https://doi.org/10.2352/issn.2169-2629.2020.28.16

Preferred skin reproduction centres for different skin groups

Rui Peng[1], Ming Ronnier Luo[1,], Mingkai Cao[1], Yuechen Zhu[1], Xiaoxuan Liu[1] and Guoxiang Liu[2]*
[1]State Key Laboratory of Modern Optical Instrumentation, Zhejiang University; Hangzhou, China
[2]Hisilicon Technologies, China

m.r.luo@zju.edu.cn

Abstract

Producing preferred skin colours is vital for the digital images on mobile phone manufacturers. Previous studies investigated the skin colours only in chromatic plane excluding lightness. A psychophysical experiment was conducted to determine preferred skin colour centres for different skin colour types on mobile displays in a darkened room. Ten facial images were selected for the experiment to cover different skin colour types (Caucasian, Oriental, South Asian and African). A set of 49 predetermined colour centres uniformly sampled within the skin colour ellipsoid in CIELAB colour space was used to morph skin colours of test images. Thirty observers from each of the 3 ethnic groups (Caucasian, Oriental and South Asian) participated in the experiment. The preferred skin colour centre and region in the form of ellipsoid for each skin group were reported. It was found that the preferred colour centres from different skin colour types were very similar except their lightness as expected, and were also quite similar between the observers from different ethnic groups.

Introduction

With the rapid development of the Internet and the popularity of mobile devices, creating and sharing digital images using mobile phone at anytime and anywhere is already a common behavior in people's daily lives. At the same time, people's expectations of image quality are also increasing. One aspect of improving the perceived image quality is to improve the colour reproduction of images. Preferred colour rendering by observers is an important factor in improving photo image quality.

The human skin tones play an important role in the colour reproduction of digital photographic images. Skin colour preference has been an active research subject in the last few years. Various researches support the idea that there is a preferred skin colour centre for observers [1-5]. Moving skin colours toward the preferred centre could improve the colour preference. Therefore, finding the preferred skin colour centre is a basic step for preferred skin colour reproduction.

The skin colour preferences of different ethnic skin tones judged by observer groups with individual-ethnic backgrounds or mixed ethnic backgrounds have been studied in the past [1-11]. Bartleson [2, 3], Bartleson and Bray [4], Sanders [5], and Hunt *et al.* [6] studied the skin colour preference of Caucasian. They found that the preferred skin tone appeared to be yellower and more chromatic than the colours of real skin tone. Sanger *et al.* [7] used portrait photos of Mongoloid, Caucasoid, and Negroid to study preferred skin colours, and found that chroma of preferred skin colours increases steadily in the order of Caucasoid, Mongoloid, and Negroid, preferred hue angles among three groups are about the same. Yano and Hashimoto [8] studied the preference of Japanese facial skin and found that the preferred skin colour of Japanese women was shifted to a slightly higher chroma and was more reddish in hue than the actual skin of Japanese women; the direction of hue shift is different from that of the preferred Caucasian women; and the preferred skin colour of Caucasian women is more colorful than that of the Japanese woman. Kuang *et al.* [9] conducted psychophysical experiments to study the influence of different factors on skin colour preference for photographic colour reproduction. They found no significant ethnic group difference among different ethnic observers. Fernandez and Fairchild [10] studied the observer and cultural variability for preferred colour reproductions of pictorial images. Although the preference variability due to observers' cultural background was found to be statistically significant, it was not visually significant. The preference variability due to image contents and the preference variability among observers were more significant than the variability due to cultural background. Zeng and Luo [1] conducted a series of psychophysical experiments to study the colour preference of African, Caucasian, and Oriental skin tones judged by a pool of observers with mixed ethnic groups (African, Caucasian, Asian, and Hispanics). The experimental result demonstrates that the preferred hue angle in CIELAB adapted to the D50 white point is about 49° in all three groups.

From the earlier studies, it was found that different studies did have a large variation. Furthermore, it was realized that preferred skin colours found from different studies are somewhat different. From the earlier studies, only few investigations included the lightness of skin colour. However, preferred skin colour centre should vary at different lightness levels. Therefore, skin lightness should be considered into account for preferred skin colour. In this study, ellipsoid skin colour model is proposed to model the preferred skin colour cluster in a 3-dimensional lightness-chrominance colour space. An advantage of this model over the ellipse model is that the lightness dependency of the shape of skin cluster is included in the modelling.

The goals of this study were to establish preferred skin colour data to cover a comprehensive range of skin colour types on mobile phone, and to investigate the difference of preference perception between three ethnic group observers.

Experiment

Experimental setup and procedure

Fig. 1 shows an example image of the model to represent Oriental male. Ten models were invited for the experiment to cover 5 different groups, African, Caucasian, Pakistani and Oriental (young) and Oriental (aged). Each group included male and female. All images were captured by a NIKON Z6 under the same lighting condition (6500 K, 550 lux) with a neutral grey background. In the formal experiment, the model's eyes on each test image were masked. Note that in the images used in the experiment, the background colour was fixed at L^*=50. The chromaticity values of test images were calculated with CIE D65 and CIE 1964 standard colorimetric observer condition.

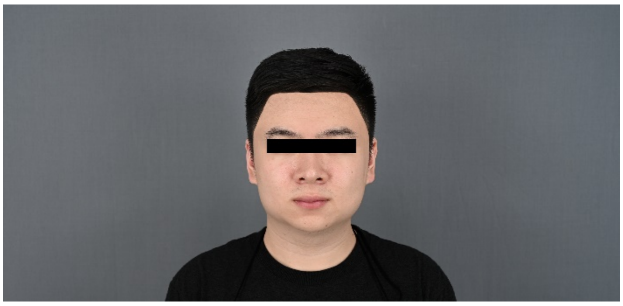

Figure 1. An example image used in Experiment.

The shape of the skin colour cluster of digital images in CIELAB colour space is approximately elliptical [11]. In this study, the ellipsoid skin colour model was applied to prepare the images well distributed in CIELAB colour space. A set of 49 pre-determined colour centres uniformly sampled in CIELAB colour space was used to morph skin colours of test images. Fig. 2 shows 16 colour points within the skin colour ellipsoid projections in CIE a*b* diagram, L*b* diagram and L*a* diagram respectively, and the black dot in the centre is the ellipsoid skin colour centre in CIELAB colour space. In addition, the red dots showed the most preferred colours (see later). Colour centre and ellipse as reported by Zeng and Luo [11] were plotted to include all possible skin colours across all skin colour types. Skin colours of each original image were extracted using image processing software Photoshop to create a skin mask. The extracted skin colours were morphed toward 49 pre-determined skin colour centres to produce 49 versions of images in which only skin colours were different and the other colours in the image were the same (see Fig. 1). In total, 490 adjusted images were generated corresponding to 49 skin colours.

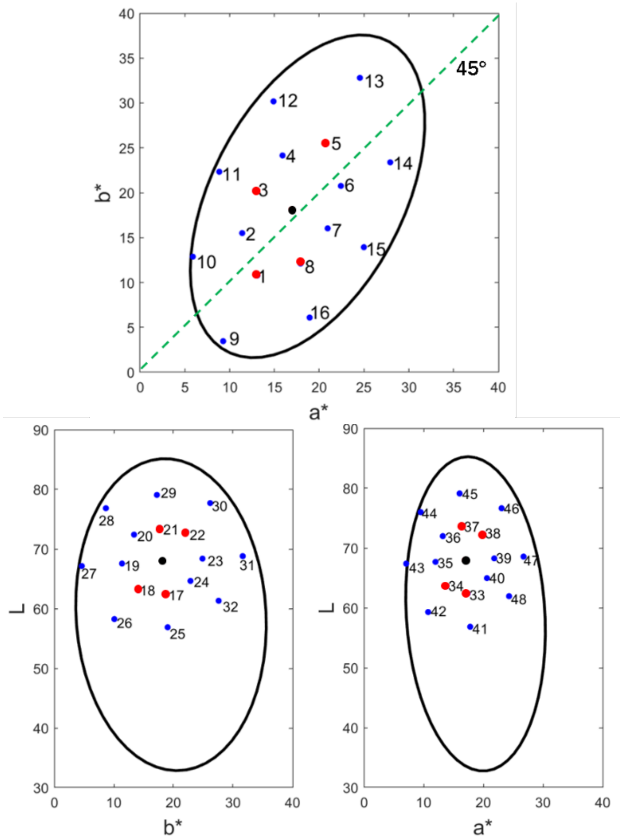

Figure 2. 49 predetermined skin colour centres in CIELAB a-b*, L*-b*, L*-a* diagram respectively.*

Psychophysical experiments were conducted to determine preferred skin colour centres. Altogether ninety observers participated in the experiment, including 30 Caucasians (Europeans dominated), 30 Orientals (Chinese) and 30 South Asians (Pakistanis dominated) between 18 and 40 years old. All of them came from Zhejiang University and they all passed the Ishihara colour vision test and had normal color vision.

Five Huawei P20 mobile phones were used to display images in a darkened room, as shown in Fig. 3 The screen was set to maximum peak luminance of 460 cd/m^2. The number of observers could be 3-4 in each session. Each observer first sat at a distance that was most comfortable for viewing. Before the experiment began, mobile screen was set at black for 30 seconds for adaptation. 49 adjusted images of the same model were assigned a separate group to avoid the interference of different facial features. Observers were asked to make a forced choice to judge whether 'like' or 'dislike' the skin colour of image. After the response was recorded, the next image was displayed following a random sequence. The observer continued until all stimuli were evaluated. There was a black screen lasting for 20 seconds between two test groups. The image groups of two Orientals were repeated twice to test intra-observer agreement. The total number of judgements is 90 observers × 49 colour centres × 12 image groups (plus 2 repeated groups) = 52,920. There was a training session before the formal experiment for each observer to evaluate five images to familiarize with the experiment procedure. The entire experiment was lasted for approximately 40 minutes for each observer.

***Figure 3.** Experimental condition.*

Colour Consistency of Five Displays

Since five mobile phones were used to conduct the experiment simultaneously, it is essential to have all five displays to be reasonably agreed with each other. The 3-D colour lookup tables (LUTs) [12] was used to characterize each display. The differences between the measurement and prediction results can be used to evaluate the accuracy of the forward models. The results were inter-compared between different mobile displays to have an average of 1.53 ranged from 1.24 to 1.79 CIEDE2000 units using the 24 Macbeth Color Checker chart colours. From the above colour differences, the displays were in good agreement and the characterization model was accurate.

Results and discussions

The raw data were arranged in terms of Preference% for each image, i.e. the number of '**preferred**' decisions divided by the total number of decisions multiplying 100.

Inter- and intra-observer variations

The intra- and inter-observer variations were quantified using the Standardized Residual Sum of Squares (*STRESS*) [13], which has been widely used in colour appearance evaluations. A larger *STRESS* means a larger disagreement. A *STRESS* of 0 and 20 means perfect agreement and 20% variation between two sets of data respectively.

The inter-observer variation was calculated between the individual results and the mean results rated by all observers on each image. Table 1 summarizes the *STRESS* values of three race groups in terms of inter-observer variances, ranged between 33 and 49, which was quite typical compared with another study [14].

Each observer evaluated 98 images (2 Oriental portrait groups) twice to reveal the intra-observer variation. It was computed by comparing the repeated evaluations for each observer. Table 2 summarizes the *STRESS* values of three race groups in terms of intra-observer variances, ranged between 22 and 27, which was again typical compared with the other study [14].

It was found that typically, inter-observer variation was greatest for evaluating African facial image and least for evaluating Caucasian facial image regardless of the observer races. And Caucasian observers have better agreement than the other two races. The preference variability due to image contents and the preference variability among observers were more significant than the variability due to ethnic background.

Table 1. The results of the inter-observer variations in terms of *STRESS* unit.

Image / Observer	Caucasian	Oriental	South Asian	African	Mean
Caucasian	33	41	42	49	41
Oriental	34	38	39	49	40
South Asian	38	40	41	48	42
Mean	35	40	41	49	41

Table 2. The results of the intra-observer variations with 49 skin colour centres for each test image in terms of *STRESS* unit.

Image / Observer	Oriental-female	Oriental-male	Mean
Caucasian	24	23	24
Oriental	22	22	22
South Asian	27	25	26
Mean	24	23	24

The z-scores of each image

The categorical raw data were transformed into z-scores. Fig. 4 shows the z-scores of each image at skin centres from 1 to 49 obtained from all judgements. The skin centre #49 is at ellipsoid centre. A higher z-score means a more preferred (or less 'dislike'). The figure shows that the preference trend of different images is similar. The skin centres #8, #21, #37 and #49 were the most preferred from all the 10 images (see the green circles in Fig. 2) in a*-b*, L*-b* and L*-a* diagrams respectively. It can also be seen that all the preferred points were located far away from the ellipse boundary. This indicates that the colour range selected had a good coverage of the skin colours, i.e., all the visual results were found to be well within the range.

Preferred ellipsoid skin colour model

The ellipsoid skin colour model, is proposed to model the preferred skin colour cluster in CIELAB colour space. An elliptical boundary model is defined as:

$$\Phi(X) = (X - X_c)^T \bullet \Lambda^{-1} \bullet (X - X_c) \quad (1)$$

where X is (L^*, a^*, b^*) of the skin colour stimulus, X_c is the estimated centre (L_c^*, a_c^*, b_c^*), representing the estimated most preferred skin colour chromaticities, and Σ is the 2-by-2 covariance matrix. Φ(X) in Eq. (1) is reorganized as:

$$\begin{aligned}\Phi(L^*, a^*, b^*) &= \mu_0(L^* - L_c^*)^2 + \mu_1(L^* - L_c^*)(a^* - a_c^*) \\ &+ \mu_2(L^* - L_c^*)(b^* - b_c^*) + \mu_3(a^* - a_c^*)^2 \\ &+ \mu_4(a^* - a_c^*)(b^* - b_c^*) + \mu_5(b^* - b_c^*)^2\end{aligned} \quad (2)$$

where μ_0 to μ_5 are the parameters to be optimized. Given a threshold ρ and an input colour X (L^*, a^*, b^*) of a pixel, X is classified as a preferred skin colour if $\Phi(X) < \rho$ and as a non-preferred skin colour otherwise. In this study, $\Phi(X) = 1$ defines an elliptical boundary between preferred and non- preferred skin colours. The ellipsoid centre is preferred skin colour centre.

Skin colours evaluated as 'like' were used to train ellipsoid models. After a preferred skin colour from each of 30 observers on each image is computed, an ellipsoid is generated from the 30 preferred skin colours of each image. Fig. 5 shows trained ellipsoids (each image judged by all observers) that covers 95% of the preferred skin colours in CIELAB colour space. The ellipsoid defines the preferred skin colour area, and the colour within the ellipsoid is considered as appreciated.

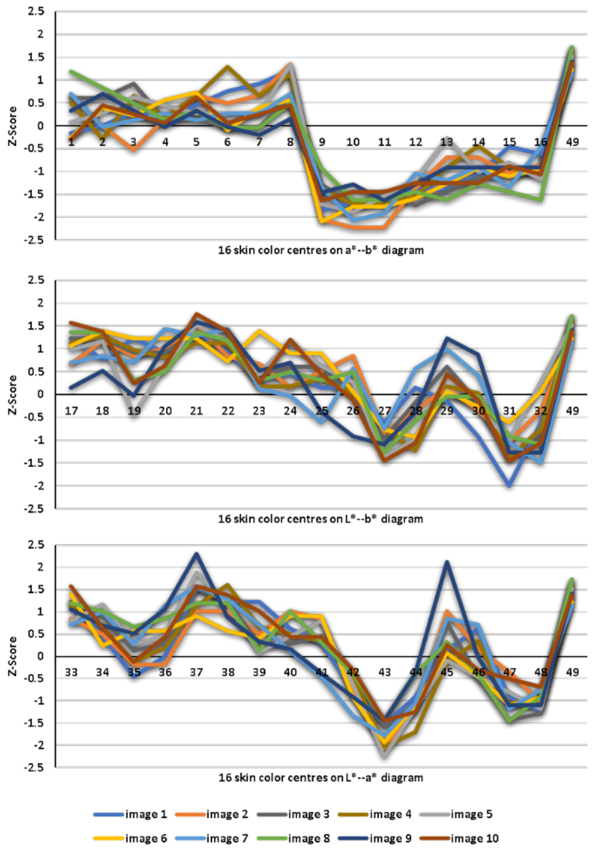

***Figure 4.** Z-score of each individual image at each skin colour Centre.*

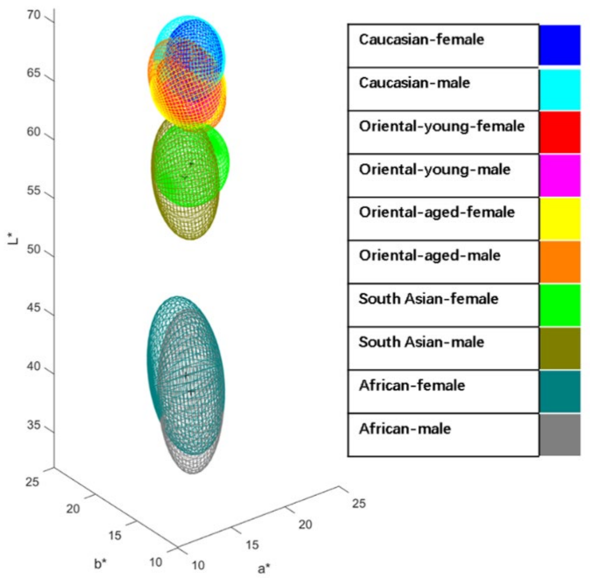

__Figure 5.__ Ellipsoids to cover 95% of preferred skin colours of each image judged by all observers

Skin Colour Preference of Each Ethnic group

To analyze the differences between the observers from different ethnic groups, the 10 images were categorized into Caucasian, Oriental, South Asian and African groups. Preferred ellipsoid skin colour model was applied to find preferred skin colour entre of 4 skin colour types judged by Caucasian, Oriental and South Asian observers respectively. Fig. 6 shows the preferred skin colour ellipsoids from the three observer groups plotted in a*-b* plane, where ellipses of Caucasian, Oriental, South Asian and African images are drawn in blue, red, green and cyan, respectively.

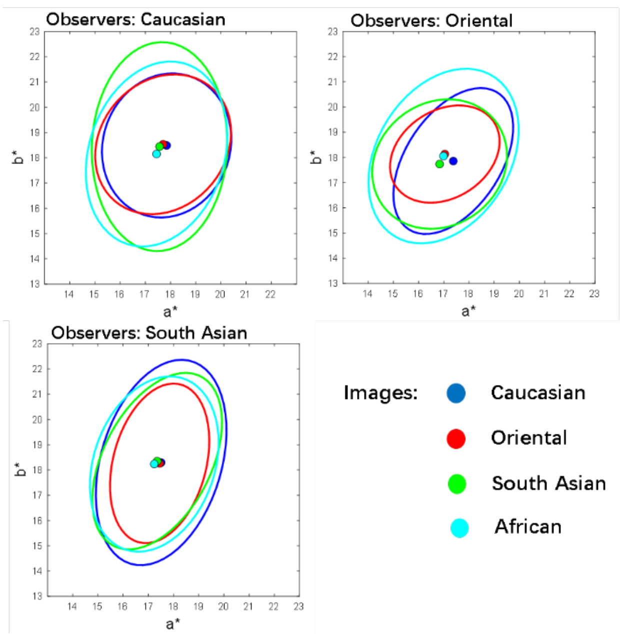

__Figure 6.__ Preferred skin colours of Caucasian, Oriental, South Asian and African images judged by Caucasian, Oriental and South Asian observers respectively.

In Fig. 6, each ellipse represented a preferred skin colour region judged by observers on one skin colour type. The preferred skin colour centre locates at the centre of its corresponding ellipse. The points with different colours are the mean preferred skin colour centre from different skin colour type images. The results showed that preferred skin colour coordinates among four image groups were quite similar. The mean preferred skin colour centres of all images judged by Caucasian, Oriental and South Asian observers were (C_{ab}*, h_{ab}) = (25.5, 46.2°), (24.8, 46.5°) and (25.3, 46.5°) respectively. Comparing the chroma values, Caucasians preferred slightly more colorful colours, followed by South Asians and Orientals. However, the differences were all very small, which implies that the preference variability due to observers' ethnic background is not significant.

Preferred skin colour results of Caucasian, Oriental, South Asian and African images obtained from all observers with mixed ethnic groups were (C_{ab}*, h_{ab}) = (25.3, 46.0°), (25.3, 46.5°), (25.1, 46.5°), and (25.0, 46.5°) respectively. The combined preferred skin colour centre was computed by averaging preferred skin colours of all skin-types images. The result of the preferred mixed skin colour is about (25, 46°) for C_{ab}* and h_{ab} values respectively. It is expected that the lightness differences will be large. The order of lightness preference on different skin types from high to low lightness is Caucasian, Oriental, South Asian and African, i.e. the preferred L* values were 67, 65, 58 and 40 for Caucasian, Oriental, South Asians and African skin colour type images respectively.

Comparing the Present Studies with the Others

In the Zeng and Luo's study [1], five LCD displays were used to display images in a dim surround viewing condition, and a single observer group with mixed ethnic groups (Caucasian dominated, plus Hispanic, African, and Asian) judged all images. Preferred skin colour centres obtained from the Zeng and Luo's study is plotted in Fig. 7 to compare with those from the present study. To compare both sets of results, all colours are adapted to a common white point, D65, and were converted to CIELAB via a chromatic adaptation transform, CAT02. The preferred skin colour centres of mixed observers found from the present study are circled with a small black ellipse. It can be seen that there are some systematic differences between the two sets of data. In their data, the models used in the experiment had a stronger makeup than the present. Hence, their colours are more colorful than those of the present. Also, their colours were slightly yellower. All above could be the reason that four preferred skin colour centres have very small discrepancies.

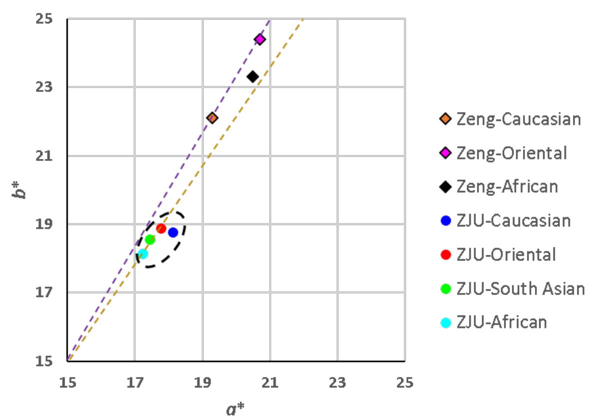

__Figure 7.__ Skin colour centres in CIELAB a-b* plane (adapted to D65) from different sources.*

Conclusions

Caucasian, Oriental, South Asian and African images were judged by Caucasian, Oriental and South Asian observers in this psychophysical experiment to study skin colour preferences of these ethnic groups. Ellipsoid model was applied to find preferred skin colour centres. In general, the colour centres from all skin-colour types and from all ethnic groups were very similar, expect the lightness, i.e. the preferred L^* values were 67.3, 65.1, 58 and 39.8 for Caucasian, Oriental, South Asians and African skin types, respectively. The preferred skin colour centre for the combined skin colour was about (25, 46°) for C_{ab}^* and h_{ab} respectively. Caucasians prefer slightly more colorful skin colours than South Asians and Orientals.

References

[1] Zeng H and Luo MR, "Colour and tolerance of preferred skin colours on digital photographic images," Color Res. Appl, 38(1), 30-45(2013).

[2] Bartleson, C.J. "Some Observations on the Reproduction of Flesh Colours," Phot.sci.eng, 3, 114-117(1959).

[3] Bartleson, C.J. "Memory Colours of Familiar Objects," J Opt Soc Am, 50(1), 73-77(1960).

[4] Bartleson, C.J. and Bray, C. P. "On the preferred Reproduction of Flesh, Blue-Sky, and Green-Grass Colors", Phot.sci.eng, 6(1), 19-25(1962).

[5] Sanders, C.L. "Colour Preference for Natural Objects. Illumination Engineering", Illuminating engineering, 54(7), 452-456(1959).

[6] Hunt, R. W. G., Pitt, I. T., and Winter, L. M.. "The Preferred Reproduction of Blue Sky, Green Grass and Caucasian Skin in Colour Photography," Journal of Photographic Science, 22(3), 144-150(1974).

[7] Sanger, D., Asada. T., Haneishi, H., and Miyake, Y. Facial Pattern Detection and Its Preferred Colour Reproduction, *IS&T/SID 2nd Colour Imaging Conference*, pp. 149-153(5). (1994).

[8] Yano, T. and Hashimoto, K. "Preference for Japanese Complexion Colour under Illumination," Color Res. Appl, 22(4), 269-274(1997).

[9] Kuang, J., Jiang, X., Quan, S., and Chiu, A. A psychophysical study on the influence factors of colour preference in photographic colour reproduction, *Proc SPIE Electronic Imaging II: Image Quality and System Performance*, 5668: 12-19(2005).

[10] Fernandez, S.R. and Fairchild, M.D. Preferred Colour Reproduction of Images with Unknown Colorimetry, *Proc IS&T/SID 9th Colour Imaging Conference*, 274-279 (2001).

[11] Zeng H and Luo MR, "Skin Color Modeling of Digital Photographic Images," Journal of Imaging Science and Technology, 55(3), p.030201.1-030201.12(2011).

[12] Liaw, M. J., Chen, C. Y., and Shieh, H. P. D.. "Color characterization of an LC projection system using multiple-regression matrix and look-up table with interpolation," Proc Spie, 17(1), 151-160(1998).

[13] P. A. García, R. Huertas, M. Melgosa, and G. Cui, "Measurement of the relationship between perceived and computed colour differences," J. Opt. Soc. Am. A 24(7), 1823–1829 (2007).

[14] H. P. Huang, M. Wei, and L. C. Ou, "White appearance of a tablet display under different ambient lighting conditions," Opt. Express 26(4), 5018–5030 (2018).

Author Biography

Rui Peng received her BSc degree in Printing Engineering from Wuhan University (2018) and has been a Master student supervised by Professor Ming Ronnier Luo at Zhejiang University since 2018. Her work is focused on colour appearance.