Multidimensional Data Visualization for Investigation of Skin Transparency

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***Abstract*—"Skin Transparency" is an important keyword for women of all generations as one of the conditions for beautiful skin. Although, no one has clear definitions of "Skin Transparency". As it stands, beauty experts are often invited to use visual methods in conducting skin transparency evaluation; however, it has not been still sufficiently clarified which visual properties are related to skin transparency. In this study, we aim to discover the relations between skin image features and sensory evaluations applying real human skin images. Specifically, we investigate "Skin Transparency" by comparing them using the Parallel Coordinate Plots. We observed their complex distributions by the visualization task.**

***Index Terms*—Human Skin, Transparency, Sensory Evaluation, Image Analysis, Multidimensional Data Visualization**

I. Introduction

Research on skin features and impressions has been developing mainly in the cosmetics industry. Quantification of skin features by photography and measurement, and sensory evaluations by observers, are major approaches for human skin research. We can contribute to the diagnosis of health conditions and the development of new cosmetics by analyzing skin features and impressions. In addition, knowledge and research on the beautification of human skin can contribute to realistic skin reproduction using computer graphics (CG) and skin image processing technology.

There have been various words to express the condition of human skin. "Transparency" is an important one. This expression is sensuous, and what kind of skin is called transparent depends on the subjectivity and experience of evaluators. Therefore, it is difficult to objectively evaluate skin transparency. Meanwhile, affective computing with sensory evaluation and exploratory observation of data visualization are useful approaches for such problems. The goal of this study to clarify the factor of "skin transparency" by comparing human skin measurement results and sensory evaluation results by applying a multidimensional data visualization technique.

Most of the conventional methods for measuring human skin conditions use specialized devices. However, such methods can only be implemented in well-equipped environments. Hence, we extract human skin features by image analysis using the photos of human skins taken by ordinary digital cameras and collate them with the sensory evaluation results. We elucidate the factors of skin transparency without using specialized devices by this approach. Also, we construct multidimensional data by comprehensively calculating the feature values on skin transparency, and visualize this data by classifying the data into several skin patterns. In this study, we aim to discover complex knowledge that spans multiple features for skin transparency and factors that are individually discovered in each pattern of human skin.

II. Related Work

A. *Transparency and Features of Human Skins*

"Skin Transparency" is a common expression for Japanese people. However, even so, there have been few cases of human skin research specialized to skin transparency in other countries. In other words, many academic papers on skin transparency have been published in Japan. This section introduces related work that pursues the factors of skin transparency.

Kuwahara et al. [1] proposed an optical measurement method for the quantitative evaluation of skin transparency. Based on the draft definition of the Japan Cosmetic Industry Association, "Skin transparency is related to the light transmission of the stratum corneum, or the ratio of transmitted light to incident light", they focused on the reflection features of human skin and developed the measurement method. They found that the greater the diffuse reflection component of human skin, the higher skin transparency. Nishimuta et al. [2] measured the reflection features of human skin from the skin images. They obtained the L*a*b* and the brightness values from the skin images and then conducted a subjective evaluation experiment using the skin images. As a result, they reported that the higher the average brightness value, the higher skin transparency. In addition, they conducted a subjective evaluation to find the optimum chromaticity that gives a sense of skin transparency. The answers of the same person were consistent, although large individual differences were observed among the answers of different persons. Namely, the relationship between skin transparency and chromaticity strongly depends on the evaluators. This report demonstrates that image-based experiments bring highly reliable results.

Masuda et al. [3] applied Partial Least Square (PLS) analysis to the measurements of physiological characteristics regarding human skins and the visual evaluation results by cosmetologists. They reported that the highly transparent skin had a fine texture, high keratin water content, and low melanin and hemoglobin content. However, the explanation dispersion of skin transparency in this experiment was only about 55%. Nakanishi et al. [4] reported that glossy skin was not preferred in the evaluation of skin transparency. On the other hand, Yasumori et al. [5] reported that the lower the gloss strength, the more noticeable the dullness. These results suggest that relationships between gloss/luster and impression regarding skin transparency are still unclear. Soya et al. [6] reported experimental results focusing on the linguistic structure of skin transparency. Specifically, they analyzed the content of consciousness regarding skin transparency linguistically. They showed that three basic requirements including texture, color, and moisturization of human skins form a complex concept. In this study, we aim to make the concept of skin transparency more concrete by performing a sensory evaluation to focus on the relationship between skin transparency and expressions on human skin features.

Most of the related studies described above focused on either of specific features such as skin light reflection, color, and internal structures of human skins directly affect skin transparency. Also, most of the studies just calculated statistical values such as correlation coefficients from all human skins without classifying. Here, we need to remark that just particular subsets (groups that satisfy a certain specific condition) of human skins may have correlations between features and impressions especially if the correlation calculated for all of them is small. Based on the above discussion, we comprehensively calculated a large number of human skin features mentioned in many related studies and analyzed the relationships among those features rather than analyzing them individually. Especially, we aimed to discover complex relationships between the features and impressions that cannot be found only by the correlation coefficient between two variables. Furthermore, we classified the human skins into several patterns and investigated the factors of the skin transparency peculiar to each pattern.

B. *Visualization of Multidimensional Data*

We extracted many features from human skin images and performed a sensory evaluation for a large number of adjective pairs to pursue their relationships in this study. We visualized them as multidimensional data.

Multidimensional data visualization methods are divided into the following approaches: 1) geometric methods that explicitly displays coordinate axes, 2) iconic methods that represent variables applying metaphors, and 3) pixel-based method that illustrates variables as RGB values of pixels. Scatterplot and Parallel Coordinate Plot (PCP) are famous visualization techniques belonging to the geometric methods. These are advantageous to read numerical values accurately which is directed toward the goal of this study.

In order to derive the relationship between human skin features and sensory evaluations, it is effective to extract a small number of variable groups that have an important relationship from the variable groups that construct multidimensional data. Itoh et al. [7] presented a high-dimensional data visualization tool as one of the Geometrical methods for multidimensional data visualization based on this idea. This technique displays low-dimensional subspace groups as multiple PCPs and a dimensional scatterplot with a mechanism to support interactive operations for selecting the subspace groups. PCP is advantageous while visually recognizing all dimensions in a dataset at once. On the other hand, it is problematic that very long and narrow screen spaces are required to display all dimensions. Also, it is difficult to visually recognize the correlation between non-adjacent dimensions on the screen. We apply the visualization technique of Itoh et al. to visualize the multidimensional data that integrates human skin features extracted from human skin images and sensory evaluation results since the technique solves the problems of PCP.

III. Visualization of Human Skin Features and Sensory Evaluation Results

This study pursues the factors that make human skin feel transparent by collating human skin features with the sensory evaluation results. This section describes imaging of human skins, calculation of human skin features, tasks for sensory evaluation, and visualization of these results.

A. *Human Skin Photography*

We estimate human skin color and reflective components from the captured image as described later in section III-B. Here, it is important to construct a photographic environment that excludes ambient light to ensure the accuracy of this estimation. Therefore, we set up a dark room of 2 m in length and 2 m in width as a dedicated photographic environment. We photographed the skins of participants under the situation that the influence of light other than the light source installed for photographing was excluded. Fig. 1 shows the photographic environment.

Cheeks are often closely watched while evaluating human skins [8]. Therefore, we defined the left and right cheeks as subjects for human skin images. Specifically, we photographed the skin of 15 women in their 20's without makeup or sunscreen using a digital single-lens reflex camera (Canon EOS Kiss X10). The direction of the light source (LED light, 5600K) and the position of participants were fixed. In particular, as shown in Fig. 1, we installed the light source at a position of 45 degrees to the right from the center viewed from the camera side while photographing the left cheek. Similarly, we installed it at a position of 45 degrees to the left from the center viewed from the camera side while photographing the right cheek. In addition, in order to prevent overexposure, we took photographs with different exposure values continuously. Then, we used the appropriate one for image analysis. High Dynamic Range (HDR) composition was not applied to human skin images because differently bright images were stored while applying the HDR composition.

B. *Extraction of Human Skin Features by Image Analysis*

Skin transparency is assumed to be greatly related to human skin color and reflection characteristics [1]– [5] as introduced

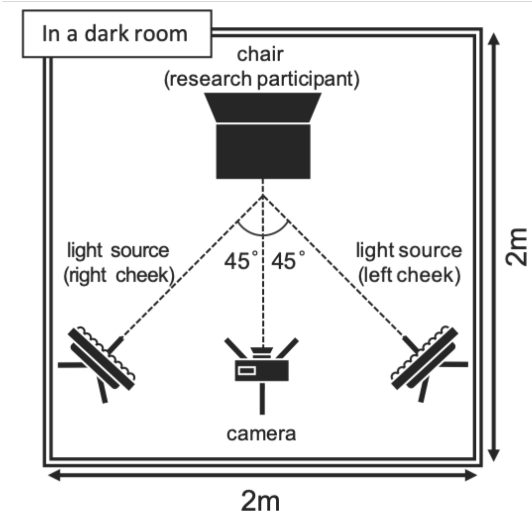

Fig. 1. Photographing environment in a dark room.

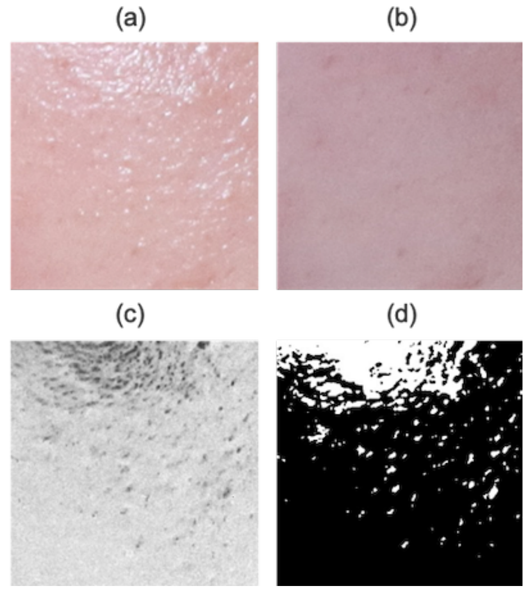

Fig. 2. (a) Normal skin image without polarizing filter. (b) Diffuse reflection image. (c) Specular reflection image (grayscale). (d) Binarized image of (c).

in Section II-A. These related studies have analyzed various human skin features. Even so, we do not apply micro skin features such as pores and furrows or features inside human skin for our visualization study since we do not use dedicated measuring devices while extracting human skin features in this study. We analyze the images taken by the procedure explained in Section III-A and extract the following human skin features related to skin color and reflection characteristics:

- F1: specular reflection
- F2: hue, saturation, lightness, redness, yellowness, brightness
- F3: hemoglobin, melanin

First, for the features in F1, we extract the specular reflection component by separating the polarized image taken using a polarizing filter [9] into a diffuse reflection image and a specular reflection image. Diffuse reflection of human skin causes by light scattering inside the skin, and generally does not have polarization. On the other hand, specular reflection of human skin is the mirror-like reflection on the surface of the skin and generally linearly polarized light that has the same polarization plane as the incident light. Fig. 2 shows an image generated by utilizing this difference in polarization. Comparing the image without using a filter (Fig. 2 (a)) and the diffuse reflection image (Fig. 2 (b)), clearly, the so-called shiny and glossy parts of Figure 2 (a) is removed in Fig. 2 (b). In addition, the specular reflection image (Figure 2 (c)) has separate glossy parts and non-glossy parts of Fig. 2 (a). Fig. 2 (d) shows the results of applying a binarization operation by setting the threshold value for each of these images. From this binary image, we extract skin area with specular reflection of a certain intensity or more, in other words, skin area with shine or gloss as human skin features.

Second, we convert the RGB values in each pixel of human skin image to HSV color system, L*a*b* color system, and grayscale to calculate features in F2. From the HSV color system, H is the hue, S is the saturation, and from the L*a*b* color system, L* is the brightness, a* is the redness, and b* is the yellowness. Besides, brightness is calculated from the grayscale. At this time, we calculate the mean value and standard deviation of each feature for each image. We consider that the standard deviation is an index of uneven skin color and uneven light reflection.

Third, to extract hemoglobin and melanin pigments from human skin image as human skin features in F3, we use the diffuse reflection image to eliminate phenomena such as gloss due to the influence of the light source. Although various pigments are present in the epidermis and dermis layers of human skin, melanin pigment is abundant in the epidermis layer and hemoglobin pigment is abundant in the dermis layer. Therefore, by applying Independent Component Analysis (ICA) to human skin image, we can separate the light reflections by hemoglobin and melanin pigments because we can suppose that the light reflections caused by the two pigments is independent [10].

Let $r^{x,y}$, $g^{x,y}$, $b^{x,y}$ denote the RGB values in each pixel of human skin color image. Fig. 3 shows the color model of human skins observed in a color density space that is the logarithm of the reciprocal of the pixel value of each value: $-\log r^{x,y}$, $-\log g^{x,y}$, $-\log b^{x,y}$. Since this model is distributed on a two-dimensional plane spread by two color vectors of hemoglobin and melanin in addition to the base skin color, we can define this model as follows:

$$-\log[r^{x,y}, r^{x,y}, r^{x,y}] = s_1^{x,y} a_1 + s_2^{x,y} a_2 + Bias \quad (1)$$

where $s_1^{x,y}$ and $s_2^{x,y}$ represent two pigments of hemoglobin and melanin. a_1 and a_2 represent the single color vectors of hemoglobin and melanin. In addition, $Bias$ represents a bias component (constant). We assume that the minimum value of the color density of each human skin image is the base color and used as the bias component in this paper. We obtain the color vectors a_1 and a_2 in Eq. (1) by independent component analysis. We normalize $A = [a_1, a_2]$ to match the volume of hemoglobin and melanin pigments in all human skin images. To define the normalized A as $E = [e_1, e_2]$, Eq. (1) can be rewritten as follows:

$$-\log[r^{x,y}, r^{x,y}, r^{x,y}] = s_1'^{x,y} e_1 + s_2'^{x,y} e_2 + Bias \qquad (2)$$

where $s_1'^{x,y}$ and $s_2'^{x,y}$ represent the corresponding hemoglobin and melanin pigments. In this paper, the average value and standard deviation of each pigment are calculated in the same manner as features in F2.

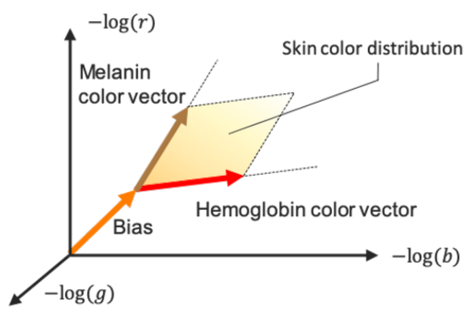

Fig. 3. Human skin color model in a color density space.

C. Sensory Evaluation

This study performs a sensory evaluation to investigate the effect of human skin features on skin transparency. We adopt the Semantic Differential (SD) method for sensory evaluation. The evaluation was conducted with a format in which the fitness for the adjective pairs representing human skin characteristics is answered in the five-point Likert scale. We positively select adjectives pairs that express or are related to skin color and light reflection referring to the case study of Takamatsu et al [11]. Besides, we adopt the adjective pairs shown in TABLE I based on the advice of the experts working for cosmetics industry.

It is often difficult for evaluators to keep concentration during the experiments if they need to evaluate too many items. The validity of sensory evaluation results may get worse due to the lack of concentration in the above case. Therefore, considering the burden of the evaluators, we carefully selected ten adjective pairs. Furthermore, we firstly showed ten human skin images different from the ones used for the evaluation to evaluators so that they get used to the evaluation task. The evaluators first evaluated these images which are randomly displayed as a test and then conducted the actual evaluation.

D. Multidimensional Data Visualization

We visualize the data obtained by the procedure shown in section III-B, III-C with Hidden [7]. Human skin features and sensory evaluation results are all real-type variables. Details are shown in TABLE II, TABLE III. In addition, TABLE III is the average value of the 5 scale evaluation results by the Likert scale in each human skin image.

TABLE I
SENSORY EVALUATION ITEMS

1	fair-skinned	1 – 2 – 3 – 4 – 5	dark-skinned
2	reddish tone	1 – 2 – 3 – 4 – 5	not reddish tone
3	yellowish tone	1 – 2 – 3 – 4 – 5	not yellowish tone
4	even color	1 – 2 – 3 – 4 – 5	uneven color
5	smooth	1 – 2 – 3 – 4 – 5	rough
6	noticeable pores	1 – 2 – 3 – 4 – 5	inconspicuous pores
7	glowing	1 – 2 – 3 – 4 – 5	not glowing
8	oily	1 – 2 – 3 – 4 – 5	not oily
9	clear	1 – 2 – 3 – 4 – 5	dull
10	transparency	1 – 2 – 3 – 4 – 5	opacity

1: Extremely, 2: Slightly, 3: Neither, 4: Slightly, 5: Extremely

TABLE II
REAL VARIABLES OBTAINED BY THE IMAGE ANALYSIS

Real Type Variables	
Hmean	Average Hue
Hstd	Standard deviation of hue
Smean	Average saturation
Sstd	Standard deviation of saturation
L*mean	Average lightness
L*std	Standard deviation of lightness
a*mean	Average color (red ⇔ green)
a*std	Standard deviation of color (red ⇔ green)
b*mean	Average color (yellow ⇔ blue)
b*std	Standard deviation of color (yellow ⇔ blue)
Ymean	Average brightness
Ystd	Standard deviation of brightness
Hmmean	Average hemoglobin pigment
Hmstd	Standard deviation of hemoglobin pigment
Mlmean	Average of melanin pigment
Mlstd	Standard deviation of melanin pigment
Specular	Glossy area

IV. VISUALIZATION RESULTS

This section introduces our experiment on a sensory evaluation and the visualization results discussing the findings obtained based on the results.

We invited 15 women as the participants of the skin photography and took photos of their left and right cheeks by the procedure shown in Section III-A. Totally we prepared 30 sets of images and used 29 of the images as targets for the evaluation since one of them was inappropriately taken. We also invited 90 women in their teens to 20's who are different from 15 women who participated as photogenic subjects as

TABLE III
REAL VARIABLES OBTAINED BY THE SENSORY EVALUATION

Real Type Variables	
Whiteness	skin color (fair or not)
Redness	skin color (reddish or not)
Yellowish	skin color (yellowish or not)
Even	skin color (even or not)
Smooth	skin condition (smooth or not)
Pore	skin condition (porous skin or not)
Gloss	skin condition (glowing skin or not)
Oily	skin condition (oily skin or not)
Clear	skin condition (clear skin or not)
Transparency	skin condition (transparent skin or not)

the evaluators of this study. The evaluators in this sensory evaluation were not experts on human skin study.

During the evaluation, we asked all evaluators to use a specific personal computer (PC) and a display device in the same room, unifying the setting of the screen and lighting of the room. After collecting the evaluation results, we scrutinized the contents and checked that no one had peculiar evaluations.

Color-coding the polygonal lines based on multiple categories can improve the comprehensibility of Parallel Coordinate Plot (PCP) while visualizing multidimensional data as a set of polygonal lines. We experimentally found that it is effective to categorize human skin image groups using any of the variables shown in TABLE II and TABLE III, and color-code the polygonal lines accordingly. This paper introduces the visualization results while the numerical range of the evaluation result of skin transparency (Transparency in TABLE III) is evenly divided into three parts. We classified these three categories as highly transparent skin (red), ordinary skin (green), and untransparent skin (blue) respectively.

A. Common Factors for Highly Transparent Skin

Fig. 4 shows the values of an automatically extracted set of four variables "mean lightness, smoothness, pores, and clearness." Comparing the values of high transparent skins drawn as red polylines and the values of untransparent skins drawn as blue polylines in Fig. 4, these values have opposite distributions between the two categories. This result suggests that highly transparent skins are relatively smooth, bright, and clear since they have inconspicuous pores. Focusing especially on the Clear axis in Fig. 4, the result is similar to the evaluation of skin transparency. Between the Transparency axis and the Clear axis, most of the polylines drawn in the three colors do not intersect and are lined up in order from the bottom: red, green, and blue, where their correlation coefficient is 0.9614. From this result, we estimate that the criteria for evaluating transparency and clearness of human skins are close, and also that the unevenness and brightness of human skins are important factors for the evaluation of skin transparency.

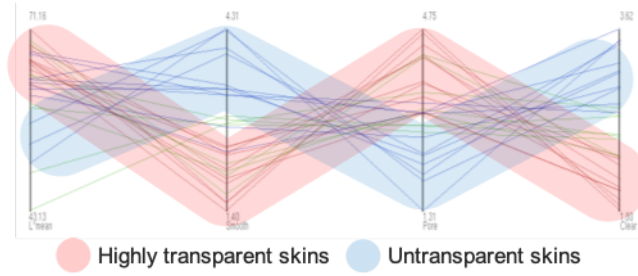

Fig. 4. Visualization result (from left to right, average Lightness, Smooth, Pore and Clear). Red polylines represent highly transparent skins while blue polylines represent untransparent skins.

B. Relationship between Transparency and Color

Fig. 5 shows the values of a set of automatically extracted five variables "average saturation, redness, yellowness, average brightness, and whiteness." We focused on the axes of saturation, redness, and yellowness shown in Fig. 5 and explored the relationship between skin color and skin transparency. As a result, skin redness did not show much difference due to skin transparency. On the other hand, we could divide saturation and yellowness of highly transparent skin into the following two patterns:

- **Pattern (1)**: Desaturated and non-yellowish skin (Skin included in the pink area in Fig. 5)
- **Pattern (2)**: Moderately saturated and yellowish skin (Skin included in the red area in Fig. 5)

Most of the highly transparent skins belong to **Pattern (1)**. It is consistent with a previous study [11] which pointed out that highly transparent skin tends to be desaturated. Meanwhile, we found that the same tendency is observed in **Pattern (2)** even with untransparent skins from the viewpoint of skin color (saturation, redness and yellowness). However, focusing on the axes of brightness and whiteness in Fig. 5, we found that highly transparent skins in **Pattern (2)** are different from untransparent skins in terms of bright and fair skins. In other words, bright and fair skins are presumed to be highly evaluated for skin transparency even if they are determined as yellowish.

Although a previous study [4] has reported that the skin transparency gets lower when the average chromaticity of human skin is far from pink, our study suggests that not only reddish but also yellowish skins may have higher skin transparency. We could discover complex relationships between skin features and skin transparency that span multiple variables and multiple patterns for the same variables thanks to adopting multidimensional data visualization, as shown in this example.

C. Relationship between Transparency and Reflection

Fig. 6 shows the values of a set of automatically extracted six variables "standard deviation of brightness, average brightness, whiteness, transparency, oily, and glow." Focusing on the relationship between brightness and whiteness, we found the following two patterns for highly transparent skin, as described in Section IV-B.

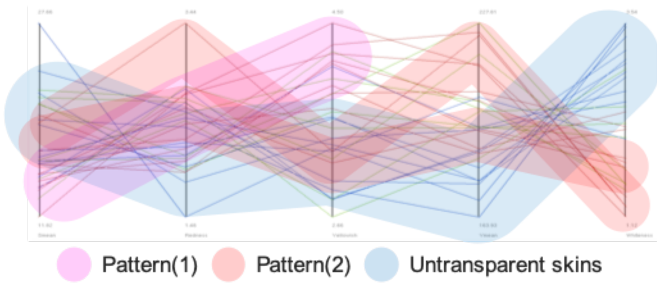

Fig. 5. Visualization result (from left to right, arange Saturation, Redness, Yellowish, average Brightness and Whiteness). Pink area: **Pattern (1)**, Red area: **Pattern (2)**, Blue area: untransparent skins.

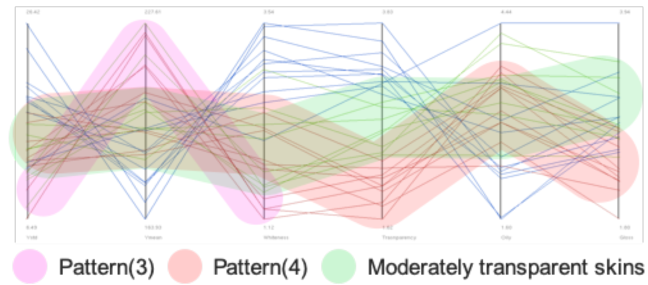

Fig. 6. Visualization result (from left to right, standard deviation of Brightness, average Brightness, Whiteness, Transparency, Oily and Gloss). Pink area: **Pattern (3)**, Red area: **Pattern (4)**, Green area: moderately transparent skins.

- **Pattern (3)**: Fairly white skins with high mean and low standard deviation brightness (Skins included in the pink area in Fig. 6)
- **Pattern (4)**: Skins with average brightness and whiteness (Skins included in the red area in Fig. 6)

We supposed that the skins with a low standard deviation of brightness in **Pattern (3)** have less unevenness in brightness. The reasons for this are that the skins are less uneven and the light reflection is uniform, or that the skin color is fair and close to the color of the light source. In particular, we observed a strong negative correlation (correlation coefficient: -0.8470) between the two axes of the standard deviation of brightness and the average brightness in **Pattern (3)**.

Next, we compared **Pattern (3)** and **Pattern (4)**. Compared to **Pattern (3)**, **Pattern (4)** included many moderately transparent skins in addition to highly transparent skins. Then, we focused on the axes of oiliness and glow in Fig. 6. We found that that the evaluation of oiliness is not so different between highly and moderately transparent skins. On the other hand, the evaluation of glow for highly transparent skins belonging to **Pattern (4)** than that for moderately transparent skins. This result suggests that glow is an important factor of skin transparency in **Pattern (4)**. The gloss is mainly due to specular reflection on the human skin surface. Against previous studies [1] [4] did not focus on specular reflection because it was less correlated with skin transparency than diffuse reflection, we demonstrated that specular reflection can also be an important factor in skin transparency in this study.

The above results suggest that not only fair and bright skin, but also glowing skin with average color and brightness is presumed to be the highly transparent skin. As described in Section IV-B, we have realized complex findings that span multiple variables and the discovery of multiple patterns for the same variable group.

V. Conclusion and Future Work

This paper introduced our exploration on the factor of skin transparency by observing the relationship between human skin features calculated by image analysis and sensory evaluation using a multidimensional data visualization tool. As a result, we found that skin unevenness and brightness are important factors for skin transparency. In addition, regarding skin color and glow, we also found multiple skin patterns on transparent skins. One of out future issues is to increase the amount of human skin image data. Furthermore, it is necessary to consider the use of categorical variables. By increasing the number of images and utilizing categorical variables, we can expect to generate convincing visualization results and discover new findings. As a long-term perspective, we plan to apply the same experiment to makeup skin and pursue the difference in the factors of the transparency of makeup skin.

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