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Estimation Concentration of Pigment Component from Lip Image Using Light Scattering Analysis

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Abstract

In this study, we propose a method to estimate the concentration of components of lips from RGB lip images. The lips are an essential part of the body, as their shape and color determine a person's facial expression, age, health status, and other aspects of their impression. Therefore, the lips have been of interest in cosmetology, psychology, and medicine as the subject of much research. However, only a few studies measure lip components noninvasively or analyze them histologically. Therefore, our goal is to measure the components of the lips noninvasively. We build a model for each of the vermillion regions and mucosa regions of the lip and the skin regions and discuss the differences in the concentration of the components. The results showed differences in the melanin concentration and blood volume in the skin, vermillion, and mucosa regions.

Introduction

When diseases or injuries occur on the lips, they are treated in dermatology or cosmetic dermatology. Also, preventing mild diseases and injuries is generally treated with lip balm, other medicines, and make-up products. When treating these conditions, it is necessary first to identify the illness or injuries. When treating dermatology and cosmetic dermatology patients, doctors mainly use visual examination and palpation to diagnose them. However, these diagnostic methods are subjective. Therefore, objective and quantitative diagnostic techniques for the cause of the disease or injuries are desirable.

Several studies estimate the pigment components of normal skin. Tsumura et al. proposed a method to obtain the concentration of melanin and hemoglobin components by applying independent component analysis to internal reflectance images of skin [1]. Iuchi et al. proposed a method for nonlinearly estimating the concentration of pigment components by using Monte Carlo Modeling of Light Transport in Multi-layered Tissues (MCML) and functionalizing the nonlinear relationship between skin absorbance and pigment concentration [2]. MCML was proposed by Jacques S. L. et al. [3]. This is a method for obtaining spectral reflectance by injecting photons into the generated skin model on the computer and tracking their attenuation due to absorption and scattering. Fig. 1 shows a conceptual diagram of MCML.

On the other hand, there have not been many reports on histological analysis of lips, and there have not been many studies on concentration estimation. Since the thickness of the epidermis and dermis of the lips differs from that of other skin layers, it is impossible to use a skin model directly. Therefore, estimating lip pigment concentration would contribute to cosmetology, medicine, and biometrics. In this study, we propose a method to estimate the concentration of pigment components of lips from RGB lip images by constructing a lips model and using a dataset created by MCML.

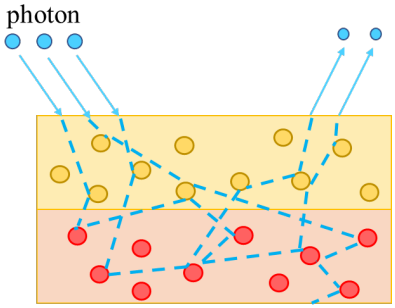


Figure 1. *A conceptual diagram of MCML*

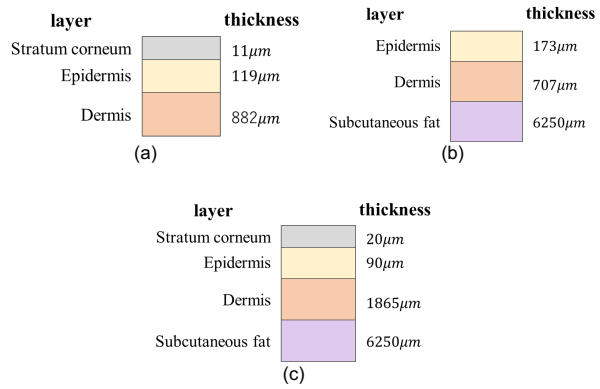


Figure 2. *Two lip models and a skin model : (a)* Vermillion region, (b) Mucosa region, (c) Skin region

We produced models of the lips in three regions: the vermillion region, the mucosa region, and the skin region, and discussed the differences in the concentration of melanin and hemoglobin components in each of these regions. Furthermore, we verify the effectiveness of this method for them.

Proposed Method

The method for estimating the concentration of pigment components is as follows. First, we create the models for MCML, and the pigment component and their concentration of them are determined. Next, we calculate the spectral reflectance of the model by performing MCML on the created model, and RGB values are obtained based on it. Then look-up tables are made based on the pigment component, its concentration, and the pattern of its RGB values. Finally, we estimate the concentration by comparing look-up tables with the RGB values of the captured images.

Setting Model

It is necessary to define the absorbing and scattering layers of the target to perform a light-scattering Monte Carlo simulation

(MCML). We present a layered lip model corresponding to the lip structure as absorbing and scattering layers. In this study, three types of models are created: a vermillion region commonly called a lip, a mucosa region inside the lip, and a general skin region [2][4]. The created models are shown in Fig. 2, respectively.

For each layer, the five optical parameters are set: thickness t, refractive index n, anisotropy factor g, scattering coefficient μ_s, and absorption coefficient μ_a. t was set as shown in Fig.2 for each layer in each region[2][4]. n was set to 1.5 for the stratum corneum, 1.34 for the epidermis, 1.4 for the dermis, and 1.44 for the subcutaneous fat. g and μ_s were selected to the values shown in Fig.3[5]. The melanin was assumed to be present in the epidermis and blood in the dermis. Therefore, the absorption coefficient μ_a expressed by the absorption coefficients of melanin, oxy-hemoglobin, and deoxy-hemoglobin. This study calculates the absorption coefficients as in Eq. (1).

$$\mu_{a.epi}(\lambda) = Mel \times \mu_{a.mel}(\lambda)$$
$$\mu_{a.der}(\lambda) = Ohb \times \mu_{a.ohb}(\lambda) + Hb \times \mu_{a.hb}(\lambda) \quad (1)$$

Where λ is the wavelength. The subscript of *epi* and *der* represents the epidermis and dermis. The *mel*, *ohb*, and *hb* subscript represent the melanin, deoxy-hemoglobin, and oxy-hemoglobin, respectively. *Mel*, *Ohb,* and *Hb* represent the concentration of melanin, oxy-hemoglobin, and deoxy-hemoglobin in the model layers. The respective absorption coefficients are shown in Fig.4[6]. The blood volume is calculated by the sum of oxy-hemoglobin volume [*Ohb*] and deoxy-hemoglobin volume [*Hb*]. Oxygen saturation *StO* defines the ratio of oxy-hemoglobin to deoxy-hemoglobin. The equation for oxygen saturation is shown in Eq. (2). In this study, oxygen saturation was set to 80%, melanin concentration ranged from 0.01% to 10%, and blood volume ranged from 0.1% to 20% in all models. The total number of combinations is 812 per model.

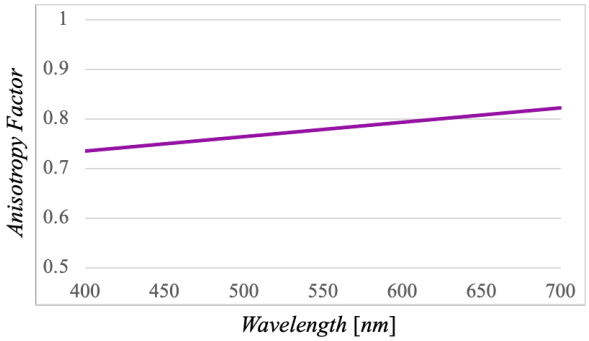
$$StO = \frac{[Ohb]}{[Ohb] + [Hb]} \quad (2)$$

Calculating the Spectral Reflectance and Creating the Look-up Tables

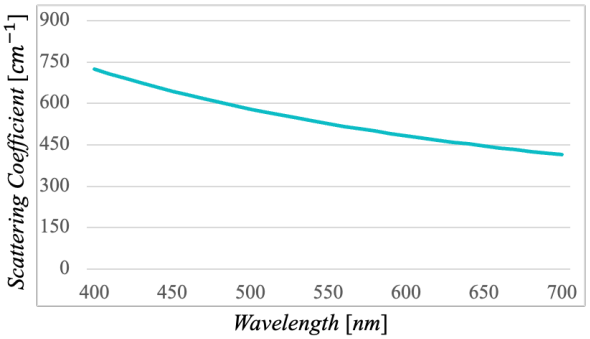
The three models and parameters created are input into MCML to calculate the spectral reflectance. As a result, 812 spectral reflectance combinations can be obtained for each model. After acquiring the spectral reflectance, convert the spectral reflectance to RGB values using the following Eq. (3).

$$R = \int_{400}^{700} R(\lambda)P(\lambda)\bar{r}(\lambda)\,d\lambda$$
$$G = \int_{400}^{700} R(\lambda)P(\lambda)\bar{g}(\lambda)\,d\lambda \quad (3)$$
$$B = \int_{400}^{700} R(\lambda)P(\lambda)\bar{b}(\lambda)\,d\lambda$$

Where $R(\lambda)$ is the spectral reflectance, $P(\lambda)$ is the spectral distribution of the light source, and $\bar{r}(\lambda)$, $\bar{g}(\lambda)$, and $\bar{b}(\lambda)$ are the spectral sensitivity of the camera. Then, RGB values can be calculated for three models and combinations of concentration.

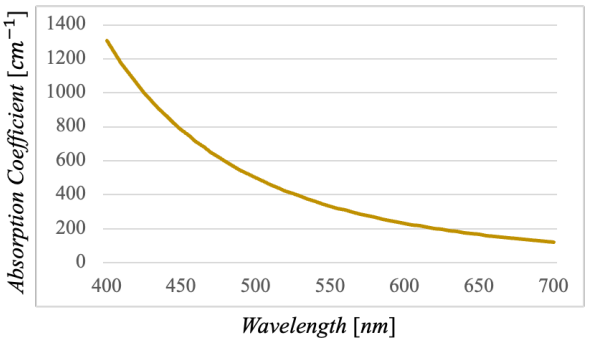


(a)

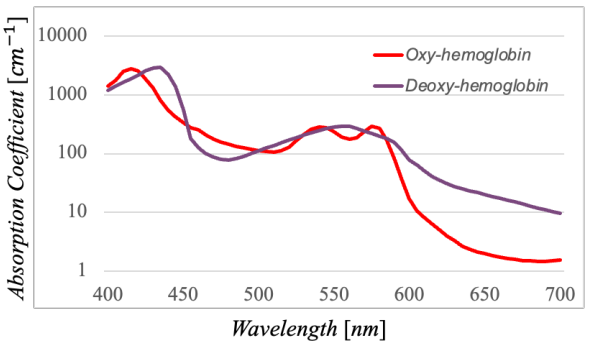


(b)

Figure 3. *Scattering parameters: (a)* Anisotropy factor g, (b) Scattering coefficient μ_s



(a)



(b)

Figure 4. *Absorption coefficients: (a) Melanin, (b) Oxy-hemoglobin and deoxy-hemoglobin [6]*

Next, the look-up tables are created for each of the three models. We can estimate the concentration of the actual image from the relationship between the calculated RGB values and concentration, but the actual image will have shading because of illumination. Therefore, we defined the shading as the image's brightness, and the RGB values' brightness is varied, as shown in Eq. (4).

$$\begin{aligned} R' &= R \times (1 - S/100) \\ G' &= G \times (1 - S/100) \\ B' &= B \times (1 - S/100) \end{aligned} \quad (4)$$

Where S represents the additional shading component. We added that in 5% steps in the range of 5~95%. Table.1 shows a part of the look-up table created. The combination of melanin concentration, blood volume, shading, and RGB values are displayed.

Table 1. Part of the look-up table in the vermillion region

Melanin	Blood	Shading	R	G	B
0.1	13	15	122	89	69
0.1	13	20	114	84	65
0.1	13	25	107	79	61
0.1	13	30	100	74	57

Estimation of Pigment Concentration and Shading from Captured Images

We crop the estimated area of the lip image to 30 × 30 pixels and find the closest RGB value in the look-up table for each pixel using Euclidean distance in the RGB coordinate. The melanin concentration, blood volume, and shading with that RGB value are estimated as the concentration of components in that pixel.

Subject Experiment

Acquisition of Actual Images

The experimental environment is shown in Fig.5. The camera used to acquire images is DFK33UP1300 (The Imaging Source, Bremen, Germany). We set the resolution to 1280 × 960 pixels. The light source we used is SOLAX XC-500 (SERIC, Tokyo, Japan).

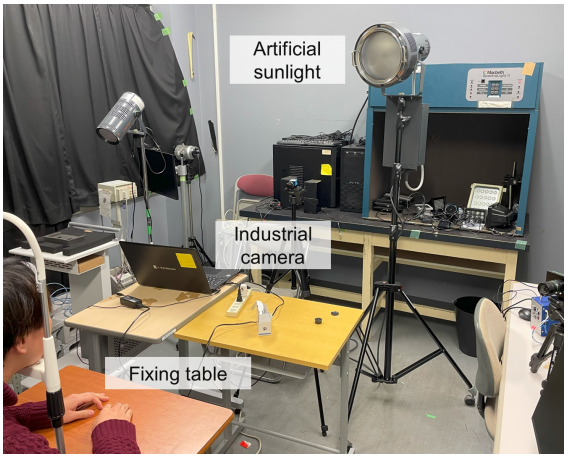


Figure 5. *Experimental environment*

Experimental Procedure

We took three images per subject: The first is an image of the vermillion lip, the second is an image of the mucosa, and the third is an image of the lower lip pressed with a finger for 5 seconds and immediately after the finger was removed to change the blood volume in the vermillion lip. We took the images of four male subjects in their 20s. The captured images and the trimming areas are shown in Fig. 6.

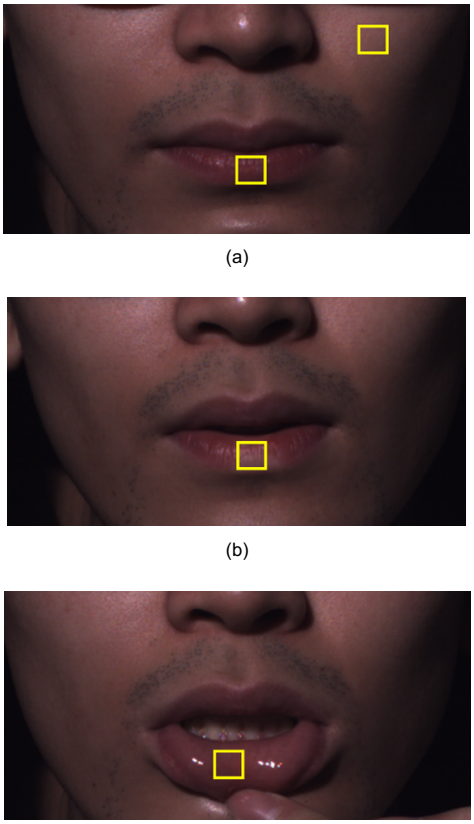


Figure 6. *The captured images and trimming area: (a) the vermillion and skin region, (b) the vermillion region after blood volume change, (c) the mucosa region*

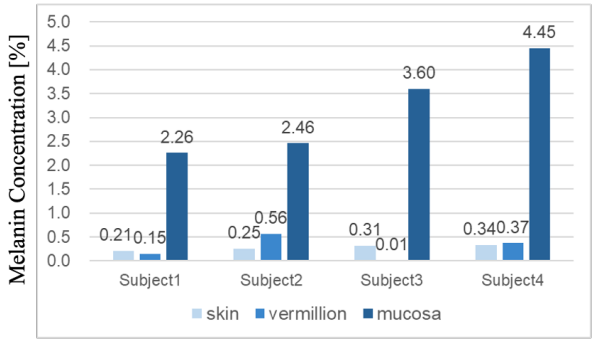
Result and Discussion

The estimation results of melanin concentration and blood volume in the skin, vermillion, and mucosa regions are shown in Fig.7, respectively. That shows the average melanin concentration and blood volume values for the four subjects within the trimming area. Fig.8 shows the trimmed images of Subject1, and Fig.9 shows the one of Subject2 before and after changing the blood volume. Fig.10 and Fig.11 show the melanin concentration and blood volume before and after the blood volume change in the vermillion region for Subject 1 and Subject 2. This figure shows the concentration in 30 × 30 pixels with coloring.

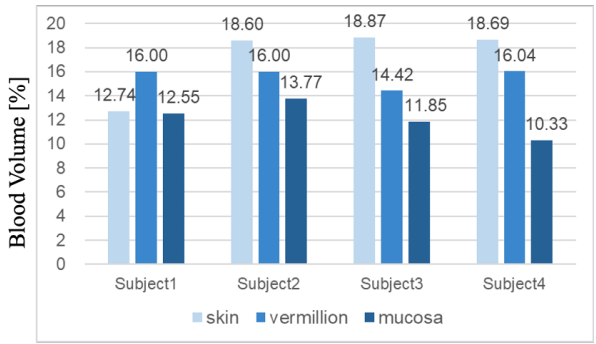
The estimated melanin concentrations in the skin and vermillion regions were not significantly different, but the mucosa region had a higher concentration than the other two regions. The results show a change in blood volume for Subject 1, as shown in Fig. 10. However, as shown in Fig. 11, this could not be confirmed for Subjects 2 through 4. One of the causes of these results is that the blood volume is estimated as a change in

melanin concentration instead of a change in blood volume because the model we constructed was unsuitable.

It is known that the thickness of each layer in the lips varies with age [7]. Therefore, it is necessary to determine each layer's thickness according to the subject's age. There is also a possibility that we set a small number of parameters or that it needed to be more accurate in the range of the concentration set.



(a)

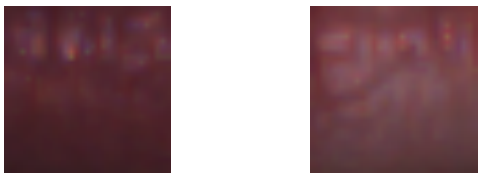


(b)

Figure 7. *The results of the comparison of melanin concentration and blood volume: (a) melanin concentration, (b) blood volume*

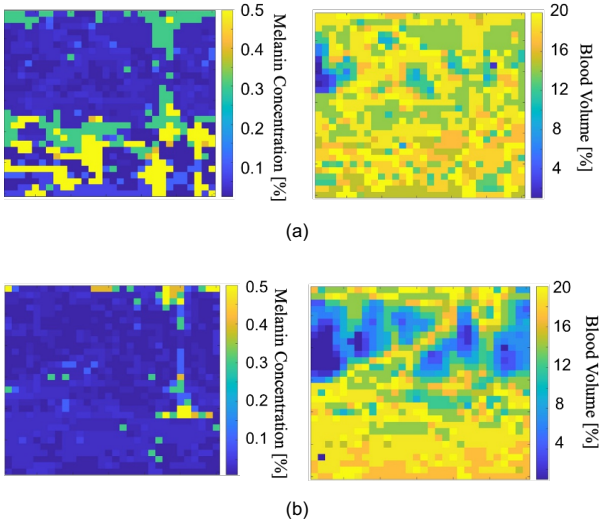
(a) (b)

Figure 8. *The trimmed image of Subject1: (a) before the change, (b) after the change*



(a) (b)

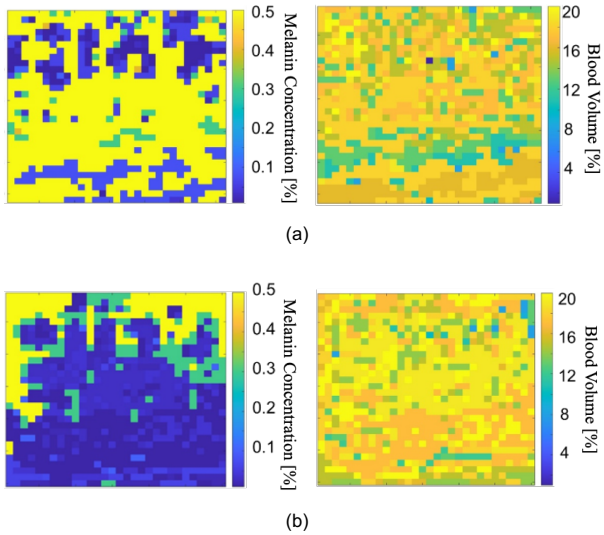
Figure 9. *The trimmed image of Subject2: (a) before the change, (b) after the change*



(a)

(b)

Figure 10. *The results of Subject1: (a) before the change, (b) after the change*



(a)

(b)

Figure 11. *The results of Subject2: (a) before the change, (b) after the change*

Conclusion

In this paper, we propose a method for estimating melanin concentration, blood volume, and shading in skin and lips and verify the estimation accuracy of the proposed method. The results showed differences in the melanin concentration and the blood volume in the skin regions, the vermillion regions, and the mucosa regions. However, we could not estimate some subjects before and after changes in blood volume, which suggests that the method's accuracy needs to be improved.

As a future work, the thickness of the layer structure in the skin regions, the vermillion regions, and the mucosa regions should be changed according to the age of the subject to be estimated, and the range of the concentration parameter should be increased. This research aims to apply this method, or an improved version, to the fields of medicine, cosmetology, and anatomy. Therefore, it would be ideal to estimate the concentration of components by using an ordinary camera in the future.

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Author Biography

Ryosuke Imai received his BS in engineering from the University of Chiba (2023).