LETTER *Special Section on Image Media Quality*

# Adaptive ambient illumination based on color harmony model

**Ayano KIKUCHI**[†], ***Nonmember***, **Keita HIRAI**[†], ***Student Member***, **Toshiya NAKAGUCHI**[†], **Norimichi TSUMURA**[†], ***and*** **Yoichi MIYAKE**[††], ***Members***

**SUMMARY** We investigated the relationship between ambient illumination and psychological effect by applying a modified color harmony model. We verified the proposed model by analyzing correlation between psychological value and modified color harmony score. Experimental results showed the possibility to obtain the best color for illumination using this model.

***key words:*** *display, illumination, subjective evaluation, factor analysis, color harmony*

## 1. Introduction

It is said that the changes of ambient illuminations while viewing a display significantly affect human impressions and psychology. In general, we can feel highly realistic sensation, dynamism and fatigue in a dark room, and low dynamism and fatigue in a bright room. Thus, it is important to investigate the availability of ambient illuminations with keeping highly realistic sensation, dynamism and low fatigue.

Previous research has reported that realistic sensation and dynamism are increased as FPD's size is getting larger, and as number of pixels is increased [1]. On the other hand, for improving the realistic sensation and dynamism while viewing FPDs, some researches tried to change ambient illuminations by using the information of displayed images such as color and contrast [2],[3].

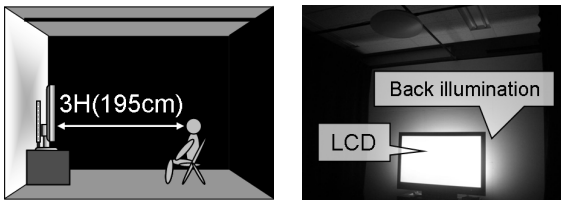
In our previous research, we investigated the relationship between ambient illuminations and psychological effects while viewing display [4],[5]. In the psychological experiments, observers watched the displayed images with changing the ambient illuminations. They also evaluated various keyword pairs which were prepared based on semantic differential (SD) method [6],[7]. By applying factor analysis method to the experimental result and we clarified psychological effects by ambient illuminations. By using illumination, it showed us "dynamism" factor was increased and "tiring" factor was decreased. However the best color for illumination while viewing FPD depended on displaying image content. In addition, the method to decide the best color for illumination is not found.

Manuscript received April 15, 2009.
Manuscript revised July 31, 2009.

[†]Graduate School of Advanced Integration Science, Chiba University, 1-33, Yayoi-cho, Inage-ku, Chiba, 263-8522

[††]Research Center for Frontier Medical Engineering, Chiba University, 1-33, Yayoi-cho, Inage-ku, Chiba, 263-8522

DOI: 10.1587/transfun.E0.A.1




(a) (b)

**Fig. 1** Experimental set up, (a)viewing distance, (b)display and illumination

In this research, we propose a decision technique for the best color of illumination, which employs the color harmony model[8]. Color harmony scores [8] indicate how pleasant in the emotion while viewing any color pairs. We verify the availability of the proposed method by analyzing correlation between psychological value and color harmony score while viewing the combination of 4 kinds of displayed images and 12 kinds of illuminating colors.

## 2. Psychological experiment

In the psychological experiments, we used SD method for investigating psychological effects by changing ambient illuminations. Observers evaluated the displayed images with changing colors of ambient illuminations around a display.

### 2.1 Experimental setup

Figure 1 shows the experimental room designed like actual living rooms. Color illumination located in back of the display (back illumination). Its intensity and color can be controlled by adjusting the mixing ratio of RGB components. The display was 52 inch LCD and the viewing distance was approximately 195 cm that corresponded with 3H (H: screen height [9]) of the display.

### 2.2 Experimental method and keyword

In the experiment, SD method [6],[7] was employed.

**Table 1** Back illuminations

(a)Illuminated conditions and CIE$L^*C^*h$ values

| | White (5000K) | Red (low chroma) | Green (low chroma) | Blue (low chroma) | Ave color of image | No illumination |
|---|---|---|---|---|---|---|
| Beach | | | | | $L^*$:60.0 $C^*$:31.4 $h$:299.9 | |
| Sunset | $L^*$:60.0 | $L^*$:59.2 | $L^*$:72.4 | $L^*$:48.1 | $L^*$:69.9 $C^*$:97.3 $h$:59.8 | $L^*$:0 |
| Greenery | $C^*$:31.4 $h$:299.9 | $C^*$:73.9 $h$:357.6 | $C^*$:53.1 $h$:166.3 | $C^*$:75.3 $h$:286.6 | $L^*$:79.4 $C^*$:90.8 $h$:119.1 | $C^*$:0 $h$:0 |
| Blue sky | | | | | $L^*$:51.9 $C^*$:62.1 $h$:280.4 | |

(b)Additional illuminations for "Beach" image

| | Red (high chroma) | Green (high chroma) | Blue (high chroma) | Cyan (low chroma) | Magenta (low chroma) | Yellow (low chroma) |
|---|---|---|---|---|---|---|
| Beach | $L^*$:61.5 $C^*$:157.0 $h$:42.5 | $L^*$:87.3 $C^*$:174.0 $h$:153.8 | $L^*$:20.7 $C^*$:172.1 $h$:307.3 | $L^*$:52.9 $C^*$:60.0 $h$:269.7 | $L^*$:51.1 $C^*$:72.8 $h$:311.2 | $L^*$:69.6 $C^*$:22.6 $h$:82.8 |

**Table 2** CIE$L^*C^*h$ values of mean color of displayed images

| | $L^*$ | $C^*$ | $h$ |
|---|---|---|---|
| Beach | 79.1 | 18.6 | 268.0 |
| Sunset | 39.6 | 34.6 | 63.3 |
| Greenery | 58.0 | 48.5 | 139.6 |
| Blue sky | 45.6 | 60.3 | 280.5 |

Twenty keyword pairs (twenty bipolar word pairs) are prepared for investigating the psychological effects by the illuminations. In fact, the keyword pairs were provided in Japanese because the common language of every observer is Japanese. Each observer evaluated the impressions of displayed image under various ambient illuminations. The experimental results were transformed into the values from 5 (positive) to 1 (negative) and they were applied to factor analysis method.

### 2.3 Experiment

Table 1 shows CIE$L^*C^*h$ value of the illumination used in this experiment. In this experiment, four images with natural scene (Beach, Sunset, Greenery and Blue sky) were displayed under six illuminations as shown in Table 1 (a). Moreover, as shown in Table 1 (b), six illuminations were added for only the "Beach" image. Table 2 shows the mean CIE$L^*C^*h$ values of displayed images. Each image was exhibited for 30 seconds, and after that the observers (27 imaging scientists, male: 23, female: 4) evaluated the impressions in 1 minute while viewing the same image. Totally 29 ($= 4 \times 6 + 6 - 1$, the condition of average color illumination for beach was skipped since it is the same color as white illumination) combinations were evaluated in the experiment.

### 2.4 Color harmony score

In this research, color harmony score modeled by Ou[8] was calculated. In our previous research [4],[5], we experimentally found that the opposite color combinations (e.g. red and green) provide the poor " comfortable and appreciated " impression. In order to give a preferable score of such color combination, the color harmony model proposed by Ou is the most popular and reliable model because the model is derived based on very careful and reliable experiments. Besides the concept of handing the hue angle between two colors in Ou 's model corresponds with our experimental result (which means the opposite color combination provides disharmony), therefore we employed this model to estimate the best color for illumination from the displaying image content. The score was calculated by combination of two color pairs of CIE$L^*C^*h$. Color harmony score ($CH$) can be shown as follows:

$$CH = H_C + H_L + H_H. \tag{1}$$

- $H_C$: Chromatic effect, the effect indicates that the color harmony score tends to decrease as the chromatic difference becomes larger between the constituent colors.
- $H_L$: Lightness effect, the higher the lightness value of each constituent color in a color pair, the more likely it is that they will appear harmonious, and small lightness variations between the constituent colors in a color pair may reduce the harmony.
- $H_H$: Hue effect, among various hues, blue is the one most likely to create harmony in a two-color combination and red is the least likely to do so. In addition, bright yellows more often create harmony than dark yellow.

Please refer to the paper[8] for more details.

In the experiment, the score was calculated by combinations of mean color of the displayed still images and illuminating conditions described above. Totally 29 color harmony scores was calculated.

## 3. Results and discussion

By applying factor analysis method to the experimental result, twenty keyword pairs were classified into two factors. We named the first factor " lively and active " and the second factor " comfortable and appreciated ". The

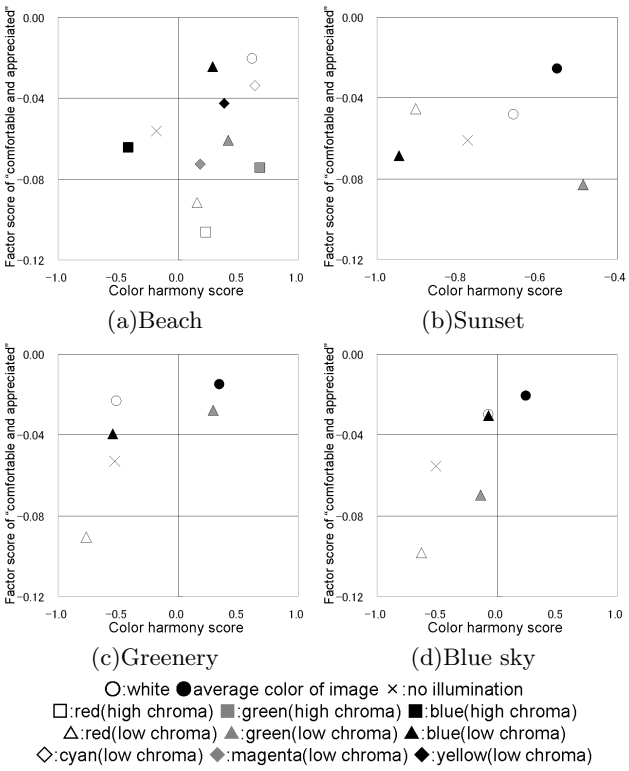



**Fig. 2** Factor scores and color harmony scores of each image

**Table 3** Coefficient of correlation for means of factor score and color harmony scores

| | All images | Beach | Sunset | Greenery | Blue sky |
|---|---|---|---|---|---|
| $R$ | 0.232 | 0.302 | 0.024 | 0.705 | 0.828 |

cumulative contribution ratio of first and second factors is 45.3 %. In this study, the factor score "comfortable and appreciated" was chosen because the contribution ratio was larger than the other.

Figure 2 plots the distribution between mean factor scores of "comfortable and appreciated" and color harmony scores, and Table 3 shows the coefficient correlation. In these results, the coefficient correlation depends on the displayed image. In " Blue sky " image, coefficient value is high, but others were not.

In "Beach" image (Fig.2 (a)), color harmony score of "Blue (high chroma)" was low. This is because the $L^*$ value of "Blue (high chroma)" is low and the $C^*$ value is high. Color harmony score is influenced the sum of lightness of two color pairs, and color harmony score goes up if sum of lightness rises. In addition, colors of chroma and hue angle influence the color harmony. The smaller difference of chroma and hue angle between two color pair, the higher color harmony score is. In the experiment for the original color harmony model [8], the highest $C^*$ value used in the experiment was 61.4 whereas it is 174.0 in this study. Hence there is a possibility that color harmony score could not accept very high $C^*$ value like "Red, Green, Blue (high chroma)" illuminations.

**Table 4** Coefficient of correlation for means of factor score and modified color harmony scores

| | All images | Beach | Sunset | Greenery | Blue sky |
|---|---|---|---|---|---|
| $R$ | 0.542 | 0.743 | 0.367 | 0.562 | 0.832 |

In "Sunset" image (Fig.2 (b)), color harmony score of "Green (low chroma)" illumination is high, but factor score is low. This is because $L^*$ value is high.

These issues are considered that our experimental conditions are different from Ou's experiment, such as color samples and viewing condition. Therefore we solve these issues by adjusting color harmony model to increase the correlation coefficient values between color harmony score and factor score in next section.

### 3.1 Modified color harmony model

To solve the above issue, we propose a modified color harmony model by adding weight coefficients into each term as follows.

$$CH = \alpha H_C + \beta H_L + \gamma H_H. \tag{2}$$

By optimizing the values of $\alpha$, $\beta$, and $\gamma$ to maximize the correlation coefficient ranging between -1 to 1, we obtained following values;

$$\alpha = 1,\ \beta = -0.087,\ \gamma = 0.192. \tag{3}$$

As the result of Eq. 2 and 3, modified color harmony scores are influenced a great deal by $H_C$. In addition, $\beta$, coefficient of $H_L$ means that the higher the lightness value of each constituent color in a color pair, the more likely it is that they will appear harmonious.

Figure 3 plots the distribution between mean factor scores of "comfortable and appreciated" and modified color harmony scores, and Table 4 shows coefficient correlation. It is found that the correlations have drastically improved. But in "Greenery" image, it shows lower value compared to Table 3. This is because color harmony score of "Green (low chroma)" is higher than the other illuminations(Fig. 3(c)). Modified color harmony scores are influenced a great deal by $H_C$ (Eq. 2, 3). Therefore, "Green (low chroma)" illumination occur highest score and thereby "Greenery" image shows low coefficient correlation.

## 4. Conclusion and future work

In this research, we investigated the relationship between ambient illumination and psychological effect by applying a modified color harmony model. It suggests that modified color harmony model have possibility to suggest the best color for illumination. Our modification means that the ratio of $H_C$, $H_L$ and $H_H$ factor influenced color harmony are different respectively. However, since our experiment conditions are different from

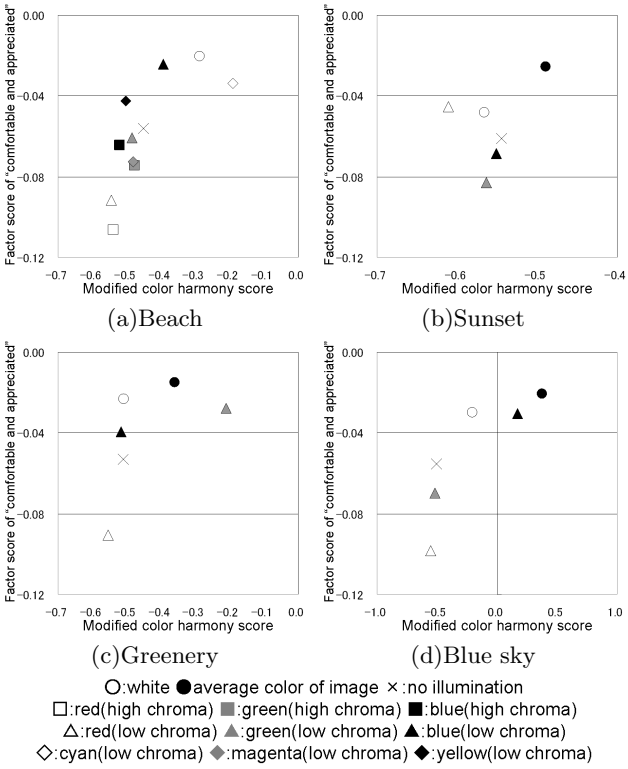



**Fig. 3** Factor scores and modified color harmony scores of each image

Ou's original experiment, it admits of improvement for color harmony model.

In future work, we would like to create an original color harmony model to fit completely to our purpose considering every factor deeply and carefully. Furthermore we also need to address the illumination conditions while viewing video images.

**References**

[1] K. Masaoka, M. Emoto, M. Sugawara, and F. Okano, "Presence and viewing conditions when using an ultrahigh-difinition large-screen display," Proc. of IEICE General Conference, AS-7-3, pp."S-99"-"S-100", March 2005.

[2] I. Vogels, D. sekulovski, and B. Rijs, "Discrimination and preference of temporal color transitions," Proc. of IS&T/SID, 15th Color Imaging Conference, pp.118-121, Albuquerque, New Mexico, Nov. 2007.

[3] C. Liu, and M.D. Fairchild, "Measuring the relationship between perceived image contrast and surround illumination," Proc. of IS&T/SID, 12th color Imaging Conference, pp.282-288, Scottsdale, USA, Nov. 2004.

[4] A. Kikuchi, K. Hirai, T. Kaneko, T. Iwanami, N. Yano, T. Nakaguchi, N. Tsumura, Y. Miyake, "Factor analysis of psychological effects by ambient illuminations while viewing display," The Third International Workshop on Image Media Quality and its Applications, pp.151-157, Kyoto, Japan, Sept. 2008.

[5] T. Iwanami, A. Kikuchi, T. Kaneko, K. Hirai, N. Yano, T. Nakaguchi, N. Tsumura, Y. Yoshida, Y. Miyake, "The relationship between ambient illumination and psychological factors in viewing of display images," Proc. of SPIE (IS&T/SPIE Electronic Imaging), Vol.7241, 72410L, San Jose, USA, Jan. 2009.

[6] C.E. Osgood, G.H. Suci, and P.H. Tannenbaum, "The measurement of meaning," University of Illinois Press, Urbana and Chicago, 1957.

[7] C.E. Osgood, "Studies of the generality of affective meaning system," American Psychologist, 17, pp.10-28, 1962.

[8] L.C. Ou, M.R. Luo, "A colour harmony model for two-colour combinations," Color Research & Application, Vol.31, no.3, pp.191-204, June 2006.

[9] ITU-R BT.710-4, "Subjective assessment methods for image quality in high-definition television," 1998.