Chapter 2
The Colour Shifting of Measuring Human Skin Colour Use Different Instruments

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Abstract Human skin colour information is important for the cosmetic industries and hospitals to develop a skin product and suggest an appropriate treatment. Human skin has multi-layered structures with non-flat surface and the colour of the human skin is unevenly distributed over the body. It is difficult to get skin colour information both exhaustively and precisely. Different ethnicities exhibit significantly different skin colour. To supply the data to the CIETC 1-92 Skin Colour Database and to achieve successful colour reproduction of skin colours on multimedia, two most widely used instruments, tele-spectroradiometers (TSRs) and spectrophotometers (SPs), were employed to collect large numbers of human skin colour, including 188 subjects from four ethnic groups (Oriental Caucasian, South Asian and African). Five or ten locations from each subject were measured. At each location, three repeated measurements performed by using both instruments and their mean values were used as the measurement results. The measurement results were reported using CIELAB colour system, in terms of lightness, chroma and hue. The colour distribution between different locations of different ethnic groups was studied by plotting the data points in a^*b^* and $L^*C^*_{ab}$ planes. Systematic trends were found between different ethnicities and instruments. The result shows a significant trend of the colour shifting between different ethnicities and instruments.

Keywords Skin colour · Colour shifting · Tele-spectroradiometer · Spectrophotometer

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2.1 Introduction

The colour of skin is a significant feature of human. It can reflect ethnic, health and habitat environment. It is also a critical factor for reproducing human facial image in printing and display industry. For diagnosing cutaneous disease, the skin colour is closely related to the effectiveness of the treatment. For the skin colour measurement, CIE colorimetry has been widely used for more than 30 years to provide objective measurements for human skin colour, which is of great importance for the cosmetic industry and hospitals to develop a skin product and suggest an appropriate treatment. Tele-spectroradiometers (TSRs) and spectrophotometers (SPs) are two instruments that were widely used for measuring skin colour in vivo. For example, TSRs are frequently used in cosmetic industry for developing a skin colour chart and for evaluating skincare products [1]. SPs are sometimes used for diagnosing skin disease symptom [2–6]. The measurement results are frequently reported using CIELAB colour system, in terms of lightness, chroma and hue. Different from other materials, i.e. paper, glass and textile, human skin has a multi-layer structure with non-flat and non-uniform colour surface. The pressure, measuring field size and measuring geometry can affect the measurement results. Although large amounts of work on human skin colour measurements were based on these two instruments, the research of the uncertainty of the measurement by using these two instruments to measure human skin colour was limited.

2.2 Objectives

These skin colour data were part of the Leeds Liverpool Skin colour database (LLSC) which is part of the CIE TC1-92 Skin Colour Database. A large-scale research project was set up between the University of Leeds and the University of Liverpool to measure and to collect skin colours from different ethnicities and using different instruments. The aim of this project was to investigate the uncertainty in skin colour measurements, such as ethnicity, age, gender and body location. This chapter presents a study, which aimed to investigate the uncertainty of using a SP (Konica Minolta CM700d spectrophotometer, referred as CM700d) and a TSR (Photo research inc. PR-650 Spectra Scan, referred as PR650) to measure skin colour. The colour shifting between different ethnicities and between these two instruments was evaluated.

2.3 Methodology

One hundred and eighty-eight subjects, including 86 Oriental, 79 Caucasian, 13 South Asian and 10 Africa with both genders, were measured by CM700d and PR650. For each subject, ten locations—forehead (FH), cheek, cheekbone (CB), neck, chin, inner forearm (IF), outer forearm (OF), back of hand (BH), nose tip (NT) and fingertip (FT)—were measured by CM700d and five locations—forehead (FH), cheek, cheekbone (CB), neck and back of hand (BH)—were measured by PR650. The measurement locations were selected based on the previous research [7, 8]. Each location was measured three times using both instruments and the average of these three repeat measurements was used as the measurement result. A specially build imaging light booth from Verivide was used to provide illumination for the PR650. This imaging light booth is painted with natural paint inside and proved D65 diffused illumination. The PR650 was placed behind the illumination to avoid project shadow on the subject. The measurement results, the spectral reflectance (CM700d) and spectral power distribution (PR650), were transformed to CIELAB values by using CIE 1931 Standard Colorimetric Observer, as both instruments' measuring angles were set in 2^{O}, and the $X_0Y_0Z_0$ which gained form the SPD measured inside the imaging light booth. This SPD was measured by using the PR650 at the same position as the skin colour measurement. The equation set list below was used to gain the $X_0Y_0Z_0$.

$$\begin{aligned} Y &= \frac{\mathrm{SPD_w}}{R_\mathrm{w}\%} \times \bar{y}(\lambda) \\ X_0 &= \sum \frac{\frac{\mathrm{SPD_w}}{R_\mathrm{w}\%} \times \bar{\mathrm{x}}(\lambda)}{Y} \times 100 \\ Z_0 &= \sum \frac{\frac{\mathrm{SPD_w}}{R_\mathrm{w}\%} \times \bar{z}(\lambda)}{Y} \times 100 \\ Y_0 &= 100 \end{aligned} \tag{2.1}$$

where $\mathrm{SPD_w}$ is the spectral power distribution of a white chart measured by the PR650. The $R_\mathrm{w}\%$ is the spectral reflectance of the same white chart that is measured by CM700d. $\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$ are the CIE 1931 Standard Colorimetric Observer (D65, 2^{o}).

The colour shifting between different ethnic groups and instruments was investigated through the $\Delta E^*_{ab}, \Delta L^*, \Delta H^*_{ab}, \Delta C^*_{ab}$ and Δh_{ab} values and the plots of the average CIELAB on a^*b^* and $L^*C^*_{ab}$ planes. $\Delta E^*_{ab}, \Delta L^*, \Delta H^*_{ab}, \Delta C^*_{ab}$ and Δh_{ab} were calculated, which is calculated using the formulas as listed in Eq. (2.2). The average of each ethnic group's each location's CIELAB was used to represent the colour of each location of each group.

$$\begin{aligned} \Delta E^*_{ab} &= \sqrt{\left(L^*_{\mathrm{PR}} - L^*_{\mathrm{CM}}\right)^2 + \left(a^*_{\mathrm{PR}} - a^*_{\mathrm{CM}}\right)^2 + \left(b^*_{\mathrm{PR}} - b^*_{\mathrm{CM}}\right)^2} \\ \Delta L^* &= L^*_{\mathrm{PR}} - L^*_{\mathrm{CM}} \\ \Delta C^*_{ab} &= C^*_{ab,\mathrm{PR}} - C^*_{ab,\mathrm{CM}} \\ \Delta H^*_{ab} &= \sqrt{(\Delta E^*_{ab})^2 - (\Delta L^*)^2 - (\Delta C^*_{ab})^2} \\ \Delta h_{ab} &= h_{ab,\mathrm{PR}} - h_{ab,\mathrm{CM}} \end{aligned} \tag{2.2}$$

2.4 Result and Analysis

The colour shift was investigated through the colour difference between two instruments at each ethnic group measurement results, as listed in Table 2.1. For each group, the mean CIELAB values of five locations, including forehead, cheek, cheekbone, neck and back of hand, which measured by both instruments, were averaged and compared. $\Delta E^*_{ab}, \Delta L^*, \Delta H^*_{ab}, \Delta C^*_{ab}$ and Δh_{ab} were calculated to indicate the colour shifting of these two instruments' measurement results in lightness, chroma and hue. From the data listed in Table 2.1, the average colour difference between these two instruments is about 2.18 ΔE^*_{ab}, which is significant. The PR650 measurement results had higher chroma and lower lightness than those of the CM700d for all ethnic groups except the African, as ΔL^* and ΔC^*_{ab} of these three groups were appear as positive and negative, respectively. From Δh_{ab}, we can find that their hue angles agree well with each other. The average hue difference between these two instruments of these four ethnic groups is about 0.4. The average hue angle difference between these two instruments' measurement results is about 2°.

In Figs. 2.1a and 2.2b, the four ethnic groups' average CIELAB gained from ten locations measured by CM700d in a^*b^* and $L^*C^*_{ab}$ planes, respectively, is plotted. It can be seen that African group has the lowest lightness than the others. The Caucasian group showed the highest lightness while the African group exhibits the lowest. The other three groups had similar hue angle and chroma. The error bar plot in Fig. 2.1 is the standard deviation of ten measurement locations of each ethnic group. From the error bar, we can see the colour shifting between different measurement locations were more significant in hue for Oriental, Caucasian and South Asian Groups, as shown in Fig. 2.1a. For the African group, the colour shifting between different locations appears most significantly in lightness.

Figure 2.2 shows the PR650's measurement results of four ethnic groups, which average from four locations. Comparing the measurement results from CM700d, the distribution of four ethnic groups' measurement results is similar to the measurement results from CM700d, as shown in Fig. 2.1. However, the chroma difference between African group and other three groups is more significant in the PR650's measurement results than the results from the CM700d. The error bar in Fig. 2.2 is the standard deviation of five locations of each ethnic group. Comparing to the CM700d's plot, as shown in Fig. 2.1, the variation of the PR650's results was less than the CM700d's, as there are only five locations measured by PR650.

Table 2.1 The colour difference ($\Delta E^*_{ab}, \Delta L^*, \Delta H^*_{ab}, \Delta C^*_{ab}$ and Δh_{ab}) of four ethnic groups measured by the CM700d and PR650

	ΔE^*_{ab}	ΔL^*_{ab}	ΔH^*_{ab}	ΔC^*_{ab}	Δh_{ab}
Oriental	2.31	2.11	0.35	−0.88	−0.110
Caucasian	1.85	1.56	0.65	−0.74	−1.980
South Asian	1.50	1.35	0.38	−0.54	0.690
African	3.05	2.68	0.25	1.44	−1.530

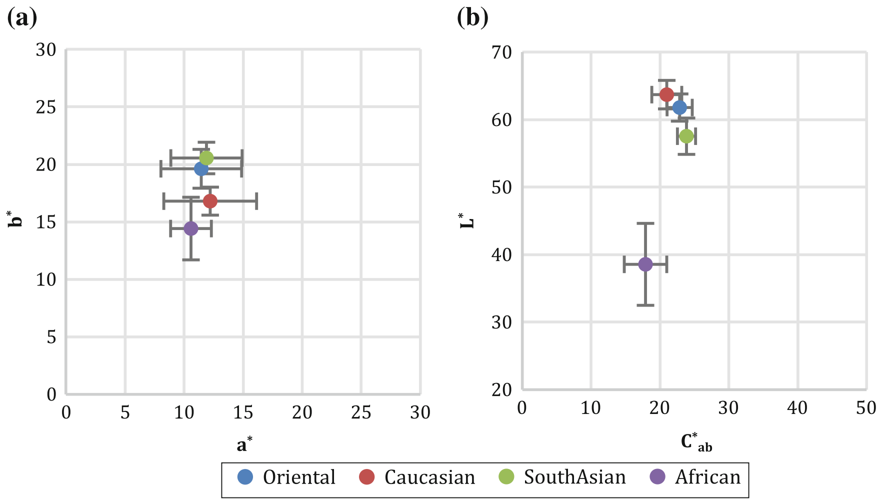

Fig. 2.1 The mean CIELAB values of ten locations of each ethnic group measured by CM700d in **a** a^*b^* plane and **b** $L^*C^*_{ab}$ plane

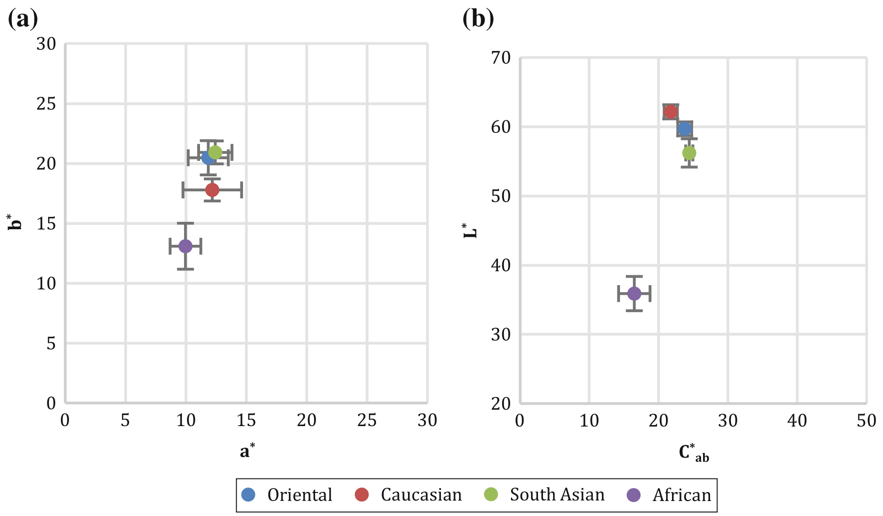

Fig. 2.2 The mean CIELAB values of five locations of each ethnic group measured by PR650 in **a** a^*b^* plane and **b** $L^*C^*_{ab}$ plane

Figure 2.3 shows the measurement results of two instruments. Figure 2.3a, b shows the 10 locations measured by the CM700d. In a^*b^* plane, we can see the locations on face are redder than the others, except the fingertip. The measurement results from the PR650 appear a similar trend, as shown in Fig. 2.3c, d.

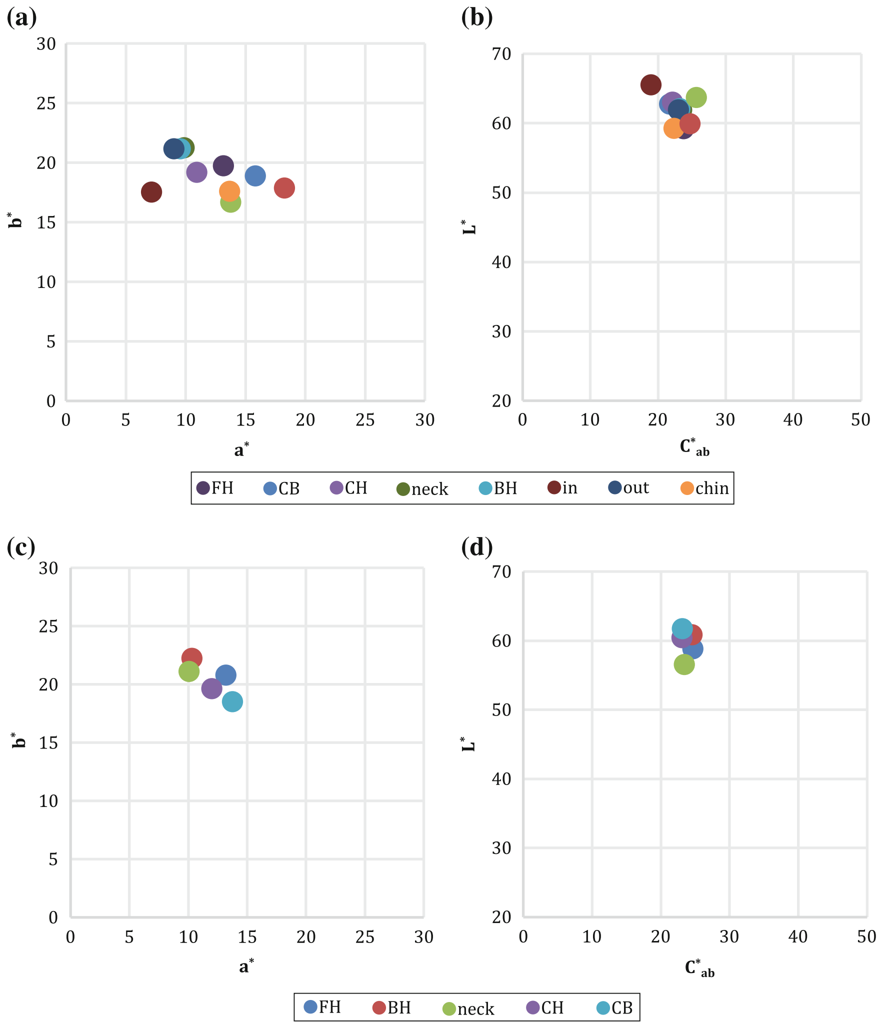

Fig. 2.3 The mean CIELAB values of ten or five locations measured by CM700d and PR650 **a** Ten locations measured by CM700d in a^*b^* plane; **b** Ten locations measured by CM700d in $L^*C^*_{ab}$ plane; **c** Five locations measured by PR650 in a^*b^* plane and **d** Five locations measured by PR650 in $L^*C^*_{ab}$ plane

The variation of the chroma and lightness between ten locations is not significant. But the data show a negative correlation in lightness and chroma. This indicates that for the Oriental group, skin with higher lightness will lower in chroma.

2.5 Conclusions

This chapter is focus on investigating the variation of four ethnic groups and two instruments. The colour appearance differences between ethnicities and instruments were determined by looking at the colour difference and plotting the results on $a^{*}b^{*}$ and $L^{*}C^{*}_{ab}$ planes. This research provides valuable information to evaluate measurement results between TSR and SP for skin colour measurement. The results from these two instruments show that two different instruments gave different results. But they are similar in trend. The measurement results from one instrument cannot be used to replace another directly. For different ethnic groups, the Caucasian group showed the highest lightness while the African group exhibits the lowest. The other three groups had similar hue angle and chroma. The distribution of the average CIELAB of each ethnic group is similar for these two instruments. In general, the non-contact instrument's (PR650) results are darker than the contact instrument's (CM700d) results with a good agreement in hue angle. For the ten or five locations of the Oriental group measured by CM700d and PR650, the locations on the facial area appear redder than the others. For the Oriental group, the skin with higher lightness will have lower chroma.

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References

1. De Rigal, J., Abella, M. L., Giron, F., Caisey, L., & Lefebvre, M. A. (2007). Development and validation of a new skin colour chart. *Skin Research and Technology, 13*, 101–109.
2. Serup, J., & Agner, T. (1990). Colourimetric quantification of erythema—A comparison of two colourimeters (Lange microcolour and Minolta chroma meter CR-200) with a clinical scoring scheme and laser-Doppler flowmetry. *Clinical and Experimental Dermatology, 15*, 267–272.
3. Clarys, P., Alewaeters, K., Lambrecht, R., & Barel, A. O. (2000). Skin colour measurements: comparison between three instruments: The Chromameter, the Derma Spectrometers and the Mexameter. *Skin Research and Technology, 6*, 230–238.
4. Barel, A. O., Clarys, P., Alewaeters, K., Duez, C., Hubinon, J.-L., & Mommaerts, M. (2001). The Visi-Chroma VC-100: A new imaging colourimeter for dermatocosmetic research. *Skin Research and Technology, 7*, 24–31.
5. Baquié, M., & Kasraee, B. (2014). Discrimination between cutaneous pigmentation and erythema: Comparison of the skin colourimeters dermacatch and mexameter. *Skin Research and Technology, 20*(2), 218–227.
6. Stamatas, G. N., Zmudzka, B., Kollias, N., & Beer, J. Z. (2008). In vivo measurement of skin erythema and pigmentation: New means of implementation of diffuse reflectance spectroscopy with a commercial instrument. *British Journal of Dermatology, 159*(3), 683–690.
7. Xiao, K., Liao, N., Zardawi, F., Liu, H., Van Noor, R., Yang, Z., et al. (2012). Investigation of Chinese skin colour and appearance for skin colour reproduction. *Chinese Optics Letters, 10*(8), 083301.
8. Tajima, J., Tsukada, M., Miyake, Y., et al. (1998). Development and standardization of a spectral characteristics database for evaluating color reproduction in image input devices. *International Society for Optics and Photonics*, pp. 42–50.