Estimation of Brightness Considering the Color Contrast Effect in Natural Images

S. Yamamoto[1], H. Aoyanagi[2], H. Takamatsu[2], Y. Shimodaira[1], G. Ohashi[1]

yamamoto.shuhei.16@shizuoka.ac.jp

[1]Shizuoka Univ., 3-5-1 Johoku, Naka-ku, Hamamatsu, Shizuoka 432-8561, Japan

[2]Sharp NEC Display Solutions, Ltd., 4-28 Mita 1-chome, Minato-ku, Tokyo, 108-0073, Japan

Keyword: Wide-color-gamut, Helmholtz-Kohlrausch effect, Estimation equation of brightness, Natural images, Color contrast effect

ABSTRACT

This study aims to improve the estimation accuracy of brightness in natural images by quantifying the effect of color contrast and introducing this effect into an equation based on the Helmholtz-Kohlrausch effect derived in our previous study.

1 Introduction

High-luminance, wide-color-gamut and high-resolution are advancing due to the high picture quality of display equipment. The wide-color-gamut changes the human perceived lightness (brightness) by changing the saturation. This phenomenon, called the Helmholtz-Kohlrausch (H-K) effect, is believed to affect images projected by displays, projectors, and mobile devices [1]-[4]. Brightness quantification can be useful for developing and evaluating display devices. Although brightness can be quantified in subjective-evaluation experiments, it is unrealistic to experiment with all conditions. Instead, it is effective to estimate brightness with a computational modeling. The H-K effect must be considered when estimating the brightness of a display device. Various color-appearance models have been proposed for brightness evaluations [5]-[8]. As these models are very complex, general-purpose estimation equations have been derived [9]-[11]. Nayatani et al. investigated and quantified the H-K effect on monochromatic images using the ratio of brightness to lightness of image (B/L) with various visual effect parameters [11]. This study considers various visual effects to estimate the brightness of natural images. Therefore, the authors extended the estimation equation based on Nayatani's equation to natural images [12] and have reported studies in IDW regarding the effect of brightness by focusing on H-K effect with the aim of further accuracy improvement of the equation [13]-[18].

The equation in [19] based on Nayatani's equation extends the estimation of monochromatic images to natural images by considering natural images as a set of monochromatic images. These studies considered the visual impact of the pixel of interest only. However, the surrounding pixels will also affect the estimation of brightness in natural images. Therefore, we consider the color contrast effect as the visual effect of the surrounding pixels. In the color contrast effect, the appearance of colors depends not only on the object but also on the relative distribution between the object and its surroundings [20][21]. Therefore, the color contrast effect must be considered in the estimation of brightness in natural images. We quantify the color contrast effect using two-color images and introduce them into equation [19] to estimate brightness accurately.

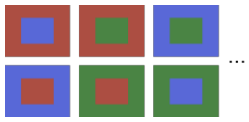

Figure 1. Various two-color images

Table 1. Experimental conditions

Method	Adjustment method (Variable-Achromatic-Color)
Environment	Darkroom
Image output device	2 projectors(ViewLight NP-L50WJD, NP-L51WJD)
Screen	CASIO Diffuse screen
Images	Various two-color images(30sheets)
Saturation / lightness conversion	lightness50%・saturation80%
Height of image	0.18[m]
Viewing distance	9H(1.62[m])
Subjects	27persons

The contributions of this study are as follows.

(1) In estimating the brightness of natural image, to consider the surrounding pixels, the color contrast effect is introduced to the equation to improve accuracy.

(2) To introduce the color contrast effect, the effect is quantified. The gaze area in natural image is automatically selected in a saliency map.

2 Equation considering the color contrast effect

2.1 Overview

Equation (1) is derived by multiplying the equation in [21] by a function that considers the color contrast effect (Equation (3)). The brightness in natural image is estimated by averaging the brightness values of all pixels as shown in Equation (2) [12].

$$\Gamma_{Corrected}' = \frac{B}{L^*} = 1 + \{-0.134 \cdot q(\theta) + 0.087 \cdot K_{Br}(L_\alpha)\} \times S_{uv}(x,y) \times h(L^*,\theta) \times C(C_{WCAG2.0}) \quad (1)$$

$$\Gamma_{Natural} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m}\Gamma_{Corrected}'}{m \times n} \quad (2)$$

Here, $\boldsymbol{B}$ and $\boldsymbol{L^*}$ are the brightness and lightness of the image, respectively, $\boldsymbol{q(\theta)}$ is the hue, $\boldsymbol{K_{Br}(L_\alpha)}$ is the magnitude of the adaptive luminance dependency relative to the background lightness $\boldsymbol{L_\alpha}$, $\boldsymbol{S_{uv}(u,v)}$ is the saturation, and $\boldsymbol{h(L^*,\theta)}$ is the lightness.

2.2 Quantification of the color contrast effect

The effect of color contrast on brightness was experimentally investigated on various two-color images as shown in Fig.1. The experimental conditions are listed in Table 1. Fig.2 plots the ratio of the monochromatic images' B/L and two-color images' B/L versus the color contrast ratio. The color contrast ratio was calculated by Equation (3) using **WCAG2.0** [22].

$$C_{WCAG2.0} = \frac{L + 0.05}{L' + 0.05} \quad (3)$$

$$L, L' = 0.2126 \cdot r + 0.7152 \cdot g + 0.0722 \cdot b$$

Here, L and L' are the relative luminances of the target (center color) and background (ambient color), respectively, and r, g, and b are the linear RGB gradation values. Equation (3) quantifies the relation between the target and background in the color contrast effect. Equation (4) is derived as a function of the color contrast effect from Fig.2. These two expressions quantify the color contrast effect.

$$C(C_{WCAG2.0}) = \begin{cases} -0.32 \times C_{WCAG2.0} + 1.30, & C_{WCAG2.0} < 1 \\ 0.46 \times C_{WCAG2.0} + 0.51, & C_{WCAG2.0} \geq 1 \end{cases} \quad (4)$$

2.3 Contrast effect in natural images

In Section 2.2, the relation between the object and the background in two-color images was given by Equation (3). However, in natural images, various colors are arranged in a complicated manner, and the target and background colors are not easily selectable. This study clarifies the target and background by changing the resolution of natural images, as shown in Fig.3.

2.3.1 Estimation of brightness considering the color contrast

If area ② in Fig.4 is selected as gaze pixel in the natural image, the color contrast effect is working for area ② as target. Therefore, our study considers color contrast effect only in area ②. The color contrast effect is calculated by Equation (5).

$$C(C_{WCAG2.0}) = \begin{cases} -0.32 \times C_{WCAG2.0} + 1.30, & C_{WCAG2.0} < 1 \\ 0.46 \times C_{WCAG2.0} + 0.51, & C_{WCAG2.0} \geq 1 \end{cases} \quad \text{: Gaze Pixel(②)} \quad (5)$$

$$C(C_{WCAG2.0}) = 1 \quad \text{: Otherwise(①)}$$

$C_{WCAG2.0}$ was calculated by the Equation (6), which considers the color contrast between the gaze pixel and the pixel with maximum contrast against the gaze pixel.

$$C_{WCAG2.0} = Max\left|\frac{L + 0.05}{L'(m, n) + 0.05} - 1\right| \quad (6)$$

Here, m and n denote the width and height of the image, respectively.

2.3.2 Selecting object (target/gaze pixel)

Selecting the gaze pixel is crucial when considering the color contrast effect. In this study, the gaze pixel was selected manually by the subject and automatically in a saliency map. Fig.5 shows the saliency maps of the images in Fig.3 [23]. A saliency map is a computed map representing the human gaze area on a scene. Objects in the gaze area are thought to be distinguished from the surrounding area [24][25]. The saliency map automatically selects the gaze pixel.

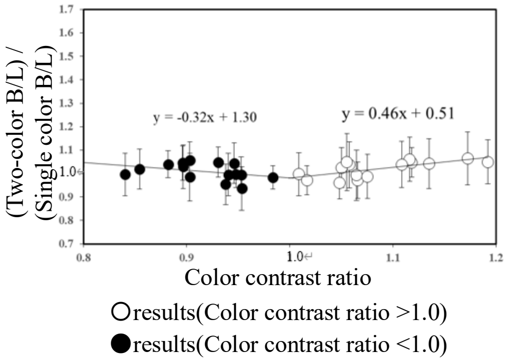

Figure 2. Ratio of B/L of two-color image to B/L of monochromatic image

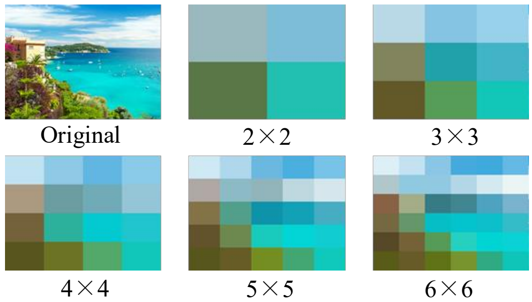

Figure 3. Natural image with changed resolution

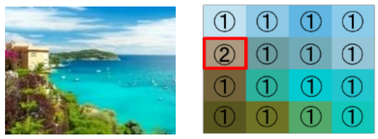

Figure 4. Estimated value calculation for resolution-changed images

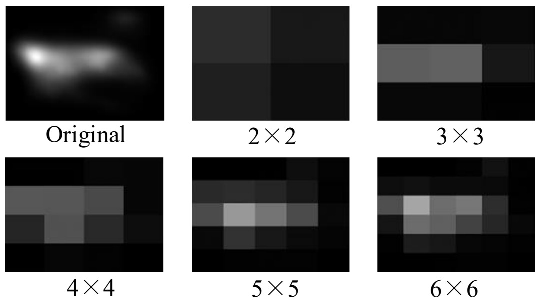

Figure 5. Saliency map of natural image with changed resolution

3 Experiment

3.1 Experimental conditions

When estimating the brightness of natural images, experimental values were used as the correct data. Experiments were conducted under the conditions shown in Table 2 using the natural images shown in Fig. 6. Fig.7 are each chromaticity diagrams in natural images of Fig.6

Figure 6. Natural image

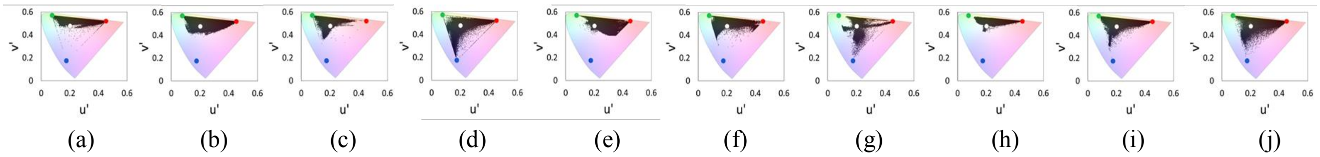

Figure 7. Chromaticity Diagram

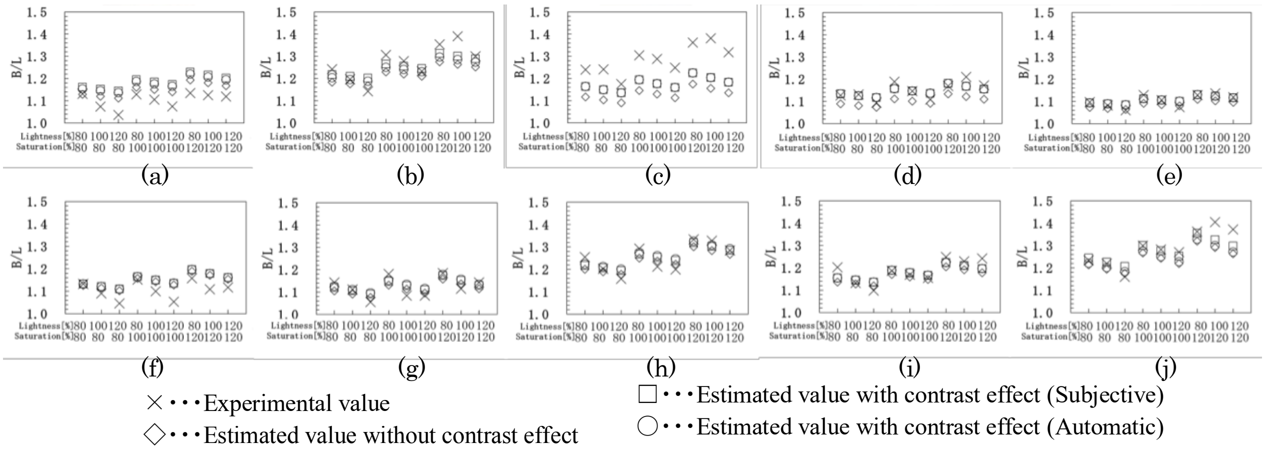

Figure 8. Experimental results

3.2 Experimental result

Figure 8 and Table 3 show the respective results. In the estimate, the natural images were changed to various resolutions and calculated the estimated value of each resolution. We selected the best estimated value among them for the corresponding image. In Fig. 8, the B/L values were calculated three types of estimated values for comparison: "subjective" when the gaze pixel was manually selected by one of the authors, "automatic" when the gaze pixel was selected on the saliency map, and the value without considering a contrastive effect. In eight out of 10 images, the result was improved by considering the contrast effect. (the exceptions were images (a) and (f)).

3.3 Discussion

Here, we discuss the results of images (a) and (f), for which the accuracy was not improved by contrast effect. The primary object is difficult to select among the many objects existing in these images and the color contrast effect may do not work. To investigate this idea, we calculated the color variations on a Luv chromaticity diagram of each image. The results are given in Table 4. Image (a) presented the highest variation, indicating the presence of various colors in the image. Therefore, the subject could not easily select the primary object. The results of image (f), with relatively few color variations, are less easily explained and must be discussed in future. In addition, there are images where accuracy is good when contrast effect is not considered as in the images (a) and (f). Therefore, it may be necessary to change the visual effects considered in the equation depending on image features and human visual tendencies. In future work, we will further improve the estimation accuracy by classifying the images and applying the equation to each image category.

Table 2. Experimental conditions

Method	Adjustment method (Variable-Achromatic-Color)
Environment	Darkroom
Image output device	2 projectors(ViewLight NP-L50WJD, NP-L51WJD)
Screen	CASIO Diffuse screen
Images	Natural images(10sheets)
Saturation / lightness conversion	Saturation(80[%]100[%]120[%])・Lightness (80[%]100[%]120[%])
Height of image	0.18[m]
Viewing distance	9H(1.62[m])
Subjects	(a)~(e):24persons, (f)~(j):22persons

Table 3 Error rate [%]

	without contrast effect	with contrast effect			without contrast effect	with contrast effect	
		Subjective	Automatic			Subjective	Automatic
(a)	4.35	7.36	6.61	(f)	3.47	3.98	3.99
(b)	4.43	2.74	3.18	(g)	2.43	2.31	2.28
(c)	11.94	8.26	8.26	(h)	2.39	2.03	2.10
(d)	4.18	1.58	1.58	(i)	2.46	1.97	1.97
(e)	1.81	0.98	0.98	(j)	3.75	2.11	2.17

Table 4. Color variations on the Luv chromaticity diagram

(a)	21.12	(f)	17.63
(b)	11.40	(g)	17.24
(c)	12.56	(h)	9.41
(d)	20.55	(i)	20.04
(e)	19.35	(j)	19.42

4 Conclusions

This study aims to improve the accuracy of brightness estimation by introducing the color contrast effect into the brightness estimation equation. This approach considers the effect of the surrounding pixels in natural images. In the experiment, the derived equation improved the previous estimation accuracy of eight out of 10 images. We also show that the color contrast effect may not be working in image (a) and (f) due to the difficulty of selecting the target area in image. In future work, estimation value will be calculated by using equation depending on the features and visual tendency of the images for further accuracy improvement.

REFERENCES

[1] R L. Donofrio, "Review Paper: The Helmholtz-Kohlrausch Effect", Journal of the Society for Information Display, Vol.19, No.10, pp.658-664, 2011.

[2] S.Liao, H.Chou, T.Yang, C.Lee, K.Chang, "Perceived Brightness of LED Projector", Society for Information Display,Vol.40,No.1,pp.262-264,2012.

[3] C.Jin, J.Wang, J.Yang, Y.Tian, F.Wang, X.Huang, H.Wang, X.Li, W.Liu, "Investigation of the Helmholtz-Kohlrausch Effect in Using Laser Projectors", The 24th International Display Workshops(IDW'17), pp.1121-1124, Sendai, Japan, 2017.

[4] Y.Imai, T.Kaneko, M.Baba, T.Itoh, "Image Gamut Expansion Using the Properties of Brightness Perception", Electronic Information Displays(EID), Vol.109, No.223, pp.33-36, 2009.

[5] R.W.G.Hunt, A Model of Colour Vision for Predicting Colour Appearance, Color Res. Appi. 7, 95-112, 1982.

[6] Y.Nayatani, "ColorAppearance Model(Nayatani Model Newly Revised)", The Illuminating Engineering Institute, Vol.78, pp.83-87, 1994.

[7] M.R. Luo and R.W.G. Hunt: The Structure of the CIE 1997Colour Appearance Model (CIECAM 97s), Col. Res. Appl.23, 3, 138, 1998.

[8] N.Moroney, M.D.Fairchild, R.W.G.Hunt, C.Li, M.R.Luo, T.Newman, "The CIECAM02 Color Appearance Model", 10th Color and Imaging Conference Final Program and Proceedings, pp.23-27(5).

[9] Y.Nakano, K.Yamada, K.Suehara, T.Yano, "A Simple Formula to Calculate Brightness Equivalent Luminance", Processing of the CIE 24th session, Vol.1, pp.33-37, 1999.

[10] CIE 200:2011, CIE Supplementary System of Photometry, CIE, 2011.

[11] Y.Nayatani, C.Tanaka, N.Tanaka, "Prediction of the Helmholtz – Kohlrausch Effect on Object and Luminous Colors-I. Estimation of Case of the Variable-Achromatic-Color Method",Journal of The Illuminating Engineering Institute of Japan, Vol.82, No.2, pp.131-136, 1998.

[12] T.Shizume, G.Ohashi, H.Takamatsu, Y.Shimodaira, "Estimation of the Helmholtz–Kohlrausch Effect for Natural Images", Journal of the Society for Information Display, Vol.22, No.11, pp.588-596, 2015.

[13] S.Hashimoto, T.Shizume, H.Takamatsu, Y.Shimodaira, G.Ohashi, "Measured and Calculated Value of the Helmholtz-Kohlrausch Effect for Natural Images under the Ambient Lighting Conditions", The 22nd International Display Workshops (IDW'15), pp.981-984, 2015.

[14] D.Takasu, S.Hashimoto, H.Aoyanagi, H.Takamatsu, Y.Shimodaira, G.Ohashi, "Measured Values of the Helmholtz-Kohlrausch Effect for Natural Images and Scrambled Pixel Images", The24th International Display Workshops (IDW'17), pp.1121-1124, 2017.

[15] Y. Hayami, D. Takasu, H. Aoyanagi, H. Takamatsu, Y.Shimodaira, G. Ohashi, "Helmholtz-Kohlrausch Effect Estimation Considering Lightness," The 25th International Display Workshops (IDW'18), pp.1042-1045, 2018.

[16] Y.hayami, D.Takasu, H.Aoyanagi, H.Takamatsu, Y.Shimodaira, G.Ohashi, "Prediction of the Helmholtz-Kohlrausch Effect for Natural Images using a Correction Function" , The Institute of Elec tronics, Information and Communication Engineers(IEICE),2019.

[17] K.Nakagawa, H.Aoyanagi, H.Takamatsu, Y.Shimodaira, G.Ohashi, "The Subjective Evaluation Experiment for the Estimation of Helmholtz-Kohlrausch Effect under the Ambient Lighting Conditions", The 26th International Display Workshops (IDW'19), pp.1207-1210, 2019.

[18] Nakagawa, H.Aoyanagi, H.Takamatsu, Y.Shimodaira, G.Ohashi, "Prediction for Helmholtz-Kohlrausch Effect of Natural Images under the Ambient Lighting Conditions", The 27th International Display Workshops (IDW'20), pp.619-622, 2020.

[19] K.Nakagawa, Y.Hayami, H.Aoyanagi, H.Takamatsu, Y.Shimodaira, G.Ohashi, "Estimating the Helmholtz-Kohlrausch Effect in Natural Images Considering the Decreasing Brightness-to-Luminance Ratio with Increasing Lightness", Journal of the Society for Information Display, Vol.29, No.6, pp.476-488, 2021.

[20] I.Fujimura, "Color Contrast and Color Appearance", television, vol24, No.4, pp.294-302,1970.

[21] O.B.Richard, I.A.M.Donald, "Color Appearance Depends on the Variance of Surround Colors", Current Biology (Research Paper), Vol.7, No.11, pp.844-849, 1997.

[22] "Web Contest Accessibility Guidelines 2.0", ISO/IEC 40500:2012, 2012.

[23] D.Kato, S.Rebeka, G.Ohashi, "Saliency map using U-Net with Residual Attention Module", The 22th Meeting on Image Recognition and Understanding(MIRU), OS1A-9, 2019. [In Japanese]

[24] L.Itti, C.Koch, E.Niebur, "A Model of Saliency-Based Visual Attention for Rapid Scene Analysis", IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol.20, No.11, pp.1254-1259, 1998.

[25] C.Koch, S.Ullman, "Shifts in Selective Visual Attention: Towards the Underlying Neural Circuitry", Matters of Intelligence, pp.115-141, 1987.