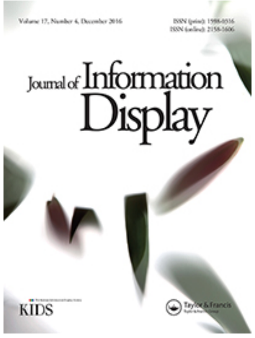

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ABSTRACT

The white-luminance display is generally considered the representative value for screen brightness, but it is not always proportional to the users' perceived brightness. The demand for the brightness of the display also changes depending on the actual use conditions, such as the ambient condition, contents, viewing object, and display device characteristics. It is important to differentiate the perceived brightness of the display by considering the device characteristics and the use conditions. A display device with a lower black level and a high saturated primary color can make the users satisfied by emitting even a relatively low luminance level. This is the result of the simultaneous contrast and Helmholtz–Kohlrausch effect. A visual experiment considering various illuminant conditions and actual use contents proved that the perceived brightness for OLED is different from the white-luminance value. It is expected that the new luminance criteria developed herein will be used for reproducing high-quality videos like those made with HDR, one of the newly rising image-quality technologies.

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KEYWORDS
Perceived brightness; perceived luminance; actual use condition; simultaneous contrast; H-K effect; OLED; LCD

Introduction

Diverse electronic goods have been adopting liquid crystal display (LCD) and organic light-emitting diode (OLED) displays as the visual output device, and digital products like smartphones, tablets, note PCs, cameras, and TVs as well as home appliances like refrigerators and washing machines have also begun employing a screen to show their status and to communicate with their users. Moreover, the market of digital information display and public information display for advertising among crowds has gradually grown. The brightness of a display integrated with various applications needs to be adjusted according to its purpose and use environment.

The displays of products mainly used outdoors have to have a brighter screen in the middle of the day compared to the displays of products used indoors. On the other hand, cases like the theater screen do not require a high luminance level. This can mean that a display's brightness level is highly affected by the environmental condition [1].

The optical property of a display can also influence its brightness level. The black-luminance level and the color gamut of a device's display can determine the white-luminance level of the display. A lower black-luminance level can create the optimal contrast level in spite of having a lower white-luminance level compared to a higher-black-luminance-level display [2].

Another significant factor affecting a display's proper brightness level is the contents used on the display [3]. Based on the contents, the optimum luminance level can change considerably. Moreover, the affected ambient-condition degree depends on what the contents are. High-grey-level and highly saturated-color-dominant images are less affected by the ambient light condition than contents with a low grey level.

This paper suggests the optimum brightness levels for OLED mobile displays in various environments. A perception test for finding the proper brightness levels was conducted by comparing the reference LCD display and OLED modules with various luminance levels under four illuminant conditions. In the perception test, images that could represent the contents used in smartphones were shown. Two displays were compared, one with the reference luminance condition used by LCD smartphones

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and the other with a variable OLED display luminance level. After the comparison, whether the OLED display was brighter compared to the reference was judged.

The factors influencing the optimum perceived-brightness level of displays were analyzed from three perspectives: the display's optical characteristics, the surrounding illuminance, and the rendered contents. The optimum brightness level changed depending on the device's black-luminance level and color reproduction ability, which can be explained by the color appearance phenomenon, such as the simultaneous-contrast and Helmholtz–Kohlrausch (H–K) effects. There were results where the brightness level enhanced by the display device's characteristics disappeared under ambient viewing conditions. This occurred under the 500 lux illuminant conditions. The rendered contents were found to be an important factor for deciding the perceived-brightness level, and it was analyzed based on the pixel level of the frame.

Experiment

Test device description

One LCD smartphone and six OLED display modules were tested in the visual experiment. Each OLED display module was set to have a different luminance level but the same color gamut property. The luminance level of the LCD smartphone, the reference display, was 500 cd/m^2, and those of the six OLED display modules were 300, 360, 420, 480, 540, and 600 cd/m^2, respectively. The color gamuts of the LCD and OLED modules that were used in the experiment herein, based on the CIE 1976 diagram, are shown in Figure 1.

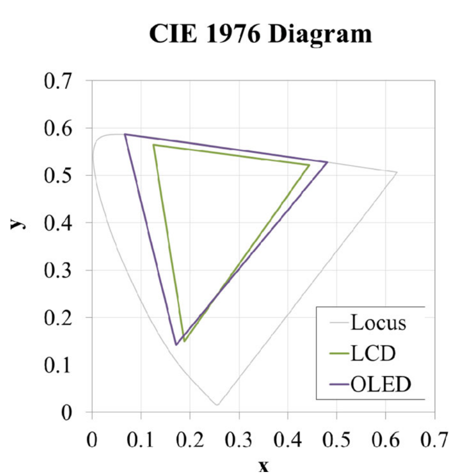


Figure 1. Color gamuts of the LCD and OLED displays that were used in the experiment, based on the CIE 1976 diagram. The gamut area of the LCD display was 99.7%, and that of the OLED display was 137.2%, compared to the sRGB color space.

Viewing environment

Various illumination levels were included as experiment conditions to consider the variety of the viewing environment [4]. In particular, 0, 500, 1000, and 5000 lux ambient conditions were created using Cold Cathode Fluorescent Lamp light sources. The 0–1000 lux conditions can be applicable as the indoor conditions of theaters, living rooms, and offices, and 5000 lux can correspond to the outdoor conditions, but over 5000 lux could not be tested due to the limitations of the light sources.

Eight representative images were used for the actual mobile use conditions. These images had diverse histogram types and grey-level distributions. The histograms of the eight images are shown in Figure 2. Image #1 is a calls list with a black UI, image #2 is an application and menu icons list with a blue background screen, image #3 is a mailing list with a white background and a black keyboard pad, image #4 is a game screen with a colorful character with a largely saturated-green background, image #5 is a YouTube movies list, image #6 is a news scene, image #7 is a fireworks scene at night, and image #8 is the web searching site Naver's main page with a white background. Table 1 presents the eight images' average R, G, B, and W signal levels and the average pixel level that was applied to the R, G, and B pixel luminance proportion and display gamma.

Perceptual test method

A total of 19 subjects participated in the visual experiment (52.6% males, 47.4% females). As for their ages, 73.7% were in the 20–30s, and 26.3% were in the 40–50s.

The subjects were instructed to judge whether each of the six OLED display modules with different luminance levels was brighter than the reference LCD smartphone, which had a 500 cd/m^2 luminance level. The participants' answer could be one of the following: brighter, equivalent level, or less bright. Figure 3 shows the experiment scene, with the subjects evaluating the luminance levels of the OLED display modules based on six different levels, and comparing them with the luminance level of the reference display. This was repeated for the eight images and for four illuminance conditions: 0, 500, 1000, and 5000 lux.

Results and discussion

Device characteristics analysis

The subjects' evaluation results were quantified by assigning a score of 1, 2, and 3 to the 'brighter', 'equivalent level', and 'less bright' answers, respectively. To determine if the device property has any influence on the optimum luminance level, the average scores of the eight

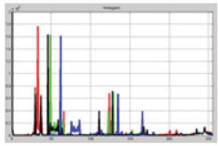
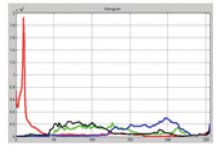
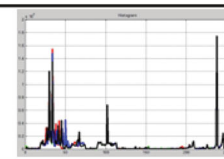
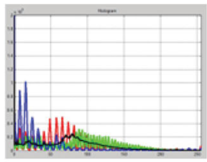
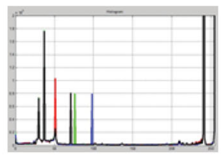
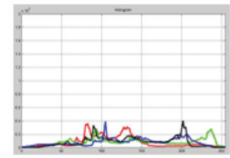
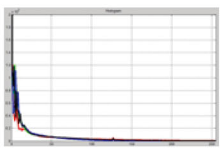
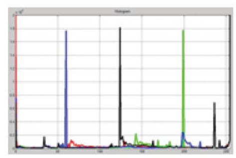
No	Histogram	No	Histogram	No	Histogram
1		2		3	
4		5		6	
7		8			

Figure 2. Histograms of the eight images that were used in the visual experiment.

Table 1. Average W, R, G, and B signal levels of the eight images that were used in the visual experiment, and the displays' pixel levels calculated by applying the R, G, and B subpixel proportion and the 2.2 gamma curve.

	Average signal level (0–255)				
Image no.	White	Red	Green	Blue	Pixel level (%)
1	40.7	37.7	41.6	43.8	8.8
2	107.4	46.2	125.8	172.9	19.9
3	142.6	142.6	142.4	143.5	45.1
4	66.3	59.9	76.6	30.2	9.2
5	170.7	171.0	170.2	171.9	58.1
6	136.0	116.1	145.4	139.9	29.7
7	23.6	32.1	20.3	18.2	2.7
8	200.3	196.5	208.5	185.3	69.7

images for the 19 subjects in the dark-room condition were calculated. As a result, the average score was plotted as shown in Figure 4. It was found that 360 cd/m^2 was the equivalent level for the test OLED display module compared to the reference LCD display (500 cd/m^2), according to the linear trend line of the plot.

There was a 140 cd/m^2 luminance gap between the LCD and OLED displays under the condition that they were presenting equivalent brightness levels to the viewers in the dark-room condition. This was caused by the low black-luminance level and the wide color gamut of the OLED display. Thus, it could be explained by the color appearance phenomenon and the simultaneous-contrast and H–K effects. Simultaneous contrast is the phenomenon in which two different colors affect each other [5]. The black luminance of the reference LCD smartphone was 0.3571 cd/m^2, and that of the six test OLED display modules was 0.00009 cd/m^2. A lower black-luminance level can boost the perceived brightness

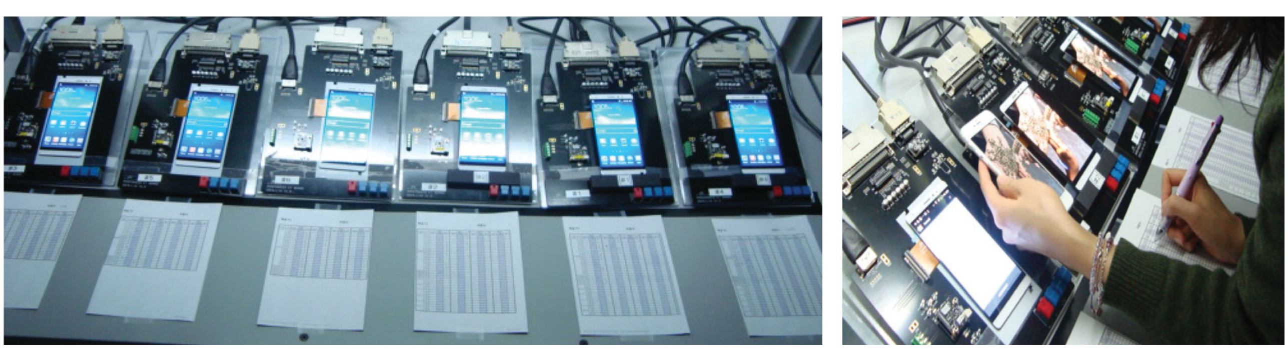


Figure 3. Visual experiment performed to judge the brightness levels of the six OLED display modules with different luminance levels for the eight images compared to the reference LCD smartphone. The reference luminance condition was 500 cd/m^2, and the six OLED display module test conditions were 300, 360, 420, 480, 540, and 600 cd/m^2. The experiment was repeated for each of the 0, 500, 1000, and 5000 lux illuminance conditions.

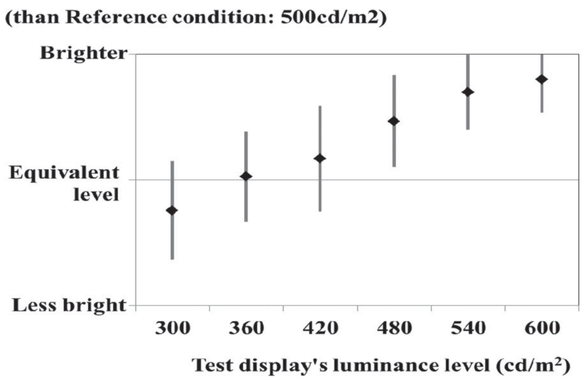


Figure 4. Average scores of the eight images for the 19 subjects in the dark-room (0 lux) condition. The grey bars represent the deviations among the observers.

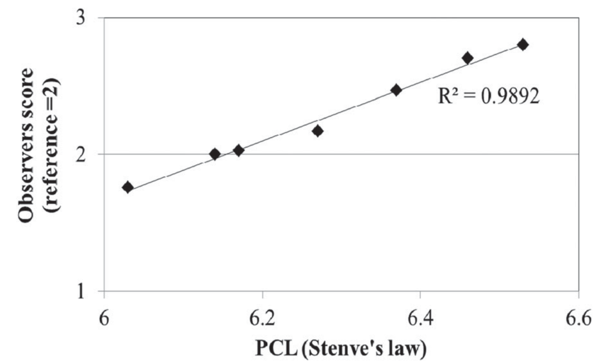


Figure 5. Experiment data linearly agreeing with the theoretical data, PCL (Steven's law), and $R^2 = 0.9892$.

Table 2. Contrast values of the reference LCD and the test OLED display modules.

Display		L_w (cd/m^2)	L_{bk} (cd/m^2)	Contrast ratio (L_w/L_{bk})	PCL (Steven's law)
Reference (LCD)		500	0.3571	1400	6.14
Test modules (OLED)	#1	300	0.00009	3.3×10^6	6.03
	#2	360		4.0×10^6	6.17
	#3	420		4.6×10^6	6.27
	#4	480		5.3×10^6	6.37
	#5	540		6.0×10^6	6.46
	#6	600		6.7×10^6	6.53

of images under an equal white-luminance condition [6]. In this study, the different black-luminance levels created a contrast level gap between the reference and test display modules. The contrast index of the display, however, does not necessarily stand for the perceived-brightness characteristics. Table 2 shows the contrast values of the reference and test OLED display modules. The contrast ratio calculated based on the ratio of the white and black luminance to the perceptual contrast length (PCL) [7] for comparing the contrast values applied Steven's law [8] between the reference and test modules. Based on the experiment result that the 360cd/m^2 OLED display module had the same perceived-brightness level (500 cd/m^2) as the LCD display in the dark-room condition, the conventional contrast ratio was completely mismatched with the result as there was a thousand-fold difference between them. On the other hand, the PCL value, a relatively new evaluation index, was 6.14 for the same perceived-brightness OLED display, and 6.17 for the reference LCD smartphone. This is confirmed by Figure 5, which shows the agreement between the experiment data and the PCL value. They are linearly matched and have the value of R^2 0.9892.

The H–K effect can also explain the luminance difference between two displays with the same perceived-brightness levels. This happens when two color stimuli have the same luminance level and different chroma in a certain hue, and when the perceived-brightness levels induced by the two stimuli are different [9]. The color gamut and variable achromatic color (VAC) values [10] for the R, G, and B primary colors, which represent the H-K effect quantity, are presented in Table 3. There was an about 36% color gamut difference between the reference LCD and the test OLED display modules. VAC refers to the ratio between the achromatic luminance and the chromatic luminance that perceive the same brightness. The VAC differences were 0.2, 0.26, and 0.03 for red, green, and blue, respectively. In this experimental case, two chromatic colors were compared, and as such, the reciprocal numbers of these values had to be accounted for. The difference in the reciprocal values can be regarded as the luminance gap caused by the H–K effect. This can be interpreted to mean that the 4% and 11% low luminance levels can be allowed by the high chroma of the OLED display's red and green colors. There was no luminance difference between the reference LCD and the test OLED display modules because the chroma levels were not much different, as shown in Figure 1.

Based on the experiment results, the perceived brightness can be affected by the display device's optical properties, such as the black-luminance level and the color gamut, and is not exactly proportional to the display's white-luminance level. Based on the experiment that was performed in this study, a 140 cd/m^2 luminance gap between the reference LCD and the test OLED display modules was derived. This was restricted to the dedicated device's and the 500 cd/m^2 reference LCD's conditions. If the reference and test devices will be changed, the luminance gap can also be changed.

Ambient-condition analysis

Four illumination levels were tested for analyzing the ambient condition's effect on the perceived-brightness

Table 3. Color gamut and VAC values of the reference LCD and the test OLED display modules (with the VAC reciprocal values within the parentheses).

Display	Color gamut (CIE 1976, %) sRGB = 100%	VAC (variable achromatic color, L_{eq}/L)		
		Red	Green	Blue
Reference (LCD)	99.7	2.03 (0.49)	1.43 (0.70)	2.20 (0.45)
Test modules (OLED)	135.8	2.23 (0.44)	1.69 (0.59)	2.23 (0.45)

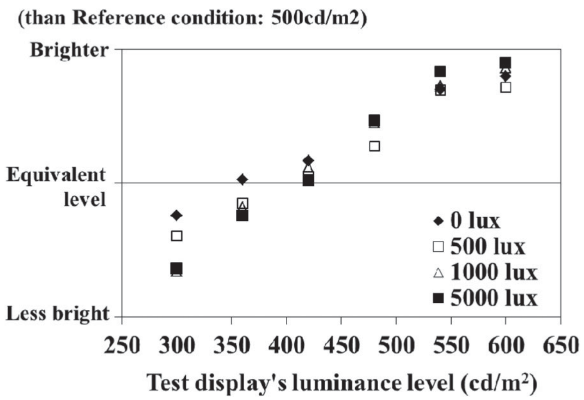


Figure 6. Average scores of the eight images for the 19 subjects in the 0, 500, 1000, and 5000 lux conditions.

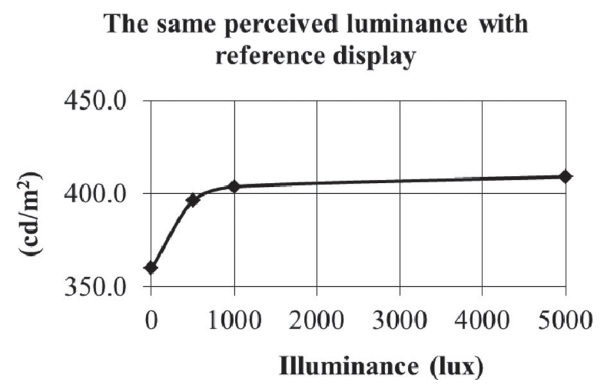


Figure 7. Luminance level for the same perceived-brightness level reference display (LCD, 500 cd/m^2) depending on the surrounding illuminance level: 0, 500, 1000, and 5000 lux.

level. The averages of the experiment results in the 0, 500, 1000, and 5000 lux conditions were calculated as described in the previous section, and were plotted. They are shown in Figures 6 and 7. While 360 cd/m^2 was the equivalent luminance level in the dark-room condition, the luminance levels for the same perceived-brightness level as the reference LCD (500 cd/m^2) were 396, 403, and 409 cd/m^2 in 500, 1000, and 5000 lux, respectively. This can be interpreted to mean that the simultaneous-contrast effect disappeared in the ambient conditions, but the luminance level did not increase much in the conditions above 500 lux. The steepest increase happened when the surrounding illuminance changed from 0 to 500 lux. This could have been because much of the simultaneous-contrast effect of the test OLED display modules' low black-luminance level, and the H–K effect, were already diluted in 500 lux. It must be noted that there was still a luminance gap between the reference LCD and the test OLED display modules even in the 5000 lux ambient condition. This can be ascribed to the OLED device characteristic that the luminance increases when the pixel area becomes smaller. This is called the 'loading ratio effect' [11]. The test OLED display modules' luminance conditions were measured in a full white pattern, but even though there was a white area (e.g. the R, G, and B digital signals were 255, 255, and 255, respectively), the luminance would change according to the content type. This can be inferred from the content analysis results that will be presented in the next section. The loading ratio also changed depending on the device characteristics. To prove this, additional measurements and analysis will be carried out, although this was not included in this paper.

Setting aside the loading ratio effect, brightness enhancement thanks to the simultaneous-contrast effect is effective when the ambient illuminance is under 500 lux. The increased shape of the OLED display module with the same perceived-brightness level as the reference LCD shown in Figure 7 was verified. The shape became flat from 500 to 1000 lux, and there was a steep increase between 0 and 500 lux. The H–K effect, where the color saturation boosts the brightness level, was also weakened by the increasing ambient illuminance. This may have been caused by the fact that the display had come to emit less saturated colors by mixing the lighting color. It is estimated, however, that the H–K effect would not completely disappear in an ambient illuminant environment, contrary to the simultaneous-contrast effect. To prove this, a brightness–color saturation experiment under various illuminant conditions will be needed.

Content analysis

As shown in Figure 2 and Table 1, diverse images were tested in the experiment for representing actual display usage. For the analysis of the content dependency, the pixel levels of the images are shown as the representative values of the test images. The pixel levels (%) in Table 1 were calculated using Equation (1) below. In the said

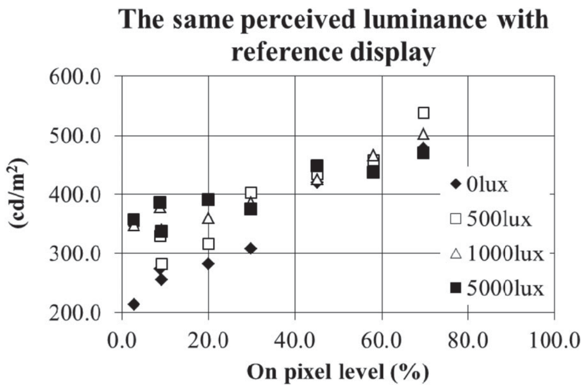


Figure 8. Luminance for the same perceived-brightness level of the reference display (LCD, 500 cd/m^2) depending on the contents' pixel level. The greater the number of on-state pixels was, the higher the perceived luminance. This trend was weakened when the surrounding illuminance level increased.

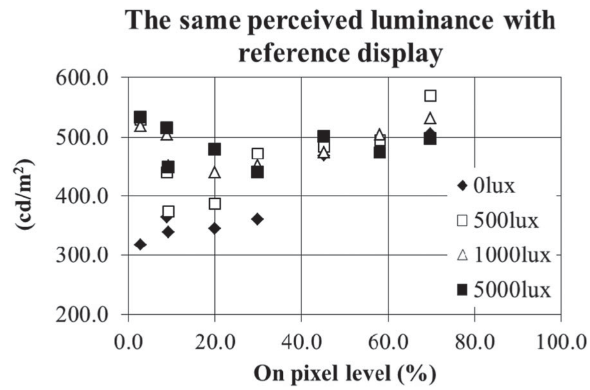


Figure 9. Luminance of the OLED display with the same perceived brightness as the reference display (LCD, 500 cd/m^2) after applying the OLED display's loading effect to the results shown in Figure 8.

equation, g stands for the 0–255 grey level, and N_g for the number of pixels of the grey level.

$$\text{On pixel level}(\%) = \sum_{g=1}^{255} \left(\frac{g}{255}\right) \times N_g. \qquad (1)$$

Figure 8 shows the relation between the pixel level of the contents and the perceived luminance level. A tendency for the perceived luminance to increase when the pixel levels of the images increased was shown. The fewer the on-state pixels were, the brighter the perceptions of the scenes. This can be interpreted to mean that various contents give rise to different visual effects, such as the simultaneous-contrast and H–K effects influencing the display's brightness, as explained above. The loading effect of the OLED device characteristic, however, can also be the reason for this trend. As explained above, some OLEDs have the device characteristic in which the luminance increases when the pixel area becomes smaller. To cancel this effect, the measured loading ratio of the test OLED displays was applied to the result. The applied values were estimated based on the data measured as 4–100% white-box luminance. This was applied as shown in Figure 8.

In Figure 8, the color appearance phenomenon according to the contents' pixel level and the test OLED's loading effect are mixed together in the perceived luminance results. The difference between the minimum and maximum pixel levels of the perceived luminance was 260 cd/m^2 in the dark-room condition. On the other hand, after compensating for the OLED's loading effect, the perceived luminance difference was 180 cd/m^2 between the minimum and maximum pixel levels, as shown in Figure 9. The 180 cd/m^2 luminance gap can be regarded as the result of the color appearance phenomenon of the various contents with different pixel levels. As such, the differences among the 260, 180, and 80 cd/m^2 luminance gaps can be inferred as the portions caused by the loading ratio effect. These amounts can explain the remaining luminance gap that appeared in the 5000 lux ambient condition even though the simultaneous-contrast and H–K effects had already worn off due to the illuminance reflection. Consequently, there was a perceived-brightness difference according to the contents, and it could be only up to 180 cd/m^2 in the dark-room condition. The number of on-state pixels displaying the contents, and the main color in the field of view, will determine the perceived-brightness level of the scenes. In a rough way, seen from the result that the same perceived luminance of the reference display became saturated to 500 cd/m^2 at the 60% pixel level in the dark-room condition, as shown in Figure 8, the color appearance phenomenon will disappear in a scene with an over 60% pixel level, and the absolute luminance level will become the criterion for judging the display's brightness.

There are many factors that affect the perceived brightness of displays. Among these are the size, viewing distance, and preference. In this study, as the size and viewing distance factors are limited to mobile application, a 5.5-inch display and a 30 cm viewing distance were used, but the preference factor was not considered. The observers' preference will considerably affect the perceived-brightness results. This will be further analyzed through more thorough interviews of the study subjects [12].

Conclusions

A visual experiment was performed using LCD and OLED displays in various ambient conditions to find the optimum luminance level of displays. By comparing the optical properties of the LCD and OLED displays, the perceived brightness depending on the display device characteristics was analyzed. The black luminance and color gamut of the display were found to largely influence the optimum white-luminance level. When the reference condition was set as LCD 500 cd/m^2, 360 cd/m^2 white luminance was enough for the same perceived brightness in the OLED display. A 140 cd/m^2 luminance gap was caused by the contrast and primary color reproduction ability difference between the LCD and OLED displays. This can be explained by the color appearance phenomenon and the simultaneous-contrast and H–K effects. The contrast difference corresponding to the simultaneous-contrast effect was quantized by the PCL values, and it was matched with the experiment result. The color gamut difference corresponding to the H–K effect was explained by the VAC values of the red and green primaries based on the results obtained under the dark-room condition. For examining the ambient condition, 0, 500, 1000, and 5000 lux illuminance conditions were created. The same perceived-brightness level of the reference increased as the illuminance increased. This could be explained by the fact that the color appearance effects by the OLED device's characteristics disappeared in the surrounding ambient condition. The luminance levels of the OLED display modules with the same perceived-brightness level as the reference LCD (500 cd/m^2) were 360, 396, 403, and 409 cd/m^2 in the 0, 500, 1000, and 5000 lux conditions, respectively.

The perceived brightness was highly dependent on the contents that were displayed on the screen. If the scene had a largely black background and highly saturated and highlighted icons, the simultaneous-contrast and H–K effects were maximized. As a result, the perceived brightness increased even though the luminance level was not that high. In the case of the scene with a largely white background, however, the perceived brightness was proportional to the white-luminance level. These results were analyzed using the images' pixel levels. At the over 60% pixel level in the dark-room condition, the expected color appearance phenomenon disappeared. This was the roughly approximated result. For the accurate analysis of the content dependency, besides the pixel level, the maximum luminance in the scene as well as the size, color, and content classification should be considered. It will be quite complicated and difficult to separate the factors' effects from one another.

The results of this study are expected to help enable displays to reproduce high-image-quality videos like the HDR videos. They can also be applied to the displays' driving algorithm for controlling their luminance according to the ambient conditions and contents.

Notes on contributors

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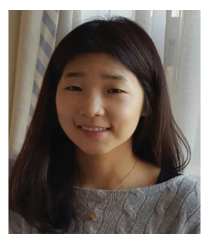
Seungbae Lee is a master at Samsung Display Co., Ltd. He received his B.S. Chemistry and M.S. Material Engineering degrees from Korea University, and his Ph.D. in Image Science from Chiba University in Japan. He has researched on the metrology standardization of the display image quality. His main interests are color and vision science in display characteristics.



Su Young Kim received her M.S. Industrial Management Engineering (Ergonomics) degree from Korea University. She is a senior engineer at the Display Research Center of Samsung Display Co., Ltd. and has been working on display and image-quality evaluation.

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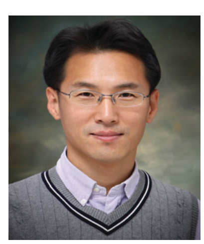

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References

[1] S. Kubota, *Proceedings of the Sixth International Conference on Human-Computer Interaction*, Vol. 20 (Tokyo, Japan, 1995), pp. 643–648.

[2] G.E. Legg and J.M. Foley, J. Opt. Soc. Am. **70** (12), 1458 (1980).

[3] A. Yoshida, V. Blanz, K. Myszkowski, and H. Seidel, Eurograph. **25** (3), 263 (2006).

[4] U.S. Department of Energy, *Room Illuminance Measurements During TV Viewing: Pilot Study* (U.S. Department of Energy, 2011).

[5] J.J. Gibson, J. Exp. Psychol. **20**, 553 (1937).

[6] J.B. Troy and C.E. Cugell, Exp. Brain Res. **93**, 383 (1993).

[7] M. Shin, J.-H. Chong, S.A. Yang, E. Lee, S.B. Lee, and B.H. Berkeley, SID Symp. Dig. Tech. Papers **42** (1), 1277 (2011).

[8] R. Teghtsoonian, Psychol. Rev. **78** (1), 71 (1971).

[9] T. Shizume, G. Ohashi, H. Takamatsu, and Y. Shimodaira, J. SID **22** (11) (2015).

[10] Y. Nayatani, Color Res. Appl. **22** (6), 385 (1997).

[11] ICDM, *Information Display Measurements Standard* (ICDM, 2012), p. 5.24.

[12] N. Camgoz, C. Yener and D. Guvenc, Color Res. Appl. **27**, 199 (2002).