Auto-brightness control technology depending on user’s pupil area

Seung-Ryeol Kim and Seung-Woo Lee
Department of Information Display and Advanced Display Research Center, Kyung Hee University, 26, Kyungheedae-ro, Dongdaemun-gu, Seoul, 02447, Republic of Korea, 02447
a) seungwoolee@khu.ac.kr

Abstract: An ambient illuminance sensor of a mobile device does not always accurately measure the light that directly affects human perception of the display brightness. Thus, viewing high-luminance displays under low-light conditions causes an unbearable glare, while viewing low-luminance displays under bright-light conditions causes very poor visibility. In this paper, an automatic brightness control (ABC) technology depending on pupil area is proposed. The experimental results revealed that the pupil area decreases by 33% as the ambient illuminance increases tenfold. A linear relation was also observed between appropriate display luminance and logarithm of ambient illuminance in our previous investigation. As a result, the comfortable display luminance is proportional to the relative pupil area, which enables us to propose a novel ABC technology depending on the pupil area.

Keywords: pupil area, auto-brightness control, displays, vision, ambient illuminance, visibility

Classification: Circuits and modules for electronics display

References


1 Introduction

Recent mobile devices are increasingly employing sensors for user convenience such as acceleration sensors, gyro sensors, a proximity sensor, an ambient light sensor, cameras, etc. In addition, the displays for mobile applications feature higher image quality like higher resolution, higher pixel density, and vivid colors. As a result, such mobile displays with high performance require more electric power [1], which shortens the battery usage time. To resolve the inconvenience, an automatic brightness control (ABC) technology has been developed. People want the high performance of mobile devices, but want to use them for a long time without charging. The usage environment of mobile devices varies widely. It can be used during nighttime as well as at office, and also during bright sunny daytime. The purpose of ABC is to increase battery life. It is also intended to maintain the visibility of the display under various usage environments. In order to increase visibility in a very bright environment, the luminance of a display should be increased a lot. However, a display with high luminance consumes too much power and the battery will run down in a shorter time. Therefore, the maximum luminance of displays applied to mobile devices is very difficult to be higher. When we turn on our mobile device in a very dark environment, we have a lot of experience that it is too bright. Conventional ABCs are forced to operate within the operating luminance limits of the display. For this reason, the mobile devices with the ABC do not sufficiently satisfy the users. Some people choose brighter display or others dimmer display depending on individual preferences. Therefore, in order to overcome the limitations of the conventional ABC technology, various techniques for finding
the optimal luminance of the display under various circumstances have been studied [2, 3]. Many people may feel that their phone is too dark in front of an operating television (TV) in the same dark room. When they use their phone while lying down, they may perceive that the phone is too dark because of the ceiling lighting. Generally, an ambient light sensor is located at the front of the phone. Thus, the ABC reduces the brightness of the phone display because the ambient light sensor at the front of the phone cannot detect the light from the bright TV screen or ceiling lighting. Further, people’s pupil area is reduced due to the bright TV screen or ceiling lighting and as a result, the light passing through the pupil is also reduced. That’s why people perceive that their phone display is too dark. Thus, the conventional ABC needs to be improved more. It is important to accurately measure the amount of light affecting the brightness perception of people, rather than measuring the amount of light incident on the ambient light sensor. Generally, people’s pupil area is enlarged under dimmer conditions and diminished under brighter conditions [4]. The pupil area can be measured using the infrared (IR) light emitting diode (LED) and IR camera of the mobile phone. Since 2016, the mobile phones already have iris recognition. Compared to the complex pattern of iris, measuring the pupil area is a very simple process. The world renowned mobile phone manufacturer’s iris recognition camera has a resolution better than full high-definition (FHD) and a refresh rate of 30 frames per second (FPS). As I know, this company will also improve the resolution of the IR camera for next generation mobile phones. Therefore, it is expected that the measurement of the pupil area will become even easier. Thus, we propose a novel ABC technology depending on the user’s pupil area.

2 Experiment

2.1 Objective

![Graph showing appropriate luminance and performance of LCD and OLED devices vs. user's preference.]

Fig. 1. Measured ABC performance when applied to LCD and OLED devices vs. user’s preference.

Fig. 1 shows measurement results of conventional ABC technologies applied to commercially available mobile devices. We compared the ABC performance with
our previous research results on appropriate display luminance depending on ambient illuminance [2]. As shown in Fig. 1, the ABC applied to organic light emitting diode (OLED) device (open squares with solid line) shows a good match with our investigation. However, there is no other options for brighter screen conditions. People may perceive the OLED display seems dimmer if they prefer brighter screen. On the other hand, the ABC applied to liquid crystal display (LCD) device has more options to support various preference for display brightness. However, when the ABC with 100% is applied, the luminance does not change even though ambient illuminance changes, which cannot be called as ABC. When the ABC with 50% or 0%, the luminance changes only under the illuminance conditions from 200 lx to 1,000 lx. The ABC does not respond to ambient illuminance when the illuminance is beyond the condition. Various techniques have been proposed to improve the conventional ABC technology such as backlight control in the dark environment [5], color temperature adjustment under varying illuminants [6], and adaptive contrast for enhancing reading performance and visual comfort on smartphone displays [7]. A study has shown that visual performance of displays can be improved when the luminance or contrast ratio becomes higher [8]. In addition, there are studies on the image quality due to the reflection of the glass of the LCD top plate along with the ambient illuminance [9, 10]. However, a dynamic visual information processing task of LCD and OLED display can induce visual fatigue and both temporal and environmental factors affected visual load [11]. Therefore, it has been reported that viewing conditions, luminance, special physical environments, and visual artifacts should be considered for use of visual fatigue-free display [12]. It is reported that reflective displays are visually comfortable when used as a visual display terminal [13, 14].

As mentioned above, many studies have been made to improve ABC technology, which means the ABC is not a mature technology. The main purpose of our new ABC technology is to make the display more comfortable to watch and highly visible to users. As mentioned above, conventional ABC technology was lacking in many points. In particular, due to the position where the illuminance sensor is located, the ambient illuminance perceived by the user and the measured counterpart by the sensor are sometimes different. How can we accurately measure the ambient illuminance that directly affects human perception? The ambient illuminance sensor is mounted on the front of a mobile device in general. However, the ambient illuminance sensor should be near human eyes to accurately measure the amount of light entering them, but it is not possible realistically to do so. When the surroundings are bright or dark, the sensor of our body that perform a role of the ambient illuminance sensor is the pupil area. We know that the brighter the surrounding becomes, the smaller the pupil area is and the darker the surrounding, the larger the pupil area.

2.2 Experimental setup

The pupil areas of all the subjects have been measured under various light conditions. Ten college students participated in the experiment. The average age of the subjects was 25.4 years. The subjects had normal or corrected-to-normal visual acuity. During the experiment, the subjects were made to fix their heads on a
Their pupil areas were measured using an IR camera and IR LEDs under eight ambient light conditions as shown in Fig. 2(b). Using LED lamps as shown in Fig. 2(a), the eight-illuminance conditions were determined as shown in Table I.

Table 1. Illuminance levels used in the experiment.

<table>
<thead>
<tr>
<th>Illuminance (lx)</th>
<th>Illuminance (lx)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>200</td>
</tr>
<tr>
<td>4</td>
<td>500</td>
</tr>
<tr>
<td>5</td>
<td>1,000</td>
</tr>
<tr>
<td>6</td>
<td>2,000</td>
</tr>
<tr>
<td>7</td>
<td>5,000</td>
</tr>
<tr>
<td>8</td>
<td>10,000</td>
</tr>
</tbody>
</table>

Fig. 3. Photos of pupil (a) Under low-light condition. (b) Under high-light condition.
3 Experiment

3.1 Relative pupil area

After measuring the pupil areas of ten different subjects depending on ambient light conditions, we normalized the pupil areas to the maximum value of each subject measured at 50 lx. Fig. 4 shows the average values of relative pupil areas depending on ambient illuminance levels. As shown in Fig. 4, the average values of relative pupil areas had a linear relation with logarithms of ambient illuminance levels, i.e. $P \propto \log(I)$ where $P$ and $I$ are relative pupil area and ambient illuminance, respectively. We found that the pupil area decreased by 33% as the ambient illuminance increased tenfold.

3.2 Comfortable display luminance

Fig. 4. Average values of relative pupil areas depending on ambient illuminance (straight line: linear approximation).

After measuring the pupil areas of ten different subjects depending on ambient light conditions, we normalized the pupil areas to the maximum value of each subject measured at 50 lx. Fig. 4 shows the average values of relative pupil areas depending on ambient illuminance levels. As shown in Fig. 4, the average values of relative pupil areas had a linear relation with logarithms of ambient illuminance levels, i.e. $P \propto \log(I)$ where $P$ and $I$ are relative pupil area and ambient illuminance, respectively. We found that the pupil area decreased by 33% as the ambient illuminance increased tenfold.

Fig. 5. Luminance levels vs. ambient illuminance depending on comfort scores (dashed lines: linear approximations).
We measured the pupil areas and approximated it. The luminance-illuminance data depending on comfort scores from 1.6 to 2.4 is provided as shown in Fig. 5. The higher number in Fig. 5 represents the preference for brighter display screen. As shown in Fig. 5, the luminance levels had a linear relation with logarithms of ambient illuminance, i.e. \( L \propto \log(I) \) where \( L \) is the luminance of the display. These linear relations found in Figs. 4 and 5 can be expressed as follows:

\[
P = C_1 \times \log(I) + C_2. \\
P = C_3 \times \log(I) + C_4.
\]

In (1) and (2), \( C_1, C_2, C_3, \) and \( C_4 \) are coefficients. \( C_3 \) and \( C_4 \) are determined depending on the selected comfort score as shown in Fig. 5.

### 4 Proposed auto-brightness control depending on pupil area

As mentioned above, Fig. 4 shows that the average values of relative pupil areas have a linear relation with the logarithms of ambient illuminance. Fig. 5 shows that the appropriate luminance is proportional to the logarithm of the ambient illuminance. Thus, we can calculate an ambient illuminance level by measuring one’s pupil area by (1). Further, the ambient illuminance level calculated by (1) enables us to obtain an appropriate display luminance level by (2). This implies that it is possible to calculate appropriate luminance level depending on the pupil area. Therefore, we propose a novel ABC technique depending on pupil area, which can be implemented by the following equation:

\[
L = C_3 \times \frac{(P - C_2)}{C_1} + C_4.
\]

In Fig. 6, the short-dashed and dot-dash lines represent the calculated appropriate display luminance levels for comfort scores 2.0 and 1.6 respectively, calculated by our proposed ABC technology. If a user prefers a relatively darker display, the user may choose the comfort score 1.6 such as the dot-dash line in
Fig. 6. Some users prefer a brighter display depending on age, environment, etc. In this case, the users can brighten the luminance of display by selecting a comfort score higher than 2.0.

5 Conclusion

A novel ABC technology has been proposed depending on user’s pupil area. We believe that our technology will work well without any inconvenience even when the conventional ABC won’t. Furthermore, the appropriate combination of the proposed technique and the conventional ABC using ambient light sensor will ensure far better user experience effectively.

Acknowledgments

This work was supported by the ICT R&D program of MSIP/IITP [10041416, The core technology development of light and space adaptable energy-saving I/O platform for future advertising service], the Industrial Strategic Technology Development Program [10060207, Development of transparent screen and projection technology for day-time augmented display], and the BK21 Plus Program (Future-oriented innovative brain raising type, 21A20130000018), funded by the Ministry of Education (MOE, Korea) and the National Research Foundation of Korea (NRF).