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The Changes of Memory Colours Under Different Environmental Conditions

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Abstract

This study investigates the sky and grass memory colours. Experiment was conducted to perform preferred and naturalness judgements by 21 subjects on images having sky and grass contents according to different environmental conditions. Thirty-three scene images were selected from 7 world wide websites. Thirty-one images were generated surrounding the original image. Each image was assessed in terms of naturalness and preference using the force choice method. The results were used to construct model to obtain memory colour centers, to compare the results between preferred and natural perceptions, and to model colour changes over environmental conditions. A model was developed to predict sky memory colour according to the cloud information in each image.

1. Introduction

Hering [1] defined ‘memory colours’ as colours that are closely associated with familiar objects. Due to the repetitive nature of people's perception of specific objects, memory colours are usually relatively stable [2]. In the imaging field, accurate reproduction of memory colours directly determines the image colour quality, for which memory colour is a measure for image quality assessment and can effectively measure the accuracy and naturalness of image colour reproduction. Naturalness, as one of the core criteria for subjective image quality assessment, is significantly positively correlated with preference, and a variety of image naturalness models were also developed [3-8].

Numerous studies have been devoted to the construction of models related to memory colours. Zhu et al. [9] studied long-term memory colours to investigate the effects of Chinese and German observers. Tian et al. [10] established ellipsoidal models of typical memory colours for the sky, grass, and skin. Extensive studies were carried out in-depth study of skin colour [11-14]. Cao and Luo [15] explored the differences between the preferred and natural memory colours and between different ethnic groups using 24 familiar objects. Based upon large number of research data, the preferred memory colour card (PMC) chart was proposed [16], as shown in Figure 1. It is divided into three groups of colours. Each has their own applications [16]. The limitation of this chart is only a single colour corresponding to one memory colour on the chart. In real life, memory colours are normally biological objects. They change colour over time. Hence, there is a lack of tool to evaluate memory colour changes over time and environmental conditions

In the present study, the images having sky and grass memory contents are studied under different dynamic natural environments. The goal is to predict memory colours according to environmental conditions.

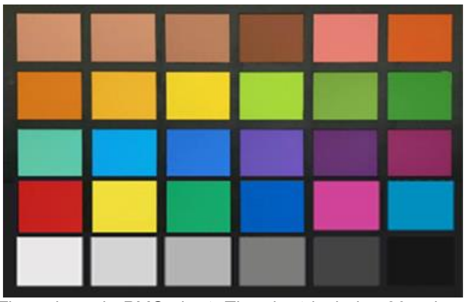

Figure 1. *The colours in PMC chart. The chart includes 30 colour patches which are divided into three groups: the top three rows are preferred memory colours; row 4 defines reference gamut colours, and bottom row provides a neutral scale.*

2. Experiments

Six cell phones having a 6.78-inch AMOLED screen with 3200×1440 pixel resolution were used in the study. The 3D colour look-up-table (LUT) [17] method was adopted to characterise each display between device dependent RGB and devise independent XYZ values. The predictive error is 0.8 CIEDE2000 (ΔE_{00}) [18] colour difference units using the 24 Macbeth ColorCheck chart colours, indicating the colour accuracy to meet the experimental requirements.

A large effort was made to collect colour change images via different webcam worldwide. Finally, 33 images from 7 websites were selected (South Africa, Shenzhen, St. Petersburg, Australia, Brazil, Kansas US, and California US). Figure 2 shows the images studied, 15 sky images of sky, 12 grass images and 6 images taken in the same place in a day.

Image processing including 3 steps was carried out to prepare images for the psychophysical experiment.

Step 1 is to extract the region of interests such as sky and grass in an image. An image segmentation model of the Kirillov image segmentation algorithm [19] was implemented to perform initial cropping. The coordinates of a pixel point of the target region are manually inputted to obtain the relevant image region by propagation. In order to improve the segmentation accuracy of part of the image, the image was further cropped and extracted pixel manually in Photoshop®.

Step 2 is to transform the RGB of each pixel in the cropped region from Step 1 to XYZ using sRGB space, and then converted to them to CIELAB coordinates. The subsequent calculation of the cloud content of the sky image requires a detailed segmentation operation of the sky image by using the L* and b* thresholds to determine the blue region, and at the same time, the edge detection to exclude the region of the heavier texture, which results in the region of the sky with a blue background, and the percentage of clouds can be calculated.

Figure 2. The images used in this study: Row 1-4 (sky images), Row 5-7 (grass images), and Row 8 (morning, midday, and evening images including both sky and grass).

Step 3 is to perform colour rendering. 30 target colours surrounding the colour centre (see Figure 3) were selected uniformly in CIELAB a*b* plane. The target colours were selected to cover the typical ellipse parameters found from earlier studies, shape and orientation of ellipse. Finally, three sizes of ellipses including 6, 10 and 14 rendered images from the centre. This is to ensure the diversity of the visual perception of the image, i.e., covering the large colour region to include some of the unnatural and dislike images. Once the target colour is determined, Δa* and Δb* between the original mean and the target colours are calculated to generate the 30 new memory object colour.

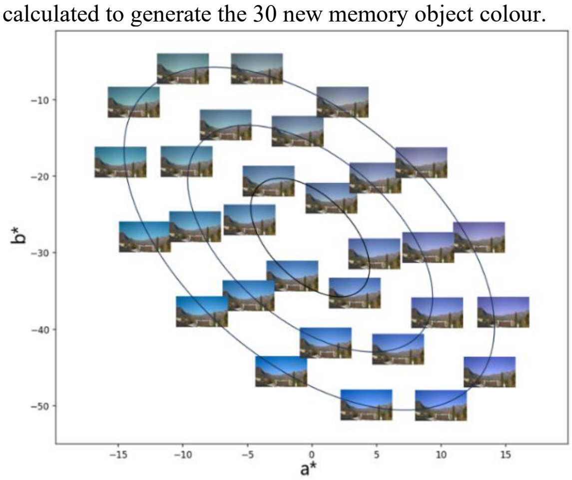

Figure 3. An example of the target colour.

The force choice method is used in the experiment. Figure 4 shows the user interface on a display. Each observer makes judgement, i.e. preferred or not preferred, or natural or not natural for the preference and naturalness perceptions respectively. The texts in the upper left indicates to scale preference or naturalness of the image in question. The bottom two buttons are for yes or no decision. Once the decision is made then it moves to the next image. If press the top right button, observers can redo the earlier image.

A total of 21 normal colour vision subjects participated in this experiment, including 11 females and 10 males, aged between 20 and 31 years old, with an average age of 23 years old. Prior to the experiment, an instruction was read to observers. The experiment was conducted in a dark room. To assess the intra observer variation (repeatability), 20% of the images in each group were randomly selected to repeat the judgment. Therefore, each observer performed 2454 assessments, i.e. (33 sample images x 31 colours + 204 repeated images) × 2 attributes (natural/preferred). A total of 51,534 assessments were made, i.e. 21 observers×2454 assessments.

Figure 4. The user interface in the experiment.

3. Data analysis

Observer variation

Intra-observer variation reflects the consistency of each observer's own results. To assess the accuracy of the observers' assessment results, 20% of the images were randomly selected for repeated judgment. In this study, the percentage of correct decisions (CD%) was used to quantify intra-observer variability. According to the experimental design, each observer was required to repeat the assessment for 408 random images. CD% is the percentage of consistent judgments among between the repeated judgments. The CD% of each observer ranged from 67% to 85%, with a mean value of 75%, indicating a high reliability of the observers' assessments.

Inter-observer variation reflects the spread of the results for all observers. Mean-colour-difference-from-mean (MCDM) measure, as shown in Equation (1), was used here to calculate the inter-observer variation of all observers. For example, each observer evaluates each test image as "natural" or "unnatural". For each test image, the average colour of the "natural" images selected by each observer is taken as the most natural colour (a_i^*, b_i^*) for observers. MCDM is the average colour difference between the most natural colour for each observer and the average value for all observers.

$$MCDM = \frac{1}{N}\sum_{i=1}^{N}\sqrt{\left(a_i^* - \overline{a^*}\right)^2 + \left(b_i^* - \overline{b^*}\right)^2} \qquad (1)$$

where $\overline{a^*}$ and $\overline{b^*}$ are the average values of the most natural colours for all observers.

The higher the MCDM means the greater the deviation of experimental data. The results indicate that the inter observer differences in naturalness (3.76 ΔE_{ab}^*) are lower than the differences in preference (4.55ΔE_{ab}^*), suggesting that observers perceive image naturalness more consistently.

Modeling

According to the previous study [20-22], colours with the same naturalness are distributed as an ellipsoid in CIELAB colour space or as ellipses in the a*b* plane. This experiment was fitted with an ellipsoid model.

The typical model for predicting the probability of naturalness using the relative colour shift ΔE' was implemented, where N% is the predicted naturalness probability. The modeling equation for the relationship between relative colour shift ΔE' and naturalness is given in Equation (2).

$$N\% = \frac{1}{1 + e^{(\Delta E' - \alpha)}} \quad (2)$$

$$\Delta E' = \sqrt{k_1(a^* - a_0^*)^2 + k_2(b^* - b_0^*)^2 + k_3(a^* - a_0^*)(b^* - b_0^*)} \quad (3)$$

where a^*, b^* represent the colour of the surrounding image in question ; a_0^* , b_0^* are the memory colour center; the a_0^*, b_0^*, k_i (i = 1,2,3), α coefficients are obtained by minimising the difference between the N% and the visual results P%. Finally, α is the $\Delta E'$ value corresponding to a N% value of 50% preference or naturalness ellipse.

Figure 5 is a plot of visual results in P% values against $\Delta E'$ values calculated from Equation (2) for one of the images studied. Also, the curve calculated from Equation (2) is plotted, which gives reasonable fit to the data.

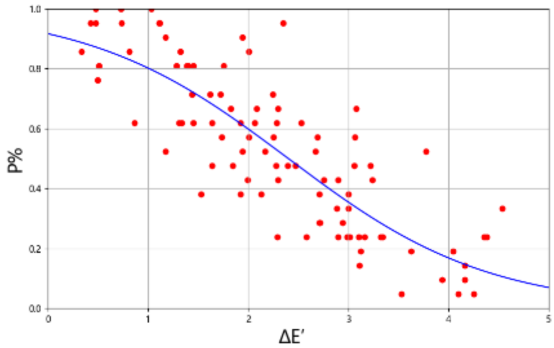

Figure 5. *Relative colour shift ΔE' versus naturalness probability.*

4. Results

In this study, all the sky image data are divided into four categories based on the actual cloud coverage in each image: 1) the sunny sky image (e.g. see the top left of Figure 1), 2) the cloudy sky image, typically showing a uniform greyish-white colour tone (e.g. Row 2 Column 4 of Figure 1). 3) the so-called cumulus cloud images, which are low, puffy, fair-weather clouds that often resemble cotton balls (e.g. all images in Row 5 of Figure 1), and 4) the cloud cover image, which shows fuzzy and irregular cloud edges, and hairy or flocculent features. This category can be further divided into three subcategories: low, medium, and high cloudiness according to the percentage of the white clouds in the image. Figure 6 summarises the results in terms of experimental ellipses under different environmental conditions. Figure 7 plots the ellipses for different time of a day.

By comparing ellipses in the two subfigures in Figures 6, it can be seen that some preference ellipses to be smaller in size, than those of naturalness. For the sky ellipses in both figures, there is an increase of sizes along with chroma, and both sets of ellipses point towards neutral point, i.e. having constant hue.

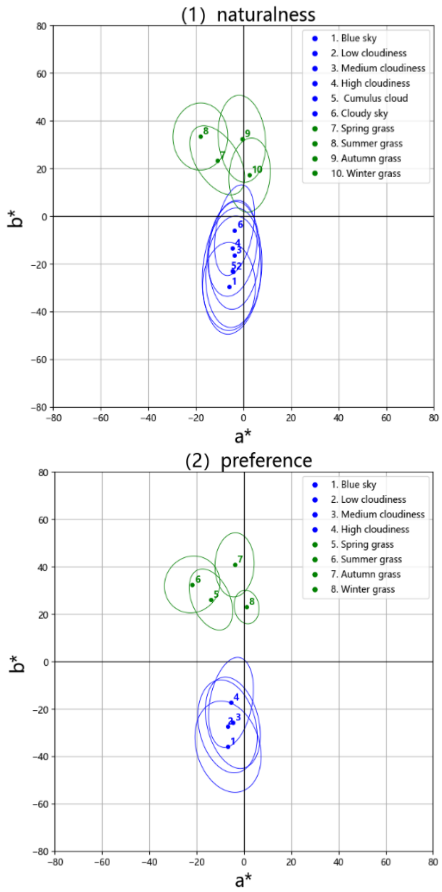

Figure 6. *Plot of the ellipses under different environmental conditions.*

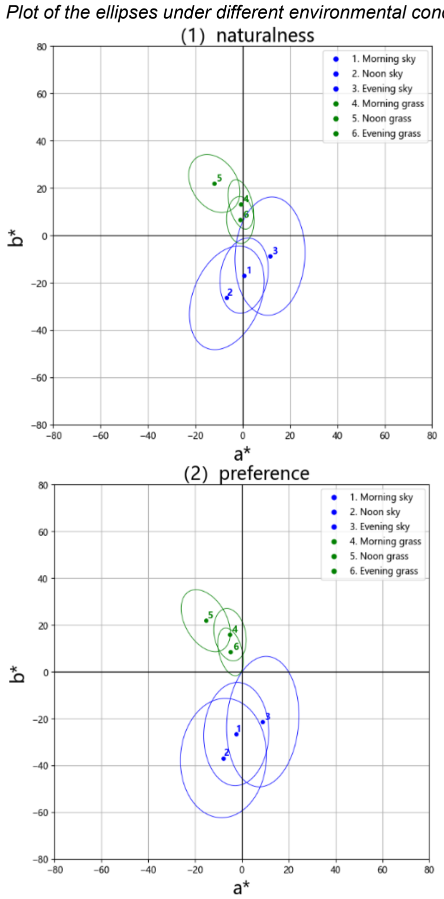

Figure 7. *Plot of ellipses under different time of a day.*

By comparing ellipses in the two subfigures in Figures 7, it can be found that the noon images are the most colourful, followed by the morning and night images least colorful. Also, the two grass ellipses at night are much smaller than those in the day time. Again, the preferred ellipses are more colourful than those of naturalness ones.

The next analysis is to model the memory colours according to different environmental conditions. Figure 8 plots the cloud content against the C^*_{ab} and h_{ab} values for the sky naturalness images, respectively.

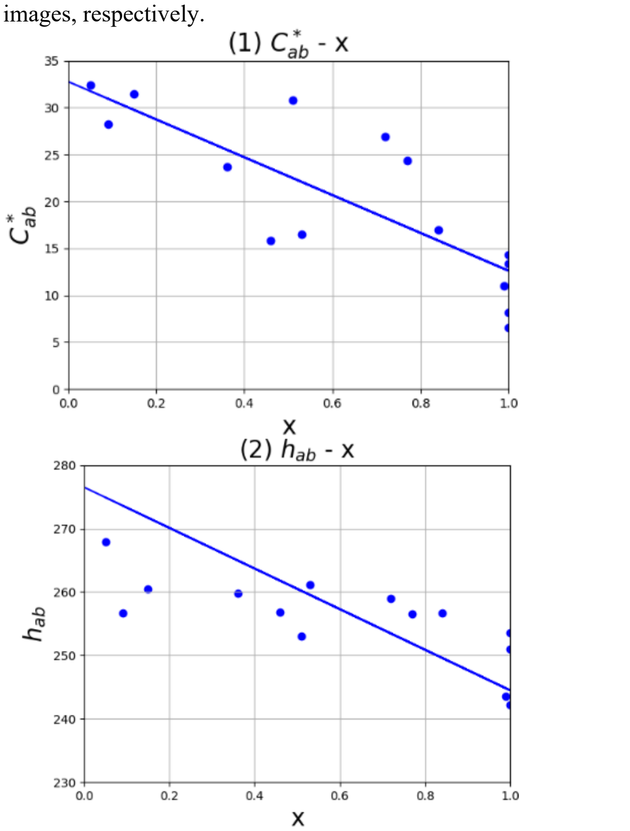

Figure 8. *The plot of cloud content (x) vs. natural memory colour data against 1) C^*_{ab} and 2) h_{ab} respectively, together with best fitted line.*

The two equations are given in Equations (4) and (5) to predict the C^*_{ab} and h_{ab} values of naturalness perception respectively from the cloud contents (normalized to unity). In order to include the most comprehensive range, the fitting line is proposed. The line was also fitted to the data.

$$C^*_{ab} = -20\ Cloud + 32.8 \qquad (4)$$

$$h_{ab} = -32\ Cloud + 276.5 \qquad (5)$$

Figure 9 shows 112 sky colour centers independently collected plotted in a*b* plane together with the loci of 25, 50 and 75% of cloud from Equation (4) and the boundaries of Equation (5). It can be seen that most of the data points are within the hue boundaries.

Figure 10 illustrates the rendering effect of 4 images by showing the original, and naturalness and preference rendered images from left to right respectively. It can be seen that for each scene, the two rendered images are more appealing than the original image. Also, the preferred images are more colourful than the naturalness images.

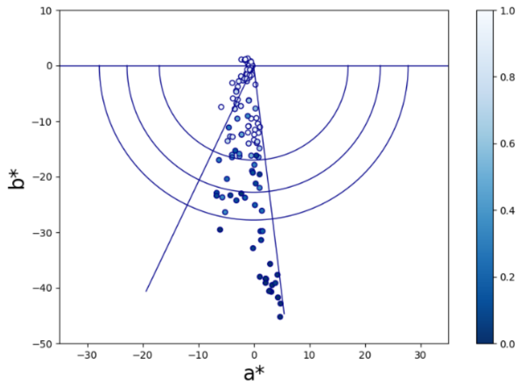

Figure 9. *The 112 sky image colours plotted in a*b* plane together with the loci of constant cloud % and hue ranges.*

Figure 10. *The original image, and the natural and preferred sky memory image from left to right respectively.*

The next analysis is to compare the difference between the present naturalness and preference results. Figure 11 shows the plot of C^*_{ab} between two sets of data. The figure shows that chroma of the preferred colours is generally higher than those of naturalness, i.e. preferred colours are more saturated or vibrant Than natural colours. Note it was found little hue angle difference between the two sets. This phenomenon showed clearly in Figure 10.

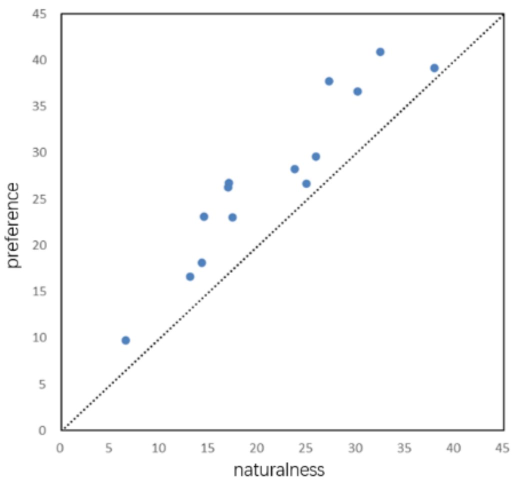

Figure 11. *The plot of the chroma for naturalness and preference data respectively.*

The last analysis in figure 12 is to compare the present to the earlier published results, including the Tian et al.'s [10], Zeng and Luo's [20] and the corresponding colours from the Preferred Memory Colour (PMC) chart [16], and the Macbeth ColorChecker (MCC) Chart [23,24].

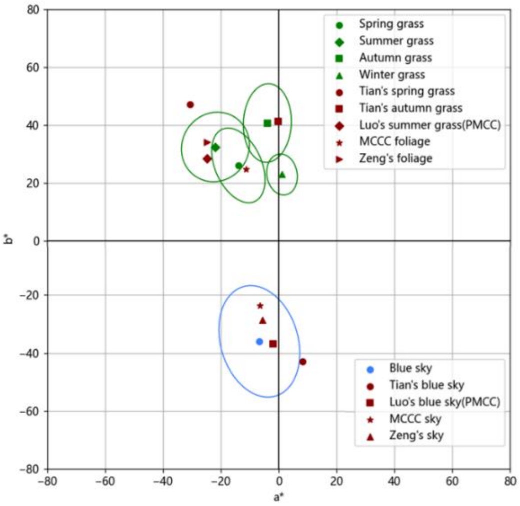

Figure 12.*Comparison of preference data with previous results.*

The results showed that the present results are closer to the corresponding colours of the Preferred Memory Colour (PMC) Chart, with ΔE_{ab} values of 4.9 and 5.0 for the sky and summer grass respectively. There are some differences between the present and the Tian’s colour centers. This could be caused by the sources of the original images. Tian’s images were selected from the photographic database, including more vivid and saturated pictures, while the present images were selected from real-time photos taken by webcams, which retain the original information such as the natural lighting conditions in the scene, and are closer to the typical images taken in real-life.

5. Conclusion

This paper collected images of colour changes of the sky and grass under different natural environments. The colour of the target regions (sky and grass) were obtained through image segmentation. Subjects with normal colour vision participated psychophysical experiment to scale images in terms of preference and naturalness. These results were used to fit elliptic model to construct a memory colour model. The present results are summarised below :

(1) The memory colour regions of the sky and grass, including the sky with different cloud patterns and contents and the grass in all seasons, as well as the sky and grass in the early morning, midday, and late evening;

(2) The relationship between the memory colour and the natural parameters was established, so that the appropriate natural memory colour can be selected according to the cloud content of the sky, and the different seasons of the grass;

(3) The natural memory colours were compared with the preferred memory colours, and analyse the connection between human cognition of natural colours and subjective aesthetic preferences;

(4) The present results were found to reasonably agree with the earlier ones. This demonstrates the robust of the present work.

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