Assessment of the effect on the human body of the flicker of OLED displays of smartphones

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ABSTRACT
This paper considers the effects on the human body of the flicker of organic light-emitting diode (OLED) displays. Related studies have been conducted due to reports of cases of adverse health effects of the use of artificial lighting. Interest in this problem recently intensified with the development of various new displays and the longer exposure time of people to them. Therefore, the previous studies on the effects of artificial lighting on the human body are described in this paper, and based on them, the dimming technique for liquid-crystal displays and OLED displays of smartphones is explained and the effect of the flicker of OLED displays on the human body is assessed.

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1. Introduction
The light-emitting diode (LED), developed in 1962, is still widely used as artificial lighting in various fields due to its low power consumption and long lifespan. It is mainly used as the light source for the liquid-crystal display (LCD) of electronic devices such as TVs and mobile phones. However, the wide use of electronic devices equipped with LEDs and the long exposure of the eyes to LED screens have caused side effects such as fatigue and headache [1,2]. These adverse health effects on the human body are caused by the flicker generated by the pulse-width method (PWM) dimming technique [3]. The IEEE Standards Working Group on Lighting, IEEE Standards PAR1789, was established in 2008 to report on the effects on the human body of LED flicker and of the flicker reducing driving technique [3]. The standard flicker assessment method enacted here is currently being used to study the adverse health effects of flicker not only in LEDs but in various other light sources [4,5].

Organic light-emitting diode (OLED) displays, which have been mass-produced since 2007, are replacing LCDs in many fields due to their slimness, flexibility, low power use, and high contrast ratio. Yet again, however, adverse health effects of OLED display flicker are posing problems in some Internet user communities. Detailed research is still insignificant [6,7], though; and as the influence of OLED displays in the market grows, interest in their health issues is also increasing.

In this paper, the IEEE Standards PAR1789s recommended criteria are reviewed to evaluate the effects of OLED display flicker on the human body. The effects of pulse-width modulation (PWM) driving of LCD and OLED displays are assessed through measurements based on the criteria. Besides, the cognitive characteristics of each display are evaluated by varying the distance to determine the difference according to the PWM methods. Lastly, the effect of the OLED display on the human body is described.

2. IEEE Standards PAR1789
Flicker is defined as a rapid and repetitive change in brightness [3]. The effects of flicker on the human body can be divided based on the length of user exposure to the flicker. Effects of temporary exposure to a visible flicker of $3 \sim 70$ Hz are epileptic seizures. Long-term exposure to invisible flickers with higher frequencies can lead to malaise, headache, eye strain, and impaired visual performance.

The Illuminating Engineering Society of North America (IESNA) has two methods of measuring flicker [8]. The percent flicker measurement method is mainly used in visual science and photobiology. It measures the percent flicker as shown in Equation (1).

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\text{Percent flicker} = 100 \times \frac{(L_{\text{max}} - L_{\text{min}})}{(L_{\text{max}} + L_{\text{min}})}
\]
In Equation (1), $L_{\text{max}}$ and $L_{\text{min}}$ are the maximum and minimum values of the luminance measured from the light source. Note that (1) is not related to the change in frequency. The IEEE Standards PAR1789 group uses the results of several independent experiments to describe, as follows, the relationship between the frequency of the flicker and the percent flicker that affects the human body. First, the no-observable-effect limit is set by combining the data from [9] and [10]. Then the low-risk region is derived by comparing it with the data from [10,11] and the results of a case study by the U.S. Department of Energy/Pacific Northwest National Laboratory (DOE/PNNL) [12]. The criterion recommends that the percent flicker be 5% or below at 90 Hz or less, because this is the luminance range at which flicker can be detected, which can cause serious symptoms such as seizures. The 5% criterion alone does not cause intense symptoms and may still cause discomfort. The standards for the flicker frequency, $f_{\text{flicker}}$, have been established for invisible flicker at frequencies higher than a visible flicker.

- Low-risk level: percent flicker $\leq 0.08 \times f_{\text{flicker}}$
- No-observable-effect level: percent flicker $\leq 0.0333 \times f_{\text{flicker}}$

Note that the percent flicker has a maximum level of 100%. Figure 1 shows the IEEE Standards PAR1789 recommendations by frequency.

The low-risk and no-observable effect level regions are shown in Figure 1 as functions of the frequency and the percent flicker. The upper margin of the low-risk region is indicated by the line percent flicker $= 0.08 \times f_{\text{flicker}}$, and the low-risk and no-observable-effect areas are separated by the line percent flicker $= 0.0333 \times f_{\text{flicker}}$ [12].

Figure 1. IEEE Standards PAR1789.

3. Comparison of PWM dimming methods for LCD and OLED displays

The PWM technique is generally used to control the brightness of a display. Although this technique is used in both LCD and OLED displays, its driving method differs between the two displays, as shown in Figure 2.

As shown in Figure 2(a), the LCD controls the brightness by repeating the complete On/Off process of the entire screen. When the same driving method is used in an OLED display, mura occurs on the OLED display under a certain luminance. Therefore, OLED displays adjust dimming by driving at 240 Hz consisting of a few cycles, as shown in Figure 2(b). Figure 2(b) shows an example of PWM dimming for 4 cycles. The following section evaluates the effects on the human body of flicker resulting from these two methods based on the IEEE Standards PAR1789 described above.

4. Results and discussion

The following experiment was conducted to analyze percent flicker according to the flickers from the driving methods of LED and OLED displays.

As shown in Figure 3, for the device under test (DUT), 3 different brightness levels (50 cd/m², adjustable minimum, and maximum) were set using a color analyzer (model CA-210, Konica Minolta, Japan). The brightness level of 50 cd/m² was selected as the median value of the low luminance (0–100 cd/m²) range, where flicker can be easily detected. The other brightness levels were chosen as extreme environment usage values. The photodetector (model PDA100A, Thorlabs, USA) was placed at a distance D from the center of the DUT, at which point it measured the flicker in place of the human eye, according to the measurement setup described in [3]. The photodetector then converted the light intensity into an electric signal, and the voltage was measured with an oscilloscope (model MDO4104C, Tektronix, USA).
At first, comparative studies were conducted on two types of LCD smartphones using LEDs as backlight, since the IEEE Standards PAR1789 was established for LEDs. In the said standards, percent flicker (1) has a maximum level of 100%, and the frequency that satisfies the low-risk level is 1,250 Hz or higher. Although IEEE Standards PAR1789s recommended level is over 1,250 Hz, some experiment results have revealed that in special cases, flicker can be recognized at about 3 kHz. Therefore, in LCDs, DC driving is sometimes used instead of the PWM method, which can be used as flickerless [12].

Figures 4 and 5 show the flicker measurement results for LCD smartphones S1 and S2 using PWM and DC dimming, respectively, wherein D is 1 cm. Figure 4 shows that S1 used DC at a high luminance level and the PWM technique at a 2,500 Hz low luminance level to adjust the dimming, and Figure 5 shows that S2 used DC dimming even at low luminance, unlike S1. These confirmed that recent LCD smartphones use a PWM frequency above the recommended guidelines or DC dimming to minimize adverse health effects.

On the other hand, for some media, the effects of OLED display smartphones on the human body are causing concern because such smartphones use PWM dimming at a frequency lower than the IEEE Standards PAR1789 recommended guidelines. The evaluation was conducted in the same environment as above using an OLED display smartphone, to compare the difference from the LCD devices. Figure 6 shows the measurement results for the OLED display smartphone S3 using PWM dimming wherein D was 1 cm. S3 used 240 Hz PWM dimming at every luminance. The percent frequency was calculated to determine the adverse health effects at each luminance level shown in Table 1.

The IEEE Standards PAR1789 low-risk-level percent flicker for artificial lighting operating at a frequency of 240 Hz is 19.2 or less. According to Table 1, the OLED display did not meet the criteria when it was at a low luminance level at a distance of 1 cm. In general, however, the adverse health effects of display flicker are assessed...
in an environment where humans actually see lighting. Therefore, the controversy behind OLED display flicker, which is raised based on the above experiment results in some Internet communities, is too ambiguous to use for judging the harmfulness of flicker to the human body. To ascertain the effect of the change in distance in the actual mobile phone use environment, identical experiments were conducted by changing the distance at 50 and 200 cd/m².

Figure 7 shows the measurement results according to the distance of the low-luminance point. The frequency component of 240 Hz was still slightly visible at up to 4 cm, but was hardly seen above 5 cm, similar to DC dimming. The above results were analyzed in the frequency domain using the Fourier transform, as shown in Figure 8. The 240 Hz component was confirmed to have rapidly decreased as the distance increased; and at a distance of 5 cm or more, the 240 Hz band was confirmed as undistinguishable from ambient noise.

Figure 9 shows the flicker measurement results at a high luminance according to a change in distance. At a low luminance, the flicker was above 5 cm, similar to that in the DC dimming. Figure 10 shows the frequency domain result of the previous result. At the high luminance, the 240 Hz component hardly appeared above 4 cm, and the overall amplitude of the frequency spectrum was much smaller than that at the low luminance. This is because at a high luminance, the PWM technique was used with a higher duty cycle than at a low luminance. Therefore, the visibility of the flicker was low at the high-luminance level.

Figure 11 shows the percent flicker by distance calculated from the measurement results. The low- and high-luminance flickers satisfy the recommended criteria for over 4 cm and in all areas, respectively, which is explained by the amplitude difference in the frequency domain. Although the calculated percent flicker at a distance of
Figure 11. Calculation of the percent flicker of the OLED display by distance.

Figure 12. LCD luminance results of according to the change in distance.

4 cm or less at the low luminance did not satisfy the IEEE Standards PAR1789, it did not appear to be typical in a general mobile phone use environment.

The luminance change measurement test according to changes in distance was also conducted on the LCD display to analyze why the percent flicker of the OLED display was small even at low frequencies, unlike that of the LCDs that used DC or higher frequencies above 1,250 Hz.

As shown in Figure 12, the constant frequency component of LCDs was seen regardless of the change in distance from that in the OLED display. This result is explained by the different types of PWM dimming methods, as shown in Figure 2. The PWM of the OLED display is similar to the PWM of the LCD display in terms of pixels, but is recognized as DC when viewed from a certain distance as in the actual use environment, as shown in Figure 13.

Generally, the viewing distance of smartphones is greater (mean = 33.95 cm, SD = 5.90 cm, range 19.0–51.3 cm) than that of the smartphones tested in this research [13,14]. Besides, as the PWM frequency increases with the development of technology, the effects on the human body of the flicker of OLED displays are expected to become more insignificant.

5. Conclusion

With the expansion of the use of LEDs for artificial lighting, several cases of its adverse human effects have been reported. The IEEE Standards PAR1789 group was established in 2008 to address these issues. In this paper, the effects on the human body of flicker caused by PWM dimming control of LEDs were described. Also, the difference between the PWM dimming of LCD displays and of OLED displays was explained. Finally, the effects of smartphone displays on the human body were evaluated through experiments. Since this study is about the OLED display that uses the PWM driving method, further research is needed on displays that use other driving techniques, such as TVs. The evaluation results of this paper are expected to be utilized for research in relevant fields as interest in the adverse health effects of OLED flicker increases due to the expansion of devices with OLED displays that use the PWM method.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Notes on contributor

Minhyuk Kim is a staff engineer at Samsung Display Co., Ltd. He obtained a B.S. degree in Electronic Engineering from Konkuk University in 2009 and a Ph.D. degree in Electrical and Computer Engineering from Seoul National University in 2017. Since he joined Samsung Display Co., Ltd., he has been working on the OLED display electronics development.
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References

[1] A.J. Wilkins, I. Nimmo-Smith, A.I. Slater, L. Bedocs, Lighting Res. Technol. 21 (1), 11 (1989).
[2] J. Davis, Y.H. Hsieh, and H.C. Lee, Sci. Rep. 5 (1), 1 (2015). doi:10.1038/srep07861.
[3] A. Wilkins, J. Veitch, and B. Lehman, Presented at the 2010 IEEE Energy Conversion Congress and Exposition, 2010 (unpublished).
[4] C.A. Bouroussis, E.D. Tsirbas, L. Canale, et al., Presented at the IECON 2020 The 46th Annual Conference of the IEEE Industrial Electronics Society, 2020 (unpublished).
[5] Ciprian Ionescu, Mihai Dima, and Detlef Bonfert, Presented at the 2016 IEEE 22nd International Symposium for Design and Technology in Electronic Packaging (SITME), 2016 (unpublished).
[6] OLED-info, https://www.oled-info.com/pulse-width-modulation-pwm-oled-displays
[7] REWA, https://blog.rewatechnology.com/one-harmful-eyes-oled-led/
[8] D.L. DiLaura and America Illuminating Engineering Society of North, The lighting handbook: reference and application, edited by Editor. (2011).
[9] J.D. Bullough, K. Sweater Hickcox, T.R. Klein, A. Lok, N. Narendran, Lighting Res. Technol. 44 (4), 477 (2012).
[10] J.E. Roberts, and A.J. Wilkins, Lighting Res. Technol. 45 (1), 124 (2013).
[11] M. Perz, I.M.L.C. Vogels, D. Sekulovski, L. Wang, Y. Tu, I.E.J. Heynderickx, Lighting Res. Technol. 47 (3), 281 (2015).
[12] B. Lehman, and A.J. Wilkins, IEEE Power Electron. Mag. 1 (3), 18 (2014). doi:10.1109/MPEL.2014.2330442.
[13] M. Rosenfield, M. Lan, and L. Liu, Invest. Ophthalmology Visual Sci. 58 (8), 5420 (2017).
[14] L. Boccardo, J. Optometry 14 (2), 120 (2020).