

MEASUREMENT OF PERCEIVED BRIGHTNESS AND CONTRAST SENSITIVITY FOR OUTDOOR CONDITION

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ABSTRACT

Eight neutral patches displayed on a mobile display were visually assessed under a dark and an outdoor ambient viewing condition. Those data were used to establish the contrast sensitivity function (CSF) under the outdoor condition. It was verified by the results measured using the contrast threshold detection method.⁴

Keywords: Perceived brightness, mobile display, outdoor and contrast sensitivity

1. INTRODUCTION

The mobile displays are viewed under a large range of ambient illumination from dark and bright sunny conditions. Currently, the majority of experimental data for CSF was derived under dark condition¹ and thus it is important to investigate the change of CSF under varied ambient conditions. The dark and outdoor viewing conditions are denoted as *DVC* and *OVC*, respectively.

2. HYPOTHESES

In our daily lives, we experience images on a mobile display with a loss of contrast under *OVC*. In this study, there are two hypotheses: 1) there is an inverse relationship between the perceived brightness of stimuli on a display and the ambient illumination intensity, and 2) the loss of contrast sensitivity caused by the increase of ambient illumination is resulted from the reduction of the perceived brightness. This study aims to investigate the physiological evidence of the contrast loss under *OVC* and model its CSF.

Barten³ introduced a CSF formula which is a function of a mean luminance of sinusoidal gratings under *DVC*. In other words, when mean luminance of the gratings increases, contrast sensitivity should also be increased. However, this rule is invalid under *OVC*. For example, the mean luminance of the gratings should be boosted due to the flare, but a huge loss of contrast is in fact observed. This may be because of the fact that the human visual system adapts to the *OVC* and perceive much darker stimuli. In order to test the hypotheses, a series of neutral patches was displayed on a mobile LCD and their perceived brightness values were visually measured using the magnitude estimation method.⁵ The brightness reduction from *DVC* to *OVC* was taken into account to compute the CSF. The computed CSF was compared with the measurement data using the contrast threshold detection method.⁴

2. EXPERIMENTAL

Experiment 1 (Perceived Brightness Magnitude Estimation)

The test stimuli used in this study were displayed on a Samsung SCH-S250 mobile phone. The display size was 2-inch along diagonal direction. A Minolta CS-1000 tele-spectroradiometer was used for measurement. Nine uniform grey patches were evenly sampled across the 8-bit RGB channel (0 to 255). Their luminance values were measured in a dark room as listed in Table 1. Experiments were performed under both of *DVC* and *OVC*. The average illuminance of sunlight under the *OVC* was approximately 16000 lx. A photometer (Gigahertz Optik Phtometer X9₁) was used for measuring the illuminance. One of the 9 patches was used as the reference brightness of 100 when it was displayed under *DVC*. The RGB value of the reference grey was (255, 255, 255) and its luminance was 176.80 cd/m².

Five observers with normal colour vision carried out the perceived brightness magnitude estimations. Prior to the experiment, they were required to memorise the reference patch (brightness of 100) on the mobile LCD under DVC and judge a ratio of brightness of each test stimulus under the two viewing conditions. Each of the 8 patches (P1 to 8) was assessed three times by each observer. In total, 240 judgments were made. The mobile display was located from an observer at a distance of 25 cm and the angular geometry between them was fixed to be perpendicular.

Table 1. Measured luminance values of the neutral patches.

Patch No.	RGB	Luminance (cd/m ²)	Brightness (DVC)	Brightness (OVC)
P1	0	1.33	10.1	0.8
P2	32	5.05	20.3	0.9
P3	64	17.92	34.1	3.8
P4	96	38.21	45.9	10.1
P5	128	65.62	62.5	22.4
P6	160	96.39	71.7	28.1
P7	192	134.30	86.7	43.7
P8	224	177.00	98.7	53.7

Experiment 2 (Contrast Threshold Detection)

In order to verify the hypothetical CSF predicted in the brightness magnitude estimation experiment, the contrast threshold detection method⁴ was used to measure the actual CSF. Sinusoidal patterns with gradual contrast modulation along the vertical axis were displayed on a 22.2-inch Eizo ColorEdge221 LCD and 11 observers were asked to identify a certain vertical position in the patterns when the sine wave becomes just indistinguishable (contrast threshold). The contrast threshold can be defined as the inverse of contrast sensitivity. The pattern (**Q**) was produced by means of the product of a non-linear gradient function in the vertical way (**M**) and an one-dimensional sinusoidal function across the horizontal axis (**F**). Practically, those functions can be discretely sampled and expressed by matrices and its product can be illustrated as Equation 1.

$$\mathbf{Q} = \mathbf{M}\mathbf{F}^T \quad (1)$$

where \mathbf{F}^T denotes transpose of **F**.

Each of the sinusoidal patterns contains a single spatial frequency. In each pattern, contrast appears the highest in the bottom and the lowest in the top as can be seen in Figure 1(a). The OVC was simulated using an indoor spotlight projector (EVL Lighting ColourChanger 250) because this experiment took longer time than the brightness magnitude estimation experiment and the sunlight was not stable enough for a longer period. Each pattern was displayed on the LCD screen at a distance of about 1 m (See Figure 1(b)). In total, 11 different spatial frequencies were sampled and their contrast thresholds were judged (1, 2, 3, 4, 5, 6, 7, 13, 23, 32 and 65 cycles per degree: cpd). Each observer repeated all judgments five times and their average values were used for data analysis under both DVC and simulated OVC. The viewing distance between observer and LCD was 3 meters (5° in angular distance). It minimised the quantisation error of the display because of its lack of bit depth (8 bits).

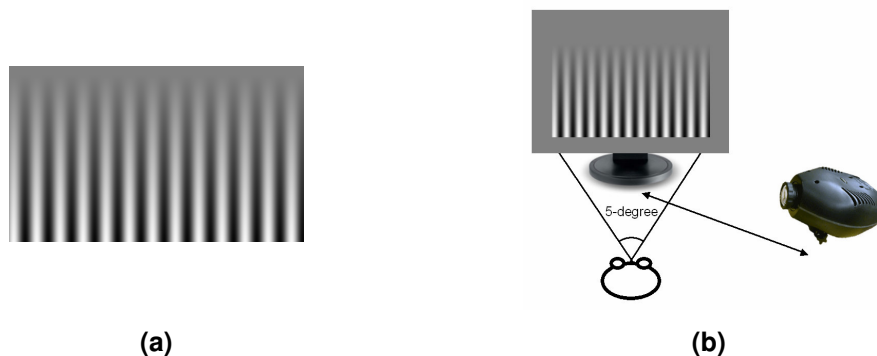


Figure 1. (a) Example of a sinusoidal pattern and (b) experimental geometry

3. RESULTS AND DISCUSSIONS

Perceived Brightness Magnitude Estimation

The visual results (brightness) under DVC are plotted in Figure 2 against the luminance values. The brightness function under DVC was fitted to the experimental data well ($R^2 = 0.998$) by the power law $B = kL^n$ as suggested by Stevens² in 1961 (Equation 2).

$$B = 9.10L^{0.46} \quad (2)$$

where B is perceived brightness magnitude and L is luminance.

The brightness estimation data under DVC and OVC are listed in Table 1 and their relation is revealed in Figure 3. As the viewing conditions varied from DVC to OVC, in general, the brightness estimation values of the all patches were decreased, but they showed a nonlinear effect. It was shown that the eight patches appeared darker under OVC as the effect of ambient illumination. Therefore, the first hypothesis that there is an inverse relationship between the perceived brightness of stimuli on a display and the ambient illumination intensity can be accepted.

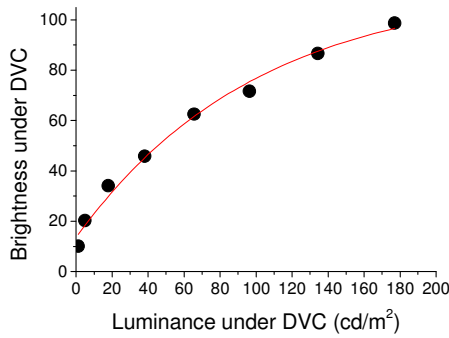


Figure 2. Relation between luminance and brightness estimation under the DVC

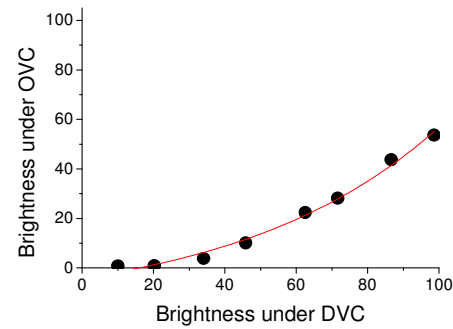
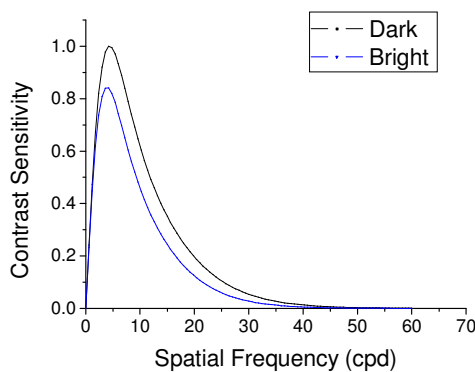


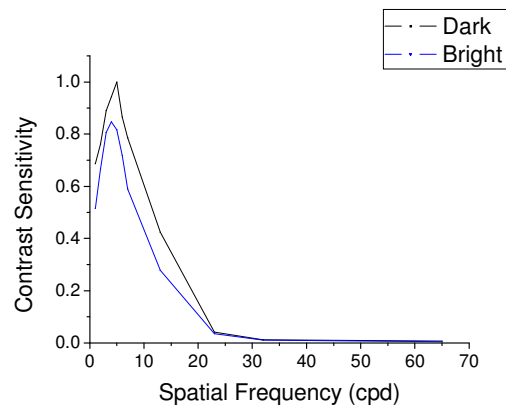
Figure 3. Relation of brightness estimation between the DVC and OVC

Computing Contrast Sensitivity Function (CSF)

If we design a sinusoidal grating (or Gabor patches) under a certain viewing condition, its mean luminance can be simply calculated by $(\min + \max)/2$. For example, the mean luminance under DVC would be $(1.33+177.00)/2 \approx 89.17 \text{ cd/m}^2$. For a field size of 11° , the CSF under DVC can be computed using the Barten's formula³ as depicted in Figure 4(a) (the upper curve). It was normalised at the maximum contrast sensitivity value.



(a)



(b)

Figure 4. The CSFs obtained using (a) the perceived brightness magnitude estimation and (b) the contrast threshold detection under DVC (the upper curves) and OVC (the lower curves)

However, since luminance is not a key factor for determining CSF under OVC, it requires a different approach. The actual measurement of luminance under OVC is not helpful to predict the contrast sensitivity, but it is possible to calibrate the mean luminance value using brightness estimation data in order to compensate for the ambient illumination effect. For example, the maximum (P8) and the minimum bright (P1) patches' brightness values measured under OVC were 53.7 and 0.8 under OVC, respectively. (See Table 1) Then, using Equation 2 (or Figure 2), the two brightness values can be converted into luminance under DVC, which are 47.36 and 0.01 cd/m^2 . Therefore, the calibrated mean luminance under OVC can be calculated as $(0.01+47.36)/2 \approx 23.69 \text{ cd/m}^2$. The mean luminance value in the Barten's formula³ was replaced by the calibrated mean luminance to compute the CSF under OVC as shown in Figure 4(a) (the lower curve). The curve was normalised at the maximum contrast sensitivity value of CSF under DVC. The peak contrast sensitivity for the OVC was reduced to about 85% of the upper curve (the CSF under DVC) and the spatial frequency where maxima occurred shifted toward lower frequency (4 to 3 cpd) when the ambient illumination condition changed from DVC to OVC.

Verifying the Results (Contrast Threshold Detection)

The CSFs measured using the contrast threshold detection method⁴ under the two viewing conditions are depicted in Figure 4(b). The peak contrast sensitivity for the OVC (the lower curve) was reduced by about 85% of the upper curve (the CSF under DVC) and the frequency having the highest contrast sensitivity moved toward a slightly lower frequency. This corresponds to the results derived from the perceived brightness magnitude estimation method as can be seen in Figures 4(a) and 4(b). The change of CSF from DVC to OVC could be quantified by the perceived brightness reduction; thus the second hypothesis that the loss of contrast sensitivity caused by the increase of ambient illumination is resulted from the reduction of the perceived brightness can be accepted.

4. CONCLUSION

Two hypotheses were made in the beginning of this study: 1) there is an inverse relationship between the perceived brightness of stimuli on a display and the ambient illumination intensity, and 2) the loss of contrast sensitivity caused by the increase of ambient illumination is resulted from the reduction of the perceived brightness. Those hypotheses were accepted through the perceived brightness magnitude estimation and the contrast threshold detection experiments. The former experiment exhibited the perceived brightness reduction from DVC to OVC and the calibration of luminance values using the brightness function. The latter demonstrated the actual CSF measurement data under both of DVC and simulated OVC using the contrast threshold detection method.⁵ They showed a very similar performance to the CSF measured by the perceived brightness magnitude estimation experiment. For the future study, the CSFs under different levels of ambient illumination will be measured and the effect of the ambient illumination will be quantified in order to develop an ambient-adaptive CSF, which can be applied for image quality metrics for mobile displays to take into account a large variation of ambient lighting.

REFERENCES

- [1] MARTINEZ-URIEGAS, E., Chp 13, Spatial and Temporal Problems of Colorimetry, CIE, 2006.
- [2] STEVENS, S. S. and GALANTER, E. H., Ratio scales and category scales for a dozen perceptual continua, J. Exptl. Psychol. 54, 377, 1957.
- [3] BARTEN, P. G. J., *Contrast Sensitivity of The Human Eye and Its Effects on Image Quality*. SPIE Press, Bellingham, Washington, 1999.
- [4] Kitaguchi, S. and MacDonald, L., Westland S, Evaluating contrast sensitivity, Proc. of SPIE, Human vision and electronic imaging XI, Vol. 6057, 22-31, 2006.
- [5] Luo, M. R., Clarke, A. A., Rhodes, P. A., Schappo, A., Scrivener, S. A. R. and Tait, C. J. Quantifying colour appearance. Part I. LUTCHI colour appearance data. Part II. Testing colour models performance using LUTCHI colour appearance data, Color Res. Appl. 16, 166-197, 1991.

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