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New Spectral Data for Skin Colours

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Abstract

Two experiments were conducted for collecting skin database at the Universities of Liverpool and Leeds (UK), and Zhejiang University (China). Overall, 235 subjects from 4 different skin groups (Caucasians, Chinese, South Asian and Dark) were recruited. Each was measured using 4 types of colour measuring methods (tele-spectroradiometer, spectrophotometer, digital camera and visual assessment) including 6 instruments and 2 sets of colour charts. The results from the former two types are summarised here. The results were analysed in terms of skin colour distribution, repeatability and inter-instrumental agreement between 4 skin groups in CIELAB coordinates and spectral domain.

Introduction

Skin colour has been one of the most extensively studies over the years. It has been involved with many applications such as photography, display, imaging, printing, medical, lighting, etc. It is important to reproduce skin colours to make them either preferable or accurate. So, many experiments were conducted using different colour measuring instruments. According to the target measured, they can be divided into non-contact and contact methods. For contact method, spectrophotometers are normally used, including a light source, a grating and a detector. They have the illumination/viewing geometry of either diffuse integrating sphere or 45^o:0^o. For measuring skin colours, caution should be taken to apply constant pressure to the surface because skin colour varies with different pressure applied [1]. Different from cosmetic, printing and imaging industries which are interested on the colour management and colour specification, the medicals are also interested in the pigments in the skin. Spectrophotometers are normally used to measure colours at a fixed skin location to obtain the haemoglobin concentration [2,3]. The non-contact methods include tele-spectroradiometer (TSR), camera and visual assessment. They have been widely used for measuring skin colours. The visual assessment was also used by means of reference colours presented by a fan deck or a colour chart. A typical example is that De Rigal [4] measured skin colours to design skin colour charts as a visual aid for evaluating skin whitening product. It provides a fast and inexpensive method to evaluate the effect of clinic treatment or to find a cosmetic product to match the skin colour in stores. TSR measures the spectral power distribution (SPD) of a colour illuminated by a source, and spectrophotometer measures the spectral reflectance of a surface colour. More recently, colour calibrated digital cameras were used to measure colours of objects [5]. It can obtain the colour information of the whole region rather than a selected location like the other measuring methods. Although the above methods have been used, there is a lack of research to investigate their differences.

Because of the importance of skin spectral database, ISO ISO/TR 16066-2003 Graphic Technology – Standard object colour spectra database for colour reproduction evaluation (SOCS) [6] provides a database including 51182 sets of spectral reflectance, for which 8213 of them are skin colours. There are 6 skin groups, provided by 5 organisations. Each subject was measured at forehead, cheek, neck, zygomatic region and arm. However, they did not define the instruments and their measuring conditions used. It can be found that the colour distribution covers a very large colour gamut. So, it is not able to be used for further research.

With the above in mind, the CIE has established a technical committee, TC 1-92 Skin Colour Database. It is aimed to investigate the uncertainty in skin colour measurement, to recommend protocols for good measurement practice, and to evaluate skin colour measurements that according with these protocols covering different ethnicity, gender, age and body location.

This paper summarises the results of the two datasets, which carried out at Liverpool and Leeds Universities, UK, and Zhejiang University, China. The objectives are to report the performance of repeatability and inter-instrument agreement, to reveal the colour distributions for each instrument, and to compare the measuring results between two sites having same type of instrument, such as between two TSRs or between two SPs. It is hoped to provide a general understanding of colour variation using different instrument for measuring different skin groups.

Experimental Data

Two datasets accumulated at Liverpool/Leeds Universities and Zhejiang University, called UK data and China data, respectively. Table 1 shows the details of the data collected from each site. It includes number of subjects, male and female, of each skin group and the number of locations measured for each subject. Four measurement methods were used: TSR, spectrophotometer (SP), digital camera, and visual assessment. Only the measurement results from SP and TSR are investigated here, because these instruments were used in both experiments and are more widely used to accumulate skin colour database. Table 2 describes the specification about the 4 instruments used.

Table 1 shows that there are 4 times more subjects participated in the UK experiment than that of China experiment. It can alsobe found that there is also a shortage of female subjects for the South Asian and Dark skin groups in both data.

Table 1 The number of subjects in the UK and China experiments.

	UK data		Chinese data	
Skin group	**Male**	**Female**	**Male**	**Female**
Caucasian	14	65	3	7
Chinese	45	41	10	10
South Asian	7	6	10	0
Dark	5	5	7	0
Total	71	117	30	17
No of locations	10	10	8	8

Table 2. The instruments used in the present paper

	TSR (UK)	TSR (China)	SP (UK)	SP (China)
Image				
Maker	Photo Research	JETI TechnischeInstrumente GmbH	KONICA MINOLTA	Datacolor
Model	SpectraScan PR650	Specbos 1211	CM-700d	SF600
Geometry	0º:0º	0º:0º	di:8°	de:8°

For measuring skin colours using TSRs, the illumination conditions were quite different. Figure 1 shows the skin capturing conditions between the two sites. In UK, to achieve uniform lighting, a lighting cabinet was specially built, which was painted with a mid-grey matte colour inside and was illuminated by a D65 fluorescent simulator offering evenly diffused illumination. The PR650 TSR was located in the aperture in front of the subject. The measurement angle was fixed to 0º, and the measurement distance was 57 cm. In the Chinese experiment, a luminaire, the same fluorescent D65 simulator as the one in UK was hang on the ceiling, with a distance at about 1 metre and the measurement distance was about 1metre as well. The UK setup had a more uniform illumination than that in China.

Their measurement results were arranged in terms of spectral reflectance. These were then transformed to CIELAB coordinates under D65/10º condition.

a) U.K. condition b) China condition

Figure 1. The measuring conditions used for TSR measurements in a) U.K. and b) China

Results

Short-term repeatability

The first test was the short-term repeatability using a matte sample from Pantone Skintone chart. It was repeatedly measured by the same operator, at same position, continuously 5 times. The second test measured the forehead and cheek of a Chinese subject in each site using the same measuring condition as the chart sample. The results in terms of MCDM (colour difference against the mean in ΔE^*_{ab} unit) were reported for evaluating the repeatability [1]. For measuring Pantone colours®, these were 0.05, 0.12, 0.05, 0.02 and for the human subjects, these were 0.69, 0.56, 0.29 and 0.22 for PR650, JETI, CM700d and SF600, respectively. The results indicate that all of them had an excellent performance, as much less than 1 ΔE^*_{ab}unit roughly corresponding to human perceptibility. The two spectrophotometers are more repeatable than the two TSRs as expected, because contact methods are normally more stable at the position of measurement and have less human body movement than that of non-contact methods. This concluded that measuring skin colour have about ten time larger variation than measuring a paint sample.

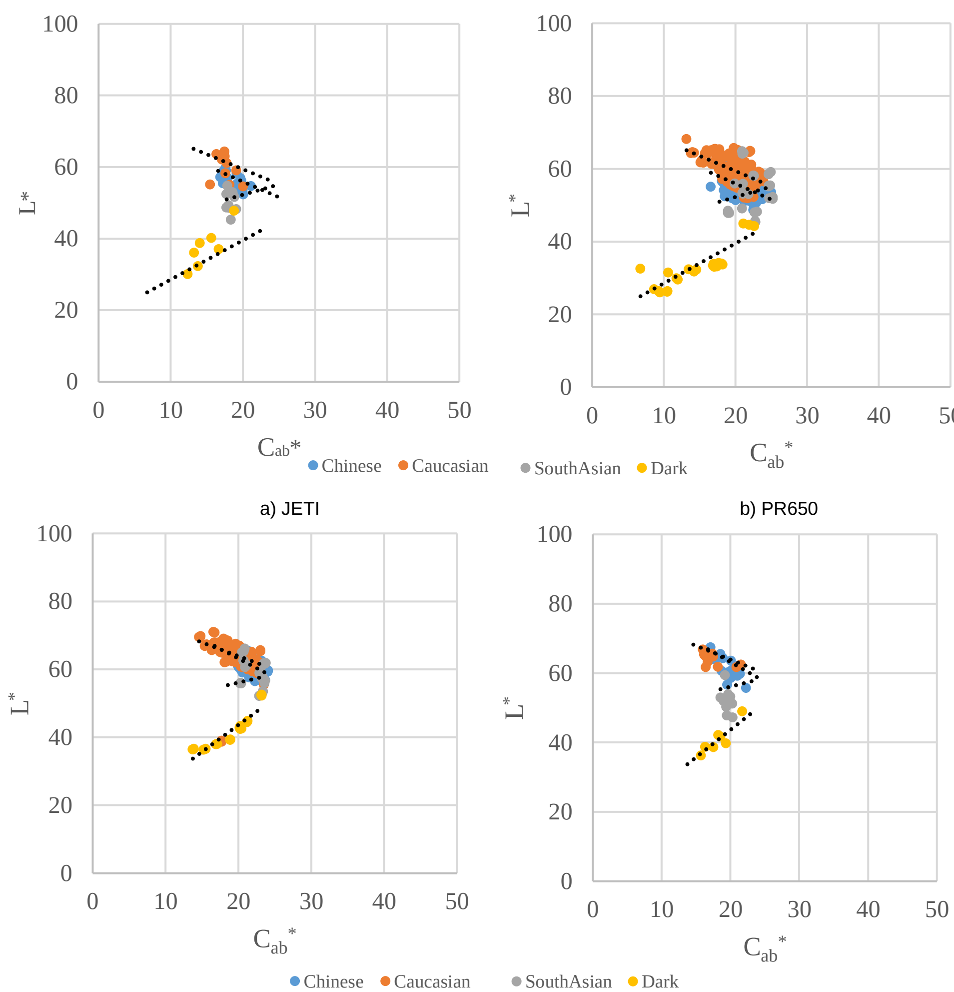
Inter-instrument agreement

The inter-instrument agreement was also compared. 24 colours at the XRite ColorChecker® Chart were measured and inter-compared between the results from two sites. Two separate charts were used. The results here indicate the variation of both test targets and the instruments. The inter-instrument agreements were 2.8 ΔE_{ab}^* between two TSRs and 1.8 ΔE_{ab}^* between two spectrophotometers.

Trends for skin colours

Figure 2 plots the colour distribution of all individual participants in CIELAB $L^*C_{ab}^*$ diagram. The measuring results from all locations for each participant were averaged and plotted. It can be seen that the skin colours from each skin group are following a straight line fitted by $\sqrt{(L_o' - L^*)^2 + (C_{ab}^*)^2}$ and $\sqrt{(L^* - L_o)^2 + (C_{ab}^*)^2}$, where L_o' and L_o are the coefficients optimised using the dark group and the Caucasian and Chinese groups, respectively. These lines point towards a lighter grey in the neutral axis for Caucasian and Chinese groups, and pointing to a darker grey for dark group, respectively. These trends are similar to those found by Chardon et al [7] who studied the sun-product efficacy using a lab based solar simulator.

In Figure 2, a trend line was fitted to each skin group for the same type of 2 instruments. It can be seen that these lines can represent well the distribution of a particular skin group in $L^*C_{ab}^*$ plane for both instruments. They can be used in the applications such as cosmetic, skin care, sun product. Also, those trends can be explained well by the new colour appearance scales such as the depth and vividness scales developed by Berns [8] and the whiteness and blackness scales developed by Cho et al [9], i.e. a lighter Caucasian or Chinese skin colour will also appear to be whiter, lower depth (less saturated).



a) JETI

b) PR650

c) CM700d

d) Datacolor

Figure 2. shows the skin colours for each subject in each skin group for a) JETI, b) PR650, c) CM700d, and d) Datacolor in L*Cab* plane

Inter-data agreement

In real practice, skin colours were measured using different instruments on different subjects at different locations. The present UK and China data represent this situation. So, the inter-data agreement was conducted by comparing the same locations for each skin group measured using same type of instrument, i.e. TSR and spectrophotometer.

Tables 3a and 3b show the results of L^*, C^* and hue angle of the UK data and ΔL^*, ΔC_{ab}^*, Δh_{ab}^*, ΔE_{ab}^* values (the UK data is subtracted by the China data) at different locations for each skin group between the two TSRs and between two SPs, respectively. Note that only these locations (forehead (FH), Cheek Bone (CB) and Back of Hand (BH)) were measured in both sites and the other locations were different between each other.

It can be found that the better inter-instrument agreement is between two spectrophotometers having a mean ΔE_{ab}^{*} of 3.1, which is about 200% smaller than that of two TSRs, ΔE_{ab}^{*} of 6.7. For both types of instrument, the largest difference is occurred in ΔL^{*} term.

Inter-instrument agreement in spectral reflectance

Figures 3a to 3d show the comparison of spectral reflectance of each skin group from 4 instruments. It can be seen that the difference between two spectral is quite small. The two spectrophotometers have very similar lightness, the main difference between the data from these two sits are from 600nm to 700 nm, except the dark skin group.

Detailed inspection can find that there is a good agreement between the two spectrophotometers. They are almost overlapped for the reflectance ranged between 400 and 600nm, and a systematic discrepancy can be found above 600nm, i.e. CM700d spectra are above 580nm. This could be due to the difference between the specular inclusion and exclusion measuring conditions used by CM700d and PR650, respectively. The reflectance functions from all skin groups except Dark clearly showed a ‘w’ shape (two dips with a bump in the middle) between the 520-680 nm. It can reflect the absorption of Oxygenated haemoglobin in the blood vessel. Dark group subjects increase amount of melanin which absorbed most of the light so that the w shape pattern is weak, and not detectable [10].

Table 3a. The inter-data agreement in CIELAB ΔE unit between 2 TSRs

TSR	Location	L^*	C_{ab}^*	h_{ab}	ΔL^*	ΔC_{ab}^*	Δh_{ab}^*	ΔE_{ab}^*
CHINESE	FH	58.6	23.1	59.2	-2.9	-3.3	-0.2	4.4
	CH	60.3	21.6	60.1	-10.8	-3.1	-1.4	11.3
	BH	60.7	23.1	66.2	-5.2	-3.2	-0.9	6.1
CAUCASIAN	FH	62.7	20.5	54.9	0.3	-2.9	0.3	2.9
	CH	61.9	20.0	55.0	-6.5	-2.0	-0.7	6.8
	BH	64.2	19.8	64.9	-3.2	-0.6	0.0	3.2
SOUTH ASIAN	FH	55.0	23.4	57.8	0.1	-4.1	-0.9	4.2
	CH	56.6	22.2	59.0	-11.4	-3.9	-1.6	12.2
	BH	57.3	23.3	64.8	-10.0	-3.8	-1.5	10.8
DARK	FH	40.4	19.3	54.1	0.4	-5.4	-1.9	5.7
	CH	38.9	17.5	54.9	-4.4	-2.7	-1.4	5.4
	BH	37.8	19.5	56.1	-4.1	-5.0	-2.4	6.9
				MEAN	-4.8	-3.3	-1.0	6.7

Table 3b. The inter-data agreement in CIELAB ΔE unit between 2 SPs

Spectrophotometer	Location	L^*	C_{ab}^*	h_{ab}	ΔL^*	ΔC_{ab}^*	Δh_{ab}^*	ΔE_{ab}^*
CHINESE	FH	59.1	22.2	58.4	-1.0	-0.7	-0.1	1.2
	CH	62.9	20.7	62.3	-2.5	-1.6	-2.2	3.7
	BH	62.0	21.8	67.2	-0.4	-1.8	0.8	2.0
CAUCASIAN	FH	63.3	19.4	54.3	-2.1	-0.6	-0.8	2.4
	CH	63.9	19.1	56.1	-0.6	-1.4	-2.0	2.5
	BH	64.3	19.2	64.9	-1.6	0.4	1.3	2.1
SOUTH ASIAN	FH	56.0	22.7	58.2	-6.0	-1.2	-1.2	6.3
	CH	57.0	21.6	62.9	-4.4	-1.3	-2.6	5.3
	BH	57.8	22.7	65.2	-4.8	-2.0	-0.1	5.3
AFREICAN	FH	39.2	17.6	53.4	-0.7	-0.2	-0.7	1.0
	CH	37.1	15.8	54.8	4.1	3.4	0.0	5.3
	BH	38.1	18.0	55.8	-0.6	0.0	-0.1	0.6
				MEAN	-1.7	-0.6	-0.6	3.1

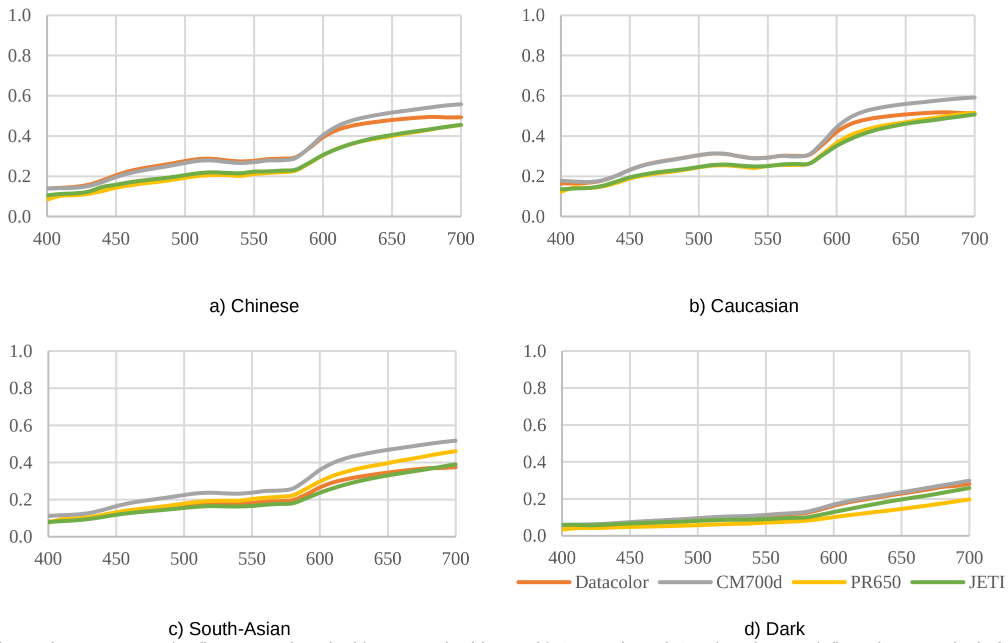


Figure 3. comparison of mean spectral reflectance of each skin group a) Chinese, b) Caucasian, c) South-Asian, and d) Dark respectively from 4 instruments (Datacolor, CM700d, PR650, and JETI)

Conclusion

Two comprehensive skin database were accumulated. Each was divided into 4 different skin groups using 8 colour measuring instruments. The results from the TSR and spectrophotometer from each site were compared. The findings are summarised below:

- Short-term instrumental repeatability study: Measuring skin colours is less repeatable than measuring colour patches. The TSR results are less repeatable than Spectrophotometers.
- Inter-instrumental agreement study: The results from spectrophotometers agreed with each other much better than those from the two TSRs.
- Skin colur distribution: The colour distribution within each skin group is quite constenent in CIELAB space. It is possible to be explained by the best fitted line to each skin colour group. This may provide an effective tool for precisely estimating the amount of UV exposure, for classifying skin colour classification.
- Inter-comparison between instrument was also made in CIELAB and reflectance spaces. The results showed that the typical variation could be as large as 3 and 6 ΔEab*units between 2 spectrophotometers, and between 2 TSRs, respectively.

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