Correlation map analysis between appearances of Japanese facial images and amount of melanin and hemoglobin components in the skin

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ABSTRACT

Skin color reproduction becomes increasingly important with the recent progress in various imaging systems. In this paper, based on subjective experiments, correlation maps are analyzed between appearance of Japanese facial images and amount of melanin and hemoglobin components in the facial skin. Facial color images were taken by digital still camera. The spatial distributions of melanin and hemoglobin components in the facial color image were separated by independent component analysis of skin colors. The separated components were synthesized to simulate the various facial color images by changing the quantities of the two separated pigments. The synthesized images were evaluated subjectively by comparing with the original facial images. From the analysis of correlation map, we could find the visual or psychological terms that are well related to change of hemoglobin or melanin components. From different point of view, we could find how the changes of hemoglobin or melanin components influence the appearance of facial color image.
Keywords: independent component analysis, skin color, melanin, hemoglobin, visual and psychological terms, appearance, face, facial color image

1. INTRODUCTION

With the recent progress of various imaging systems[1-3] such as multi-media, computer graphic and telemedicine systems, the skin color becomes increasingly important for communication, image reproduction on hardcopy and softcopy, medical diagnosis, cosmetic development and so on. Human skin is a turbid medium with multi-layered structure, and contains various pigments such as melanin and hemoglobin. Slight changes in structure and pigment construction produce great skin color variation[4-6]. This makes it necessary to analyze skin color on the basis of its structure and pigment construction in reproducing various skin colors.

The independent component analysis (ICA)[7-12] is a technique that extracts the original signals from mixtures of many independent sources without *a priori* information on the sources and the process of the mixture. In our previous paper[13,14], we proposed a technique to separate skin color image into the spatial distributions of hemoglobin and melanin. The separated components are synthesized to simulate the various facial color images by changing the quantities of the two separated pigments.

In this paper, the synthesized images were evaluated subjectively by comparing with the original facial images, and the correlation maps are analyzed between evaluated appearance of Japanese facial images and amount of melanin and hemoglobin components in the facial skin. The evaluations were performed using the twenty-five visual or psychological terms. The subjects were ten students in our laboratory. The correlation maps between the rating value and changing rate of hemoglobin and melanin components were displayed to discuss the relation between them.

In the next section, the independent component analysis for color image separation is reviewed based on our previous paper[13]. In the section 3, skin color is modeled, and facial skin color is separated and synthesized by changing the quantities of the two separated pigments. In the section 4, the synthesized facial images are evaluated subjectively.

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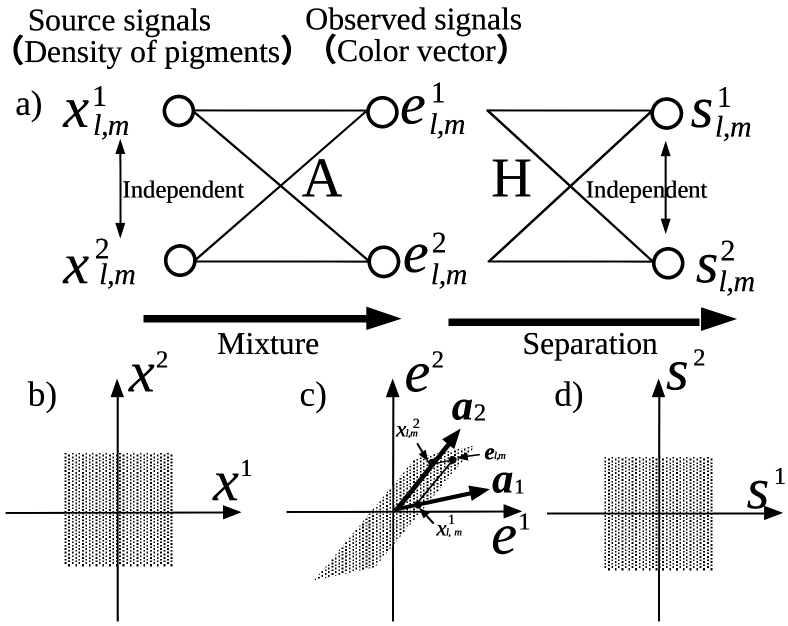

Figure 1: Mixture and separation of independent signals

2. INDEPENDENT COMPONENT ANALYSIS FOR COLOR IMAGE SEPARATION

The application of independent component analysis to the color image separation is briefly reviewed in this section. It is assumed that the medium is constructed of two pigments and captured by an imaging system with two color channels, or captured at any two wavelengths.

Let $x^1{}_{l,m}$ and $x^2{}_{l,m}$ denote the quantities of the two pigments on the coordinates (l, m) in the digital color image and $\boldsymbol{a}^1$ and $\boldsymbol{a}^2$ denote pure color vectors of the two pigments per unit quantity, respectively. It is assumed that $\boldsymbol{a}^1$ and $\boldsymbol{a}^2$ are different from each other. It is also assumed that the compound color vector $\boldsymbol{e}_{l,m}$ on the image coordinates (l, m) can be calculated by the linear combination of pure color vectors with the quantities $x^1{}_{l,m}$ and $x^2{}_{l,m}$ as

$$\boldsymbol{e}_{l,m} = x^1{}_{l,m}\boldsymbol{a}^1 + x^2{}_{l,m}\boldsymbol{a}^2 . \qquad (1)$$

The elements in compound color vector indicate pixel values of the corresponding channels. Let denote $A = [\boldsymbol{a}^1, \boldsymbol{a}^2]$ the constant 2 × 2 mixing matrix whose column vectors are pure color vectors, and $\boldsymbol{x}_{l,m} = [x^1{}_{l,m}, x^2{}_{l,m}]^t$ the quantity vector on the image coordinates (l, m). The equation (1) can be rewritten in vector and matrix form as follows:

$$\boldsymbol{e}_{l,m} = A\boldsymbol{x}_{l,m} . \qquad (2)$$

In the independent component analysis, it is also assumed that the values $x^1{}_{l,m}$ and $x^2{}_{l,m}$ of the quantity vector are mutually independent for the image coordinates (l, m). Figure 1(a) shows the process of mixing, and Fig. 1(b) is an example of the probability density distribution of $x^1{}_{l,m}$ and $x^2{}_{l,m}$, which are mutually independent. Figure 1(c) shows the probability density distribution in the image, of $e^1{}_{l,m}$ and $e^2{}_{l,m}$, which are elements of the compound color vector $\boldsymbol{e}_{l,m}$. It is noted that the observed color signals $e^1{}_{l,m}$, $e^2{}_{l,m}$, are not mutually independent.

We can extract the relative quantity and the pure color vector of each pigment from compound color vectors by independent component analysis, without *a priori* information on the quantity and the color vector. Let us define the following equation by using the separating matrix H and the separated vector $\boldsymbol{s}_{l,m}$ as shown in Fig. 1(a):

$$\boldsymbol{s}_{l,m} = H\boldsymbol{e}_{l,m}, \tag{3}$$

where $H = [\boldsymbol{h}^1, \boldsymbol{h}^2]$ is a separating matrix, and $\boldsymbol{s}_{l,m} = [s^1{}_{l,m}, s^2{}_{l,m}]^t$ is an extracted signal vector. By finding the appropriate separating matrix H, we can extract the mutually independent signals $s_{l,m}(1)$ and $s_{l,m}(2)$ from the compound color vectors in the image. Many methods for finding separating matrix H have been proposed[7-12]. In this paper, optimization techniques based on the fixed-point method[9] is used to find separating matrix H.

The extracted independent vector $\boldsymbol{s}_{l,m}$ is given by

$$\boldsymbol{s}_{l,m} = R\Lambda\boldsymbol{x}_{l,m}, \tag{4}$$

where R is the permutation matrix that may substitute the elements of the vectors for each other, and Λ is the diagonal matrix that relates the absolute quantities to the relative qualities. Substituting equations (2) and (3) into equation (4), we can obtain

$$HA\boldsymbol{x}_{l,m} = R\Lambda\boldsymbol{x}_{l,m}. \tag{5}$$

If we take Eq. (5) in the arbitrary quantity vector, the matrix HA should be equal to the matrix $R\Lambda$, and the mixing matrix A is calculated by using the inverse matrix of H as follows:

$$A = H^{-1}R\Lambda. \tag{6}$$

It is note that what we can obtain by ICA are relative quantities and directions of compound color vectors. In our application of color image separation and synthesis, however, the absolute values are not required.

If the number of pigments is larger than the number of channels, it is impossible to extract the independent components caused by reduction of the signals. On the other hand, if the number of pigments is smaller than the number of channels, it is possible to make the number of channels equal to the number of pigments by using principal component analysis (PCA). This technique is also used in our analysis.

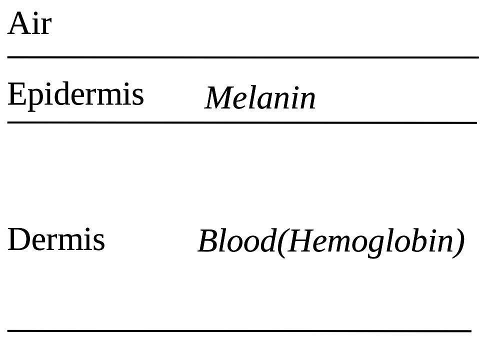

Figure 2: Schematic model of human skin with plane-parallel epidermal and dermal layers

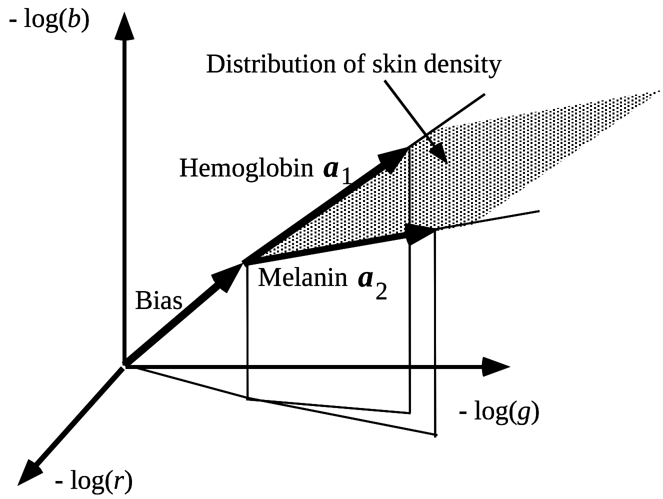

Figure 3: Skin color model in the optical density domain of three channels

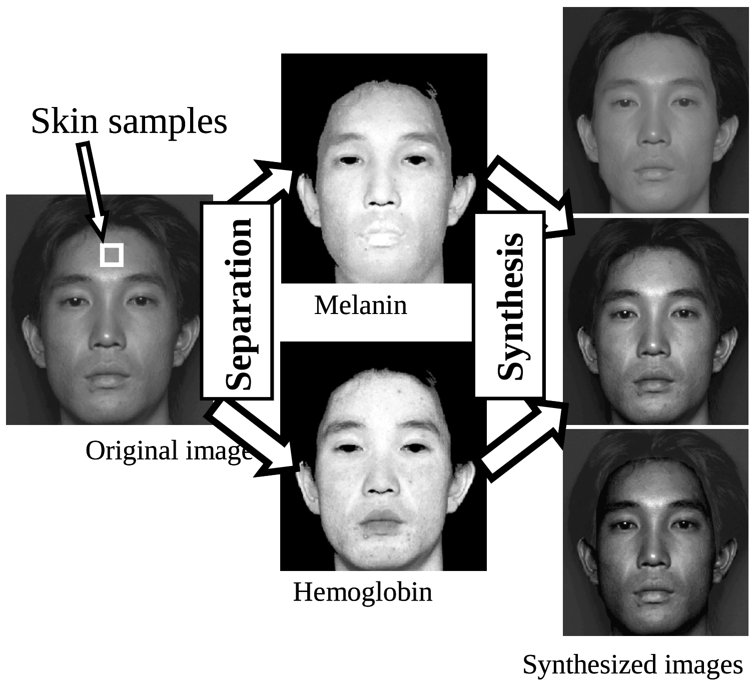

Figure 4: Process of separation and synthesis of facial color images

3. FACIAL SKIN COLOR SEPARATION AND SYNTHESIS BASED ON SKIN COLOR MODEL

A schematic model of human skin is shown in Fig. 2 with plane-parallel epidermal and dermal layers. The epidermal and dermal layers are turbid media. Various pigments such as melanin, hemoglobin, bilirubin, and β-carotene are contained in the layers; in particular, melanin and hemoglobin are predominantly found in the epidermal and the dermal layer, respectively. Let $r_{l,m}$, $g_{l,m}$, $b_{l,m}$ be the pixel values in red, green, and blue channels of the skin color image on the image coordinates (*l*, *m*), respectively.

Analyzing this skin color, we made four assumptions about skin color. First, the Lambert–Beer law, or rather the modified Lambert–Beer law, holds with respect to the reflected light among the quantities and the observed color signals. Second, the spectral distribution of the skin is not abrupt in the sensitive spectral range of each channel in the imaging system. Third, the spatial variations of color in the skin are caused by two pigments: melanin and hemoglobin. Fourth, the pigment quantities are mutually independent spatially. The first assumption ensures linearity among the observed color signals and pure color signals of the pigments in the spectral density domain. The second assumption ensures linearity in the optical density domain of three channels: $-\log(r_{l,m})$, $-\log(g_{l,m})$, $-\log(b_{l,m})$. On the basis of the linearity and the third assumption, the color in the skin image is modeled as Fig. 3 in the optical density domain of three channels. It is seen that the three densities of skin color are distributed on the two-dimensional plane spanned by the pure color vectors of melanin and hemoglobin.

By applying the independent component analysis into the two-dimensional plane, it is possible to separate the skin colors into the two pure colors corresponding to the melanin and hemoglobin pigmentations. The obtained pure colors are used to separate the facial color image. Figure 4 shows the process of separation and synthesis of facial color images. The skin color region where is uniformly illuminated is segmented from facial color image. The independent component analysis is applied to the segmented skin color region, and the obtained pure colors of pigments are used to separate the facial skin color. The region of facial skin color is segmented manually by using the function in Adobe Photoshop. The quantities of separated components are changed some times higher than those of original images. The changed components are synthesized by using the inverse process of separation.

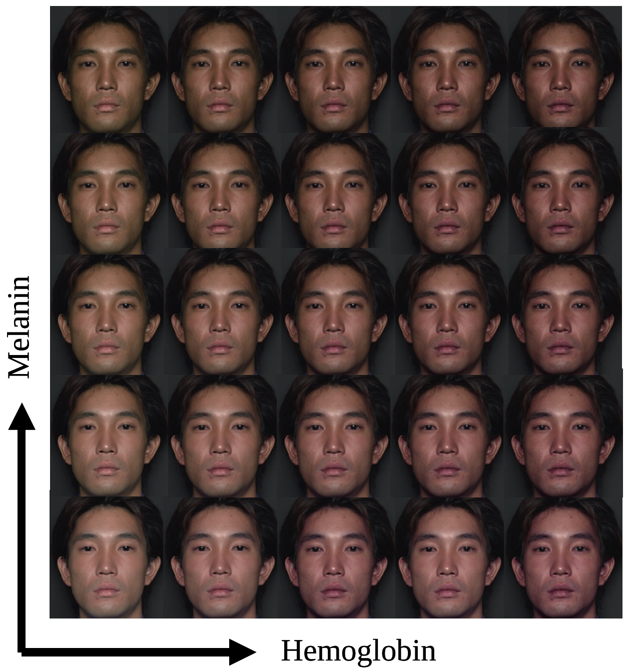

Figure 5: Synthesized images used in the subjective evaluations

Table 1 Pairs of terms to describe the appearance

1. Clean	- Filthy	14. Natural	- Unnatural
2. Beautiful	- Dirty	15. Moist	- Arid
3. Healthy	- Unhealthy	16. Rough texture	- Fine texture
4. Fresh	- Dry	17. Old	- Young
5. Flashy	- Plain	18. Lifeless	- Lively
6. Elegant	- Crude	19. Luster	- Lusterless
7. Bright	- Dark	20. Opaque	- Transparent
8. Desirable	- Undesirable	21. Light complexion	- Dark complexion
9. Passionate	- Cold	22. Strong redness	- Strong yellowness
10. Soft	- Hard	23. Pale	- Dark yellow
11. Clear	- Turbid	24. Look of bare skin	- Look of made-up skin
12. Feminine	- Masculine	25. Tight	- Loose
13. Vibrant	- Dull		

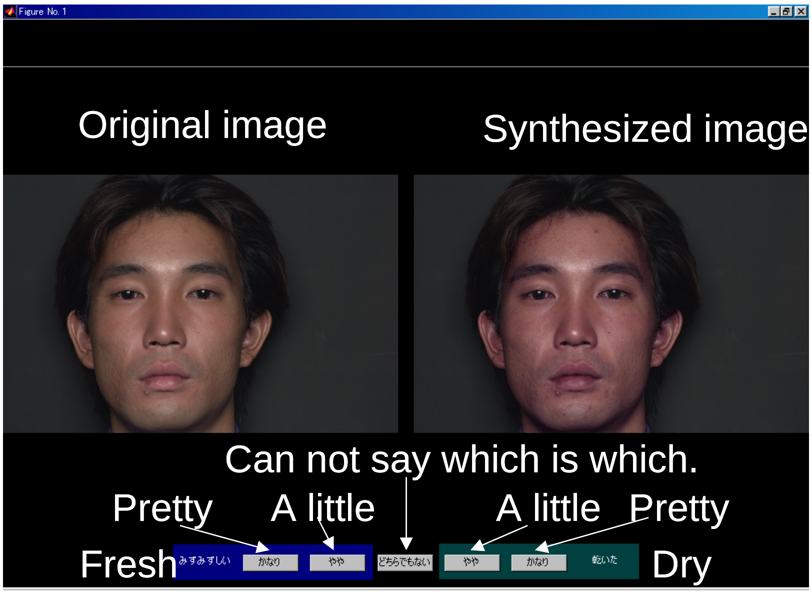

Figure 6: Interface used in the subjective evaluations

4. SUBJECTIVE EXPERIMENTS FOR SYNTHESIZED FACIAL COLOR IMAGES

Facial color images are taken by digital still camera (Nikon D1). The specular reflection is separated by using polarization filters, and the separated specular component is added into the synthesized image. The quantities of hemoglobin components are changed 0.7, 1.0, 1.3, 1.6, 1.9 times higher than those of original images, and the quantities of melanin components are changed

0.7, 1.0, 1.3, 1.6, 1.9 times higher than those of original images. Total number of synthesized images was twenty-five of all combinations. Figure 5 shows the synthesized images. The synthesized images are evaluated subjectively by comparing with the original facial images. The evaluation was performed using the dozen of visual or psychological pairs of terms as shown in Table 1.

The subjects select one degree from five degrees of evaluation for each pair of terms as shown in Fig. 6. The subjects were ten students in our laboratory. The correlation maps between the rating value and changing rate of hemoglobin and melanin components are displayed to discuss the relation between them. Figures 7 show the resultant correlation maps. The horizontal and vertical axis indicates the changed ratio between the original and synthesized quantities for hemoglobin and melanin, respectively. The black region in the map indicates the left side of term is evaluated higher, and white region indicates the right side of term is evaluated higher. By looking at the correlation maps, we can categorize the pairs of terms into 4 types of categories. The first is the term that monotonously correlates with amount of hemoglobin. The pairs of terms such as ’strong redness - strong yellowness’, ’passionate - cold’ were classified into this category. The second is the pairs of terms that monotonously correlate with amount of melanin. The pairs of terms such as ’feminine - masculine’, ’clear - turbid’ were classified into this category. The third is the term that monotonously correlates with amount of both hemoglobin and melanin. The pairs of terms such as ’luster -lusterless’ were classified into this category. The last is the term that gives the unimodal shape of map. The pairs of terms, such as ’health - unhealthy’, ’natural - unnatural’ were classified into this category.

From these analyses, we could find the visual or psychological terms that are well related to change of hemoglobin or melanin components. From different point of view, we could find how the changes of hemoglobin or melanin components influence the appearance of facial color image.

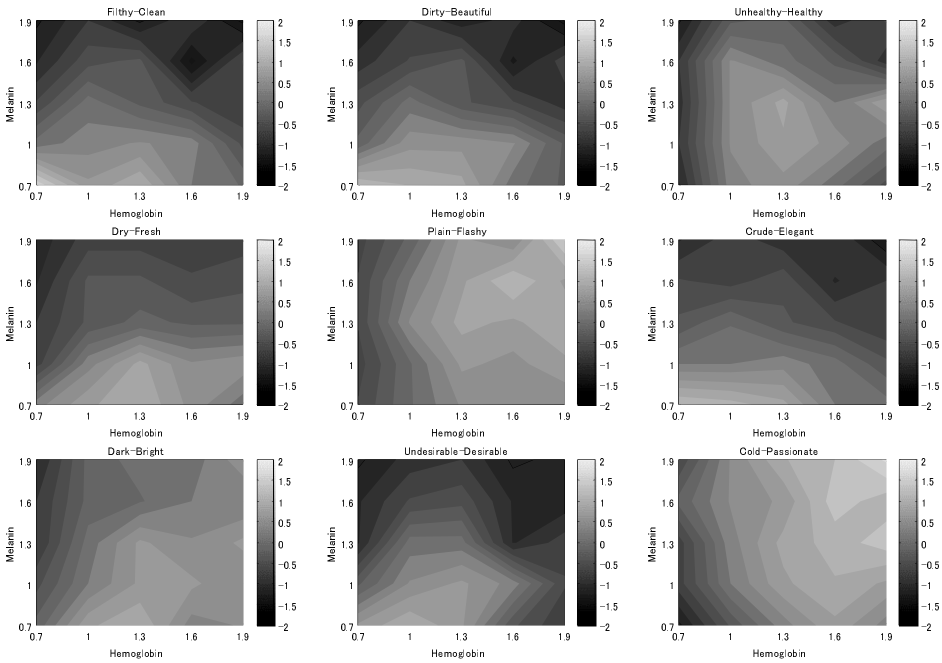

Figure 7: Correlation maps

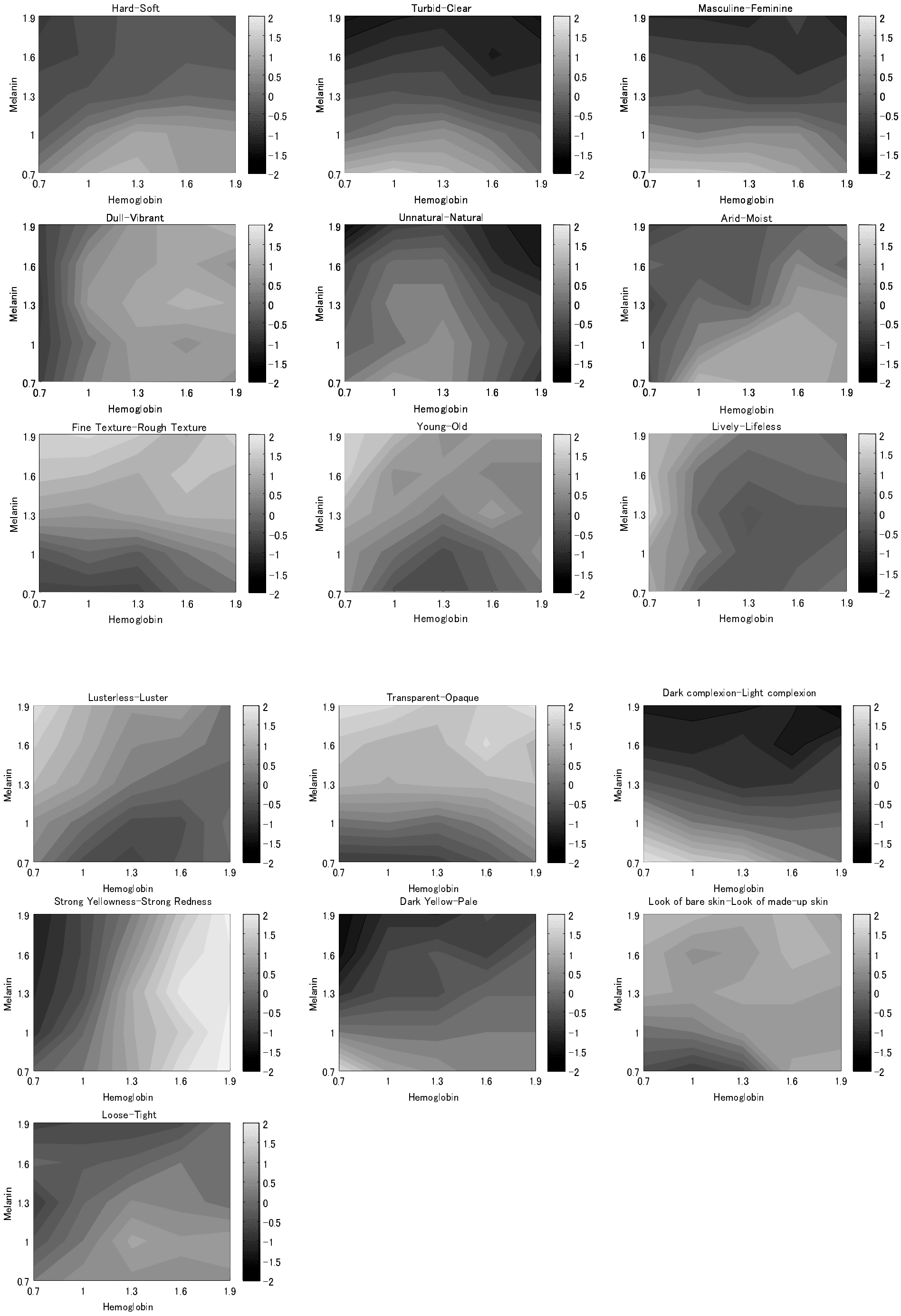

Figure 7: Correlation maps (continued)

5. CONCLUSION

The spatial distributions of melanin and hemoglobin components in the facial color image were separated by independent-component analysis of skin colors. The separated components were synthesized to simulate the various facial color images by changing the quantities of the two separated pigments. The twenty five synthesized images were evaluated subjectively by comparing with the original facial images. From the analysis of correlation map, we could find the visual or psychological terms that are well related to change of hemoglobin or melanin components.

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