Skin Image Synthesis Based on Pigment Concentration Distribution

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ABSTRACT

An image synthesis algorithm based on three dominant pigments is proposed in this paper to reproduce high fidelity skin image. Combined the Lambert Beer law with skin multiple layers structure, the mathematical relationship between skin pigments concentration and image pixel value is firstly introduced. To eliminate the influence of surface reflection component, the difference of each color channel in log space is applied to form 2D mixture signals. The ICA algorithm is then followed to obtain melanin and hemoglobin concentration distribution. Successively, carotene concentration distribution is given by linear regression. The three pigment concentration coefficients will dominate skin image synthesis. The experiments demonstrate the reproduced skin images based on change of pigment concentration coefficients. In addition, the comparisons with manual data show the effectiveness of proposed algorithm.

1. INTRODUCTION

Recently, e-cosmetic which used to simulate make-up by recomposing skin image becomes a noticeable research direction in field of skin image processing. Be different from traditional image processing software like Photoshop, e-cosmetic requires higher fidelity and has little tolerance to image composition artifact. Actually, color distribution of human skin image is limited because of

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multi-layer structure and optical properties of skin [1]. Therefore, recomposed skin images are always unacceptable when uneven color or texture is introduced. So far, there are two methods when it comes to e-cosmetic:

1) E-cosmetic based on traditional image features. The basic idea is recomposing skin image in pre-defined skin regions, like eyes, lip, eyelash etc., by applying either color transfer or texture synthesis algorithms [2-3]. In addition, make-up samples based algorithms are also developed [4-5].

2) E-cosmetic based on skin optical properties. The basic idea is founded on physiological structure and optical properties of human skin. Kim [6] et al. re-synthesized skin image by introducing skin reflection model. Tsumura [7] et al. creatively generated electronic make-up result by using skin pigment concentration. Similar researches [8] were then conducted.

In terms of fidelity, the second methods relatively give better results. However, only dominant pigments like melanin and hemoglobin are considered in existing algorithms and minor pigment like carotene is actually omitted. In addition, only subsurface reflection is involved. This paper builds complete relationship between skin appearance and various pigments by defining skin image as integral of surface reflection and surface reflection. And then simulate kinds of skin effect, like skin tanning, skin redness after drinking, after modifying concentration coefficient of different pigments.

2. SKIN IMAGE MODEL

Human skin is generally considered to be composed of three layers [11]: the epidermis (including the stratum corneum), the dermis, and subcutaneous fat tissue. Skin color is highly related to pigmentation. Most importantly, melanin in the epidermis and hemoglobin in the dermis play dominant roles in light
absorption. There are researchers who applied the Lambert-Beer law, which is broadly used in field of light absorption in liquid, to measure skin absorbance [7, 9]. The skin absorbance A can be expressed as a linear combination of dominant pigments, including melanin and hemoglobin:

$$A = V_m C_m + V_h C_h + V_c C_c + A_0$$  \hspace{1cm} (1)

Where $V=l\varepsilon$, $l$ and $\varepsilon$ denote skin thickness (more accurately mean path length of photons in the skin layer) and pigment extinction coefficient respectively. $m$, $h$ and $c$ represent melanin, hemoglobin and carotene respectively. $C$ denotes pigment concentration and $V_{mCm}$ means absorbance of melanin. Here, $A_0$ denotes human skin basic absorption. Meanwhile, we can use light transmittance to redefine Lambert-Beer law: $A = -\log (I_b / I)$. Here I means incident light and $I_b$ means transmitted light. Due to skin special structure and optical property, most incident light will penetrate into skin after arriving surface, except for small part of incident light is directly reflected, which is called surface reflection and represented as $I_s$. The penetrated light will be transmitted, absorbed and scattered in skin and finally return back to air (See Fig. 1) [1,10], which is called subsurface reflection and is represented as $I_b$. After combining Eq. (1), subsurface reflection can be represented as:

$$I_b = -I_s \exp (V_m C_m + V_h C_h + V_c C_c + A_0)$$  \hspace{1cm} (2)

Generally, digital image can be expressed as the integral of reflected light in the visible spectral. Since skin reflection is formed by both of surface reflection and subsurface reflection, we model pixel in image as linear combination of surface reflection and subsurface reflection as following:

$$P = \int s(\lambda) (I_b + I_s) d\lambda$$  \hspace{1cm} (3)

Where $s(\lambda)$ means CCD response function at wavelength $\lambda$. We can regard response function as pulse function [7, 12] because of its narrow band feature. Based on Eq.(2) and Eq.(3), pixel $P$ in channel $i$ ($i=R, G, B$) can be represented as:

$$P(i) - I_s(i) = -I(i) \exp \{V_m(i) C_m + V_h(i) C_h + V_c(i) C_c + A_0(i)\}$$  \hspace{1cm} (4)

Where $V(i)=l\varepsilon(i)$. Notice that pigments have completely different extinction coefficient in each channel [1, 13]. Eq. (4) shows the relationship between skin image pixel $P$ and skin pigment concentration $C$. 
3. PIGMENT CONCENTRATION DISTRIBUTION

Taking logarithm in both sides of Eq. (4) yields:

\[-\log \{ P(R) - I_s(R) \} = \log I(R) + A(R) \]  \hspace{1cm} (5.1) \]

\[-\log \{ P(G) - I_s(G) \} = \log I(G) + A(G) \]  \hspace{1cm} (5.2) \]

\[-\log \{ P(B) - I_s(B) \} = \log I(B) + A(B) \]  \hspace{1cm} (5.3) \]

Surface reflection \( I_s \) contributes little to pixel value in absence of highlight. In addition, we can assume the illumination as white light under normal environment. That means the intensity of each channel is equal and can be denoted by \( I(R) \approx I(G) \approx I(B) \). Since surface reflection actually shows intrinsic properties of illumination, we have \( I_s(R) \approx I_s(G) \approx I_s(B) \). Based on above assumption, we can obtain following equations after subtraction between Eq.(5.2) and Eq.(5.1), and subtraction between Eq.(5.3) and Eq.(5.1).

\[
\log \{ P(R) / P(G) \} = \Delta V_{m1} C_m + \Delta V_{h1} C_h + \Delta V_{c1} C_c \]  \hspace{1cm} (6.1) \\

Here, \( \Delta V_{m1} = V_m(G) - V_m(R) \), \( \Delta V_{m2} = V_m(B) - V_m(R) \), and so on. Eq. (6.1) and Eq. (6) can be treated as traditional problem of blind mixture separation. We then can obtain melanin and hemoglobin concentration \( C_m \) and \( C_h \) by applying ICA (Independent Component Analysis) algorithm. The pigment concentration can be visualized as Fig. 2.

Then we obtain mixture coefficients of pigment concentration after ICA algorithm. However, it is difficult to show contribution of carotene to the composed image, since the proportion of carotene in human skin is small. Giving image size \( N \), we have \( N \) linear equations like \( y = ax_1 + bx_2 + c \) according to Eq. (6.1) and Eq. (6.2). Here \( x_1 \) and \( x_2 \) denote \( C_m \) and \( C_h \) respectively. \( \Delta V_m \) and \( \Delta V_h \) in Eq.(6.1) and Eq. (6.2) are then obtained after applying linear regression, as well as \( \Delta V_c C_c \), which corresponds to carotene absorbance component.

![Figure 2. Pigment concentration visualization. (Left)Original image (Image courtesy of L’Oreal). (Middle) Melanin concentration visualization. (Right). Hemoglobin concentration visualization.](image-url)
4. EXPERIMENTS

Modification of pigment concentration will lead to change of skin absorbance, and eventually lead to change of skin color. Therefore, we generate various realistic skin images according to modifying skin pigments concentration. Based on Eq. (6.1) and Eq. (6.2), new skin image can be composed by redefining each channel:

\[
\text{newR} = P(R) \\
\text{newG} = -\exp\left\{\Delta V_m k_1 C_m + \Delta V_h k_2 C_h + \Delta V_c k_3 C_c\right\} * P(R) \\
\text{newB} = -\exp\left\{\Delta V_m k_1 C_m + \Delta V_h k_2 C_h + \Delta V_c k_3 C_c\right\} * P(R)
\]

(7)

Where \(k_1, k_2\) and \(k_3\) mean quantities of melanin, hemoglobin and carotene. Fig. 3 shows recomposed skin images based on different pigment concentration. We can see that lip and red spots in face are obviously redden after increasing hemoglobin, while more paler after decreasing it. Similarly, change of melanin or carotene lead to darker or yellower face.

To better show the affectivity of proposed algorithm, synthesized images and man-made images are compared in Fig.4. The original images and man-made images are both copied from research article (http://phys.org/news/2011-01-greens.html). The man-made images simulate results of skin tanning and increase of carotene in skin. We then generate similar images by synthesizing skin image using different pigment concentration distribution. To simulate skin tannin, hemoglobin concentration coefficient \(k_2\) is decreased, meanwhile melanin concentration coefficient \(k_1\) is increased. To simulate possible appearance of increasing carotene, both hemoglobin and carotene concentration
coefficient $k_2, k_3$ are increasing. Fig. 4 demonstrates that synthesized images show great consistency with man-made images.

5 CONCLUSIONS

This paper proposed a new method to re-synthesize skin image based on dominant pigments (like melanin, hemoglobin and carotene) in human skin, to simulate various skin like tanning, drinking. As three main pigments in human skin, melanin, hemoglobin and carotene actually dominant skin color in terms of darkness, redness and yellowness. Modifying each pigment concentration will lead to change of skin color and create realistic new skin image. We can also edit skin image only in local region (like lip) of interest. However, the proposed algorithm will fail under non-white illumination, which means uneven intensity of each channel. In the future, we would like to focus on estimating illumination chromaticity to build skin pigment model under arbitrary illumination.
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