Investigation of Chinese skin colour and appearance for skin colour reproduction

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A Chinese skin colour database is established based on measurements taken from nine bodies areas of 202 Chinese individuals to move towards accurate skin colour reproduction. The colour appearance of each skin point is predicted, and a comprehensive colour gamut for Chinese skin is determined. A consistent colour shift between facial and arm colours is identified, in which facial colour tends to be more reddish, more colourful, and darker than arm colour. Moreover, Chinese females are found to have lighter, paler, and more yellowish skin than Chinese males. Variations in Chinese skin colour are quantified, and body area differences and gender differences are shown to have significant effects on Chinese skin colour.

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Interest in the colour of human skin has been greatly stimulated by the increased need in the application of the colour of human skin within multidisciplinary teams in various industries, including skin colour measurement for the diagnosis of cutaneous disease[1], skin colour segmentation for face detection and recognition[2], skin colour reproduction for graphic arts[3], and skin colour matching for body and maxillofacial soft tissue prostheses[4]. A new technology has recently allowed for unique and innovative methods of three-dimensional (3D) data capture, storage, and manufacturing of the geometry and colour data of a body to produce replacements as either images or physical objects (hard or soft). For such applications, a comprehensive knowledge of the range of skin shades that represent individuals, an understanding of how skin colour varies, and how people perceive these differences in a wide range of viewing conditions are strongly desired.

Previous studies have reported the use of Commission Internationale de I'Eclairage (CIE) colorimetry[5] for skin colour evaluation[6−8]. CIE colorimetry consists of objective colour measurements that use colour measuring instruments and colour attributes prediction using the CIELAB uniform colour space. In using CIELAB colour attributes, skin colours are compared with one another based on three different perceptual attributes, and skin colour differences are evaluated in $\Delta E^*_{\rm ab}$ units. The CIELAB uniform colour space has been used for more than 30 years and is still widely used in many industrial applications for both colour appearance prediction and colour difference evaluation. However, the accuracy of the CIELAB uniform colour space is not optimal unless pre-determined and defined parameters are set for the environment in which the information is to be captured. More specifically, the CIELAB uniform colour space does not consider colour reproduction across different viewing environments or the translation of these data into and through different colour media. CIE recommended several alternative advanced colour appearance model applications, known as advanced colorimetric techniques, which require colour reproduction and colour difference evaluation. In 2002, CIE TC8–01 recommended the use of the CIECAM02[9] colour appearance model for colour management. Therefore, CIECAM02 appears to be appropriate when advanced colorimetric techniques for the application of skin colour reproduction are considered because it allows the possibility of identifying skin colour appearance under various viewing conditions and the accurate translation of this information through digital processes.

Colour gamut is defined as a complete subset or range of colours that can be achieved under a specific viewing condition. For example, a display colour gamut indicates all colours generated by a specific display under a specific viewing condition. Skin colour gamut represents the entire range of skin colour appearances for a defined population of individuals. For modern colour reproduction systems, identifying the colour gamuts of a task material using different digital media under different viewing conditions before they can be truly reproduced is important.

Moreover, although skin colour measurements have been conducted for different ethnic groups[6,7], no available skin colour data could be considered representative of Chinese skin, and thus, reproduced digitally either as an image of physical object.

The current study aims to generate a comprehensive skin colour database for Chinese skin, to further investigate and identify the colour appearance and colour gamut of Chinese skin, to analyze factors that may affect the colour appearance of Chinese skin, and to evaluate colour variations in Chinese skin. In this letter, colour measurements for 202 Chinese individuals were taken using a spectrophotometer. CIE XYZ tristimulus values were obtained from nine different areas on the face and arms of each subject and the corresponding colour appearances of the subjects were predicted using the CIECAM02 colour appearance model. The colour appearance shifts were then investigated for gender differences and body area differences. Finally, the variations in the skin colour of the Chinese population were predicted.

In this letter, a Minolta CM-2600d spectrophotometer with a SpectraMagic NX Colour Data Software was used to take skin colour measurements in CIE XYZ tristimulus values with a 2° standard observer. The illuminant was set to the CIE standard D65 to simulate skin colour in a day light condition. During the measurements, a viewing geometry of $d/8$ (diffuse illumination, 8° viewing) was used with the included specular component, and the aperture size was set as 3 mm. The instrument provides consistent (repeatability within 0.04 $\Delta E^*_{\rm ab}$) and reliable colour measurements (inter-instrument agreement within 0.2 $\Delta E^*_{\rm ab}$).

Two hundred and two Chinese volunteers, including 65 females and 137 males participated in the current study following informed consent. The individuals are from 28 provinces across China within the age range of 19–32 years old (median of 22.1 years old). All volunteers are students and attended in one of the three universities in Beijing, namely, Beijing Institute of Technology, Minzu University of China, and Beijing Institute of Graphic Communication. Using the spectrophotometer, skin colour measurements were conducted on the following nine body areas of each subject: forehead, tip of nose, cheek, ear lobe, chin, back of hand, palm, outer forearm, and inner forearm (Fig. 1). CIE XYZ tristimulus values were recorded during each measurement. After the measurements, all subjects provided further information, including age, gender, nationality, and native place.

The CIECAM02 colour appearance model was used to predict the colour appearance of Chinese skin in terms of three human perceptual attributes, namely, lightness (J), chroma (C), and hue composition (H). Hue composition is a 400-step hue scale that directly relates to Unique Hues[10,11]. Unique red, unique yellow, unique green, and unique blue are represented by hue composition values of 0, 100, 200, and 300, respectively. In other words, hue can be described in terms of the percentages of two unique hues from which the test hue is composed. For example, a hue composition of 60 represents 60% of unique yellow and 40% of unique red. The skin colour gamuts of the Chinese subjects were achieved in CIECAM02 colour appearance attributes using the colour appearance of the entire skin colour database.

The colour appearance shift was evaluated by

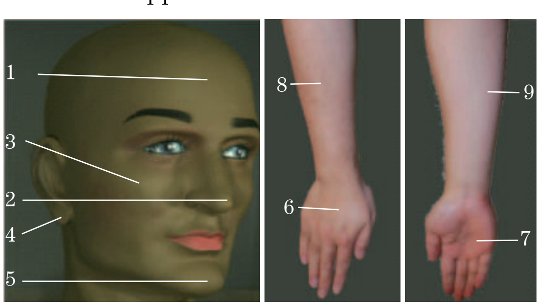

Fig. 1. Body areas for skin measurements (1: forehead; 2: tip of nose; 3: cheek; 4: ear lobe; 5: chin; 6: back of hand; 7: palm; 8: outer forearm; 9: inner forearm).

subtracting one skin colour from another based on the colour appearance attributes of skin colours. We use

$$\Delta H = 2\sin\left(\frac{\Delta h}{2}\right)\sqrt{C_1C_2}(\Delta h = h_1 - h_2)$$

to predict the perceptual hue differences and fairly compare hue difference (ΔH) with lightness difference (ΔJ) and chroma difference (ΔC). Statistical comparison was also conducted to test if colour appearance attributed shifts had significant differences with one another using a two-tailed unpaired student's t-test.

Skin colour variation indicates the extent to which the skin colour of a subject matches the average skin colour of the individuals assessed, and it is a basic measure of how skin colour varies within a population. In this letter, the colour variation of different Chinese skins was investigated and was undertaken by calculating the colour difference between the skin colour of each individual subject with the mean colour difference of a group skin colours. The CIELAB colour difference formula was used to measure skin colour difference.

A Chinese skin colour database was established based on 1 818 (202 subjects × 9 body areas) Chinese skin colour data in terms of CIE XYZ tristimulus values. Moreover, skin colour appearance, skin colour gamut, skin colour variation, and other factors that affect the skin colour were investigated based on the database.

The values of the three corresponding colour appearance attributes were obtained by inputting the XYZ tristimulus values of the 1 818 Chinese skin colour samples into CIECAM02. It should be noted that the average surround was selected for inputting the parameters into CIECAM02 to simulate skin colours viewed under a normal lighting condition. The mean, minima, maxima, and standard deviation (STDEV) of the Chinese skin colour of each perceptual attribute was calculated, and the results were provided in Table 1.

As can be seen in the CIECAM02 colour space, the Chinese skin has a range of lightness from 33 to 62 with a standard deviation of 4.2, whereas the chroma range is from 10 to 25 with a standard deviation of 2.3. The hue composition is from 14 to 73 within a 400-hue scale, indicating that the Chinese skin covers only the red-yellow area. These results show that the colour gamut for Chinese skin colour could be assumed to be relatively small.

The skin colour gamut for Chinese skin was achieved using the CIECAM02 colour appearance attributes of all Chinese skin colours examined. Figure 2 shows the two-dimensional (2D) plots of the skin colour gamuts for Chinese skin. Figure 2(a) illustrates the skin colours within the CIECAM02 ac-bc chromatics diagram, whereas Fig. 2(b) demonstrates the relationship between lightness and chroma. Each point in the figure represents one

Table 1. Skin Colour Appearance of Chinese Skin Colour in CIECAM02

CIECAM02	Lightness (J)	Chroma (C)	Hue (H)
Mean	49.3	17.5	43.1
Min	33.3	10.0	14.1
Max	61.6	24.5	72.6
STDEV	4.2	2.3	10.4

skin colour of a specific body area of a specific subject. As can be seen in Fig. 2(a), all skin colours are within the red-yellow range with a relatively small chroma. On the other hand, as can be seen in Fig. 2(b), majority of the skin colour samples are in the middle range of lightness, and the chroma tends to decrease with the increasing of lightness.

The mean value of each colour appearance attribute was calculated for each body area of all subjects to further investigate the Chinese skin colour of the subgroups. The results of the calculations are provided in Table 2. The site of the lightest skin is the female palm (J = 54.6), whereas the darkest skin appears to be the male chin (J = 44.9). Male forehead and tip of nose (C = 19.5) demonstrates the highest chroma values, whereas the female inner forearm (C = 13.9) appears to be the palest among the nine body areas. The red component of the colour is highest on the male ear lobe (H = 33.2) and the most yellow skin is the inner forearm (H = 60.4).

As can be seen in Table 2, the face and the arm have similar colour appearance shifts. The facial and arm colours were divided into two groups to further investigate the difference between the facial and arm colours of the nine different body areas. The facial colours includes five areas, whereas the arm colours includes four areas. The skin colour appearances for each group were then averaged, and the results are provided in Table 2.

The colour appearance shift due to the body area difference was evaluated using the difference in each

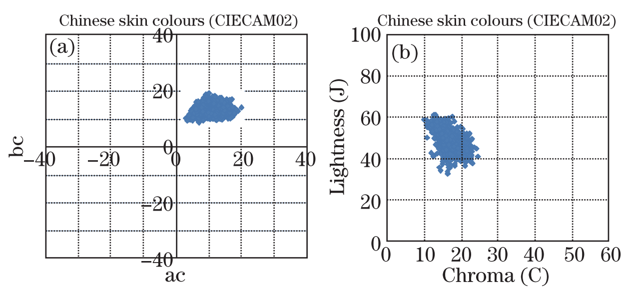

Fig. 2. Colour gamut for Chinese skin.

Table 2. Colour Appearance for Chinese Skin of Different Genders Under Different Body Areas in CIECAM02

Body Areas		(Female)			(Male)		
		J	C	H	J	C	H
	Forehead	49.3	18.2	42.9	45.8	19.5	38.2
	Tip of Nose	51.1	18.5	47.1	47.9	19.5	39.0
Facial	Cheek	52.6	16.1	37.9	48.2	18.1	34.9
Colours	Ear Lobe	52.2	17.1	37.7	49.9	18.5	31.8
	Chin	50.3	19.2	36.1	44.9	18.5	36.1
	Mean	50.8	17.7	41.4	47.3	18.8	36.3
	Back Hand	50.4	16.7	52.8	47.5	17.8	45.0
Arm	Palm	54.6	14.0	49.5	52.1	14.9	44.5
Colours	Outer Forearm	50.9	15.6	57.8	46.9	17.9	50.2
	Inner Forearm	54.2	13.9	60.4	50.3	16.0	52.3
	Mean	52.5	15.1	55.1	49.2	16.6	48.0

Table 3. Colour Appearance Shift for Chinese Skin in Different Genders and Body Areas in CIECAM02

Appearance Shift	ΔJ	ΔC	ΔH
Facial versus Arm (Body Area)	–1.8*	2.4*	–2.8*
Female versus Male (Gender)	3.6*	–1.3*	1.2*

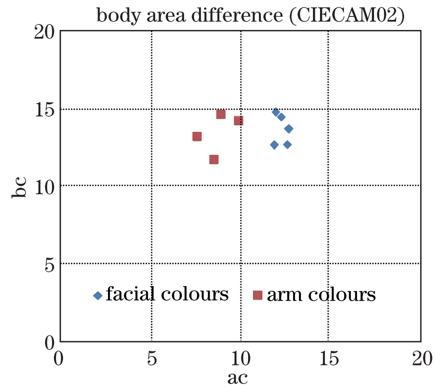

Fig. 3. Body area differences for Chinese skin colour appearance.

perceptual attribute between the mean of facial colours and the mean of arm colours. The results are given in Table 3.

As can be seen in Table 3, the values that represent facial colour are relatively darker and more colourful compared with those collected from the arm. Moreover, a significant hue shift occurred, indicating that facial colours tend to be more yellowish than arm colours. Statistical comparison of the collected data was conducted, and the results demonstrated the significant difference in the colour appearance shift between facial and arm colours ($p < 0.05$). It should be noted that all significant appearance shifts were signed with.

Figure 3 shows a CIECAM02 ac-bc chromatic diagram that illustrates the differences between facial and arm colours, where the diamond and square shapes represent facial and arm colours, respectively. As can be seen in Fig. 3, facial and arm colours have clear differences, in which the arm colours are skewed to the left of the facial colours, implying that arm colours are more yellowish than facial colours.

The quantitative appearance shifts between the two genders were evaluated using perceptual attribute differences between the averages of Chinese female data and male data. The appearance shifts of all perceptual attributes are given in Table 3. The statistical significance of the colour appearance shift was evaluated and all significant appearance shifts in Table 3 were signed with "*". The results clearly show that a consistent gender difference exists between the skin colours of male and female Chinese individuals. The skin colours of Chinese females are much lighter and less colourful, but more yellowish compared with those of Chinese males. Lightness shift showed the largest effect among the three appearance shifts.

Figure 4 shows the colour shift between female data (lines with full point) and male data (open-ended lines) in CIECAM02 ac and bc diagrams. This pattern clearly shows a skew to the right, indicating that male skin is more colourful than female skin. As can be seen in Fig.

4, female skin is more yellowish than male skin.

The overall colour variations in Chinese skin were measured using the average colour difference between each individual skin colour and the overall mean of 1 818 Chinese skin colours. The results were approximately 4.7 $\Delta E^*_{\rm ab}$ with a standard deviation of 2.4 $\Delta E^*_{\rm ab}$.

Both skin colour variation for a Chinese subject and skin colour variation between Chinese subjects were evaluated to further investigate the factors that affect skin colour variation in Chinese skin. For skin colour variation of a Chinese subject, body area differences that affect Chinese skin colour were investigated by calculating the colour differences between each body area and the mean of the nine body areas for each of Chinese subject, respectively. The average and standard deviation of the colour differences of each body area among 202 Chinese subjects were calculated, and the results are listed in Table 4.

As can be seen in Table 4, the skin colour variation due to body area difference for the same Chinese subject is approximately 4.7 $\Delta E^*_{\rm ab}$. The largest variation is in the palm of the hand, whereas the smallest variation is in the back of the hand. Data show that different body areas can significantly affect Chinese skin colour.

In terms of skin colour variation among Chinese subjects, the skin colour difference between each individual subject and the overall mean of 202 Chinese subjects for each specific body area was calculated, and the results are provided in Table 5. All Chinese skin data were divided into two sub-groups based on the two genders, and the colour variation between Chinese subjects were calculated within each sub-group to further investigate the gender differences that affect colour variation in Chinese skin. The colour variations in Chinese males and females for each body area were calculated, respectively, and the results are given in Table 5.

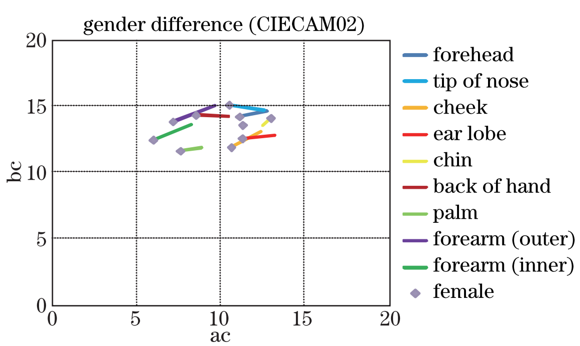

Fig. 4. (Color online) Gender differences for Chinese skin colour appearance.

Table 4. Skin Colour Variation for a Chinese Subject (Body Area Differences)

Body Area ($\Delta E^*_{\rm ab}$)	Mean	STDEV
Forehead	4.7	2.3
Tip of Nose	5.1	5.9
Cheek	4.1	1.8
Ear Lobe	5.9	6.1
Chin	5.1	2.3
Back Hand	3.9	2.2
Palm	6.0	2.8
Forearm Outer	4.5	2.0
Forearm Inner	5.0	2.5
Overall Mean	4.7	2.3

Table 5. Skin Colour Variations Among Chinese Subjects

Body Area ($\Delta E^*_{\rm ab}$)	All Subjects	Female	Male
Forehead	3.7	3.4	3.3
Tip of Nose	3.7	2.7	3.3
Cheek	3.6	3.1	3.0
Ear Lobe	4.3	4.5	4.1
Chin	4.0	2.9	3.5
Back Hand	3.7	3.1	3.5
Palm	4.0	3.9	3.7
Forearm Outer	3.8	2.9	3.5
Forearm Inner	3.5	2.6	3.1
Overall Mean	3.8	3.3	3.4

Following the investigations in the current study, the skin colour variation among 202 Chinese subjects for each body area was approximately 3.8 $\Delta E^*_{\rm ab}$ (Table 2). The colour variation was further reduced to approximately 3.3 $\Delta E^*_{\rm ab}$ considering a specific gender.

For the evaluation, both body area differences and gender differences were found to affect colour variation in Chinese skin. The skin colour variation can be significantly reduced when specific body areas and genders are selected.

Three types of instrumentations, namely, spectrophotometer, tele-spectroradiometer, and digital camera with a characterisation tool, have been used to measure human skin colours previously. Skin colour measurements were then transformed into the CIELAB uniform colour space, where CIE $L*a*b*$ or CIE $L*C*h_{\rm ab}$ values expressed skin colours objectively. Several articles have detailed skin colour ranges for different ethnic groups using CIE $L*$, $a*$, and $b*$ values[6−8]. However, although the CIELAB uniform colour space can be considered a simple colour appearance model, it cannot predict colours accurately under different viewing conditions, suggesting that consistent and uniform comparisons between different skin colour data drawn from different viewing conditions using LABs cannot be achieved easily or with a high degree of accuracy. In this study, the advanced colour appearance model, namely, CIECAM02, was used to predict skin colour appearance, and the obtained colour data were observed to be independent of viewing condition and, therefore, were accurate, reliable, and consistent.

The quantity, quality, nature, and localization of melanin granules within the epidermis primarily determine the basic or constitutive skin colours. Genetic and environmental factors, including exposure to sunlight are known to influence the composition and location of melanin within the epidermis[12,13]. Therefore, it is highly reasonable to assume that there can be significant differences in skin colour appearances because of gender differences. Genetic and body area differences, which can be influenced by environmental factors, contribute to skin colour appearance. In the current study, hue consistently demonstrated the largest variation compared with chroma or lightness and with the specific colour shift in terms of the three human perceptual attributes among the different body areas. Previous studies have demonstrated that the darkness of the skin, in relation to the lightness attribute, is routinely the most significant factor for skin colour variations among different ethnic groups. Previous research on gender differences in skin colours has been conducted in other ethnic groups with different measurement methodologies[1,6,7]. Majority of previously published reports obtained similar results as the current study with regards to the determination that female skin color is lighter and more yellowish than male skin color, which is evident in Caucasian and Korean skin[1,6,7]. The results of the current study are consistent with previously published data. In the current study, all Chinese subjects that participated in the skin colour measurements are from one age group. The skin colour appearance shift between different ages has not been investigated yet.

Skin colour variation can be considered as a basic threshold for skin colour identification. For example, if the difference between a particular colour and the default skin colour is smaller than the inherent variation within the default skin colour range, then the colour can be considered as a representative sample of that skin colour. The current study not only investigated colour variations within the Chinese population, but also identified colour variations between sub-groups, including specific genders and specific body areas. Colour variation was found to be significantly reduced in the sub-groups, indicating that the overall skin colour and the skin colours for the entire population do not accurately represent the different sub-groups (gender or body points) given the inherent variations within a population. Therefore, variations in gender and body points should be taken into account relative to specific requirements, such as disease diagnosis, imaging, identification, and manufacturing processes, for applications that require a specific, consistent, and accurate skin colour representation.

In conclusion, a Chinese skin colour database is developed based on 1 818 Chinese skin colour measurements from nine different body points of 202 Chinese subjects. The data are accumulated using CIE XYZ tristimulus values, which are then transformed to any colour space under differing viewing conditions. Skin colour appearances are predicted using CIECAM02 colour appearance models, and an entire skin gamut range is established. In addition to the inherent variations, body area differences are further investigated, and facial colour is found to be darker, more colorful, and more yellowish than other colours in the arm. Furthermore, it can be concluded that the female skin is lighter, paler, and more yellow is than the male skin. Finally, colour variation between Chinese skin samples is identified. Both skin colour variation within a Chinese subject and skin colour variations among Chinese subjects are evaluated, and results show that both gender differences and body area differences affect Chinese skin colour variation.

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