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Color-Based Non-Contact Analysis of Skin Changed by Sweating for Emotion Estimation

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Abstract

In this study, we analyzed the visual difference between dry skin and wet skin for non-contact sweat detection. Recently, there are many researches on emotion recognition using some indexes related to emotion such as electrocardiogram, respiratory, skin temperature, and so on. This is because using some indexes is said to make the accuracy of emotion recognition higher and to help to recognize more various and complex emotions. Also, non-contact method is needed from view point of infection, simplicity when using, and so on. In this paper, we focused on the sweating because detecting the sweating is expected to give us important information on emotion and sympathetic nerve system. For instance, feeling nervous makes palm sweating. Therefore, we considered sweating detection may be useful for emotion recognition. Sweating is conventionally evaluated based on electrodermal activity as known as skin conductance, and that is obtained with a contact method such as attaching electrodes. However, contact methods can cause infection and prevent subjects from concentrating on stimulus to evoke emotion when sweating is used as index of emotion for emotion recognition. Then, we focused on color change caused by wetness. Because total reflection is occurred at water-air interface by water on a material and it makes the light paths longer, the color of material is changed as getting darker and more saturated by wetness. Therefore, we thought that the color change can be useful index for non-contact sweat detection. In this study, we obtained feature values with respect to color using image processing and compared those feature values of dry palm and wet palm. As a result, we found that wetness makes the mean of luminance component smaller, the mean of saturation larger, and the entropy of hue smaller.

1. Introduction

Recently, service robots are required to interact with human more more naturally. In this situation, robots are asked to imagine customers' emotion to give good service. There are robots that can recognize emotions with facial expression recognition and speech recognition [1]. However, they can fail to recognize the emotions of the poker-faced person and the person who speaks in monotonous voice because their system cannot detect any emotional signals from facial expression and speech. Therefore, it is needed to combine facial expression and speech with other index related to emotion, which does not depend on them.

There are a lot of researches of estimating emotion with biological information. For instance, it is possible to estimate emotion with electroencephalogram [2]. It is general to attach electrodes on subjects when measuring biological information as electroencephalogram and electrocardiogram. However, attaching electrodes itself can be stress for them and it is natural situations for robots to sense emotion with non-contact method using cameras and microphones. Also, the pressure of attaching electrodes can be change the range of values. It is also discussed that electroencephalogram may not be enough or suitable information to estimate emotion in service industry. It is required to find the additional method to monitor the emotion by non-contact method.

There are also a lot of researches of estimating emotion estimation using two or more indexes of biological information. For example, there are researches of emotion estimation using not only electrocardiogram but also skin temperature, skin conductance, and respiratory [3-4]. It is considered that the combination of various biological information can help us to estimate more complex emotion, to estimate emotion more accurately, to estimate how the degree of the emotion is, and so on. Therefore, it is important to obtain more various biological information with the non-contact methods. Actually, there are researches of obtaining heart rate variability with non-contact method [5-8] and researches of respiratory rate with non-contact method [9-11]. Then we focused on skin conductance, which is the biological information related to emotion and conventionally measured using attached electrodes.

The skin conductance reflects the variation in the electrical characteristics of the skin and this is the index related to sweating. This is based on that the resistance of the skin changes depending on the state of sweat glands [12]. As you know, there are several types of sweating [13]. The first one is sweating when feeling hot. This is called "thermal sweating" and the purpose of the thermal sweating is to modulate body temperature by sweat evaporating. The sweat glands for the thermal sweating are distributed over almost all skin surface. The second one is sweating when feeling nervous or anxiety. This is called "emotional sweating". The emotional sweating is said to be related to fight or flight response and its purpose is to increase friction for climbing and fleeing by wetness. The sweat glands for emotional sweating are distributed over whole body but especially palms and soles. It is noted that the sweat glands on palms and soles don't respond when feeling hot. If the emotional sweating, which is detected using attached electrodes, can be detected by non-contact method, the emotion recognition will become better.

In this study, therefore, we analyzed visual color changes of palm skin when it is gotten wet. This study is structured as follows. Firstly, we consider how the color of skin change through physical change when the surface gets wet in Section 2. Secondly, we describe our image processing method to obtain feature values in Section 3. Then, we describe you our experimental method in Section 4. In Section 5, we show our results. Then, we discuss our results in Section 6. Finally, we conclude with a summary and our future works in Section 7. This study will help skin conductance measurement without any electrodes. This will also help emotion estimation improved.

2. Physical change when the surface of a material gets wet

In this section, we consider the physical change of skin by its surface gotten wet because sweating makes skin surface wet. Skin surface has many grooves. On the other hand, skin contains pigments such as melanin and hemoglobin and so on. These pigments behave as scattering particles. Therefore, it can be assumed that skin is the material which has rough surface and contains scattering particles.

At first, we will show you light paths of surface reflectance. When the rough surface is dry, the examples of the light paths are shown in Fig. 1. One of the light paths is the path of which the light is reflected at the air-material interface only once, and the other light path is the path of which the light is reflected at the air-material interface more than twice. Both paths are the Fresnel reflection, but we can see light of the former path as a sharp highlight whereas we can see light of the latter path as haze. On the other hand, when the rough surface gets wet, the surface becomes smooth by water. The example of the light path is shown in Fig. 2. Different from the rough surface, the light path of surface reflection on the smooth surface is only the path of which the light is reflected at the air-material interface only once. This is the Fresnel reflection and appears as a sharp highlight. [14]

Then, we will show you the light path of internal reflection. Figure 3 shows the example of light paths which penetrate in the material having dry surface. The light which penetrates in material containing scattering particle is reflected and absorbed by the scattering particles again and again. After that, the light is emitted to the air. On the other hand, figure 4 shows the examples of the light paths which penetrate in the material covered with water. As same as the surface is dry, the lights which penetrate in the material are reflected and absorbed by the scattering particles again and again, then emitted to the water. After that, some are emitted to the air, but the others are reflected at water-air interface. The latter lights penetrate in the material again and the lights are reflected and absorbed again. Therefore, the lights reflected at water-air interface get more saturated and darker [14].

Because of these reasons, the skin is expected to have more sharp highlights, to get more saturated, and to get darker when the surface is covered with water.

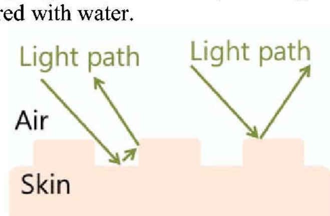


Figure 1 The surface reflection of dry skin

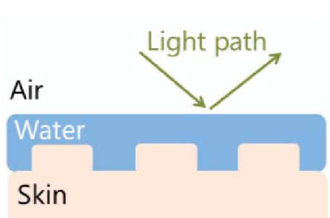


Figure 2 The surface reflection of wet skin

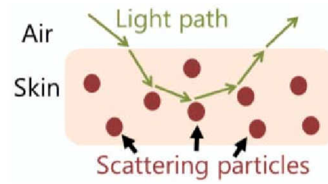


Figure 3 The internal reflection of dry skin

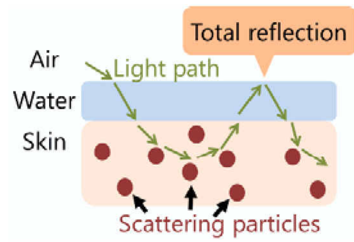


Figure 4 The internal reflection of wet skin

3. Method to obtain color statistics

This section describes the method to obtain color statistic features as the flow shown in Fig. 5. Firstly, *RGB* values are converted into *XYZ* coordinates and this conversion is denoted as following formula [15]:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} 0.412391 & 0.357584 & 0.180481 \\ 0.212639 & 0.715169 & 0.072192 \\ 0.019331 & 0.119195 & 0.950532 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix} \quad (1)$$

where X, Y, and Z is the tristimulus values and R, G, and B is the pixel value of red, green, and blue channel respectively. Especially, the Y component expresses luminance. Then XYZ coordinates are converted to $u'v'Y$ coordinates and this conversion is denoted as following formula [16]:

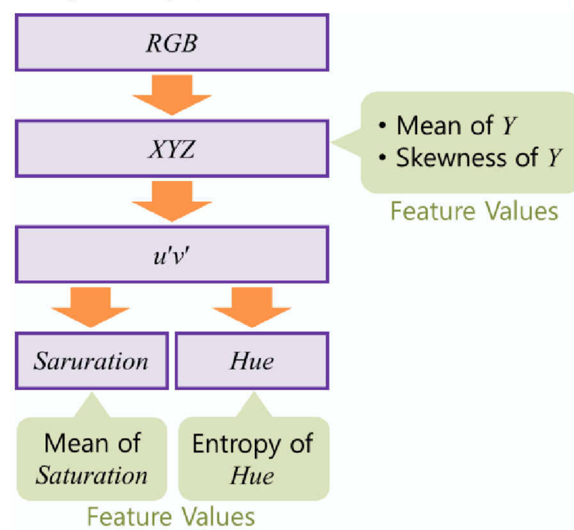


Figure 5 The flow of our method

$$u' = \frac{4X}{X + 15Y + 3Z} \quad (2)$$

$$v' = \frac{9Y}{X + 15Y + 3Z} \quad (3)$$

where u' and v' is the value of $u'v'$ chromaticity coordinates and X, Y, and Z is the tristimulus values. After that, hue and saturation are calculated using following formula [14]:

$$S = 13\sqrt{(u' - u'_n)^2 + (v' - v'_n)^2} \quad (4)$$

$$H = \tan^{-1}\left(\frac{v' - v'_n}{u' - u'_n}\right) \quad (5)$$

where S is the saturation and H is hue. Then u' and v' is the value of $u'v'$ chromaticity coordinates and u'_n and v'_n are the values of white point in $u'v'$ chromaticity coordinates. We decided the white point $(u', v') = (0.199, 0.470)$ as the white area in the Macbeth color checker. Then, we obtained the four feature values: mean of Y, skewness of Y, mean of S, and entropy of H. Sawayama *el al.* showed that wetness makes the mean of Y smaller, the skewness of Y larger, mean of S larger, and entropy of H larger [14].

4. Experiment

We captured the images of palm of the subjects' nondominant hand. We analyzed dry palms and wet palms using feature extractions described in Section 2. Then, we compared the feature values of dry palm images and wet palm images.

4.1. Settings

Figure 6 shows our experimental setup. In dim room, we captured the palm of subjects. The working distance was approximately 0.35 m and the subjects' palms were lit by two artificial solar light sources. The resolution of the camera was 4928 × 3264. The F number was 36. The shutter speed 1/2. The ISO speed was 100.

Figure 6 Our experimental setup

4.2. Participants

All subjects were in their twenties and there were three males and one female. Their dominant hands were the right hand respectively. They all had not done kitchen work and washed their hands just before the experiment to keep their palms dry.

4.3. Procedure

At first, their palm was wiped with dry KimWipes, which remain few fibers on palm after wiping. This is the step to reproduce dry palm. Then, their palm was captured for five second and the capturing interval was approximately 1 second. This was done to cancel the vital color change because of beating with averaging feature values. After that, their palm was wiped with wet hand wipes. This is the step to reproduce wet palm. Then similar to dry palm, their palm was captured for five second and the capturing interval was approximately 1 second.

4.4. Obtaining images for analysis

At first, the data were saved as NEF files, which are the raw data. And then NEF files were converted into 16-bit TIFF files using a software (Nikon View NX 2). To obtain 600 × 600 pixel images of skin for analyses, which is capturing approximately 2.2 cm × 2.2 cm on the real skin surface, we trimmed whole images at same coordinate. We obtained skin images of three areas as (1) the area between the base of index finger and the base of middle finger, (2) the area between the base of middle finger and the base of ring finger, (3) the area between the base of ring finger and the base of pinky finger, as shown in Fig.7. We decide to analyze these areas because they contain the sharp highlight.

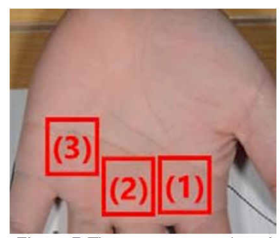
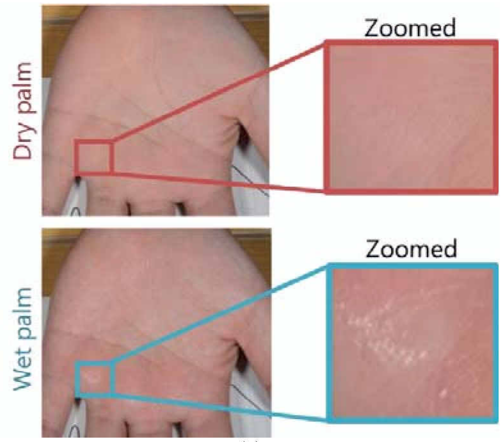


Figure 7 The areas we analyzed

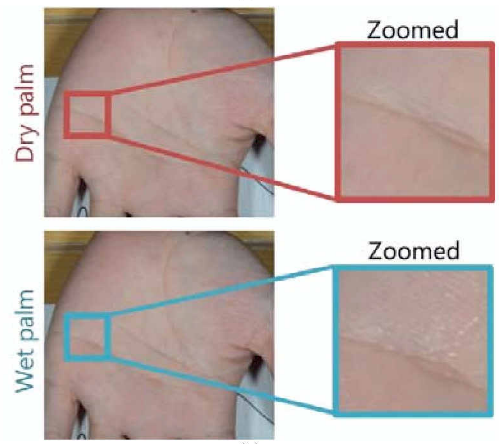
5. Results

Figures 8 shows example images of the dry palm and the wet palm of each subject, and the top is the image of dry palm and the bottom is the image of wet palm. (a) is the palm of Subject 1, (b) is the palm of Subject 2, (c) is the palm of Subject 3, and (d) is the palm of Subject 4. You can see that the wet palm has a lot of sharp highlights rather than haze, compared with dry palm. Furthermore, the wet palm looks to have more favorable complexion than the dry palm.

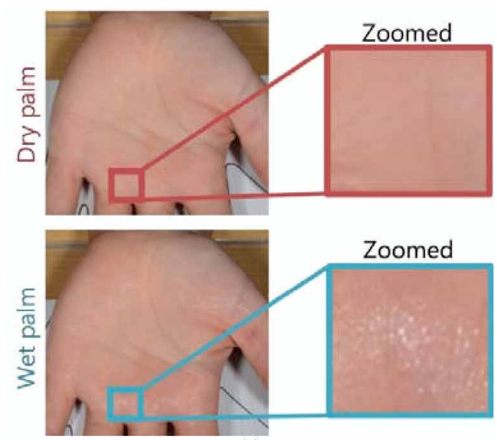
Figures 9–13 show the results of (1) the area between the base of index finger and the base of middle finger. Figure 9 shows the result of the mean of Y component. Figure 10 shows the result of the skewness of Y component. Figure 11 shows the result of the mean of saturation. Figure 12 shows the result of the entropy of hue. The horizontal axis of each graph is the state, and the vertical axis is the feature value of the graph. Figure 13 also shows the result of the entropy of hue to easily display the standard deviation. The horizontal axis of Fig. 13 is the state and the subject, and the vertical axis of Fig. 13 is the feature value of the graph. The bars show the averaged feature values of skin images continuously captured and the error bars show the standard deviations, respectively. The bars are colored to distinguish each subject and the left bar of each color shows the feature value of dry skin



(a)

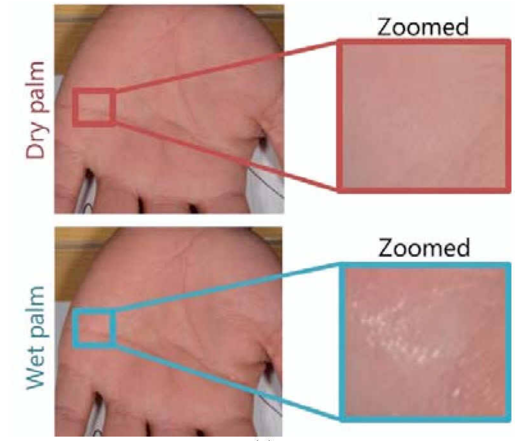


(b)



(c)

surface whereas the right bar shows that of wet skin surface. As shown in Fig. 9, the mean of *Y* component of this area on the wet palm is smaller than that on the dry palm. As shown in Fig. 10, the skewness of *Y* component of this area on the wet palm tends to be smaller than that on the dry palm. As shown in Fig. 11, the mean of saturation of this area on the wet palm tends to be larger than that on the dry palm. As shown in Fig. 12, the entropy of hue of this area on the wet palm is smaller than that on the dry palm. As shown in fig. 13, the standard deviation of hue entropy tends to be smaller as getting wet.



(d)

Figure 8 The images of dry palm and wet palm of each subject: (a) Subject 1, (b) Subject 2, (c) Subject 3, (d) Subject 4

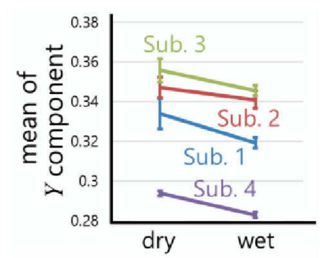


Figure 9 The mean of Y component on (1) the area between the base of index finger and the base of middle finger

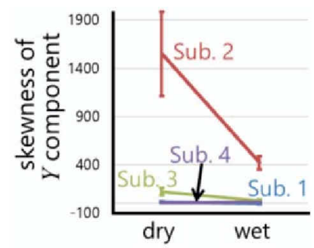


Figure 10 The skewness of Y component on (1) the area between the base of index finger and the base of middle finger

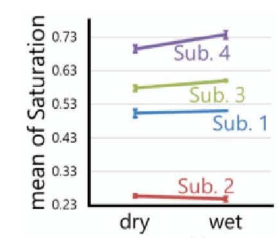


Figure 11 The mean of Saturation on (1) the area between the base of index finger and the base of middle finger

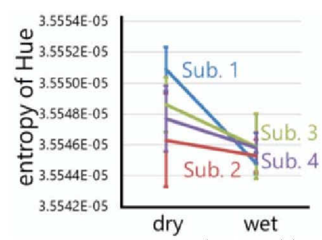


Figure 12 The entropy of Hue on (1) the area between the base of index finger and the base of middle finger

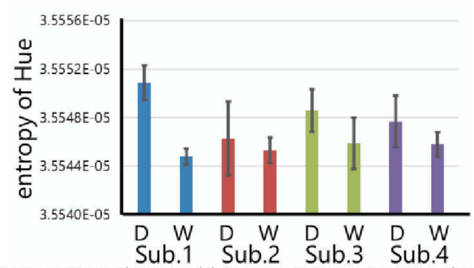


Figure 13 The entropy of Hue on (1) the area between the base of index finger and the base of middle finger

Figures 14-18 show the results of (2) the area between the base of middle finger and the base of ring finger. Figure 14 shows the result of the mean of *Y* component. Figure 15 shows the result of the skewness of *Y* component. Figure 16 shows the result of the mean of saturation. Figure 17 shows the result of the entropy of hue. The horizontal axis of each graph is the state, and the vertical axis is the feature value of the graph. Figure 18 also shows the result of the entropy of hue to easily display the standard deviation. The horizontal axis of Fig. 18 is the state and the subject, and the vertical axis of Fig. 18 is the feature value of the graph. The bars show the averaged feature values of skin images continuously captured and the error bars show the standard deviations, respectively. The bars are colored to distinguish each subject and the left bar of each color shows the feature value of dry skin surface whereas the right bar shows that of wet skin surface. As shown in Fig. 14, the mean of *Y* component of this area on the wet palm is smaller than that on the dry palm. As shown in Fig. 15, the skewness of *Y* component of this area on the wet palm tends to be smaller than that on the dry palm. As shown in Fig. 16, the mean of saturation of this area on the wet palm is larger than that on the dry palm. As shown in Fig. 17, the entropy of hue of this area on the wet palm is smaller than that on the dry palm. As shown in fig. 18, the standard deviation of hue entropy tends to be smaller as getting wet.

Figures 19-22 show the results of (3) the area between the base of ring finger and the base of pinky finger. Figure 19 shows the result of the mean of *Y* component. Figure 20 shows the result of the skewness of *Y* component. Figure 21 shows the result of the mean of saturation. Figure 22 shows the result of the entropy of hue. The horizontal axis of each graph is the state, and the vertical axis is the feature value of the graph. The bars show the averaged feature values of skin images continuously captured and the error bars show the standard deviations, respectively. As shown in Fig. 19, the mean of *Y* component of this area on the wet palm tends to be smaller than that on the dry palm. As shown in Fig. 20, the skewness of *Y* component of this area on the wet palm tends to be smaller than that on the dry palm. As shown in Fig. 21, the mean of saturation of this area on the wet palm is larger than that on the dry palm. As shown in Fig. 22, the entropy of hue of this area shows no significant trend, but the standard deviation of hue entropy tends to be smaller as getting wet.

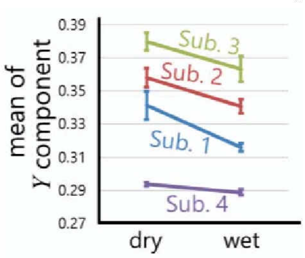


Figure 14 The mean of Y component on (2) the area between the base of middle finger and the base of ring finger

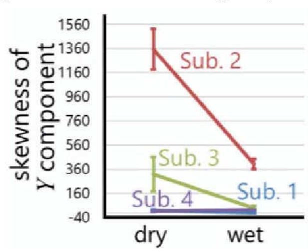


Figure 15 The skewness of Y component on (2) the area between the base of middle finger and the base of ring finger

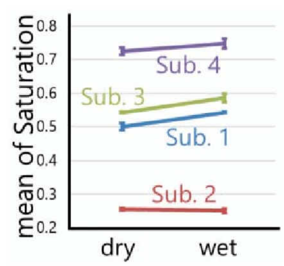


Figure 16 The mean of Saturation on (2) the area between the base of middle finger and the base of ring finger

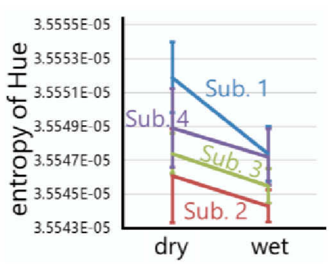


Figure 17 The entropy of Hue on (2) the area between the base of middle finger and the base of ring finger

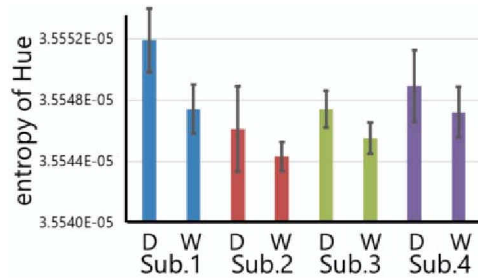


Figure 18 The entropy of Hue on (2) the area between the base of middle finger and the base of ring finger

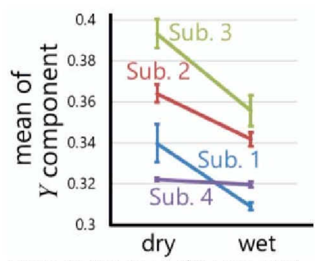


Figure 19 The mean of Y component on (3) the area between the base of ring finger and the base of pinky finger

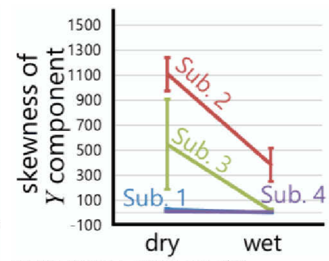


Figure 20 The skewness of Y component on (3) the area between the base of ring finger and the base of pinky finger

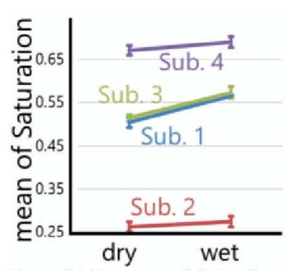


Figure 21 The mean of Saturation on (3) the area between the base of ring finger and the base of pinky finger

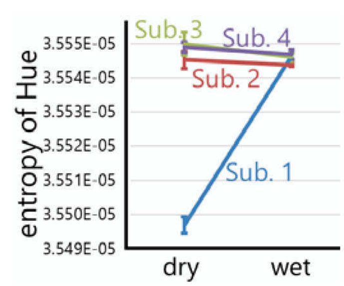


Figure 22 The entropy of Hue on (3) the area between the base of ring finger and the base of pinky finger

6. Discussion

As mentioned in Section 5, the wet palm has sharp highlights rather than haze whereas the dry palm has few sharp highlights. This is the expected change because water on palm makes surface of palm smooth and help to occur the specular reflection. Moreover, most sharp highlights are on slope areas. Therefore, it can be said that the geometry of the area may be important to capture the change by wetness. Also, as mentioned in Section 5, the wet palm became to look favorable complexion. This is considered to be related to increasing saturation. That might be because of increasing blood volume by wiping.

The mean of *Y* component tends to be smaller through all analyzed area after the skin gets wet. Also, the mean of saturation tends to be larger through all analyzed area after the skin gets wet. This is almost the same as the results which Sawayama *et al.* showed [14]. It makes sure that the physically change by wetness can be captured on the living body.

The values of the skewness of *Y* component are very different among individual. Also, some subjects' trend on the skewness of *Y* component are randomly change as increasing and decreasing after the palm get wet whereas the skewness of *Y* component of the other subjects' is constantly decreasing. Therefore, the skewness of *Y* component may be useful for limited individuals or it may be not useful feature values to evaluate wetness of skin. It can be considered that non-polarized capturing makes the skewness of *Y* component no significant trend. Therefore, it is needed to verify with polarized images.

It is different from the result of Sawayama *et al.* [14], but the entropy of hue tends to be smaller through all analyzed area after the skin gets wet. This may be because the haze on the dry palm makes the number of gradation increased. It might be possibly treated of a trivial change because the small region of skin originally has few color variations expressed as very low entropy. This is not mentioned in the study which Sawayama *et al.* performed, but the standard deviation of the entropy of hue tends to decrease after the skin gets wet. Therefore, the standard deviation of the entropy of hue is possibly considered as the feature value which is important to evaluate wetness of skin.

7. Conclusion and Future Work

In this study, we analyzed the visual difference between dry palm and wet palm. The analyzed regions are 3 regions as (1) the area between the base of index finger and the base of middle finger, (2) the area between the base of middle finger and the base of ring finger, and (3) the area between the base of ring finger and the base of pinky finger. We obtained four feature values using image processing. Firstly, *RGB* values are converted into *XYZ* coordinates. Then, *XYZ* coordinates are converted to *u'v'Y* coordinates. After that, hue and saturation are calculated from *u'v'Y* coordinates. Finally, we obtained feature values as mean of *Y* component, skewness of *Y* component, mean of saturation, and entropy of hue. Compared with dry palm, wet palm has a lot of sharp highlights rather than haze. Also, the wet palm looked to have favorable complexion compared with dry palm. From feature values, we can see that wetness makes the mean of *Y* component tend to decrease, the mean of saturation tends to increase, the entropy of hue tends to decrease. Some results imply that there are effects of Fresnel reflection on the feature values. It can be said that the geometry of palm is important because the trend of feature values is a little bit different between each analyzed area.

As written above, the effect of Fresnel reflection is implied. Therefore, it is needed to analyze with polarizing plates to remove surface reflection and compare with the result of non-polarized image. Furthermore, extracting gloss component to obtain feature value not related color may make the wetness detection on the skin easier. In this study, we reproduced the wet palm with water. However, the components are different between water and sweat. The difference of component may have effect on color. Therefore, it is needed to analyze the difference between water and sweat. This is the study for emotion recognition. So, it is needed not to depend on skin color. The analyses on the various skin type are also our future works.

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