Distinct Contrast in CIECAM02 for Mobile Display

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Abstract

The absolute contrast ratio of a display is a distinctive measure of the display contrast. However, this contrast ratio does not match the perceived contrast as it only uses the physical characteristic of the display. Therefore, this paper proposes a contrast measure that considers the perceptually discriminable brightness within the display brightness ranges. First, the Weber-Fechner ratio is applied to determine the brightness ranges of the display gamut in CIECAM02. Thereafter, the number of brightness values for each brightness range is computed and the perceptually discriminable brightness is then estimated based on the sum of the ratio between the number of brightness values in each brightness range and the brightness length in the display gamut. A preference test was conducted on various displays using random brightness patches to evaluate the perceived contrast. Experimental results showed that the proposed measure is more consistent with human perception than previous contrast measures.

Introduction

With the recent interest in advanced display techniques for reproducing high quality images, display quality evaluation studies are growing in significance. Display quality evaluations are generally divided into objective and subjective evaluations. Objective evaluations are based on the physical properties, such as the brightness, contrast, size of the color gamut, and color temperature, and can be shown quantitatively using colorimetric devices.

The absolute contrast ratio is a quantitative value used for display quality evaluations [1-3]. However, Lee showed a lack of difference in the perceptual contrast between two displays, even when the displays had remarkably different absolute contrast ratios [1]. Thus, to consider the perceptual contrast, Chong proposed measuring the perceptual contrast length (PCL) [4,5] based on CIECAM02 color space [6,7]. The PCL is calculated using the brightness length in a CIECAM02 color space-based display gamut with surrounding conditions. However, there is a difference between the PCL and the perceptual contrast related to human vision due to changes in the display gamut according to the surrounding conditions.

Accordingly, this paper proposes a distinct contrast to quantify the perceptual contrast. First, the proposed measure applies the Weber-Fechner ratio to determine the brightness ranges of the display gamut in CIECAM02, which are perceptually the same at each brightness level. Thereafter, the number of brightness values within each brightness range is counted. Finally, the perceptually discriminable brightness is estimated as the sum of the ratio between the number of brightness values in each brightness range and the perceptual contrast length of the display.

The remainder of this paper is as follows. Section 2 discusses the existing perceptual contrast length, and then section 3 introduces the proposed perceptual contrast quantification algorithm based on the brightness distribution. Experimental results using the proposed quantification algorithm are compared with those using existing methods in section 4, and some final conclusions are given in section 5.

Table 1. Comparison absolute contrast ratio with perceptual contrast length.

	MD-A	MD-B	MD-C
Contrast ratio	3410:1	19480:1	321:1
Perceptual contrast length	115.55	119.47	119.47

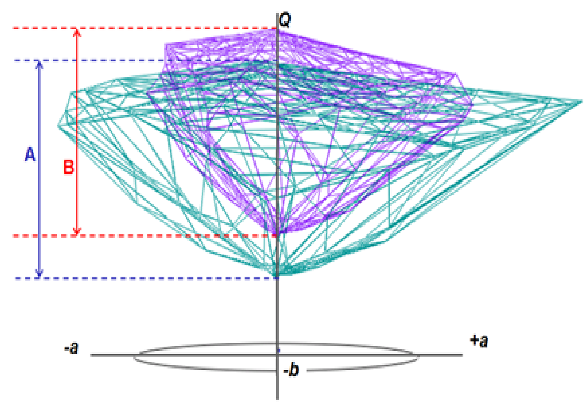


***Figure 1**. Perceptual contrast length for two mobile displays.*

Perceptual Contrast Length

The absolute contrast ratio is used as a quantitative evaluation method of display contrast. However, this ratio does not reflect the characteristics perceived by human vision, and there can be a significant difference between the actual perceived contrast and the absolute contrast ratio. To overcome this difference, Chong[5] proposed using the perceptual contrast based on the difference between the maximum and minimum brightness in CIECAM02 color space considering the visual characteristics of the surrounding conditions. Figure 1 shows the method used to measure the perceptual contrast length, where A and B represent the gamut for each display and the perceptual contrast denotes the length of the difference between the maximum and minimum perceptual brightness in CIECAM02 color space.

Table 1 shows the results of the perceptual contrast length and contrast ratio for several mobile displays (MD-A, MD-B, and MD-C). The contrast results based on the absolute contrast ratio show a 60-fold difference or more. However, the contrast perceived by human vision only shows a slight difference, even though the displays have remarkably different absolute contrast ratios. Plus, when the difference in the absolute contrast ratios is more than 60

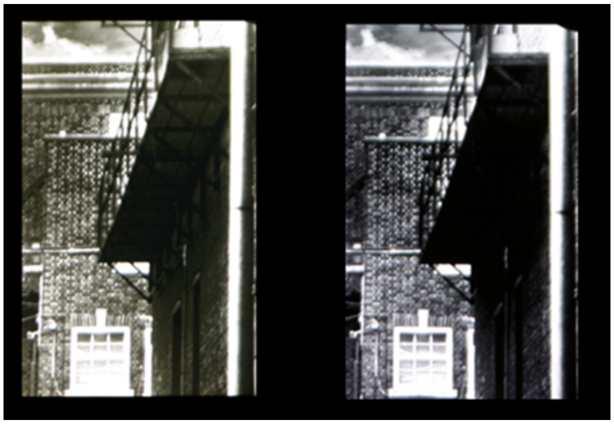


***Figure 2**. Captured images of mobile displays using a camera. (a) MD-C (b) MD-B.*

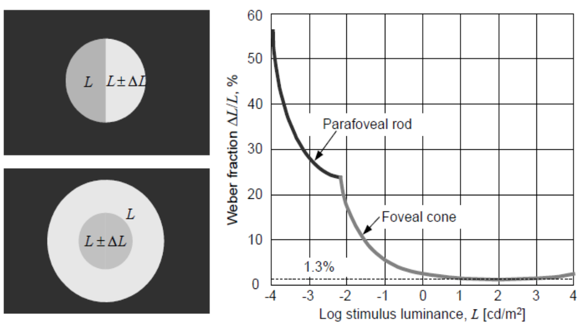


***Figure 3.** The rule of Weber-Fechner fraction.*

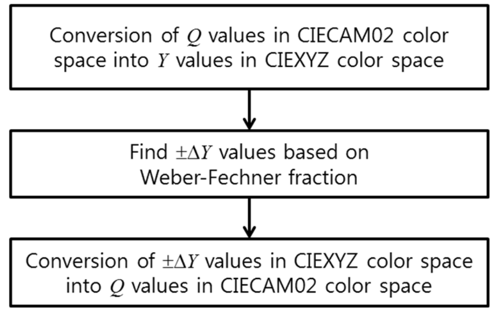


***Figure 4.** Flowchart for calculation of region of perceived same brightness.*

fold between the mobile displays, the perceptual contrast length remains the same or similar. Yet, there is also a difference in the contrast perceived by human vision between mobile devices with the same perceptual contrast length. Figure 2 shows the results captured at the same time when the same image was represented on two mobile devices. In Fig. 2, a perceptual contrast difference appears in the support fixture under the handrail, showing that despite similar perceptual contrast lengths for each display in Table 1, the perceived ratios are actually different. In other words, the perceptual contrast length is closer to the contrast perceived by human vision than the absolute contrast ratio. However, even the same perceptual contrast length can be perceived differently by human vision, as shown in Fig. 2. Therefore, measuring the contrast perceived by human vision using the just the perceptual contrast length is inadequate. Accordingly, this paper proposes a perceptual contrast measure based on analyzing the brightness distribution in the perceptual contrast length.

The Proposed Perceptual Contrast Evaluation

Brightness distribution analysis based on Weber-Fechner Fraction

Weber-Fechner proposed a model for measuring the characteristics of the human visual system based on the perceptual brightness difference [8]. The human visual system is better at recognizing brightness differences in bright areas than in dark areas. In Fig. 3, if the luminance range is 10 to 1000, human eyes are unable to perceive a brightness difference in the case of a 1.3% brightness difference from the surrounding brightness. Therefore, this study determined the boundary of the perceptual brightness difference based on Weber-Fechner's law, where a sample value is determined from the same distance to the brightness axis of the device gamut, a region in the color space is determined that recognizes the same brightness for each sample value, and the color distribution is analyzed in that area.

Figure 4 shows the procedure for selecting a region with the same perceived brightness based on Weber-Fechner's law. First, as CIECAM02 color space uses brightness(Q) information, the brightness values(Q) are converted to luminance values(Y) to apply Weber-Fechner's law. Therefore, the extracted sample brightness levels(Q) are converted to luminance values(Y) to determine the luminance variation ΔY for the minimum perceptual brightness. The maximum luminance variation perceived at the same brightness is then obtained by applying Weber-Fechner's law to the converted luminance samples. The $+\Delta Y$ and $-\Delta Y$ for each sample luminance are converted into Q values to determine the area in CIECAM02 color space.

The Number of perceived gray colors at same brightness

Previously, the area perceived at the same brightness for the sample values in CIECAM02 color space was derived based Weber-Fechner's law. Next, the number of gray colors included in the sample region is calculated.

Qab values are obtained for the gray colors on the basis of the RGB values. This study used 256 gray color values based on an 8bit input. The number of gray colors contained in the sample region are then calculated. In this case, for all the color values, the gray colors and color differences in each sample region(ΔQab) include color values below 3.0 and gray patches in the sample area. This is because human vision is unable to perceive color differences under 3.0[9]. Thus, the perceived contrast is calculated, including both the numerical grayscale and the perceived colors with a low saturation for human vision.

The number of colors perceived by such brightness based on the abovementioned process contains the sample area, as shown in Table 2. That is, the number of colors visible at the same brightness as the brightness of the 70 sample value of the MD-A used in the experiments was 493. Even though these colors in display gamut were also represented by 493 pieces of varying brightness, human vision was perceived as same brightness. Thus, the lower portion of the handrail in Fig. 2, depending on the mobile display characteristics, was input using different brightness values, yet the output used the same brightness value, resulting in a dark appearance due to the absence of any brightness difference. In other words, the phenomenon shown in Fig. 2 is due to the lack of heterogeneous luminance value distances on the mobile display. Therefore, this study provides a method for measuring the cognitive ratio in these regions.

The Proposed distinct contrast

After calculating the number of patches that can be recognized by the same brightness in the sample region, as shown in Table 2, we calculate the distinct contrast using it. The distinct contrast C_r for each sample area of brightness r is as follows.

$$C_r = \frac{N_r}{Q_{r,\max} - Q_{r,\min}} \quad (1)$$

In Eq (1), N_r shows the number of gray colors in the sample area. $Q_{r,\max}$ and $Q_{r,\min}$ represent the maximum and minimum Q values for the sample area. In other words, this shows the ratio between the number of gray color with same perceived brightness and the length of brightness in the sampled area as shown in Table 3. The normalized ratio CN_r is calculated by the number of total gray colors in each mobile display.

$$CN_r = \frac{C_r}{N_T} \quad (2)$$

In Eq. (2), N_T shows the entire gray color count. The proposed distinct contrast measure CR is defined as follows.

$$CR = 1 - A\sum_{n=0}^{N_S} CN_n \quad (3)$$

The normalization factor A used in Eq. (3) is 100, and N_S is the number of samples. The results of Eq. (3), shown in Table 4, represent the distinct contrast corresponding to each mobile display.

Experiments

In experiments to verify the proposed measure, the perceptual contrast based on human vision was determined for three mobile displays. In this study, the CIECAM02 color gamut was used to measure the perceptual contrast of the mobile displays based on the assumption of indoor environment values as the surrounding environment required for CIECAM02 color space conversion. Thus, the ambient light expressed by lux (Lux) was fixed at 38 lux.

Firstly, the subjective test is performed to evaluate perceptual contrast of the mobile display. Figure 5 presents a gray scale patch that shows black to gray and white to gray, while giving the change in brightness for each separate interval shade of gray.

In Fig. 5, points shown in the gray patches means that a place from which it begins to recognize the difference in brightness by the subjective evaluation. The shades of gray on the left of the square box indicate values beginning with 0 or 255. From left to right in Fig 5, the interval value is shown in right side as 1 to 7.
The 15 human participants included experts in the field of image processing. In the experimental procedure, the participants select the point in the gray patches from which they start recognizing the difference in brightness. The mark × means the unperceived difference in brightness for each step. In other word, the difference of brightness in the display for the line in the gray patches where the mark × is not recognized for that tone patches. For example, starting from the leftmost brightness 0 in the first line in (a) of Fig. 5, the brightness increased by one in the forward direction. Taking the MD-B as an example, the brightness of the eighth column of the first row was distinguished between the brightness of the 7th column and 8th column. In other word, the difference of brightness between the first column and the seventh column was not recognized.

Table 2. The number of colors in range of each sampled level.

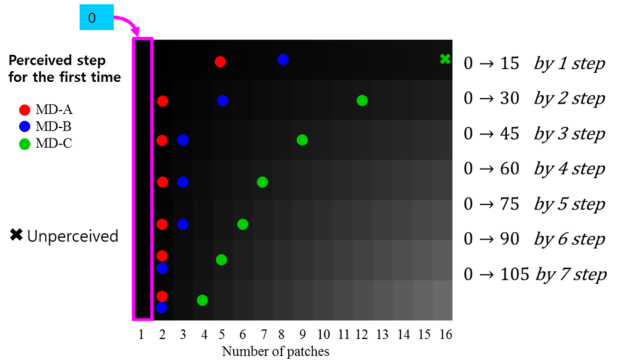
Sample Brightness	MD-A	MD-B	MD-C
60	-	-	441
70	493	248	569
80	416	286	590
90	425	335	695
100	492	384	805
110	548	491	922
120	622	590	1110
130	683	694	1280
140	740	819	1430
150	850	926	1587
160	925	1108	1889
170	1012	1264	1755
180	580	744	-

Table 3. Ratio of the number of colors as perceived same brightness to length for each region of sampling level.

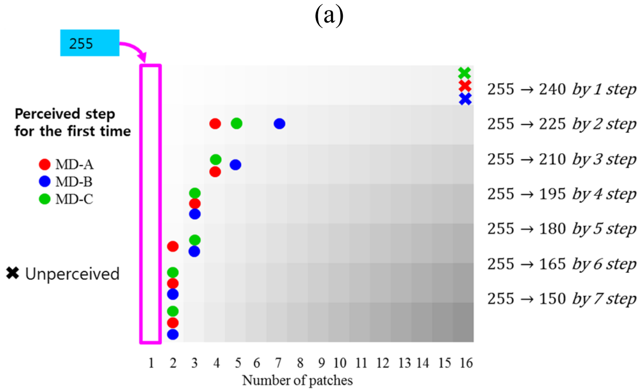
Sample Brightness	MD-A	MD-B	MD-C
60	-	-	36.539
70	41.035	19.725	24.847
80	17.880	12.414	24.140
90	16.863	13.376	27.134
100	18.407	14.336	30.223
110	19.585	17.589	33.761
120	21.978	20.921	39.181
130	23.608	24.105	43.790
140	25.118	27.923	47.714
150	28.015	30.251	51.028
160	29.244	35.342	62.966
170	39.013	45.533	84.293
180	35.626	41.727	-

Table 4. Distinct contrast for each mobile display.

	MD-A	MD-B	MD-C
Distinct contrast	0.89	0.83	0.86



(a)



(b)

Figure 5. *Perceived brightness difference for each display.*

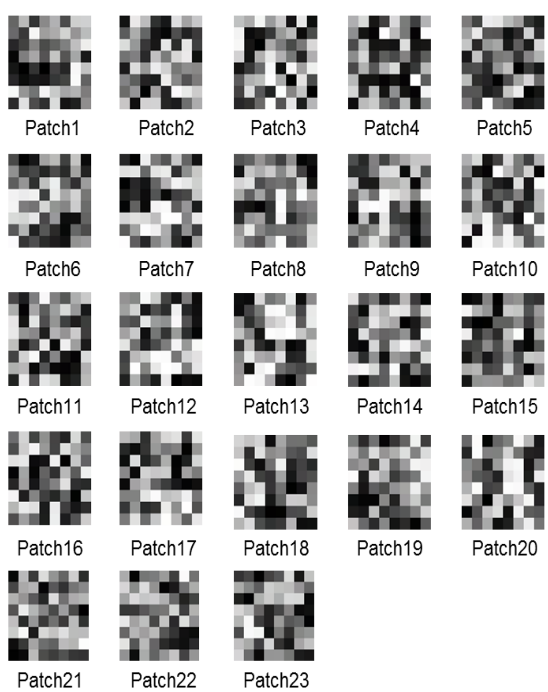


Figure 6. *8×8 random gray scale patches.*

As described above, the points corresponding to the display shown in Fig. 5 indicate the first brightness that represents perceived brightness difference from black. As a result, MD-A has highest contrast perception in the case of black and white. Perceptions of changing of brightness on three mobile devices are impossible for brightness changes of one interval from white. Perception of changing brightness on MD-B is impossible for brightness changes of one interval from black. In the case of white, MD-B shows a little better performance of perception of changing brightness than the MD-C. However, in the case of black, MD-C shows a better performance of perception of change in brightness than the MD-B. Thus, MD-B and MD-C has the contradictory perception result of changing brightness form black to white. However, perception of changing brightness on MD-C is better than MD-B in terms of the difference in brightness.

Next, 23 random patches are used for evaluating perceived contrast. Each patch is composed of 8 × 8 pieces. Each piece was randomly filled by using the value of perceived gray. Each piece has a 128 × 128 pixel size. Accordingly, a patch has a 1024 × 1024 pixel size. Figure 6 shows the 23 random patches for evaluation. Each piece was adjacent to different gray value. To evaluate the brightness expression which can be distinguished in each patch, preference contrast tests are performed by using 23 random patches on mobile devices.

In this experiment, preference test for contrast of mobile display are performed by 15 participants, which includes experts in the field of image processing. They give preference scores for 23 random patches on three mobile displays. The question for evaluation of display is "We look at each of the displays, please scored for a fixed order in which the gray patch has the best distinction." They give preference scores for 23 random patches on three mobile displays from 1 through 3.

Table 5. Comparison resulting data from various methods with subjective evaluation test.

	MD-A	MD-B	MD-C
Preference Test	2.96 (1)	1.38 (3)	1.91 (2)
Absolute Contrast Ratio	3410:1 (2)	19480:1(1)	321:1 (3)
Perceptual Contrast Length	115.55 (3)	119.47 (1)	119.47 (1)
Proposed method	0.89 (1)	0.83 (3)	0.86 (2)

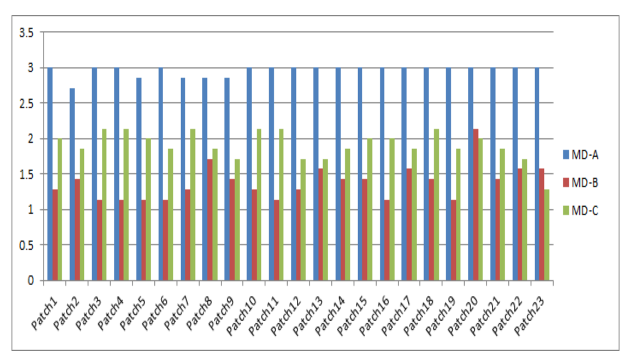


Figure 7. *Result of preference for mobile display contrast.*

Figure 7 is shows the averaging scores for the results of the preference evaluation. As a result, MD-A has a higher preference which shows as same as the perceived contrast value using the proposed method. Table 5 presents the comparison results of the proposed method with subjective evaluation. The numbers in parentheses indicate the ranking of each display. It represents that perceived contrast value using the proposed method seems to be in analogue with the results of subjective evaluation.

Conclusion

This paper proposed a method for evaluating perceived contrast in mobile displays. Perceived contrast for a display is varied with respect to the display settings and viewing conditions. However, relative comparison of perceived contrast in displays is achieved by using perceived contrast values based on the proposed method. The proposed method used CIECAM02 color space to consider the perceived characteristics of the human visual system. Moreover, to evaluate that how well represent the difference of brightness, the brightness range which represents perceived same brightness for human vision is calculated by using the ratio of Weber- Fechner. Then, perceived contrast value in a display is calculated by the ratio of the number of colors in perceived same brightness range to the length of this range. As a result, the proposed method can derive the capacity of the difference in brightness. Also, subjective evaluation was performed by using different tone patches. As a result, perceived contrast value using the proposed method seems to correspond with the results of subjective evaluation.

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