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Skin Colour Imaging That Is Insensitive to Lighting Conditions

Lilong SHI and Brian FUNT
School of Computing Science, Simon Fraser University, Canada

ABSTRACT

In previous human skin models, it has been suggested that the colour of human skin is mostly determined by the concentration of melanin in the epidermal layer combined with the concentration of hemoglobin in the dermal layer. The colour of facial skin changes significantly with changes in the light incident upon it. In this paper we propose a method of normalizing the skin tones of human faces that eliminates the effects of illumination, preserving the skin colour and allowing variations related to melanin concentration only. The method assumes the illumination is reasonably well modelled as blackbody radiation.

1. INTRODUCTION

The factors affecting facial skin colour have been previously studied in the context of image rendering in computer graphics, face detection and tracking in computer vision, diagnosis in dermatology, and makeup and skin care in cosmetics. Skin colour is the most discriminative of skin attributes and depends on the skin's pigmentation, blood microcirculation, roughness, sebum, and perspiration, as discussed by Barel et. al (2003). Efforts in correcting skin colours under different lighting conditions have been made by Soriano et al. (1999) and Marguier et al. (2007). In previous human skin models, such as Shimada et al. (2001), it has been suggested that the colour of human skin is mostly determined by the concentration of melanin in the epidermal layer combined with the concentration of hemoglobin in the dermal layer. The change of melanin concentration in skin (e.g., caused by exposure to UV) happens more slowly than the change of blood content (e.g., after bathing). However, even for fixed melanin and hemoglobin concentrations, skin colour can change significantly and quickly as the lighting conditions change. Our study has shown that the changes in skin colour induced by changes in illumination colour are much larger than those due to biological factors.

Using measurements of the spectral reflectance of human skin from different ethnic groups, we use independent component analysis (ICA) to extract two independent colour components of skin--- the melanin component and the hemoglobin component--- such that all skin chromaticities can be represented as a linear combination of the two components in log-chromaticity space as discussed by Shimada et al. (2001) and Tsumura et al. (1999). In these coordinates, it becomes clear that the axis of change in skin colour caused by the hemoglobin concentration is almost the same as that of blackbody radiators of varying colour temperature. As a result, it is difficult to analyze whether the redness of skin in an image is the result of high hemoglobin concentration versus light of low colour temperature. On the other hand, the axis of skin colour variation caused by changing melanin concentration is at a very different orientation from the axis of illumination change. This suggests that chromaticities of skin along the melanin axis will be approximately invariant to illumination change. Therefore, the skin colour appearing in an image captured under a light of unknown colour temperature can be normalized to what it would be under a standardized light by shifting its chromaticity along the illumination direction to the projection point on the melanin axis. Since the

projection point is determined by the melanin concentration alone, not the light's colour temperature, the shifted skin chromaticity is illumination insensitive. If the skin pixels within an image can be identified, using the Viola-Jones face detector by Viola and Jones (2001) for instance, then the proposed colour correction can be applied to the identified skin pixels, as well as the entire image.

2. THE SKIN-ILLUMINATION MODEL

Previous research by Finlayson and Schaefer (1999) has shown that, given narrowband sensors, blackbody radiation models not only the spectra of direct sunlight and tungsten light bulbs, but also that of common daylight conditions. The camera's response to blackbody illumination by Wien's approximation assuming narrowband sensors can be expressed as,

$$P_i \approx S(\lambda_i) I c_1 \lambda_i^{-5} e^{-\frac{c_2}{T\lambda_i}}, \qquad i = \{R, G, B\}, \tag{1}$$

where λ_i 's are the wavelengths at which the sensitivities are concentrated; I is the power of radiation of the illumination; T is the blackbody radiator temperature, the constants c_1 and c_2 are $3.74183*10^{-16}\mathrm{Wm}^2$ and $1.4388*10^{-2}\mathrm{mK}$, respectively. The reflection spectrum, S, of arbitrary skin can be expressed as in Hiraoka et al. (1993):

$$S(\lambda) = \exp[-\rho_m \alpha_m(\lambda) l_m(\lambda) - \rho_h \alpha_h(\lambda) l_h(\lambda) - \xi(\lambda)] \tag{2}$$

Here, for a compound skin, ρ_m, ρ_h and $\alpha_m(\lambda)$, $\alpha_h(\lambda)$ are the pigment densities and spectral cross-sections of absorbance of melanin and hemoglobin respectively. $l_m(\lambda)$ and $l_h(\lambda)$ are the mean path lengths of photons in the epidermis and dermis layers. $\xi(\lambda)$ stands for the scattering loss and the absorbance of chromophores other than melanin and hemoglobin. It is reasonable to consider $\xi(\lambda)$ as a constant because it is essentially independent of ρ_m and ρ_h. Therefore, using the two spectral absorptions of melanin and hemoglobin, it is possible to model the skin spectral reflectance for any melanin concentration. The colour bases of melanin and hemoglobin for skin can be found via Independent Component Analysis of skin reflectance data as used in Tsumura et al. (2000).

This multiplicative illumination-reflectance model can be simply treated additively in log colour space. Combining the logarithms of Equation (1) and (2), we obtain the following equation:

$$\log(P_i) \approx -\rho_m \alpha_m(\lambda_i) l_m(\lambda_i) - \rho_h \alpha_h(\lambda_i) l_h(\lambda_i) - \xi(\lambda_i) - \frac{c_2}{\lambda_i}(T)^{-1} + \log(I) + [\log(c_1) + 5\log(\lambda_i)]. \tag{3}$$

Let $\mathbf{\Pi}$ represent the camera signals from the RGB channels, based on Equation (3),

$$\mathbf{\Pi}(\rho_m, \rho_h, \tau, b) \approx \rho_m \boldsymbol{\sigma}_m + \rho_h \boldsymbol{\sigma}_h + \tau \boldsymbol{\omega} + b\mathbf{1} + \mathbf{c}, \tag{4}$$

where $\mathbf{\Pi} = [\log(P_R), \log(P_G), \log(P_B)]^t$,

$\boldsymbol{\sigma}_m = [\alpha_m(\lambda_R) l_m(\lambda_R),\ \alpha_m(\lambda_G) l_m(\lambda_G), \alpha_m(\lambda_B) l_m(\lambda_B)]^t$,

$\boldsymbol{\sigma}_h = [\alpha_h(\lambda_R) l_h(\lambda_R),\ \alpha_h(\lambda_G) l_h(\lambda_G), \alpha_h(\lambda_B) l_h(\lambda_B)]^t$,

$$\boldsymbol{\omega} = [\frac{c_2}{\lambda_R}, \frac{c_2}{\lambda_G}, \frac{c_2}{\lambda_B}]^t,$$

$$\mathbf{c} = [5\log(\lambda_R) - \xi(\lambda_R), 5\log(\lambda_G) - \xi(\lambda_G), 5\log(\lambda_B) - \xi(\lambda_B)]^t,$$

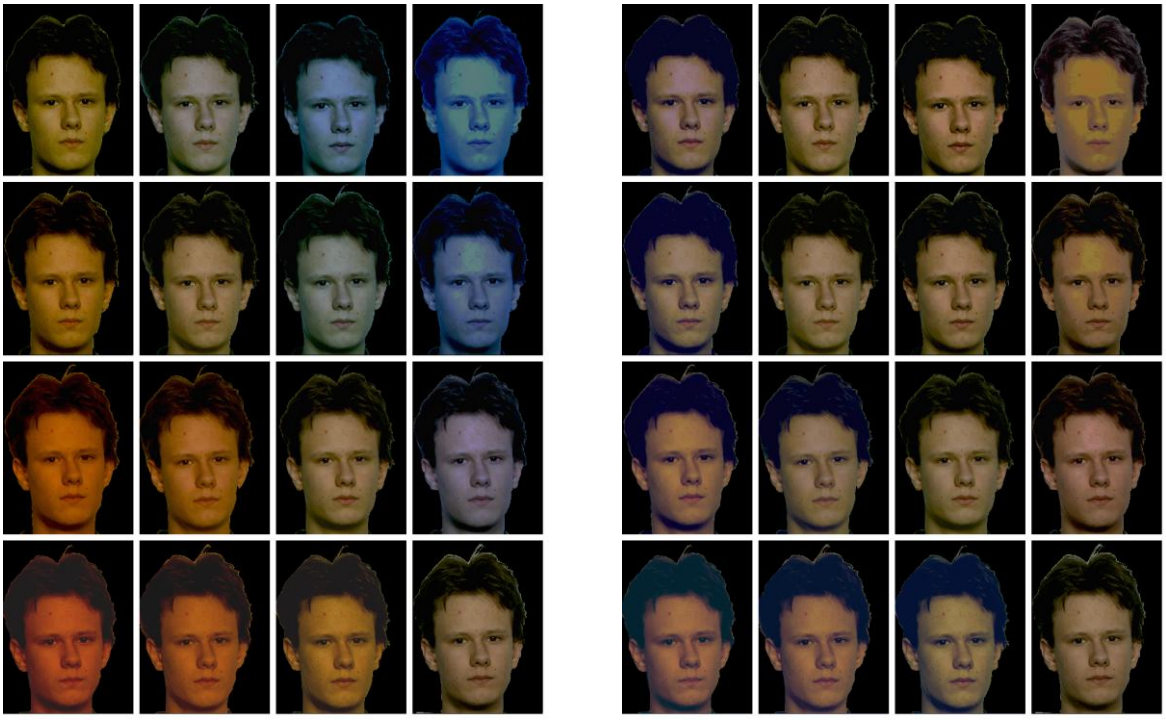
and $b = \log(I)$, $\tau = 1/T$.

The observed signal $\boldsymbol{\Pi}$ therefore is represented by the weighted linear combination of the four vectors $\boldsymbol{\sigma}_m, \boldsymbol{\sigma}_h, \boldsymbol{\omega}$ and $\mathbf{1}$ plus a bias term $\mathbf{c}$. These vectors correspond to the melanin, hemoglobin, the illumination chromaticity and the illumination brightness axis, respectively. The melanin and hemoglobin concentration, the blackbody temperature, and the intensity only vary along these four directions. The variable τ is the inverse of the temperature T and is measured in mired ($10^6 K^{-1}$). The vectors $\boldsymbol{\omega}$ and $\mathbf{c}$ are sensor dependent and therefore stay constant for a given camera.

Our proposed skin model based on simplifying Equation (4) for varying illumination colour temperature and melanin concentration is

$$\boldsymbol{\Pi}(\rho_m, \tau) \approx \rho_m \boldsymbol{\sigma}_m + \tau \boldsymbol{\omega} \ , \tag{5}$$

Here, the hemoglobin term in Equation (4) is dropped because the hemoglobin axis almost coincides with the illumination axis $\boldsymbol{\omega}$, both varying in the red-white-blue direction. Also, the brightness term is eliminated by intensity normalization. Equation (5) indicates that the melanin basis, $\boldsymbol{\sigma}_m$, and the blackbody illumination basis, $\boldsymbol{\omega}$, span the chromaticity space of arbitrary skin under different illuminations. It describes the skin-illumination model that we use in this paper.



(a) (b)

Figure 1. Results based on an individual (no. 96) in the UOPB database. (a) a series of 16 face images under different camera calibration and illumination conditions. (faces segmented from the background) (b) the same images with corrected skin tones based on our model.

3. EXPERIMENTS

The method is tested using the University of Oulu Physics-Based(UOPB) Face Database provided by Marszalec et al. (2000), which contains 357 measured spectra of human faces of 119 individuals of different races. In addition, this database contains images of 125 different individuals. An image series for one person contains 16 frontal views, each of which is captured under a different combined illuminant and camera calibration condition. An instance is shown in Figure 1(a). In our experiment, skin pixels in each linearized image are manually selected. Potentially, a face detector could be used for automated selection. The average of all pixels of skin is translated to a point on the estimated melanin axis, along the blackbody axis. The estimated melanin point is also shifted along the melanin axis until it is within the melanin range of this specific database if it is not (e.g., due to non-blackbody radiation illumination, camera overflow, etc). The overall translation is then applied to the entire image. As illustrated in Figure 1(b), the corrected images show that the skin tones of the face in the image are invariant to illumination change.

4. CONCLUSION

In summary, we present a simple and computationally inexpensive method that normalizes skin tones to be invariant to illumination change. The normalization is accomplished by shifting the colour of the entire image so that skin pixels lie on the pre-defined melanin axis.

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Address: Lilong Shi, School of Computing Science,
Simon Fraser University, 8888 University Dr., Burnaby, British Columbia, Canada
E-mails: lshia(a)cs.sfu.ca, funt(a)cs.sfu.ca