a single-channel color transformation for the gray colors according to the invention. In this example, the generation of the single-channel color transformation improves the accuracy of gray colors. In this case, one selects a set of colors $(c_s, m_s, y_s, 0)$ that correspond to the definition of gray for the input simulation space (400). This can be done either by applying previous knowledge or by searching for those colors with CIE L*a*b values given by (L, 0, 0). For these colors, one searches the output colorant space for values $(c_o, m_o, y_o, 0)$ that minimize the ΔE distance (410). The values of c_o, m_o, and y_o define the functions f_c, f_m, and f_y (per Equation 11) of the simulated colorants c_s, m_s, and y_s. The black channel is separately processed to determine the function f_k for inputs k_s.

Example 3

Fig. 5 is a flow diagram showing the generation of single-channel color transformations for flesh tones according to the invention. In this example, the invention is used to simulate Japanese DIC press inks on an electrophotographic printer, where special attention is paid to the accuracy of the flesh tones.

To motivate the selection of the set of critical colors for this transformation, the values of c_s, m_s, y_s, and k_s are considered for flesh tone regions of an image separated for DIC ink presses (500). It should be appreciated that this example is by no means limiting with regard to the scope of the invention. For example, another approach is to identify the L*a*b values that correspond to flesh tones and compute the corresponding DIC ink values for these L*a*b values. This latter approach has the advantage that the critical colors are defined in a device-independent color space and can thus be used for any simulated printer, not just one using DIC inks.

The following table shows the cyan, magenta, yellow and black values of several regions in an image, separated for DIC inks, that depict flesh tones, and where each row corresponds to a different region.

Region	C	M	Y	K
1	0	36	45	0
2	0	33	42	0
3	10	47	53	0
4	24	50	60	0
5	20	49	55	0
6	0	24	33	0

From this data, the following simplifying assumptions are made:

- DIC flesh tones consist of values without K,
- DIC flesh tones consist of substantially equal M and Y values, and
- DIC flesh tones may contain some cyan, especially where M and Y are about 0.5 (50% ink).

The following algorithm can be used to generate a single-channel color transformation that accurately renders flesh tones:

- Fit the K channel by itself (510). For DIC press values (0, 0, 0, k_s) generate the L*a*b values. For the output device (0, 0, 0, k_o), generate the L*a*b values. Minimize the ΔE distance necessary for each input k_s to generate the transformation f_k for the K channel.
- For the line $(0, m_s, y_s, 0)$, where $m_s = y_s$, generate the L*a*b values (520). Generate the L*a*b values for the plane in the output colorant space that consists of $(o, m_o, y_o, 0)$. (This plane of L*a*b data is used to explain the process: in practice the needed L*a*b values could also be found during the search process for the output values having the smallest ΔE.) Find the closest $(0, m_o, y_o, 0)$ L*a*b values for each of the input $(0, m_s, y_s, 0)$ (530).

This step simultaneously generates both the function f_m for the M channel and the function f_y for the Y channel.

- For $(c_s, .5_s, .5_s, 0)$ for the DIC input values, calculate the L*a*b values (540). For $(c_o, f_m(.5_s), f_y(.5_s), 0)$, where f_m and f_y are the function found in the previous step for magenta and yellow, calculate the L*a*b values (550). Generate the function f_c, for the C channel, that minimizes ΔE (560).

The set of lookup tables described by f_c, f_m, f_y, and f_k in practice generate very good simulations for DIC inks on many different kinds of electrophotographic printers.

<u>Example 4</u>

The invention disclosed herein can also be used to find a single-channel transformation when the printer secondary colors: reds, greens, and blues are the critical colors. One feature of this example is the use of a joint optimization to find the single-channel transformation. In other words, the critical colors lying on separate curves jointly determine the optimal single-channel transformation. Thus, for a given triple of red, green, and blue simulated colorants, three corresponding output colorant planes, the $y_o = 0$, $k_o = 0$ plane, the $c_o = 0$, $k_o = 0$ plane, and the $m_o = 0$, $k_o = 0$ plane, are searched simultaneously to find the transfer curves for cyan, magenta, and yellow.

As in previous example, the black channel is fit independently.

To explain the method of fitting for the cyan, magenta and yellow channels, definitions are needed for the critical colors, the simulated device colors, and the output device colors, together with the definition of the metric Δ_{RGB} that is to be minimized.

First, the set of critical colors are on three curves, given by:

- The "blue" curve, $(c_s, m_s, 0, 0)$, where $c_s = m_s$.
- The "red" curve, $(0, m_s, y_s, 0)$, where $m_s = y_s$.

- The "green" curve, $(c_s, 0, y_s, 0)$, where $c_s = y_s$.

For each value $\propto \in [0,1]$, consider the three simulated device colors given by $b_s = (\propto, \propto, 0, 0)$, $r_s = (0, \propto, \propto, 0)$, and $g_s = (\propto, 0, \propto, 0)$. Corresponding to these values are L*a*b values given by $t_s(b_s)$ for the blue color, $t_s(r_s)$ for the red color, and $t_s(g_s)$ for the green color (600).

Also consider the output colorant $(c_o, m_o, y_o, 0)$. This point, projected onto three planes in the output colorant space, results in the point $cm_o = (c_o, m_o, 0, 0)$, $my_o = (0, m_o, y_o, 0)$, and $cy_o = (c_o, 0, y_o, 0)$. Corresponding to these points are the corresponding L*a*b values given by $t_o(cm_o)$ for the blue color, $t_o(my_o)$ for the red color, and $t_s(cy_o)$.

Component metrics are then defined that describe how well the output candidate colorant values approximate the input values for the blue, red, and green simulated colors, respectively. These metrics are given by $\Delta E_B = d(t_s(b_s), t_o(cm_o))$, $\Delta E_R = d(t_s(r_s), t_o(my_o))$, and $\Delta E_G = d(t_s(g_s), t_o(cy_o))$, where d represents Euclidean distance between the L*a*b values of the simulated device colorants and the L*a*b values of the corresponding output device colorants. If equal importance is given to reds, greens, and blues, then the metric $\Delta_{RGB} = \Delta E_R + \Delta E_D + \Delta E_B$.

Using a numerical optimization technique, a point $(c_o, m_o, y_o, 0)$ is found that minimizes this quantity for a given $\propto$ (610). This process is repeated for all values of $\propto \in [0,1]$, or in practice for the 256 values required to build the tables. This results in the lookup tables for cyan (620), magenta (630), and yellow (640). The ΔE distance for the k channel is independently minimized (650) and values are provided for the k lookup table (660).

Other Embodiments

The invention is also readily used in conjunction with ICC profiles because these profiles contain the necessary colorimetric information. Thus, from the ICC profile for a simulated printer and the ICC profile of the output printer, a single-channel, critical color transformation may be generated by the methods described in this invention.

Further, the invention may be used to combine several critical sets and average the results to match a larger set of colors, or alternatively, the optimization step can be a joint optimization. The invention may also be used for CMY devices.

Although the invention is described herein with reference to the preferred embodiment, one skilled in the art will readily appreciate that other applications may be substituted for those set forth herein without departing from the spirit and scope of the present invention. Accordingly, the invention should only be limited by the Claims included below.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A method for generating single-channel color transformations, including the steps of:

selecting a set of colorant values in a simulated device color space that are critical to render accurately;

calculating the f_c, f_m, f_y, and f_k by finding output colorant values that minimize a colorimetric distance between input simulated colorant values and output colorant values, where said functions f_c, f_m, f_y, and f_k are single-channel color transformations given by

$c_0 = f_C(c_s)$

$m_0 = f_m(m_s)$

$y_0 = f_y(y_S)$

$k_0 = f_k(k_S)$;

and populating lookup tables with values determined as a result of said calculating step.

2. The method of Claim 1, further comprising the step of:

constraining a colorant value search space to a set of output device and simulated device colorant values before minimization takes places so that appropriate functions may be generated.

3. The method of Claim 1 or 2, wherein said critical colors lie on a set of curves in space with the following properties:

the critical colors lie on a set of curves in the simulated device colorant space;

each curve in the set is a smooth, parametric curve given by:

$s_i(t) = (c_i(t), m_i(t), y_i(t), k_i(t))$

where the curve $S_i(t)$ is a vector function of parameter t with individual components c_i, m_i, y_i, k_i each a scalar function of parameter t in the range [0,1];

wherein the set of curves, S, consists of N curves s_i where the index i = 1, …, N; and for each colorant of the simulated device, there is a curve in S that has a corresponding component function be a bijection (one-to-one, onto mapping) to [0,1].

4. The method of Claim 1, 2 or 3, wherein said single channel color transformations are calculated using an ICC profile for said simulated device and an ICC profile for an output device.

5. A method for generating single-channel color transformations for the gray colors, including steps of:

selecting a set of colors $(c_S, m_S, y_S, 0)$ that correspond to a definition of gray for an input simulation space;

searching an output colorant space for values $(c_O, m_O, y_O, 0)$ that minimize a ΔE distance;

wherein the values of c_O, m_O and y_O define functions f_c, f_m, and f_y of simulated colorants c_S, m_S and y_S; and

populating lookup tables with values identified as a result of said searching step.

6. The method of Claim 5, wherein a black channel is separately processed to determine a function f_k for inputs k_S.

7. The method of Claim or 6, wherein said set of colors is selected by applying previous knowledge.

8. The method of Claim 5 or 6, wherein said set of colors is selected by searching for those colors with CIE L*a*b values given by (L, 0, 0).

9. A method for generating single-channel color transformations for flesh tones, including the steps of:

considering values of c_S, m_S, y_S and k_S for flesh tone regions of an image;

generating by incorporating predetermined assumptions made on said values from said regions a single-channel color transformation that accurately renders flesh tones; and populating a look up table with values identified as a result of generating said transformation.

10. The method of Claim 9, wherein said generating step comprises the steps of:

generating k channel L*a*b values for a simulated input device $(0, 0, 0, k_S)$;

generating k channel L*a*b values for an output device $(0, 0, 0, k_0)$; and

minimizing the distance necessary for each input k_S to generate a transformation f_k for the k channel.

11. The method of Claim 9, wherein said generating step comprises the steps of:

generating L*a*b values for $(0, m_S, y_S, 0)$, where $m_S = y_S$;

generating L*a*b values for a plane in an output colorant space that consists of $(0, m_0, y_0, 0)$;

finding closest $(0, m_0, y_0, 0)$ L*a*b values for each input $(0, m_S, y_S, 0)$;

wherein a function f_m for m_S, and a function f_y for y_S is simultaneously generated.

12. The method of Claim 11, wherein said generating step further comprises the steps of:

calculating L*a*b values for simulated device colorants $(c_S, .5_S, .5_S, 0)$;

calculating L*a*b values for output device colorants $(c_0, f_m(.5_S), f_y(.5_S) 0)$, where f_m and f_y are functions for magenta and yellow; and

generating a function f_c that minimizes ΔE.

13. The method of any one of Claims 9 to 12, wherein Japanese DIC press inks are simulated on an electrophotographic printer.

14. The method of any one of claims 9 to 13, wherein said values c_S, m_S, y_S and k_S for flesh tone regions of an image are L*a*b values that correspond to flesh tones; and

wherein corresponding ink values are calculated for these L*a*b values.

15. The method any one of Claims 9 to 14, wherein any of the following applies:

flesh tones consist of values without black;

flesh tones consist of substantially equal magenta and yellow values; and

flesh tones may include cyan, especially where magenta and yellow are about 50% ink.

16. The method any one of Claims 9 to 15, wherein several critical sets are combined; and

wherein results obtained by said combining match a larger set of colors.

17. The method of any one of Claims 9 to 16, wherein said method is used for either of CMY devices and CMYK devices.

18. An apparatus for generating single-channel color transformations, including:

means for selecting a set of colorant values in the simulated device color space that are critical to render accurately;

means for calculating the functions f_C, f_m, f_y, and f_k by finding output colorant values that minimize a colorimetric distance between input simulated colorant values and output colorant values, where said functions f_C, f_m, f_y, and f_k are single-channel color transformations given by

$$c_0 = f_C(c_s)$$
$$m_0 = f_m(m_s)$$
$$y_0 = f_y(y_S)$$
$$k_0 = f_k(k_S);$$

and means for populating lookup tables with values determined as a result of said calculating step.

19. The apparatus of Claim 18, wherein a colorant value search space is constrained to a set of output device and simulated device colorant values before minimization takes places so that consistent functions may be generated.

20. The apparatus of Claim 18 or 19, wherein said critical colors lie on a set of curves in space with the following properties:

the critical colors lie on a set of curves in the simulated device colorant space;

each curve in the set is a smooth, parametric curve given by:

$$S_i(t) = (c_i(t), m_i(t), y_i(t), k_i(t))$$

where the curve $s_i(t)$ is a vector function of parameter t with individual components c_i, m_i, y_i, k_i each a scalar function of parameter t in the range [0,1];

wherein the set of curves, S, consists of N curves s_i, where the index i = 1, ..., N; and

for each colorant of the simulated device, there is a curve in S that has a corresponding component function be a bijection (one-to-one, onto mapping) to [0,1].

21. The apparatus of Claim 18, 19 or 20, wherein said single channel color transformations are calculated using an ICC profile for said simulated device and for an output device.

22. An apparatus for generating single-channel color transformations for the gray colors, including:

means for selecting a set of colors $(c_S, m_S, y_S, 0)$ that correspond to a definition of gray for an input simulation space;

searching an output colorant space for values $(c_0, m_0, y_0, 0)$ that minimize a ΔE distance;

wherein the values of c_0, m_0, and y_0 define functions f_C, f_m, and f_y of simulated colorants c_S, m_S, and y_S; and

populating at least one lookup table with values identified as a result of said searching step.

23. The apparatus of Claim 22, wherein a black channel is separately processed to determine a function f_k for inputs k_S.

24. The apparatus of Claim 22 or 23, wherein said set of colors is selected by applying previous knowledge.

25. The apparatus of Claim 22 or 23, wherein said set of colors is selected by searching for those colors with tristimulus values given by (L, 0, 0).

26. An apparatus for generating single-channel color transformations for flesh tones, including:

means for considering values of c_S, m_S, y_S, and k_S for flesh tone regions of an image;

means for generating by incorporating predetermined assumptions made on said values from said regions a single-channel color transformation that accurately renders flesh tones; and

means for populating a lookup table with values identified as a result of generating said transformation.

27. The apparatus of Claim 26, wherein said generating means comprises:

means for generating k channel L*a*b values for a simulated input device $(0, 0, 0, k_S)$;

means for generating k channel L*a*b values for an output device $(0, 0, 0, k_O)$; and

means for minimizing the distance necessary for each input k_S to generate a transformation f_k for the k channel.

28. The apparatus of Claim 26, wherein said generating means comprises:

means for generating L*a*b values for $(0, m_S, y_S, 0)$, where $m_S = y_S$;

means for generating L*a*b values for a plane in an output colorant space that consists of $(0, m_O, y_O, 0)$;

means for finding closest $(0, m_O, y_O, 0)$ L*a*b values for each input $(0, m_S, y_S, 0)$;

wherein a function f_m for m_S and a function f_y for y_S is simultaneously generated.

29. The apparatus of Claim 28, wherein said generating means further comprises:

means for calculating L*a*b values for input values for $(c_S, .5_S, .5_S, 0)$;

means for calculating L*a*b values for output device colorants (c_0, $f_m(.5_S)$, $f_y(.5_S)$, 0), where f_m and f_y are functions for magenta and yellow; and $f_m(.5_S)$, $f_y(.5_S)$, 0), where f_m and f_y are functions for magenta and yellow; and

means for generating a function f_C that minimizes ΔE.

30. The apparatus of any one of Claims 26 to 29, wherein Japanese DIC press inks are simulated on an electrophotographic printer.

31. The apparatus of any one of Claims 26 to 30, wherein said values c_S, m_S, y_S, and k_S, for flesh tone regions of an image are L*a*b values that correspond to flesh tones; and

wherein corresponding ink values are calculated for these L*a*b values.

32. The apparatus any one of Claims 26 to 31, wherein any of the following applies:

flesh tones consist of values without black;

flesh tones consist of substantially equal magenta and yellow values; and

flesh tones may include cyan colorants, especially where magenta and yellow are about 50% ink.

33. The apparatus of any one of Claims 26 to 32, wherein several critical sets are combined; and

wherein results obtained by said combining match a larger set of colors.

34. The apparatus of any one of Claims 26 to 33, wherein said apparatus is used in connection with either of CMY devices and CMYK devices.

35. A method for generating single-channel color transformation including the steps of:

selecting a set of colorant values in at least two planes of a simulated device color space that are critical to render accurately and their corresponding L*a*b values;

jointly searching a corresponding number of output colorant space planes for output colorset values that minimize a colorimetric distance between input simulated colorant L*a*b values and output colorant L*a*b values; and

populating lookup tables with values determined as a result of said searching step;

wherein critical colors lying on separate curves jointly determine an optimal single-channel transformation.

36. An apparatus for generating single-channel color transformations, including:

means for selecting a set of colorant values in at least two planes of a simulated device color space that are critical to render accurately and their corresponding L*a*b values;

means for jointly searching a corresponding number of output colorant space planes for output colorant values that minimize a colorimetric distance between input simulated L*a*b values and output colorant L*a*b values; and

at least two lookup tables that are populated with values determined by said searching means;

wherein critical colors lying on separate curves jointly determine an optimal single-channel transformation.

37. A method for generating single-channel color transformations substantially as hereinbefore described with reference to the accompanying drawings.

38. An apparatus for generating single-channel color transformations substantially as hereinbefore described with reference to the accompanying drawings.

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ELECTRONICS FOR IMAGING, INC.

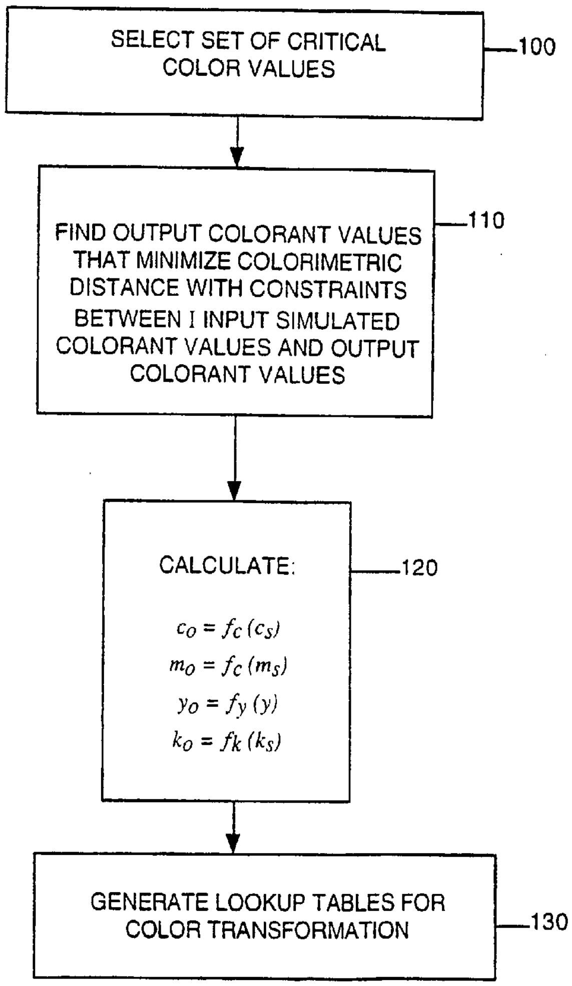
SELECT SET OF CRITICAL COLOR VALUES
100
FIND OUTPUT COLORANT VALUES THAT MINIMIZE COLORIMETRIC DISTANCE WITH CONSTRAINTS BETWEEN I INPUT SIMULATED COLORANT VALUES AND OUTPUT COLORANT VALUES
110
CALCULATE:
$c_o = f_c(c_s)$
$m_o = f_c(m_s)$
$y_o = f_y(y)$
$k_o = f_k(k_s)$
120
GENERATE LOOKUP TABLES FOR COLOR TRANSFORMATION
130

FIG. 1

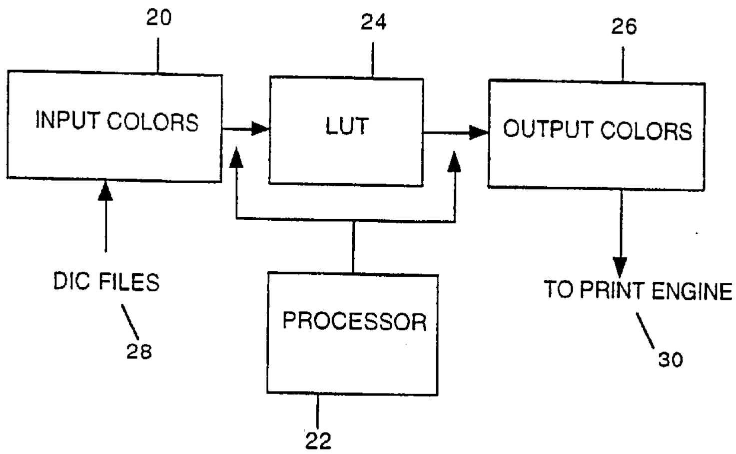
20
24
26
INPUT COLORS
LUT
OUTPUT COLORS
DIC FILES
28
PROCESSOR
TO PRINT ENGINE
30
22

FIG. 2

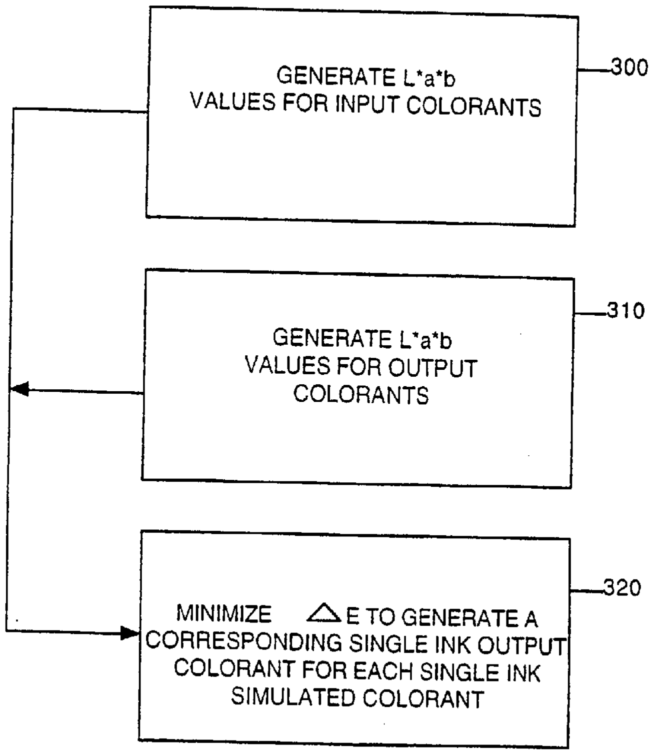

FIG. 3 (PRIOR ART)

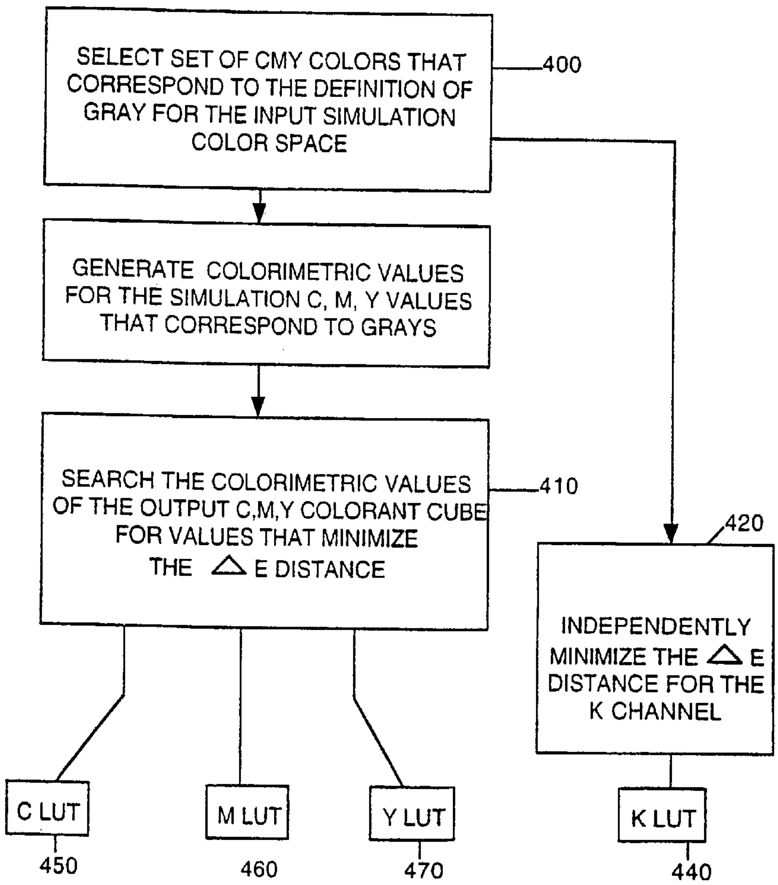
SELECT SET OF CMY COLORS THAT CORRESPOND TO THE DEFINITION OF GRAY FOR THE INPUT SIMULATION COLOR SPACE
400
GENERATE COLORIMETRIC VALUES FOR THE SIMULATION C, M, Y VALUES THAT CORRESPOND TO GRAYS
SEARCH THE COLORIMETRIC VALUES OF THE OUTPUT C,M,Y COLORANT CUBE FOR VALUES THAT MINIMIZE THE △E DISTANCE
410
420
INDEPENDENTLY MINIMIZE THE △E DISTANCE FOR THE K CHANNEL
C LUT
450
M LUT
460
Y LUT
470
K LUT
440

FIG. 4

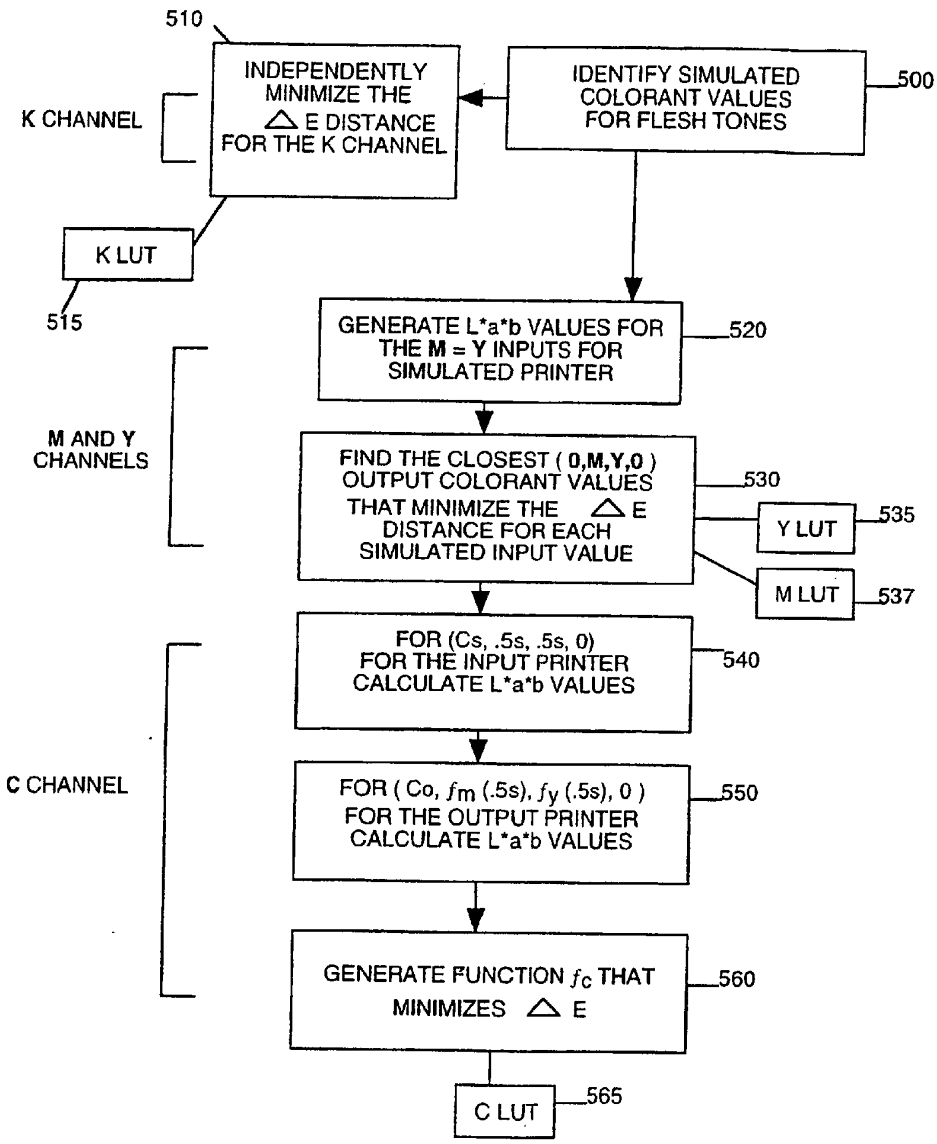
510
INDEPENDENTLY MINIMIZE THE △ E DISTANCE FOR THE K CHANNEL
IDENTIFY SIMULATED COLORANT VALUES FOR FLESH TONES
500
K CHANNEL
K LUT
515
GENERATE L*a*b VALUES FOR THE M = Y INPUTS FOR SIMULATED PRINTER
520
M AND Y CHANNELS
FIND THE CLOSEST (0,M,Y,0) OUTPUT COLORANT VALUES THAT MINIMIZE THE △ E DISTANCE FOR EACH SIMULATED INPUT VALUE
530
Y LUT
535
M LUT
537
FOR (Cs, .5s, .5s, 0) FOR THE INPUT PRINTER CALCULATE L*a*b VALUES
540
C CHANNEL
FOR (Co, fm (.5s), fy (.5s), 0) FOR THE OUTPUT PRINTER CALCULATE L*a*b VALUES
550
GENERATE FUNCTION fc THAT MINIMIZES △ E
560
C LUT
565

FIG. 5

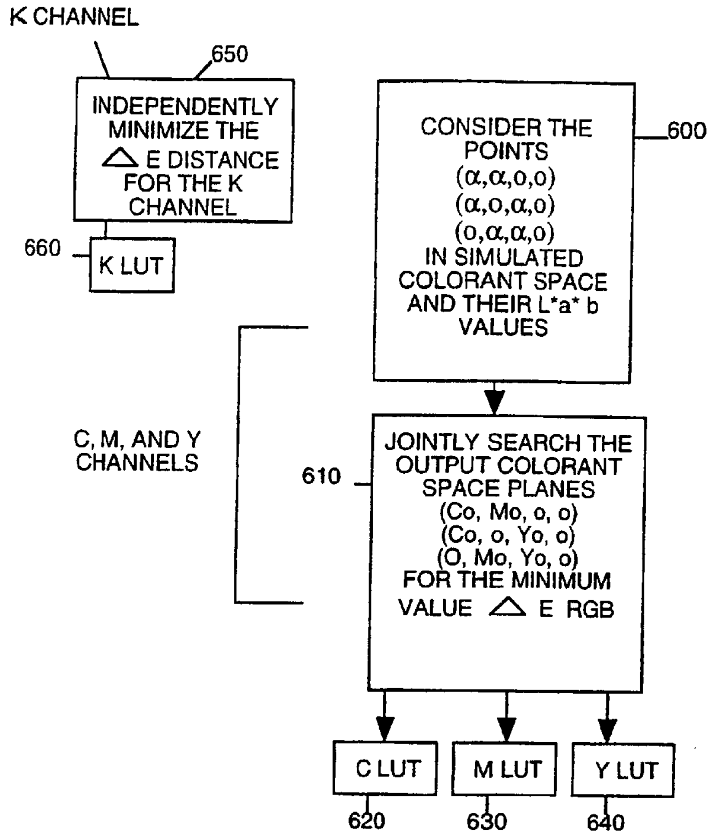
K CHANNEL
650
INDEPENDENTLY MINIMIZE THE △ E DISTANCE FOR THE K CHANNEL
660
K LUT
CONSIDER THE POINTS (α,α,o,o) (α,o,α,o) (o,α,α,o) IN SIMULATED COLORANT SPACE AND THEIR L*a* b VALUES
600
C, M, AND Y CHANNELS
610
JOINTLY SEARCH THE OUTPUT COLORANT SPACE PLANES (Co, Mo, o, o) (Co, o, Yo, o) (O, Mo, Yo, o) FOR THE MINIMUM VALUE △ E RGB
C LUT
M LUT
Y LUT
620
630
640

FIG. 6