Monitor Brightness Perception Changes under Various Surround Condition

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Abstract

The monitor brightness is affected by surround condition. The perceived brightness values of six test stimuli with different luminance levels were estimated using magnitude estimation technique to investigate the surround luminance effect. Each of the test stimuli was displayed on a LCD monitor. The nine surround conditions were controlled by illuminator which was placed behind the monitor. The range of surround ratio, S_R, was varied from 0.3 to 3.8. It was found that the perceived brightness of each test stimulus decreases when surround ratio (S_R) is higher than 1 compared to that under dark room. CIECAM02 brightness predictor, Q, was tested resulting in poor performance. CIECAM02 predicts that Q keeps increasing even when S_R is higher than 1. The Q in CIECAM02 is strongly influenced by parameter c and L_A. For this reason, new c value for dim, average and bright condition is proposed as a log function of S_R based on the new brightness data.

1. Introduction

Nowadays displays are widely used under various surround condition including dark room and bright outdoor viewing conditions. It is well known that when people watch the mobile display under dark surround condition, it looks brighter than that shown under ambient lighting [1]. It means the perceived brightness of display is affected by viewing condition. Therefore understanding the color perception changes by surround condition is critical for image quality improvement of a display.

Even though latest CIE color appearance model, CIECAM02 [2], accounts for the color changes by surround, the range of surround conditions considered in the model is rather limited. According to the CIECAM02, the surround condition is divided into three categories (dark, dim, average), which does not include outdoor condition. The several researches [3-7] have been conducted to predict the color appearance under wide surround luminance levels. They showed that CIECAM02 performs poorly under bright surround and tried to modify the CIECAM02 but the modification is limited to lightness predictor.

The aim of this study is to investigate the perceived brightness changes under well controlled various surround conditions. The first goal is to measure the perceived brightness in various surround luminance levels. The second goal is to evaluate the performance of CIECAM02 brightness using the collected visual data. The final goal is to propose a new brightness predictor for CIECAM02.

2. Psychophysical Experiments

2.1 Experimental Set Up

Figure 1 shows the experimental environment. The 107-inch (2400 × 1300 mm) illuminator was attached to the wall to form a surround. The illuminator was composed of fluorescent lamps and controlled to have nine different luminance levels. A Minolta CA-2000 2D color analyzer was used to measure the surround luminance with measuring angle of 10˚. Table 1 indicates the tristimulus values (XYZ) and correlated color temperature (CCT) of the nine surround conditions. These surround conditions cover the wide range of surround luminance from dark to bright. The average CCT was 7293K.

***Figure 1** The experimental configuration*

The 24-inch monitor was placed in front of the illuminator minimizing veiling glare from the illuminator. Six test stimuli with different luminance levels were produced on the monitor. A Minolta CS-1000 spectroradiometer was used for measurement with measuring angle of 10˚. Table 2 summarizes the XYZ and CCT of test stimuli. Each test stimulus was controlled to be 7200K except t6. The luminance of the test stimuli t1, t3 and t5 were rendered to have same luminance with s5, s6 and s7, respectively.

Therefore, there were sixty different monitor-surround combinations including dark surround. According to CIECAM02 [2], the relation between surround and monitor could be calculated by the surround ratio (S_R) as shown in Equation 1. CIECAM02 defined three surrounds; average, dim and dark for $0.2 \le S_R$, $0 \le S_R \le 0.2$ and $S_R = 0$, respectively. The S_R value was computed for each monitor-surround condition. For example, S_R for the test stimulus t1 under surround condition s5 is 1. All of monitor-surround conditions in this experiment belong to the average surround. The range of S_R was varied from 0.3 to 3.8.

$$S_R = \frac{luminance\ of\ surround\ (Y_s)}{luminance\ of\ monitor\ (Y_m)} \quad (1)$$

Table 1 Conditions of the nine surround conditions

	X	Y (cd/m^2)	Z	CCT (K)
s1	48.67	56.51	56.72	7011.79
s2	56.55	65.53	67.03	7119.27
s3	66.40	76.77	79.73	7201.74
s4	79.56	91.84	96.50	7271.75
s5	98.43	113.36	120.56	7336.90
s6	126.39	145.22	156.51	7415.86
s7	171.68	196.65	213.29	7432.52
s8	265.80	303.58	329.80	7414.41
s9	378.44	431.18	471.22	7434.20

Table 2 Conditions of the six test stimuli

	X	Y (cd/m^2)	Z	CCT (K)
t1	108.89	113.40	136.72	7214
t2	129.00	133.38	162.23	7202
t3	142.41	146.68	180.80	7280
t4	163.48	168.58	208.51	7229
t5	186.26	196.39	230.20	7115
t6	203.17	215.97	232.69	6555

2.2 Experimental Procedure

Twenty-four observers took part in the experiment. There were 12 males and 12 females, whose age ranged from 20 to 28. They passed the color vision test and Farnsworth Munsell 100 hue test.

The viewing angle was about 9° horizontally and 6° vertically at a viewing distance of 3 meter. Before performing the experiment, training session was included to notice the brightness attributes using neutral color patches of Munsell color order system.

The magnitude estimation method was used to estimate the brightness. A test stimulus was shown to the observer under dark surround condition. The observer had to memorize the brightness of the test stimulus for at least 3 minutes and it was designated to have brightness of 100. At the same time, the observer's eyes were adapted to the monitor. After the observer was fully adapted to the test stimulus, surround luminance condition was changed at random order. The observers were asked to assign the degree of brightness of the test stimulus under each surround luminance condition compared to the memory. After the experiment for a test stimulus was over, these processes were repeated for the other test stimuli. The all observations were carried out in random orders. All the experiments were repeated twice. Totally 2592 estimation observations (6 test stimuli × 9 surrounds × 24 observers × 2 repeat) were collected in this experiment.

3. Results

3.1 Observer Variation

The coefficient of variation (CV) [9], introduced in Equation 2, was used to examine the observer repeatability and reproducibility. The CV is a statistical measure of the agreement between two data sets (x_i and y_i).

$$CV = 100\frac{\sqrt{\sum_i (x_i - y_i)^2/n}}{\bar{y}} \quad (2)$$

where n is the number of samples and $\bar{y}$ is the mean value of the y set. Zero of CV means perfect agreement between two data sets. The larger CV value shows poorer agreement.

Observer Repeatability

In this experiment, observers repeated twice their judgments. For each observer, the observer repeatability was calculated to compare between the repeated data using the CV. Table 3 summarizes the observer repeatability. The CV values of each observer showed good performance under 15. The average CV value was 6.8.

Observer Reproducibility

The observer reproducibility was also calculated to compare between each individual observer and mean visual result. Table 4 summarizes the observer reproducibility. The average CV value was 9.5. It was higher than those of observer repeatability but, it also showed the good observer variation. Among 24 observers, 4 observers (1st, 19th, 20th and 21th) were outliers; therefore, it was decided to remove 4 observers' data.

3.2 Effect of Surround Luminance for Perceived Brightness

This section explains the surround effects for brightness perception. As mentioned above, the surround condition could be defined using surround ratio; S_R. Figure 2 shows that comparison of perceived brightness and S_R. The error-bars indicate the standard deviation. All of six test stimuli show similar trend. When surround ratio S_R is changed from dark to 1, there are little changes in brightness. The observer does not perceive the brightness changes, although surround luminance is changed. Illuminated light which is dimmer than monitor white do not affect the perception of displayed image on monitor because, the observers eyes were adapted to monitor white. When surround luminance is higher than luminance of monitor, the test stimuli look darker. Consequently, S_R=1 is significant threshold to show the surround luminance effect.

Table 3 Observer Repeatability

observer	ob1	ob2	ob3	ob4	ob5	ob6	ob7	ob8	ob9	ob10	ob11	ob12
CV	10.3	6.1	4.7	5.4	5.6	5.5	4.8	6.0	6.4	5.4	5.1	4.7
observer	ob13	ob14	ob15	ob16	ob17	ob18	ob19	ob20	ob21	ob22	ob23	ob24
CV	5.3	5.9	6.8	7.7	5.8	6.1	15.2	14.5	10.3	5.5	5.4	5.4
Average	6.8											

Table 4 Observer Reproducibility

observer	ob1	ob2	ob3	ob4	ob5	ob6	ob7	ob8	ob9	ob10	ob11	ob12
CV	16.9	4.0	6.4	6.8	5.4	7.0	3.0	6.4	5.4	8.2	9.4	6.3
observer	ob13	ob14	ob15	ob16	ob17	ob18	ob19	ob20	ob21	ob22	ob23	ob24
CV	4.2	2.5	10.0	7.5	7.8	3.5	25.6	29.4	26.5	11.1	8.2	5.7
Average	9.5											

Table 5 The specification for CIECAM02 input data

	S_R=0	0<S_R<1	1<S_R
XYZ	the relative XYZ of the stimulus in comparison with highest XYZ in viewing condition		
$X_wY_wZ_w$	the relative XYZ of the stimulus		the relative XYZ of the surround
L_A	the absolute stimulus luminance /5	the absolute surround luminance	
Y_B	the relative luminance of the stimulus		

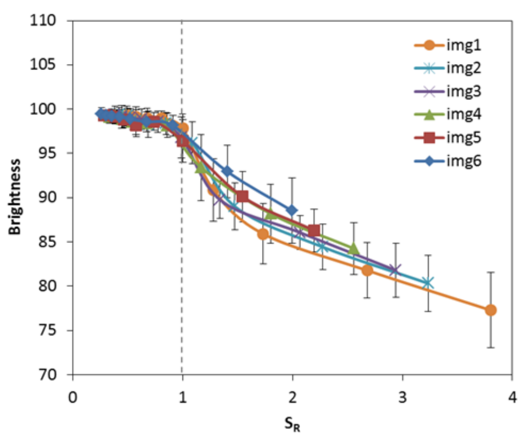
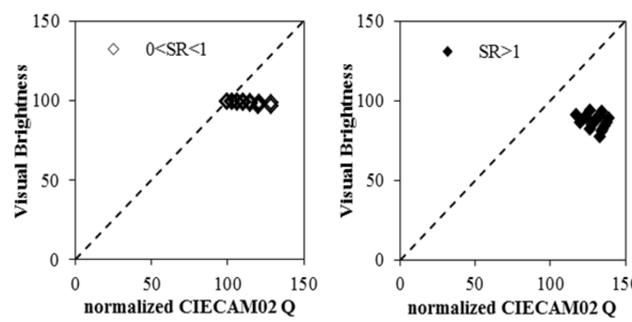


***Figure 2** The surround effects for brightness*

Table 6 Surround parameters

Surround	S_R	c	F	N_c
Dark	S_R=0	0.52	0.8	0.8
Dim	0<S_R<0.2	0.59	0.9	0.95
Average	0.2<S_R	0.69	1.0	1.0



(a) 0<S_R<1 *(b) S_R>1*

***Figure 3** Comparisons of visual brightness and the predicted brightness by CIECAM02*

3.3 Testing CIECAM02

Table 5 summarized input data for the CIECAM02 which was used in the experiment. The input data were categorized by S_R. XYZ is the relative tristimulus values of the stimulus for all S_R. $X_wY_wZ_w$ is the relative tristimulus values of white in viewing conditions. Therefore, it is the relative tristimulus values of the test stimulus for S_R <1, and it is the relative tristimulus values of surround for S_R >1. L_A is the absolute luminance of surround. In case of dark surround, it is 1/5 of the absolute luminance of stimulus. Y_B is the relative luminance of the test stimulus since there is no background and the viewing angle of stimulus is almost 10˚ as shown in Figure 1. CIECAM02 defined that the background is approximately 10° in all directions. The three surround parameters, c, F and N_c, are in Table 6. These values are divided into three surrounds determined by S_R [10].

Figure 3 shows the visual brightness result against the corresponding CIECAM02 Brightness Q. The Q values were normalized to directly compare to visual result. Figure 3 (a) indicates the data having lower S_R than 1. Figure 3 (b) indicates data having lager S_R than 1. The dashed line indicates 45˚ line. If the data points are plotted on the 45˚ line, this means that CIECAM02 can predict the visual data well. From dim to average surround conditions (S_R less than 1), data points are located below the 45˚ line. Despite the visual results maintain near 100, Q is predicted to increase up to 130. For bright surround conditions (S_R lager than 1), data points are far away from the 45˚ line. Q also increases even though the visual brightness is estimated to be decreasing.

3.4 Modification of CIECAM02 Q

CIECAM02 Lightness (J) can be calculated from achromatic signals of the stimulus (A) and reference white (A_w) using Equation 3 [9]. Q is calculated from lightness and achromatic response using Equation 4. It is greatly affected by surround (c) and luminance level adaptation factor (F_L). F_L is function of L_A, as shown in Equation 5 and 6.

$$J = 100\left(\frac{A}{A_w}\right)^{cz} \tag{3}$$

$$Q = \left(\frac{4}{c}\right)\sqrt{\left(\frac{J}{100}\right)}(A_w + 4)F_L^{\,0.25} \tag{4}$$

$$F_L = k^4(5L_A) + 0.1(1-k^4)^2(5-L_A)^{1/3} \tag{5}$$

$$k = \frac{1}{5L_A + 1} \tag{6}$$

Table 7 shows the predicted lightness J and brightness Q under various S_R. There are several issues for the Q. If J has 100, $\sqrt{J/100}$ is 1. Therefore the Q is strongly influenced by c and L_A. When S_R>1, input value of c has fixed value 0.69, as indicated in Table 4, on the other hand, L_A, that is the surround luminance, gets higher resulting in ever increasing Q as shown in Table 7. Thus, c needs to be modified based on S_R. Hence, in this paper, the Q is modified using two methods.

Table 7 CIECMA02 J and Q

S_R	J	Q
0.5	100.0	159.1
0.6	100.0	163.9
0.7	100.0	169.2
0.8	100.0	175.4
1.0	100.0	183.1
1.3	85.9	186.4
1.7	71.5	191.0
2.7	56.6	201.0
3.8	47.8	211.7

3.4.1 Interpolation of c

According to CIECAM02, parameter c is allowed to have only three values. For this reason, Fairchild [10] proposed that a piecewise-linear function can be used to determine intermediate values of parameters. Additionally, Park et al [5] developed the parameters based on S_R. Therefore, it was decided to use interpolated data of c based on S_R, as shown in Figure 4 and in Equation 7. The dashed line was obtained by extrapolation.

Q is modified into Qc' using the c'. Figure 5 shows the relation between predicted Qc' and visual brightness. When S_R < 1, Q_C' is unable to predict the visual brightness. When S_R >1, Q_C' shows slightly improved performance but it still cannot predict well.

$$c' = 0.325S_R + 0.525 \qquad for\ 0 \le S_R \le 0.2 \tag{7}$$
$$c' = 0.125S_R + 0.565 \qquad for\ S_R > 0.2$$

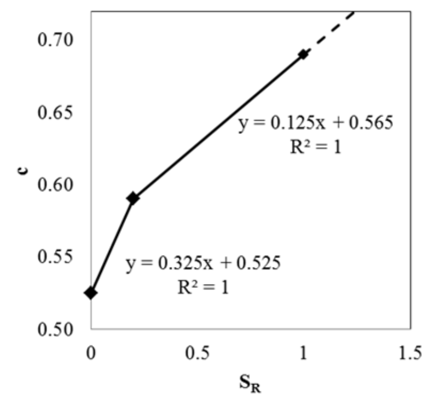
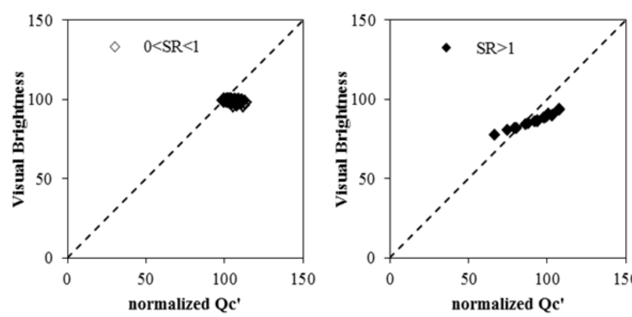


Figure 4 *A two-part piecewise-linear interpolations for c based on S_R*



(a) 0<S_R<1 *(b) S_R>1*

Figure 5 *Comparisons of visual brightness and the predicted brightness using extrapolating c'*

3.4.2 c as a function of S_R

Despite the interpolation of c, Qc' is still increased due to the increasing L_A, when S_R is less than 1. To solve this problem, optimized c'' was calculated by comparing the predicted Q and visual brightness. The function of c'' is derived as shown in Figure 6 and Equations 8, as a function of S_R. The c'' is described using logarithmic function. Finally, the revision brightness Qc'' can be calculated using Equation 9.

Figure 7 shows the relation between the Qc" and the visual brightness. The Qc" is predicted well to the visual brightness results for the all surround conditions.

$$c' = 0.1425 ln(S_R) + 0.7671 \quad (8)$$

$$Q_{C''} = \left(\frac{4}{c''}\right)\sqrt{\left(\frac{J}{100}\right)}(A_w + 4)(F_L{}^{0.25}) \quad (9)$$

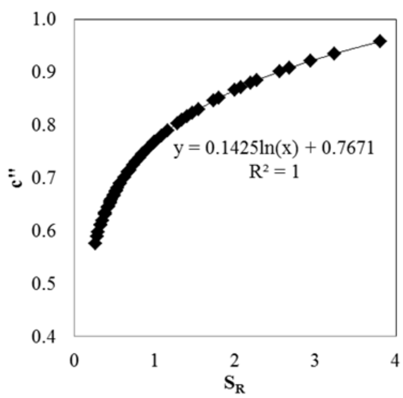
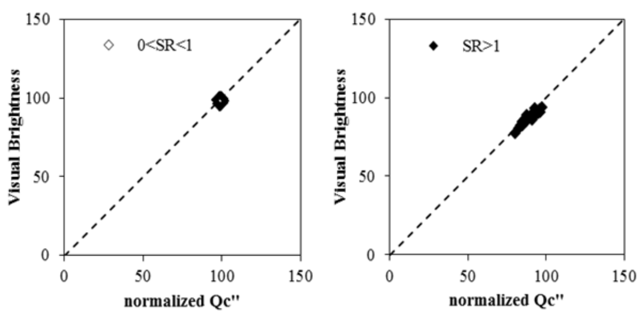


Figure 6 *The derived c" vs S_R*



(a) $0<S_R<1$ *(b) $S_R>1$*

Figure 7 *Comparisons of visual brightness and the predicted brightness using revision brightness Qc"*

4. Conclusion

The perceived brightness dataset of six test stimuli with different luminance levels under nine surround luminance conditions were collected using the magnitude estimation. Twenty-four observers (12 females and 12 males) assessed the perceived brightness for each test stimulus. The surround ratio, S_R, is varied from 0.3 to 3.8.

Experimental results showed that observers are unaware of change of brightness under lower surround ratio, S_R, than 1. Then, perceived brightness was decreased as the surround became brighter than 1of S_R.

The performance of CIECAM02 was tested. The brightness (Q) predicted by CIECAM02 was not correlated to observer's visual data well. Therefore there were two trials to modify the CIECAM02.

First, the surround parameter c was calculated using linear interpolations based on S_R. The predicted Qc' shows the improvement under bright surround but it is still poor.

Second, the optimal c was calculated to predict the visual result and c"(S_R) function is formulated using the logarithmic function. The Qc" using c"(S_R) function performed well for all surrounds corresponds. It implies that this revision could aid accurate prediction of perceived brightness under various surround conditions including over-bright.

This research shows that current color appearance model, CIECAM02, is not adequate for mobile environment but it can be improved by simple modification.

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