Measuring Human Skin Colour

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Abstract

Human skin colour measurements from four ethnic groups including 188 subjects were accumulated. Five to ten locations of each subject were measured by using two different instruments, a tele-spectroradiometer and a spectrophotometer. Three repeated measurements were accumulated for each location. Repeatability of the measurements at different locations from different ethnicities was examined using the mean CIELAB colour difference from the mean (MCDM). The colour distribution between different locations of different ethnic groups was also studied by plotting the data in a^*b^* *and* $L^*C^*_{ab}$ *planes. Systematic trends were found between different ethnicities and instruments.*

Introduction

Human skin colour is of great importance for the cosmetic industry and medicine where accurate skin colour measurement and reproduction are key factors. CIE colorimetry has been widely used to objectively measure human skin colour for more than half century. However, due to the multilayered skin structure, its non-flat surface and the uneven distribution of human skin colour over different body parts, existing databases on skin colour are not exhaustive and precise. Different ethnicities and/or genders exhibit significantly different skin colour[1]. Tele-spectroradiometers (TSRs) and spectrophotometers (SPs) are two types of instruments that are most widely used for measuring skin colour. For example, TSRs are used for measuring colour appearance such as in cosmetic industry for developing skin colour charts and evaluating skin products [2]. SPs are mainly used for diagnosing skin disease symptom, such as erythema and irritation [3-7]. The measurement results are frequently reported using CIELAB uniform colour space, in terms of lightness, chroma and hue. Although large skin databases have been obtained, they include data from different instruments. Although, some progress has been made on human skin colour measurements. However, the repeatability performance of different body locations, ethnicities and instruments are often overlooked.

With the above in mind, CIE TC 1-92 Skin Colour Database was formed. It was aimed to investigate the uncertainty in skin colour measurement and to recommend protocols for good measurement practice. A collaborative project was also established between the Leeds and Liverpool universities in UK with a goal to collect a comprehensive skin database and to achieve successful colour reproduction of skin colours on multimedia. The results from the present study should be valuable to this TC. The skin colour data obtained in this study are based on ten different body locations of 188 subjects from four different ethnic groups. Firstly, short-term repeatability was examined. Then the colour distributions from different ethnic groups and from different instruments are revealed.

Experimental Methods

Skin color measurement and database

Overall, 188 subjects participated in this study, including 86 Oriental (41 females and 45 males), 79 Caucasian (65 females and 14 males), 13 South Asian (6 females and 7 males) and 10 African (5 females and 5 males). An SP (Konica-Minolta CM700d) and a TSR (Photo Research SpectraScan Colourimeter PR650) were used for colour measurement. The former is a contact measuring instrument with a geometry of di:8^o. The latter is a non-contact measuring instrument. It was operated in a VeriVide DigiEye® light booth, painted with a mid-grey matte colour and was illuminated by a D65 fluorescent simulator offering evenly diffused illumination. A mask with a plate in front of the CM700d was used. The physical measuring sizes of the CM700d and PR650 had diameters of 8 mm and10 mm, respectively.

As a baseline measure for instrument repeatability, each of the seven chosen colour patches from the Pantone Skintone Guide® were measured three times using both instruments. The CM700d was used to measure 10 locations of each subject: forehead (FH), cheek, cheekbone (CB), neck, chin, inner forearm (IF), outer forearm (OF), back of hand (BH), nose tip (NT) and fingertip (FT). The measurement locations were selected based on the previous research [8,9]. Then the same subject was invited to sit inside the light booth of the DigiEye system where only five locations – forehead (FH), cheek, cheekbone (CB), neck and back of hand (BH) – were measured using the PR650. All measurements were repeated three times.

Measurement results were recorded in terms of spectral reflectance. For the PR650, its reflectance data were obtained by dividing the spectral power distribution (SPD) of the skin colour measured by the SPD of a reference white tile. Finally, the reflectance data were transformed to CIELAB values under the CIE D65 and 1931 standard colorimetric observer.

Repeatability

MCDM (mean colour difference from the mean value) was used to express the repeatability of each measuring instrument. It is calculated using Eq. 1. A larger MCDM value indicates a poorer repeatability.

$$MCDM = \frac{\sum_{i=1}^{n} \Delta E^*_{abi}}{n} \qquad (1)$$

where

$$\Delta E^*_{abi} = \sqrt{(L^*_i - L^*_{mean})^2 + (a^*_i - a^*_{mean})^2 + (b^*_i - b^*_{mean})^2}$$

$$L^*_{mean} = \frac{\sum_{i=1}^{n} L^*_i}{n}$$

$$a^*_{mean} = \frac{\sum_{i=1}^{n} a^*_i}{n}$$

$$b^*_{mean} = \frac{\sum_{i=1}^{n} b^*_i}{n}$$

where n is the number of samples, i.e. it is 3 in this study; I runs from 1 to 3.

MCDM is used to report the repeatability performance of an instrument according to different ethnicities and body locations.

Skin colour distribution

The three repeated colour measurements of each skin location were averaged in CIELAB colour co-ordinates and were used to represent average skin colours for different ethnic groups in different body location. The CIELAB values were plotted in a a^*b^* and $L^*C^*_{ab}$ planes to reveal the systematic colour changes between different ethnicities and instruments. .

Result and analysis

Repeatability for different ethnic groups and measurement locations

The mean MCDM values of the seven Pantone skin colour patches were 0.042 and 0.085 ΔE^*_{ab}, for the CM700d and PR650 respectively. These values represent the typical performance of the short-term repeatability of these two instruments. PR650, a non-contact instrument, is expected to perform less repeatable than CM700d, a contact instrument.

Table 1 lists the average MCDM values of ten locations for each ethnic group measured with the CM700d. It shows that the repeatability of mean location performed the best for the inner and outer forearm (MCDM about 0.17 ΔE^*_{ab}) and the worst for the fingertip and the nose tip (about 0.70 ΔE^*_{ab}). In general, arm locations result in greater repeatability due to its flat surface, with the exception of the finger tip. The results here strongly reflect that it is much less repeatable or more difficult to measure skin colours than static objects like colour patches. For different face/body locations, the repeatability can be significantly varied, which is caused by the difference of the physical properties of the measurement locations.

For different ethnic groups, repeatability was the best for the African group (MCDM= 0.25 ΔE^*_{ab}) comparing with the other three groups (about 0.45 ΔE^*_{ab}). Note that only 10 subjects in the African group.

Table 1. The average MCDM values of different ethnicities at ten different locations using CM700d

	FH	CB	Cheek	Neck	BH	IF	OF	Chin	NT	FT	Mean of ethnic group
Oriental	0.42	0.38	0.36	0.40	0.24	0.22	0.20	0.60	0.79	0.67	0.43
Caucasian	0.42	0.46	0.42	0.55	0.28	0.21	0.18	0.59	0.86	0.86	0.48
South Asian	0.40	0.76	0.34	0.41	0.26	0.13	0.19	0.46	0.63	0.77	0.43
African	0.17	0.18	0.23	0.23	0.19	0.09	0.11	0.24	0.29	0.75	0.25
Mean of locations	0.35	0.44	0.34	0.40	0.24	0.16	0.17	0.47	0.64	0.76	-
Mean MCDM	-	-	-	-	-	-	-	-	-	-	0.40

Table 2 reports the same results as Table 1 except that all results were measured by the PR650. Based on the mean MCDM values of each location, the forehead is the most repeatable location while the cheek is the least repeatable one. On average, the Oriental group results yield the highest repeatability, whereas the African group results yield the worst repeatability. For the Oriental, Caucasian and South Asian groups, forehead measurement results yield the best repeatability, while cheek measurement results were the least variable in the African group. The average MCDM values of Oriental and Caucasian's neck show the largest variation among the five locations measured. The average MCDM value was approximately 1.00 ΔE^*_{ab}. For South Asian group, the MCDM value on cheek and back of hand was approximately 1.00 ΔE^*_{ab}, which was almost double of their forehead's result. For the African group, the variation of the cheekbone's measurement results is less than those of the other locations, i.e. the average MCDM value for this location was 0.55 ΔE^*_{ab}. The average MCDM value for the African group's cheek was 2.30 ΔE^*_{ab}, which is the least repeatable one. This is due to the presence of hairs, which caused problems to select a uniform area, and difficult for the subjects to hold the position.

Table 2. The average MCDM values of different ethnicities at five different locations using PR650

	FH	CB	Cheek	Neck	BH	Mean of ethnic group
Oriental	0.33	0.76	0.87	0.98	0.63	0.71
Caucasian	0.47	0.80	1.04	1.13	1.01	0.89
South Asian	0.40	0.66	0.99	0.72	1.04	0.76
African	0.75	0.55	2.30	0.78	0.62	1.00
Mean of locations	0.49	0.69	1.30	0.90	0.82	-
MCDM of PR650	-	-	-	-	-	0.84

Comparing Tables 1 and 2, the results showed that the mean MCDM value of the CM700d (0.40 ΔE^*_{ab}) is half of that of PR650 (0.84 ΔE^*_{ab}). This is expected as non-contact instrument to have worse performance than contact measurement, mainly due to the methods of sampling. This is particularly marked for the African group results, i.e. 1.00 and 0.25 for the PR650 and CM700d, respectively.

Colour distribution between different ethnicities and instruments

In addition to repeatability, the colour shifts between different ethnic groups, for both instruments were also investigated. Mean CIELAB values for each skin colour are plotted in CIELAB a^*b^* and $L^*C^*_{ab}$ planes. Figure 1 shows the mean skin colours of four ethnic groups for the two instruments. For each ethnic group, the mean CIELAB values of five locations (forehead, cheek, cheekbone, neck and back of hand), measured by the CM700d (in red) and PR650 (in blue) were plotted. It can be seen that the PR650 measurements in general had a lower lightness than those of the CM700d for all ethnic groups. From Figure 1, it can be found that hue angles between instruments agree well. The average hue angles of four ethnic groups were 60°, 54°, 60° and 53°, when measured by the CM700d, for the Oriental, Caucasian, South Asian and African respectively. When measured by the PR650, the mean hue angles were 60°, 56°, 59° and 54°. The ΔH^*_{ab} between two instruments was about 0.41, and hue angle difference is less than 2°. The result indicates an excellent agreement in hue between two instruments. The error bars in these two figures were standard error.

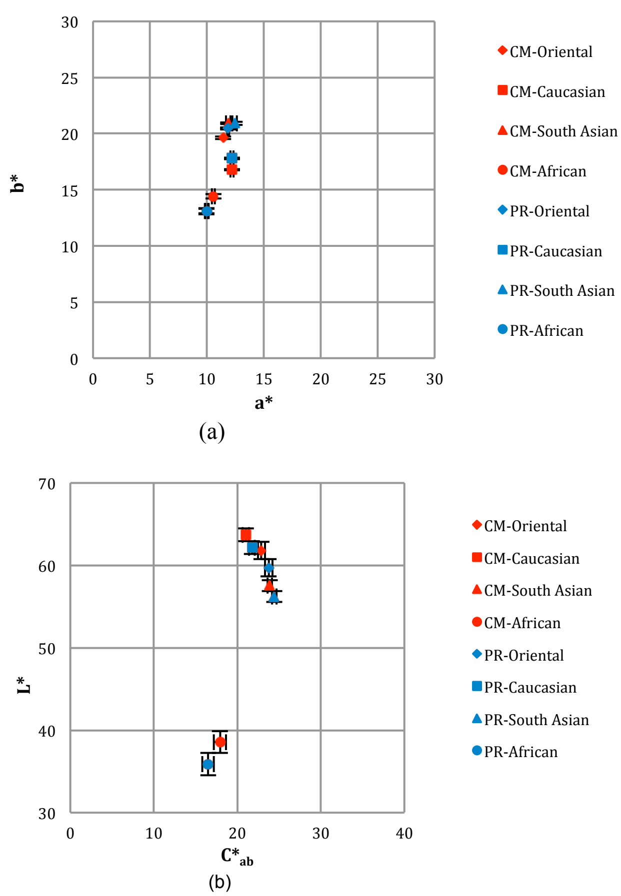
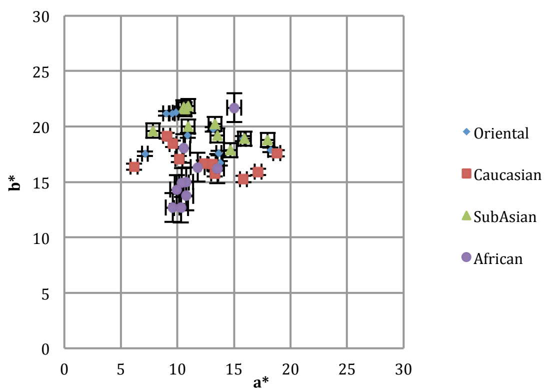
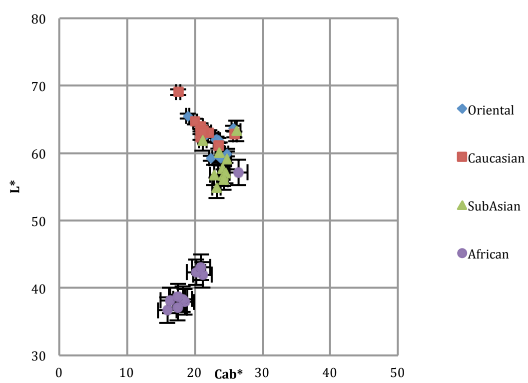


*Figure 1. The average CIELAB values of four ethnic groups measured by the CM700d (CM) and PR650 (PR) in (a) a*b* and (b) L*C*ab planes*

Figures 2(a) and 2(b) plot 40 data points from ten locations and four ethnic groups measured by CM700d in a^*b^* and $L^*C^*_{ab}$ planes, respectively. Similar trends were found for the PR650 results. It can be seen in Figure 2(b) that the African group had the lowest lightness, followed by the South Asian, and finally Oriental and Caucasian groups. The latter two groups had very similar lightness. Figure 2(a) showed that all locations in the African group had a fixed hue angle at about 53° but differed in chroma. The other three groups had a wide range of hue angle from 45° to 69° but with similar chroma. In Figure 2(b), for the Caucasian and Oriental groups, which means the higher lightness skin colours are less colourful, or appeared whiter (the best-fitted line towards the white point in the neutral axis). However, for the African group, the darker colours also appear less colourful, i.e. appeared blacker (the best-fitted line towards the black point in the neutral axis). For the South Asian group, the variation is only in lightness.



(a)



(b)

*Figure 2. The mean CIELAB values of ten locations of each ethnic group measured by CM700d in (a) a*b* plane and (b) L*C*ab plane*

Conclusions

The variation in skin measurements of different body locations in four ethnic groups were examined from two instruments, a spectrophotometer and a tele-spectoradiometer, in this paper. Overall, the repeatability varies depending upon ethnicity, body location and instrument type. On average, the spectrophotometer provided better repeatability than the tele-spectroradiometer, by a factor of 2.

The colour appearance differences as a function of ethnicity were determined by plotting the results in a^*b^* and $L^*C^*_{ab}$ planes. In the Caucasian and Oriental groups, lightness and chroma are negatively correlated, i.e. a lighter skin colour will also be less colourful, while a positive relationship exists between lightness and chroma for the African group. There is only lightness variation for the South Asian group.

The distribution of the mean skin colours is similar for the two measurement instruments. In general, the non-contact instrument, PR650, results are darker than the contact instrument, CM700d, results with excellent agreement in hue angle.

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