Verification of the Minimum Illuminance for Comfortable Reading of an E-Paper

Takehito Kojima[1], Shunta Sano[1], Nobuhiro Ishio[2], Tatsuya Koizuka[3], and Masaru Miyao[1]

[1] Graduate School of Information Science, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8601, Japan
[2] Nagoya University Miyao Laboratory Collaborator, Japan
[3] School of Engineering, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8601, Japan
tkojima45@gmail.com, sano.shunta@c.mbox.nagoya-u.ac.jp, miyao@nagoya-u.jp, chemist21@yahoo.co.jp, tatsuya.koizuka@gmail.com

Abstract. Various e-paper devices also have been released (e.g. Amazon's Kindle DX™), and their features include paper-like display and low power consumption. In our previous studies, in high light conditions, readability of the backlight LCD dropped significantly, because of the glare of the surrounding background. On the other hand, the readability of the electronic paper is increased, it was easy to read than backlit LCD. The e-paper that have low contrast ratio, evaluation of readability was low. In low light, the evaluation of the readability of the backlit LCD was high. The aim of this experiment was to verify the minimum illumination for comfortable reading with e-paper in low illumination (300 or less lx).

Keywords: e-paper, backlight LCD, minimum illumination, readability evaluation.

1 Introduction

Recent advances in display technology have led to the introduction of a wide range of reading devices as alternatives to traditional paper made books. Various tablet devices with backlit LCDs have been released onto the market (e.g. iPad™ [1]). These devices have many functions and can be used to read documents. Various e-paper devices also have been released (e.g. Amazon's Kindle™ [2]), and their features include paper-like display and low power consumption. In 2012, new models equipped with an LED front light e-paper device and color e-paper were released. Thus, the choice of consumer e-book readers has further increased. One of the biggest differences between tablet devices and e-paper is the display system. Typical tablet devices, like the iPad, have mostly self-illuminating displays, while e-paper systems have reflective panels. However, the devices show different visibilities, partly affected by this difference in illumination. The general view is that under conditions of high illuminance,

C. Stephanidis and M. Antona (Eds.): UAHCI/HCII 2013, Part III, LNCS 8011, pp. 348–355, 2013.

the visibility of self-illuminating displays is poor. On the contrary, the visibility of reflective displays is as good as paper books under the same conditions. In this study, we carried out experiments with a reading test to evaluate the visibility of backlit LCDs and e-paper under various illuminance conditions. We used the Kindle DX and 300 dpi EPD (Electronic Paper Display) as e-paper devices and an iPad 2 as a backlit LCD device. For comparison, we also used conventional paper texts. In our previous study, self-luminous device under high illuminance, the readability is reduced by a significant reflection of the surrounding background. On the other hand, the evaluation of e-paper increased, it had become more than a backlight LCD. In low light, the readability assessment of self-luminous type LCD is high, however e-paper was lower rating. This is because the contrast ratio of the e-paper is low. Therefore, in this experiment we aimed to verify the practical allowable lower limit of environment illuminance for reading e-paper in low light (less than 300 lx).

2 Materials and Methods

For the experiment, we developed a presentation apparatus for use by the subjects in which the LED was the light source and illumination was increased in six steps (10, 20, 50, 100, 200, 300 lx). In addition, a diffusion board was installed under the light source to rectify the intensity luminous distribution. A board was set at an angle of 50 degrees inside the apparatus. The test media or test paper was mounted on the center of the board (Fig. 1, 2). The text displayed on each media was set at the same height. White Kent paper was affixed to the equipment and the object mounting board. Four types of media were used in the experiment: the e-paper devices were the Amazon Kindle DX and 300 dpi EPD; new iPad (back lit LCD); and a regular paper text as a control. The resolution of each medium was 150 dpi (monochrome 16 gradation) for the Kindle DX, 300 dpi (monochrome 2 value) for the 300 dpi EPD, 264 dpi (color, 256 gradation) for the new iPad, and 1,200 dpi (monochrome 2 value) for the paper text. In order to avoid any influence on the evaluation by the frame of each device, it was covered with white Kent paper and the subjects saw only the screen (Fig. 3).

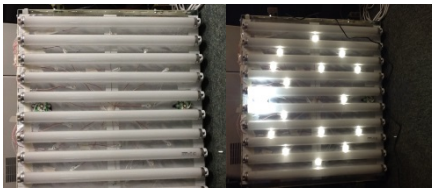

Fig. 1. Light source (left) D65 fluorescent lamp (right) FL lamp + LED

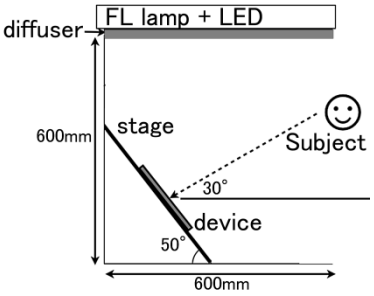

Fig. 2. Overview of the experiment

The experimental task was for the subject to read a text aloud as it was displayed on a device. There were 34 characters in Japanese per line and 13 lines in each text pas-sage. The font was 9-point Syuei Mincyo. The text color was black/dark and the background color was white/bright for screen polarity. The subjects were 130 people aged from 17 to 85 years old (average 46 years old). Subjects that needed glasses or contact lenses were allowed to use them in order to read as normal. The subjects were asked to read one line of text and the reading time and viewing distance between their eyes and the text was measured for the six illumination conditions of 10 to 300lx. After reading, the subjects subjectively evaluated the readability of the test device. The subjects rated readability as: (0): very hard (to read), (1): hard, (2): a little hard, (3): a little easy, (4): easy, and (5): very easy.

3 Results

3.1 Subjective Evaluations

Subjective evaluations in low light were higher in the order of the new iPad, paper, Kindle DX, and 300 dpi EPD. The 300 dpi EPD and Kindle DX were rated almost the same. The self-luminous new iPad had a nearly constant evaluation. On the other hand, the rating of e-paper and paper, which are reflection type media, dropped rapidly in light conditions less than 200 lx (Fig. 4).

3.2 Viewing Distance

The viewing distance with the iPad became longer as illumination decreased. On the other hand, the viewing distance with the three reflective type media decreased sharply with a low illuminance boundary of 50 lx. In addition, with illuminance between 10 lx and 50 lx the viewing distance with the paper was longer than with 300 dpi EPD, with illuminance between 50 lx and 100 lx the viewing distance was longer with 300 dpi EPD than with paper.

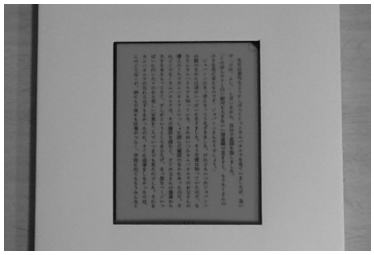

Fig. 3. bezel

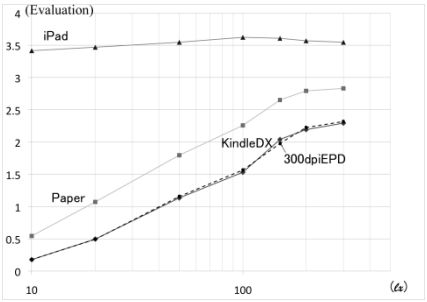

Fig. 4. Subjective evaluation

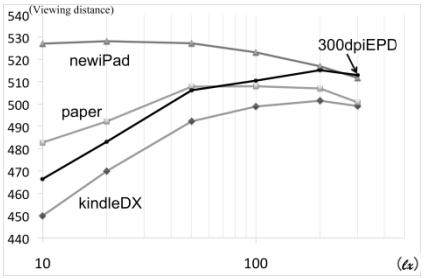

Fig. 5. Viewing distance

3.3 Contrast Ratio

With paper the contrast ratio decreases with low illuminance. Contrast ratio of KindleDX decreases with the decrease of illuminance. The case of 300dpiEPD, it rises with the decrease of illuminance. This is opposite to the paper. And, in most of illuminance, the contrast ratio is higher than KindleDX. The newiPad was set to maximize the brightness of the screen. Contrast ratio is very high compared to the other three models. Usually, the contrast ratio is reduced as environmental illuminance increases. Because with the increase of the light incident from outside, brightness of the black part also increases.

3.4 Subjective Evaluations by Age

Subjects were divided by age into a young group (up to age 43), middle-aged group (44-64 years), and advanced age group (65 years and older). Figures 6-8 shows the subjective evaluation by age. In all media, the highest Subjective evaluation of youth groups, and the second is middle-aged, advanced age was the lowest. From Figure 6-8, the results of the paper and the Kindle are very similar. However, the value of the evaluation of the paper is higher than KindleDX. Only the self-emitting iPad had nearly constant evaluations in all illuminance conditions.

3.5 Viewing Distance by Age

Figures 9-11 shows the viewing distance by age. In all media, the longest viewing distance is young groups, and the second is middle-aged, advanced age was the lowest. In addition, the viewing distance of advanced age was clearly shorter than the two other groups. The advanced age subjects wore glasses and so many subjects tended to have shorter viewing distances. The following is a reason for this. Lens accommodation power is weakened in the elderly due to the progression of presbyopia. In order to compensate for the lack of accommodative power due to the progression of presbyopia, the pupil is miosis Under high illuminance. As a result, the depth of field is deep. Thus, they can see the image without blur. However, under low illuminance conditions, miosis does not occur because the amount of light is insufficient with miosis of the pupil. So, viewing distance becomes short, because the subjects in order to close the face to the media in order to reliably read.

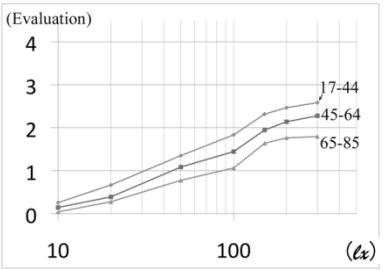

Fig. 6. Subjective evaluation (KindleDX)

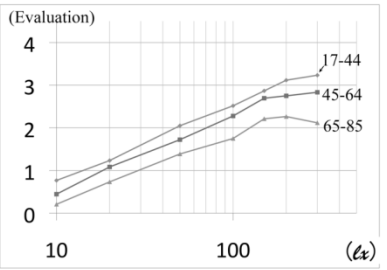

Fig. 7. Subjective evaluation (Paper)

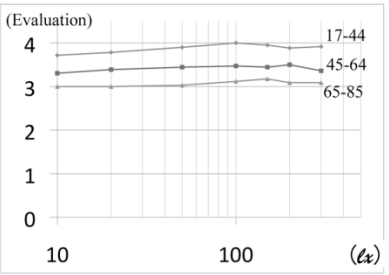

Fig. 8. Subjective evaluation (newiPad)

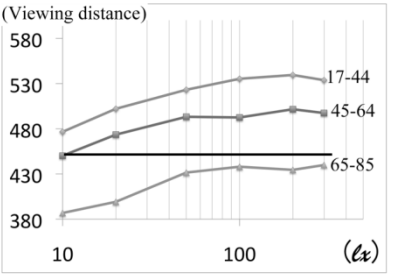

Fig. 9. Viewing distance (KindleDX)

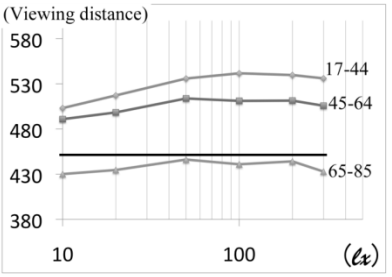

Fig. 10. Viewing distance (Paper)

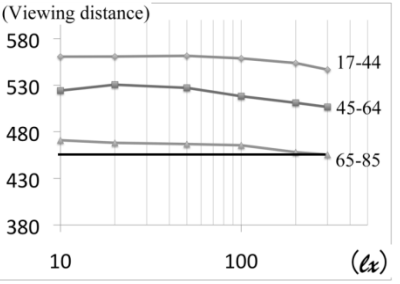

Fig. 11. Viewing distance (newiPad)

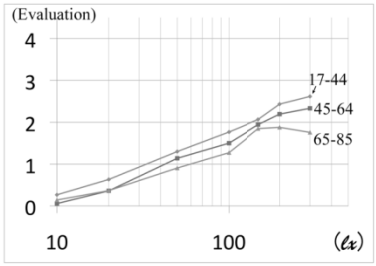

Fig. 12. Subjective evaluation (300dpiEPD)

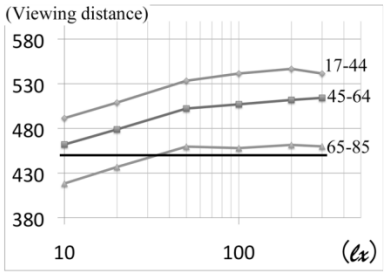

Fig. 13. Viewing distance (300dpiEPD)

Table 1. Contrast ratio

(lx)	10	20	50	100	200	300
KindleDX	8.24	8.64	9.07	9.22	9.76	9.27
300dpiEPD	12.48	10.83	10.88	10.63	9.63	10.13
newiPad	695.2	657.7	602.9	603.3	543.1	492.7
Paper	9.73	8.51	6.53	11.08	12.45	11.88

3.6 The Results of Device 300dpiEPD Device

Because it was a device of the experimental stage, is shown in this section separately from the other three models are 300dpiEPD (Fig.12-13). Subjective evaluation of graph (Fig.12) is very similar to (Fig.7) the results of the paper. Graph (Fig.13) is very similar (Fig.10) the results of the paper the viewing distance. However, the number, which is a low value of about 0.5 to 1 than paper. Then, compare different device (Fig.4.5). Viewing distance of at least 100 lx is the longest in the reflective device. Viewing distance of 300 lx is longer than the iPad. However, Subjective evaluation was lowest in the most of illuminance.

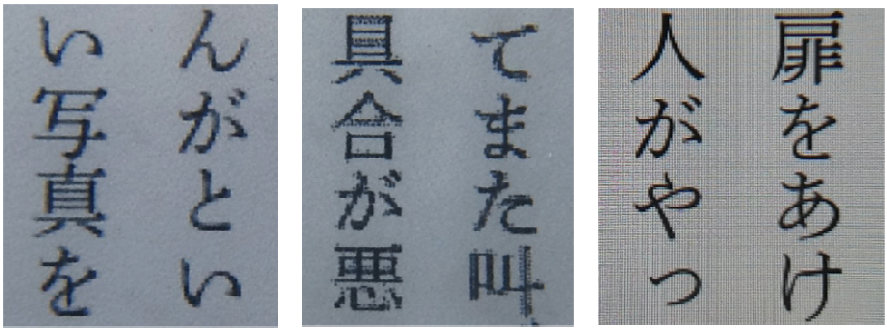

Fig. 14. Enlarged image of the display surface, (left) KindleDX, 150dpi, black-and-white tone 16, (center) 300dpiEPD, 300dpi, black-and-white two-tone, (right) newiPad, 216dpi, 256 color gradation

4 Discussion and Conclusion

In the evaluation of readability, the viewing distance is also used as an indicator. When subjects feel difficulty in reading text, it is known that they move closer to the text. Contrast ratio and resolution is also a factor in readability. In addition, we considered whether the anti-aliasing process to the characters to affect the subjective evaluation. The resolution of 300dpiEPD, there are two times of KindleDX. Further, viewing distance is longer than the paper in the illuminance of 50 lx or more. Because this device has higher contrast ratio than paper. However, subjective evaluation of readability is the lowest. There are two possible reasons. First, screen display is black and white binary, and anti-aliasing has not been done in the font. Second, (see enlarged view of Fig. 14) during the display of the file that has been introduced from the outside, there is a possibility that the image is degraded (the middle of Fig. 14).

The viewing distance became a little shorter with the iPad as the illuminance level increased. On the other hand, paper and e-paper showed a tendency for the viewing distance to become longer with increasing illumination. It is suggested that paper and e-paper had an advantage in bright illuminance environments. In the present experiment, we used six different illuminations (10, 20, 50, 100, 200, 300 lx). In dark environments the iPad obtained good readability ratings, which decreased with increasing illuminance. Conversely, evaluation of e-paper and paper was poor in dark environments, and improved with higher illuminance. Ultimately, , the viewing distance was similar with all the media used in this experiment at illuminance of 200-300 lx. Considering the results of the present experiment, 200 lx might be a critical illuminance point where more than one third of subjects evaluated ease of reading at 3 or higher. Furthermore, in the 200 lx environment the viewing distance for the e-paper was similar to the backlit LCD and the regular paper text. Thus, we consider the 200 lx illuminance level to be the minimum optimum limit for comfortable reading of e-paper. E-book readers equipped with LED front light have begun to be released. These readers can compensate for the disadvantages of e-paper in low light. In the future, it will be necessary to evaluate those products and compare them with conventional products.

Acknowledgements. This research was partially supported by JSPS Kakenhi (B) Number 24300046 and 23300032.

References

1. Apple - iPad 2, http://www.apple.com/ipad/
2. Amazon's Original Wireless Reading Device (1st generation) Kindle Store, http://www.amazon.com/gp/product/B000FI73MA
3. Isono, H., Takahashi, S., Takiguchi, Y., Yamada, C.: Comparison of Visual Fatigue from Reading Between Electronic Paper and Conventional Paper, The Institute of Electronics, Information and Communication Engineers, Technical Report of IECE. EID, 104(666), pp.9–12 (2005)

4. Lee, D.S., Yeh, Y.Y.: Visual fatigue for using electronic paper displays. OIT Journal 27, 105–114 (2007)
5. Kang, Y.Y., Wang, M.J.J., Lin, R.: Usability Evaluation of E-books. Displays 30, 49–52 (2009)
6. Omodani, M.: Electronic Paper(<Special Section>Flat Panel Displays). The Institute of Electronics, Information and Communication Engineers 88(8), 659–665 (2005)
7. Shen, I.-H., et al.: Lighting, font style, and polarity on visual performance and visual fatigue with electronic paper displays. Displays 30, 53–58 (2009)
8. Isono, H., Takahashi, S., Takiguchi, Y., Yamada, C.: Measurement of visual fatigue from reading on electronic paper. In: IDW 2004, pp. 1647–1648 (2004)
9. Lee, D.-S., et al.: Effect of character size and lighting on legibility of electronic papers. Displays 29, 10–17 (2008)
10. Shieh, K.K., Lee, D.-S.: Preferred viewing distance and screen angle of electronic paper displays. Applied Ergonomics 38, 601–608 (2007)
11. Lee, D.-S.: Effect of light source, ambient illumination, character size and interline spacing on visual performance and visual fatigue with electronic paper displays. Displays 32, 1–7 (2011)
12. Siegenthaler, E.: Reading on LCD vs e-Ink displays: effects on fatigue and visual strain. Ophthalmic & Physiological Optics 32, 367–374 (2012)
13. Dillon, A.: Reading from paper versus screens: a critical review of the empirical literature. Ergonomics 35(10), 1297–1326 (1992)