Ergonomic Evaluation of the Readability of High-Resolution 15-inch UXGA Format TFT-LCDs

Kenji Ido¹, Hisako Hayashi², Hiroaki Miyagi³ and Nozomu Harada⁴ (member)

Abstract High-resolution LCDs with large work information area are required for PC and monitor applications. However, the high resolution leads to finer lines and smaller size in characters. In order to investigate a relationship between LCD resolution and character readability, the authors performed an ergonomic evaluation of character readability using a 15-inch XGA TFT-LCD (86ppi) and UXGA TFT-LCD (133ppi). The results indicated that the 15-inch UXGA offered superior readability. Additionally, we were able to find some factors affecting character readability, including the balance of character size and stroke width.

Keywords: High-Resolution, Readability, Character Stroke Width, Character Size

1. Introduction

In recent years there has been a great expansion in the amount of content displayed on computer screens and similar displays. There is growing demand for high-resolution TFT-LCDs that have a large work information display area. In response to this demand, UXGA displays (with 1600×1200 pixels), which have more pixels than the widely used XGA displays (1024×768 pixels), are coming into use.

In the UXGA LCD, the number of pixels per unit of area is greater than that in XGA displays. As a result, a character with the same size as that displayed on an XGA display can be represented with smoother lines. However, when characters are displayed at a stroke width of one dot, the stroke width of the character becomes narrower relative to character size. In addition, if the font retains the same character format (i.e., the same number of pixels of a character), the character will actually be smaller on the display due to the reduced pixel size.

Fig.1 shows the characteristics of a character displayed on XGA and UXGA LCDs (both with the same screen size). Compared to XGA, stroke width on a UXGA display is only 65% as wide, and the character height is also reduced to only 65%. In terms of area, characters were reduced to 42% of their previous size.

There are many factors affecting character readability such as visual distance, display luminance, font design, illumination in addition to the LCD resolution. In this study, we focused to investigate the relationship between LCD resolution and character readability. Wright investigated the superiority of high resolution LCD from the viewpoint of how smaller characters can be expressed using 83ppi and 157ppi LCDs. Our study was performed to investigate the relationship between LCD resolution and the ease of character reading using several sizes of characters that were used in typical VDT work. As a
first step, we compared the character readability of a Japanese font as displayed with the currently available resolution of a 15-inch XGA-LCD (86ppi) and a high-resolution 15-inch UXGA-LCD (133ppi). In this paper each LCDs were reported as "XGA" and "UXGA" respectively. Additionally, we investigated how such factors as character size and stroke width affect readability.

2. Evaluation Method

2.1 Stimuli

Table 1 shows the lists of stimuli that we used in this evaluation. In total, we prepared 12 types of stimuli with varying sizes and pixel formats. We displayed a Japanese font (based on MS Gothic but adapted for our experiments) with character format ranging in height from 1.5mm to 4.4mm. We then conducted our experiments with a viewing distance of 400mm, which approximates a normal distance for viewing an ordinary notebook PC screen. The visual angles of the fonts are in a range from 13 to 38 arcmin. All characters are expressed with one-dot strokes. Fig.2 shows a sample of the sentence that we used in our experiments. We prepared two sentences as stimuli for evaluating character readability. Both were one line long. These sentences were each displayed to the subjects under the 12 sets of conditions listed in Table 1 in random order. We displayed black text on a white background, and set the display luminance to approximately 110cd/m² for the white portions and approximately 3cd/m² for the black portions.

2.2 Subjective Evaluation

Fig.3 shows the evaluation scale for the various subjective evaluation categories. "Readability" was defined as an overall evaluation of the ease of reading of a character. Subjects were asked to evaluate character readability assuming the characters on the notebook PC screen. In addition to the readability evaluation, we also evaluated such four factors of readability as the suitability of character size, the suitability of character stroke width, the jaggedness of the characters, and the sharpness of the characters. "Suitability of character size" was defined as the size appropriateness for the characters displayed on the LCD. "Suitability of character stroke width" was defined as the appropriateness of the stroke width for the size of the character. "Jaggedness" was defined as the degree of whether the jaggedness of the character was noticeable or not. "Sharpness" was defined as the overall index of finesse of character design, beauty or goodness of character design, and so on.

2.3 Test Environment and Subjects

Fig.4 shows the test setup. The test subject would turn to face the UXGA and XGA panels on the left and right as instructed by the test supervisor and would then evaluate the display. Chin rest was used to fix the viewing distance at 400mm. The displays were at an angle of about 80° to each other. Illumination was set to approximately 500 lx on the table plane. The test subject held a board on which the scales of subjective evaluations were

<table>
<thead>
<tr>
<th>Character Height (mm)</th>
<th>Visual Angle at 400mm Distance (arcmin)</th>
<th>Character Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>13</td>
<td>XGA 8×8</td>
</tr>
<tr>
<td>1.7</td>
<td>15</td>
<td>XGA 9×9</td>
</tr>
<tr>
<td>2.3</td>
<td>20</td>
<td>UXGA 8×8</td>
</tr>
<tr>
<td>2.7</td>
<td>23</td>
<td>UXGA 9×9</td>
</tr>
<tr>
<td>3.2</td>
<td>28</td>
<td>UXGA 11×11</td>
</tr>
<tr>
<td>3.8</td>
<td>33</td>
<td>UXGA 13×13</td>
</tr>
<tr>
<td>4.4</td>
<td>38</td>
<td>UXGA 15×15</td>
</tr>
</tbody>
</table>
written. The test subjects reported their evaluation score orally.

A total of 39 subjects participated, including 26 males and 13 females. The subjects were in their twenties and thirties and had sufficient eyesight (at least 0.7 for each eye, with correction allowed.)

3. Results

3.1 Readability

Fig. 5 shows a comparison of the readability of the XGA LCD and the UXGA LCD.

To investigate the difference of readability between XGA and UXGA statistically, subjective evaluation data were analyzed using one-factor ANOVA. In the Japan Industrial Standards (JIS), the minimum recommended size for Japanese text for VDT work is defined as 25 arcmin. If readability is not very important in the course of work, text of even smaller sizes may be used. In a survey conducted by Kubota et al., it was found that the most commonly used character height among notebook PC users was 3.5mm. At a viewing distance of 400mm, this produces a visual angle of approximately 30 arcmin. Based on these findings, we can expect that the most common character sizes used in typical VDTs have a visual angle ranging from 20 to 30 arcmin. In these experiments, the character heights that produced a visual angle in the range from 20 to 30 arcmin were 2.3mm, 2.7mm, and 3.2mm. In this range, Fisher's post hoc test showed that character readability of UXGA were significantly higher than that of XGA (p<0.05) regardless of the fact that the stroke width of characters is thinner. However, there was a tendency that the larger the character, the smaller the difference was between the evaluation of same-size characters in UXGA and XGA. At a visual angle of 38 arcmin, the evaluation scores crossed over for the UXGA 23x23 and XGA 15x15, meaning that from this point XGA is more readable (p<0.05). The reason is thought to be because the stroke width has become too narrow for the character size. This is discussed in more detail in the results for "Suitability of character stroke width."

Line A in Fig. 5 shows the comparison of the XGA 11x11 and UXGA 12x12, which got nearly the same evaluation. Generally, in work involving the writing of e-mail or other documents, the most commonly used character format of Japanese fonts is approximately 11×11 pixels. When we compared the readability of an 11×11 font on an XGA display with that of a 12×12 font on a UXGA display (character height : 1 : 0.72), we did not find any significant differences in the evaluations of readability. This means that UXGA provides sufficient readability even if the characters appear to be slightly smaller. Therefore it is possible to operate a greater amount of readable information on the screen. Based on the results that we obtained with the 11×11 font on an XGA display and the 12×12 font on a UXGA display, we can calculate that the UXGA display can display 1.96 times as many characters as the XGA display while maintaining the same readability.

3.2 Sharpness

Fig. 6 shows a subjective evaluation of the XGA LCD.
and UXGA LCD for the sharpness of the characters. As shown in this figure, UXGA LCD has a better sharpness evaluation than does the XGA LCD. If we focus in on the range of visual angles from 20 arcmin to 30 arcmin that is typical in VDT work, the XGA display is evaluated as poor, while the UXGA is found to produce sharp characters. The better sharpness of the UXGA LCD leads to the higher character readability.

3.3 Jaggedness

Fig. 7 shows the results of the jaggedness evaluation. These results clearly demonstrate that a finer dot pitch results in a higher evaluation regarding jaggedness. If we focus in on the range of visual angles from 20 to 30 arcmin, jaggedness of the XGA is evaluated as "Noticeable" or "Slightly noticeable." On the other hand, jaggedness of the UXGA was evaluated around "Hardly noticeable." In Kubota's research, the jaggedness of characters at about 150ppi was evaluated as "Visable but not noticeable." Based on these results, the 133ppi (of the resolution of 15-inch UXGA) was thought to be enough resolution in terms of "Noticeable" instead of whether the jaggedness is visible or not.

3.4 Suitability of Character Stroke Width

Fig.8 shows the results of the suitability of character stroke width. Characters displayed on the UXGA display were evaluated as being sharp and easily read. But they were also evaluated as having thin character stroke width for the character size, and the trend was more pronounced for larger visual angles. On the other hand, evaluation of XGA LCD was "Suitable" for large characters. Looking at the readability results (Fig.5), the evaluations of UXGA and XGA cross each other when the character has a visual angle of 38 arcmin. These results were caused by the difference of suitability of character stroke width. At 133ppi, the one-dot stroke width was too thin for larger characters.

LCDs definitely improve character readability. However, because most current Japanese fonts are designed for display devices with a resolution of 100ppi or less, problems arise when those fonts are displayed without modification on a high-resolution TFT-LCD, since those fonts will appear smaller and will have thin stroke widths. We can expect further improvements in character readability by developing of fonts, operating systems, and applications that are suited to the characteristics of high-resolution TFT-LCDs.

3.5 Suitability of Character Size

Fig.9 shows the results for "Suitability of Character Size." Suitability of character size of UXGA was evaluated slightly larger than that of XGA at visual angle of 20 and 23 arcmin though the character sizes were same for both LCD. It may be explained that as the resolution increased, the "space" among strokes making up the characters got larger and this is one reason the characters appeared larger overall. Or, it may be explained, there may be a tendency to think that characters are "larger" when they are simply easier to read. Characters evaluated as "suitable" were those displayed at a viewing angle of 33 arcmin. At the some sizes of characters that were considered smaller than "suitable", the characters displayed on UXGA tend to be evaluated larger than those on XGA.

Fig. 7 Results of Evaluation of Jaggedness.

Fig. 8 Results of Evaluation of Suitability of Character Stroke Width.

Fig. 9 Results of Evaluation of Suitability of Character Size.

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4. Discussion

Under the conditions of this experiment, the data from this experiment indicate the superior character readability of 15-inch UXGA (133ppi). These results provide some directions for font selection and character design for designers of fonts, GUIs, Web pages, etc.

If the subjects in our study had been elderly people with poorer eyesight, it is possible that character size and stroke width would have been major negative factors influencing readability. Data from this experiment should only be used with sufficient consideration of the target user. In the future, investigations should be performed of differences in readability caused by differences in age and eyesight of the subjects.

The present study examined only one-dot-stroke fonts. As a result, the Readability evaluation decreased for reasons of stroke thickness in larger characters. It is necessary to display two-dot-stroke characters in order to avoid a mismatch of stroke width with these character sizes. Because two-dot stroke fonts require many more pixels, higher-resolution displays will be needed to display more readable characters. However, increasing pixel density is a factor making characters smaller. Future research must study the relationship between resolution and appropriate stroke width.

This experiment showed the overall superior character readability of 15-inch UXGA (133ppi). Some of the results, however, showed that when character size and stroke width are mismatched, it has a negative impact on character readability. This mismatch occurs when the display resolution is changed, because today’s fonts were made for displays of about 100ppi. With high-resolution LCDs, achieving greater character readability will require designing characters suited to the degree of resolution of the display and developing applications and operating systems capable of controlling these.

5. Conclusion

High-resolution LCDs with large work information area is advantageous than conventional LCDs. However, the effects of the accompanying narrowing of stroke width in characters and the smaller character sizes were previously unclear. Using an ergonomic method, we found that the finer and smaller characters on the 15-inch UXGA format (133ppi) high-resolution LCD provide sufficient readability. We think this result will contribute to the development of higher resolution TFT-LCDs. Also, we expect software, control devices, content, and fonts that take full advantage of the benefits of high-resolution LCDs to be developed in the future. This will lead to the production of more attractive products for users.

6. Acknowledgement

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