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YOSHIKAWA, H. / TOYODA, N. / KIJIMA, A. / FUKUOKA, M. / KOBAYASHI, K. / WATANABE, K.

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A study of estimation of foundation-applied skin color

K. Kobayashi *, A. Kijima*, K. Watanabe*, M. Fukuoka**, N. Toyoda**, H. Yoshikawa**

Selection of suitable foundation is annoying matter for the user. Because there is a difference between the material color that we sense by looking at the foundation in a case and the color of the foundation applied on the skin, it is hard to predict the resultant color without actually applying it. In this paper, we propose a new method to predict a foundation -applied skin color based on the spectr al reflectance of the skin and the skin texture from captured skin images. The spectral reflectance of the skin is used to estimate anisotropic physical properties of the skin. The texture of skin is analyzed based on the image of the skin by using an image processing technique. The SVD based (Singular value decomposition) back propagation artificial neural network is trained to estimate the foundation-applied skin color.

Key Words *: Singular value decomposition, foundatio n, skin color, cosmetics*

1. INTRODUCTION

When applying cosmetic foundation to the skin, serious care is needed to determine whether the material color suits the user's own skin color. Because of the difference between the material color that we sense by looking at the foundation in a package and the color of the foundation as applied on the skin, it is hard to predict the resultant color without actually applying it. In order to predict the applied skin color of foundation before applying it, we need take into account the effect of skin optics as well as types of foundations.

Current commercially available foundations can be classified into two types of foundations: liquid type and powder type.

For liquid type foundations, it is relatively easy to predict the resultant applied skin color because the skin color can be determined by the skin optics involving the solution of the integro-differential equation of radioactive transfer in a model representing skin geometry. One well known method for predicting foundation-applied skin color is based on the Kubelka-Munk theory of scattering and absorption within inhomogeneous materials and the physics pertaining to the material's color properties. Based on this theory, a foundation-applied skin spectral reflectance prediction method has been proposed [1].

In contrast, the applied color of the powder type foundation is relatively difficult to determine because the Kubelka-Munk theory cannot be straightforwardly applied. In order to estimate resultant skin color, we need take into account the skin condition and the thickness of the powdery foundation on the skin.

However, it is very difficult to measure the thickness of the foundations as well as to evaluate skin conditions. Instead of measuring the thickness of the foundation and the skin condition, we introduce a new parameter termed the "Foundation Ratio" (FR). The optimal Foundation Ratio is determined by the resultant applied skin color by the SHISEIDO skilled beauty adviser.

In order to implement the ability of the SISEIDO skilled beauty adviser to estimate the resultant applied skin color before applying it, we use a SVD-based artificial neural network that utilizes skin spectral reflectance and skin texture as measured by a spectrophotometer and CCD microscope, respectively.

Using thirty-six times two (left and right side of cheeks) of spectral reflectance of the skin on the face with and/or without foundation and the skin textures are measured for the applied skin color analysis. Note that we apply different foundation color at left and right side, one side is beauty adviser's first recommendation color and, the other side is second choice.

To calculate the optimal Foundation Ratio, multiple regression parameter estimation methods are applied. For calculation, we use a SVD-based data compression technique to reduce the parameters for the estimation as well as to avoid multi-collinearity of the multiple regression parameters. According to the results obtained from SVD, we can compress 31 points of spectral reflectance to 6 points of orthogonal components that can reconstruct the spectral reflectance of the skin at 99% accuracy. Using the skin image captured from the CCD microscope, we find through the cross correlation analysis that three skin texture-related parameters are significantly related to the Foundation Ratio.

By using the above results, we trained an artificial neural network using SVD-based compressed orthogonal parameters, three parameters from the CCD microscope image, and the Foundation Ratio, which is determined by the beauty advisor's recommendation results. By using a trained SVD-based artificial neural network, 85% of the foundation-applied skin color within a 3-color difference in L*a*b* color space can be achieved.

2. PROBLEM DESCRIPTIONS

In order to accurately predict foundation-applied skin color, we need to know what factors play roles in creating skin color. Foundation-applied skin color can be determined by

(1) the skin's original color,
(2) the color of the foundation,
(3) the skin condition, and
(4) the thickness of the foundation on the applied skin.

The colors of (1) and (2) can be easily measured using a spectrophotometer under standard calibrated luminance. (3) is difficult to measure, though we can infer the condition based on the skin image obtained by using CCD microscope.

However, (4), the thickness of the foundation on the skin, is very difficult to measure. Thus, instead of measuring the thickness of the foundation on the skin, we introduce a new parameter we call the "Foundation Ratio".

The idea is as follows: the skin's actual color can be observed when no foundation is applied. By applying foundation, the skin takes on the color of the foundation. If we apply foundation at an appropriate thickness to bare skin, the skin will shows the intermediate skin color between bare skin and the foundation.

* Dept. of System Engineering, Faculty of Engineering
** Institute of Beauty Sciences SHISEIDO CO.,LTD.

In order to calculate this proposed new parameter ("Foundation Ratio"), we consider following problems:

(P1) How to calculate the "Foundation Ratio" and

(P2) How to estimate the foundation-applied color before applying the foundation.

3. DEFINITION THE FOUNDATION RATIO

Fig. 1 shows the typical relation between skin, applied skin, and the foundation color, all of which are measured by the spectrometer. The foundation ratio is determined by color of the bare skin, the foundation color, and the foundation-applied color of the skin. In order to derive the Foundation ratio, we define following variables:

λ_i : Wavelength,

a_j : Reflection ratio of the foundation,

$f(\lambda_i)$: Intensity of the reflection of the foundation at wavelength λ_i,

$s_j(\lambda_i)$: Intensity of the reflection of the bare skin at wavelength λ_i,

$t_j(\lambda_i)$: Intensity of the reflection of the foundation-applied skin at wavelength λ_i.

i denotes the respective wavelengths and j denotes the respective samples.

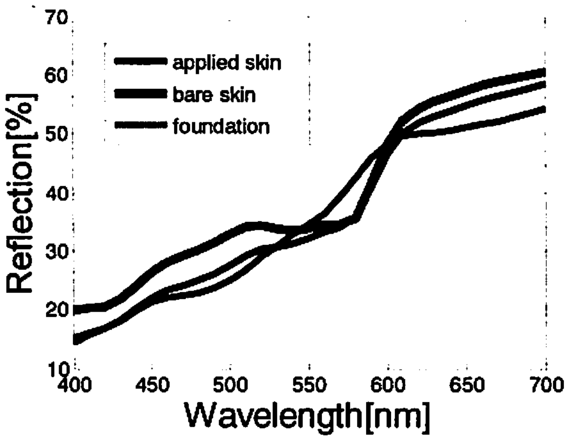

Fig. 1 Typical relation between applied skin, bare skin, and the foundation of reflectance of wavelength.

Define vectors as

$$\mathbf{f}_k = [f_k(\lambda_1) \quad f_k(\lambda_2) \quad \cdots \quad f_k(\lambda_{31})]^T \quad (1)$$

$$\mathbf{s}_j = [s_j(\lambda_1) \quad s_j(\lambda_2) \quad \cdots \quad s_j(\lambda_{31})]^T \quad (2)$$

$$\mathbf{t}_{k,j} = [t_{k,j}(\lambda_1) \quad t_{k,j}(\lambda_2) \quad \cdots \quad t_{k,j}(\lambda_{31})]^T \quad (3)$$

The ratio of effect of the foundation depends on the condition of the skin. Thus, we use the following formula to estimate the foundation ratio by using a linear relationship.

$$\mathbf{t}_{k,j} = a_{k,j} \cdot \mathbf{s}_j + b_{k,j} \cdot \mathbf{f}_k \qquad (4)$$

By using the multiple least square methods, we obtain following equation:

$$\begin{bmatrix} a_{k,j} \\ b_{k,j} \end{bmatrix} = \left(\begin{bmatrix} \mathbf{s}_j \\ \mathbf{f}_k \end{bmatrix} \begin{bmatrix} \mathbf{s}_j & \mathbf{f}_k \end{bmatrix} \right)^{-1} \begin{bmatrix} \mathbf{s}_j \\ \mathbf{f}_k \end{bmatrix} \mathbf{t}_{k,j} \quad (5)$$

4. SPECTRAL REFLECTANCE OF THE SKIN

The human faces of a total of 36 Japanese women between 20 and 40 years old were measured at the SHISEIDO institute of beauty sciences lab. For our analysis, we measured spectral reflectance of the color of the bare skin, the applied skin color, and the skin texture on the left and right cheek, employing a CCD microscope. Details of the measured part of the face are illustrated in Fig. 2. The Munsel values of the samples ranged as follows: H=9Y to 8YR, V=5 to 7, C=2 to 5. Spectral reflectance was measured at intervals of 10 nm from 400nm to 700nm, as shown in Fig. 3.

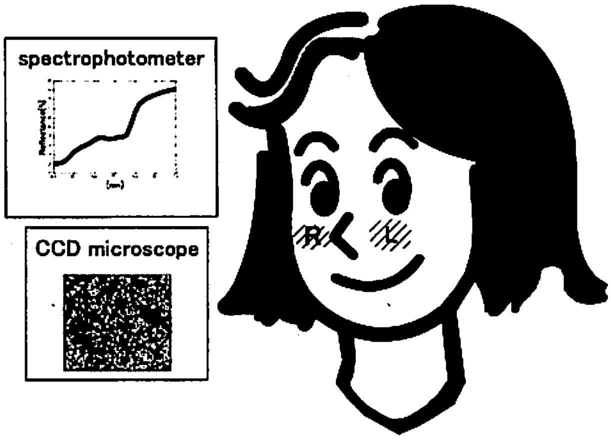

Fig. 2 spectral reflectance measured area

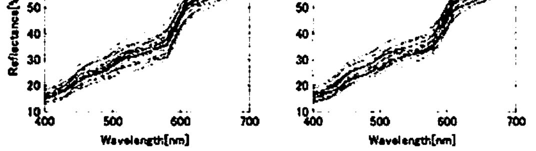

Fig. 3 Spectral reflectance of bare skin and the foundation-applied skin of the human face

Fig. 4 shows the relationship between a and b at different parts of the human face. As shown in Fig. 4, 91% of the estimated parameters are satisfied by the equation a + b = 1 within 5% accuracy, indicating that the color of the foundation-applied skin can be determined by the ratio of the skin and the foundation colors. Fig. 5 illustrates the relation of the Foundation ratio.

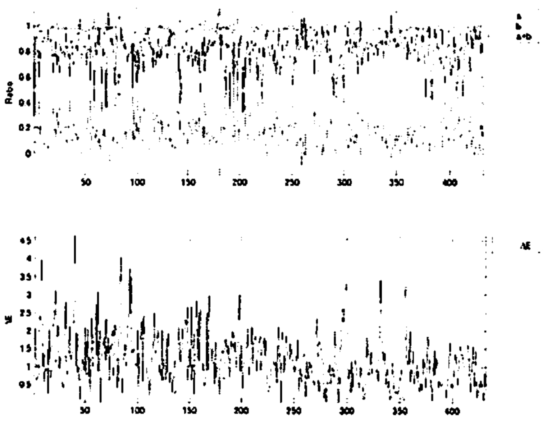

Fig. 4 Estimated a and b and a+b and Color difference in L*a*b* color space.

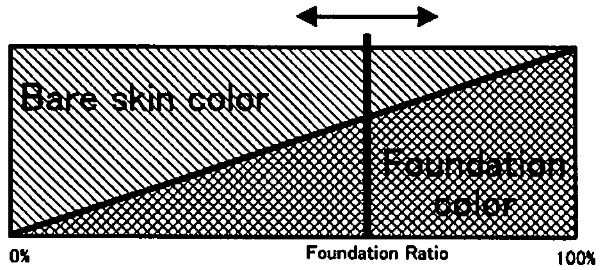

Fig. 5 Illustration of the relation of the Foundation ratio.

5. PARAMETER EXTRACTION FROM SKIN IMAGE

The skin images are captured by CCD microscope, and show the same location as that focused on by the spectrometer. Fig. 6 shows a typical sample of a captured image.

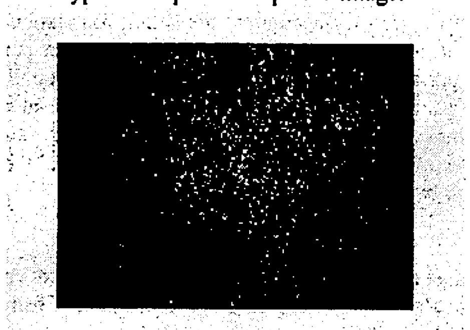

Fig. 6 Typical sample of skin image captured by CCD microscope.

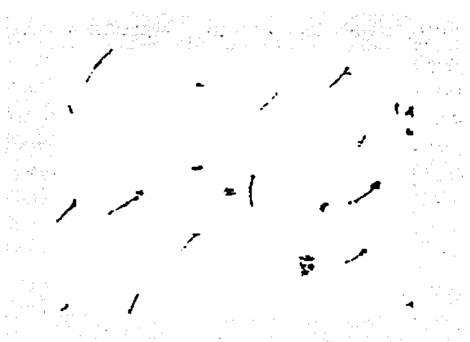

Fig. 7 Downy hair detection results.

Each captured image is analyzed by using SHISEIDO image analysis software. After extracting the parameters, we analyze the correlation between the extracted parameters and the Foundation Ratio. After extensive cross-correlation analysis, we find three independent parameters to be evidently related to the Foundation Ratio.

6. SPECTRAL COMPONENT DECOMPOSITION BY USING SVD

To avoid multicollinearity of correlated data, a SVD-based data decomposition method is applied. The summarized SVD-based data decomposition is as follows.

The SVD property needed to provide the closest rank-l approximation for a matrix can be used in data for compression and noise reduction, a very common application of SVD. We perform a Singular Value Decomposition (SVD) of the set of spectral reflectance data when different foundations are respectively applied. After removing the low energy basis vectors (in order to reduce noise), we used the coefficients of the remaining basis vectors as the representation of the orthogonal components. The measured spectral reflectances are stored in a [31x t] matrix M that that contains 31 wavelengths, each with t samples. The Singular Value Decomposition of M yields

$$M = U\Sigma V^T \qquad (6)$$

where U is a [31 x 31] matrix containing the orthogonal part of spectral reflectance stored column-wise, Σ is a [31 x t] diagonal matrix with the corresponding singular values (sorted in descending order), and V is of the dimension [t x t] holding the orthogonal coefficients. By setting the small singular values to zero, we can obtain matrix approximations whose rank equals the number of remaining singular values.

$$\tilde{M} = \begin{bmatrix} U_1 \\ \cdots \\ U_2 \end{bmatrix} \begin{bmatrix} \Sigma_1 & \vdots & 0 \\ \cdots & \cdots & \cdots \\ 0 & \vdots & 0 \end{bmatrix} \begin{bmatrix} V_1^T \\ \cdots \\ V_2^T \end{bmatrix} \qquad (7)$$

$$\tilde{M} = U_1 \Sigma_1 V_1^T \qquad (8)$$

$$V_1^T = \left((U_1\Sigma_1)^T (U_1\Sigma_1) \right)^{-1} (U_1\Sigma_1)^T \tilde{M} \qquad (9)$$

Thus, we can approximate spectral reflectance M [31x1] to the coefficient of the orthogonal component, a [6 x 1] matrix, which represents the intensity of each orthogonal component. The cumulative rates of the normalized singular value vectors for human skin are shown in Fig. 8.

As shown in Fig.5, 99% of the spectral reflection of human skin can be expressed by only 6 orders of the orthogonal components. This means we can approximate eq.(6) to eq.(8).

Fig. 9 shows the orthogonal components of the spectral reflection of human skin corresponding to the 1st to the 6th singular values.

The 1st orthogonal component enhances the higher part of reflection wavelength that is affected primarily by melanin. The 2nd and 5th components are affected primarily by oxyhemoglobin, and the 4th component is affected mainly by deoxyhemoglobin. The 3rd component is affected primarily by the foundation. Note that singular value decomposition decomposes the data orthogonally. The obtained orthogonal data cannot always assign meaningful components.

Independent Component Analysis[3] may be an appropriate separation algorithm. However, ICA is not numerically stable compared to the SVD method.

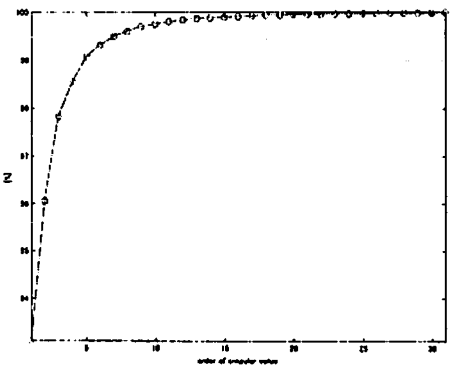

Fig. 8 The cumulative rates of the normalized singular value vectors for human skin.

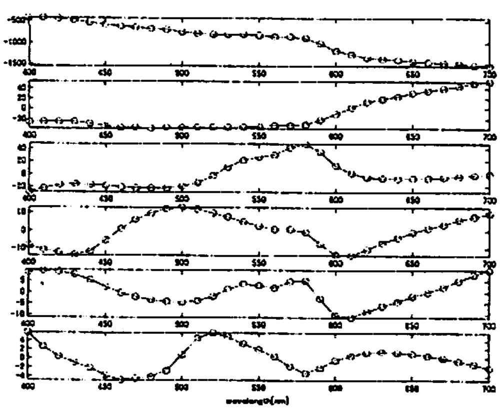

Fig. 9 The orthogonal component of human skin, corresponding to the 1st to the 6th singular values.

7. FOUNDATION RATIO ON NN IN COMBINATION WITH SVD

To predict the beauty adviser's skill of resultant applied skin color, we use an artificial neural network to approximate the behavior of the color of the skin that has had foundation applied to it. In order to apply the neural network by using useful information to avoid multi-collinearity, we use the 6 major orthogonal components of the spectral reflectance data instead of the direct spectral wavelength. Fig. 10 shows a schematic diagram of the proposed color prediction system based on NN in combination with SVD.

The input of the neural network is recalculated by using SVD (Singular value decomposition). This significantly reduces the computational time.

To avoid multicollinearity, as well as to reduce the computation time for the neural network, we use the SVD technique to compress data. The skin reflection wavelength can be reduced from 31 points to 6 points. The foundation reflection wavelength can be reduced from 31 points to 3 points. The neural network used here is a 2-layered type, back-propagation neural network that inputs 12 points and outputs 2 points. The Standard Levenberg-Marquardt back propagation algorithm is applied to solve the problems. Since FR represents the thickness of the foundation, we use optimal FR as the beauty advisor's choice, which is calculated by eq.(5). After the training, we can predict the resultant applied skin color before applying it. The results of the proposed method can estimate 85% of data to satisfy the color difference in the L*a*b* color space within a 3-color difference.

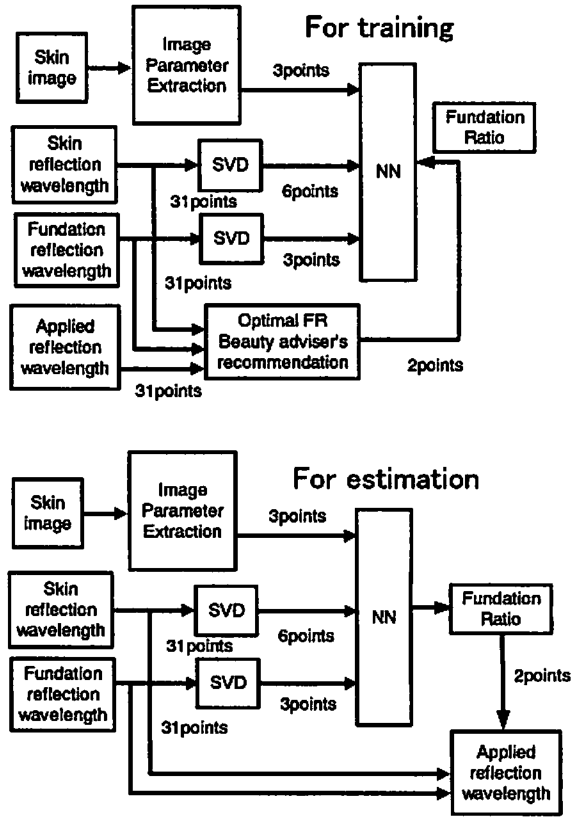

Fig. 10 Summarized schematic diagram for proposed SVD-based neural network

8. CONCLUSION

This paper describes a new method for estimating foundation-applied skin color based on a NN and SVD technique. The parameter of the Foundation Ratio (FR) is newly introduced for accurately predicting foundation-applied color. The SVD is used to extract the meaningful parameters from individual wavelength data to avoid multicollinearity. Using extracted parameters and FR, we trained an artificial neural network to determine foundation-applied skin color. The 85% of results of the estimation error in L*a*b* color space can be satisfied within a 3-color difference.

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