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Visual Costs of the Inhomogeneity of Luminance and Contrast by Viewing LCD-TFT Screens Off-Axis

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In this study the anisotropic characteristics of TFT-LCD (Thin-Film-Transistor-Liquid Crystal Display) screens were examined. Anisotropy occurs as the distribution of luminance and contrast changes over the screen surface due to different viewing angles. On the basis of detailed photometric measurements the detection performance in a visual reaction task was measured in different viewing conditions. Viewing angle (0°, frontal view; 30°, off-axis; 50°, off-axis) as well as ambient lighting (a dark or illuminated room) were varied. Reaction times and accuracy of detection performance were recorded. Results showed TFT's anisotropy to be a crucial factor deteriorating performance. With an increasing viewing angle performance decreased. It is concluded that TFT's anisotropy is a limiting factor for overall suitability and usefulness of this new display technology.

TFT-LCD   anisotropic characteristics   viewing angle
visual performance   luminance   contrast   off-axis

1. INTRODUCTION

Over the last 2 years, screen industry has been shown to produce an enormous emendation regarding the quality of electronic displays. The Cathode Ray Tube (CRT), the screen type hitherto widely spread, seems to be a phase-

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out model due to some negative visual characteristics. Most prominent here is the CRT flicker arising from intermittent lighting stimulation (refresh rates). Several ergonomic studies were concerned with the effects of CRT flicker by showing that visual performance is distinctly inferior when using a CRT as compared to flicker-free reading displays (e.g., Menozzi, Näpflin, & Krueger, 1999; Ziefle, 2001a, b, c, 2002). The development of the TFT-LCD (Thin-Film-Transistor-Liquid Crystal Display) technology was therefore highly welcome: TFT screens, lightweight and flat, run flicker-free and display information at much higher levels of luminance and contrast.

However, one major draw back in TFT screens has not been sufficiently examined up to now. As TFT-LCD users experience rather often, the displayed information is perfectly visible if the user works in front of the screen, processing centrally displayed information. Whenever this optimal position is not possible, the visibility of the displayed information is distinctly worse. This property of TFT screens is called anisotropy[1] and refers to the change of photometric variables with increasing viewing angle. Working situations in which anisotropy plays a crucial role are rather common: Contrast and luminance already decrease, if users, centrally positioned in front of the display, are looking at areas towards the screen edges. In addition, anisotropy is naturally present at extended viewing angles. In many (air, rail) traffic controlling environments or stock exchanges several screens (set in parallel or one upon another) have to be surveyed by one person. Moreover, for example, in the schooling context it is quite usual that several users work in front of one screen.

Per contra to the fairly frequent occurrence of work environments confronted with anisotropy and the deterioration of visibility, astonishingly few ergonomic studies were concerned with the anisotropic effects in TFT displays (Groeger, Ziefle, & Sommer, 2003; Hollands, Cassidy, McFadden, & Boothby, 2001; Hollands, McFadden, Cassidy, & Boothby, 2000). Possibly, the reason for this lies in the fact that users working on-screen feel less disturbed by an inhomogeneous lighting than by the screen flicker that is perceptually more prominent.

Hollands and colleagues (2000, 2001) compared the visual performance of TFT and CRT with regard to anisotropy. In a visual reaction task, bright colored symbols had to be detected on a dark background (negative screen polarity). Assessing anisotropic effects, a frontal view on the display (0°) and

[1] According to the International Organization for Standardization (ISO), a display is called anisotropic if it shows a deviation of more than 10% of its luminance subject to target location or viewing angle (Standard No. ISO 13406-2:2001; ISO, 2001).

an extended viewing angle of 60° were adopted. The results showed a CRT advantage over the TFT in the off-axis viewing condition, proving anisotropy to deteriorate visual performance in TFT screens. Some methodological limitations however weaken the explanatory power of the studies. First, the off-axis viewing angle (60°) is relatively extreme, and one should know if anisotropic effects can be also found at smaller viewing angles. Second, luminance and contrast measurements and their fluctuations over the screen are not given. Thus, it is unclear what is responsible for the lower performance: the distribution of luminance values (bright-dark) or the contrast due to different screen locations or both. Third, a minor problem, screens displayed in negative polarities are rather uncommon in today's workplaces and it seems reasonable to quantify anisotropic effects in real working situations first.

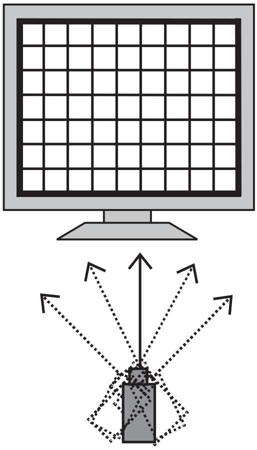

Figure 1. A user view measurement (Groeger et al., 2003).

A first attempt providing for a detailed insight into the nature of anisotropy (including photometric measurements) was undertaken in our workgroup (Groeger et al., 2003). To quantify the change of photometric measures at different viewing angles, a measurement setup was developed enabling to exactly correlate photometric measures and visual performance. The screen was virtually cut into 63 fields and luminances of bright-dark areas were individually measured and contrasts were determined. The experimental procedure followed a quite conservative approach. First, it was tested if anisotropy could be proven at all when users were turning the view to all screen positions. Thus, as measuring and viewing condition, the "user view" was realized (Figure 1): The photometer (and the user) was positioned centrally in front of the screen. As the position of the photometer (and the user) did not change within the user view, viewing angles increased with distance from the center of the screen thereby emulating users' head movements when looking towards the screen edges. A visual search task had to be completed with the targets appearing randomly in each of the 63 fields previously measured. Reaction times and accuracy were recorded and related to photometric values. The results corroborated that anisotropic properties of TFT screens should not be underestimated. Detection performance was significantly worse depending on the change of photometric measures over the screen surface (even if no extended off-axis condition was present). Answering the question which of the photometric measures is responsible for the performance drop, the level of background luminance was proven to be the crucial factor affecting visual performance. Though commonly assumed, the contrast of the display did not play a substantial role accounting for performance decrements due to TFT's anisotropy.

The present study aims at examining effects of anisotropy at extended viewing angles. Users completed a visual detection task displayed in positive polarity at three viewing angles (0, 30, 50°). In order to learn if ambient lighting is a crucial factor possibly interacting with effects of anisotropy in TFT screens, the task was completed in a dark and an illuminated room. It was furthermore of interest which of the photometric measures accounts mainly for performance differences.

2. METHOD

2.1. Experimental Variables

Three independent variables were examined: The viewing angle was varied in three steps, 0, 30, 50°; the viewing position in two steps, users were viewing from the right or the left side onto the screen; ambient lighting in two steps, the room was illuminated with 300 lx or remained dark.

Dependent variables were the speed (reaction times) and accuracy (percentage correct) of detection performance.

2.2. The Experimental Screen

As experimental screen, a TFT-LCD (LG Philips LG 577H, 1024 × 768, 15", TN [Twisted Nematic]) was used. This screen disposes of a comparatively "small" amount of anisotropy as compared to a series of other screens measured in our laboratory. Choosing this screen, a rather strict test procedure of anisotropy effects was pursued. As a baseline for the different photometric measurements, the screen luminance was adjusted to 100 cd/m^2 in the central field of the display.

2.3. Physical and Photometric Measurements

In order to quantify the change of photometric measures depending on the different viewing angles, the display was divided into 63 (9 lines × 7 rows) virtual fields (Figure 2). For each field the luminance of dark and bright areas were measured by a photometer (Bruel & Kjær, Denmark) and the contrast was determined.

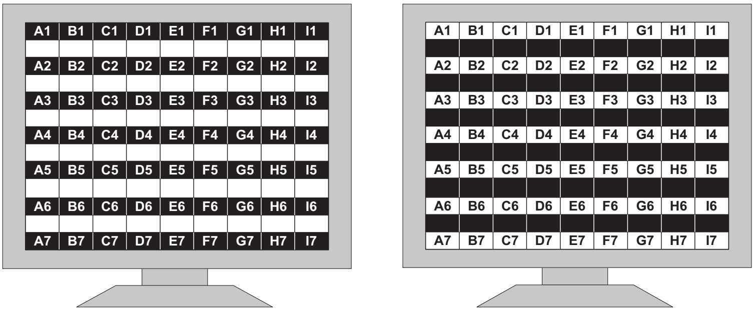

Figure 2. The measurement setup. Two screens were necessary as each screen position had to be measured in a dark and a bright version.

Two measurements were realized. On the one hand, the "standard view" was applied, commonly used by the industry. The photometer was set in front of the screen (60 cm) and displaced gradually from field to field, with the photometer always at right angles with the screen (Figure 3, left). This procedure is highly artificial though, as users do not displace themselves, but turn the view. Viewing angles change remarkably depending on where users are looking at, which is entirely disregarded using this measurement. In order to simulate real viewing conditions, the "bystander view" was realized (Figure 3, right). The photometer was set to a central point of the display and turned to the different measuring fields (0°). For the 30 and 50° conditions, the photometer was set off-axis, and its view pointed to the screen surface from aside (left and right side, respectively). The realization of the off-axis conditions can be done in two ways. If the screen is turned, luminance measures change another time due to reverberation effects, therefore participants were displaced 30 and 50° off-axis at a distance of 60 cm.

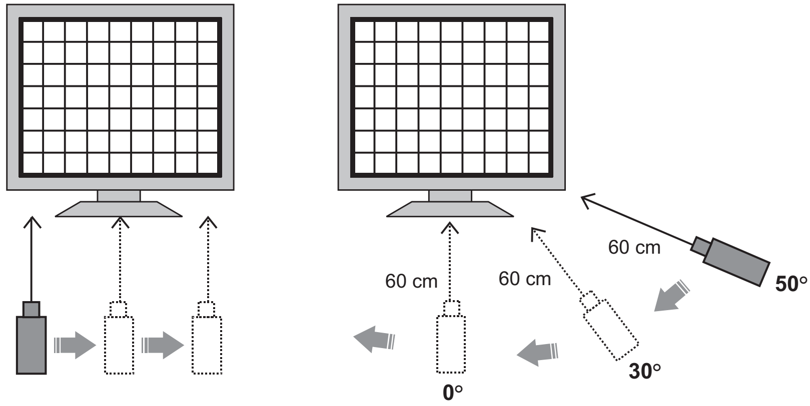

Figure 3. Left: A standard view measurement, with the photometer displaced at right angles. Right: A bystander view, with the photometer positioned off-axis.

The outcomes in photometric measures can be seen in Figure 4. Left, representing the standard view, luminance values of bright areas are visualized, remaining rather constant at about 100 cd/m^2. What is disregarded by this measurement though is that photometric measures (i.e., luminance of bright areas and contrast) change as a function of the viewing angle in TFT-LCDs.

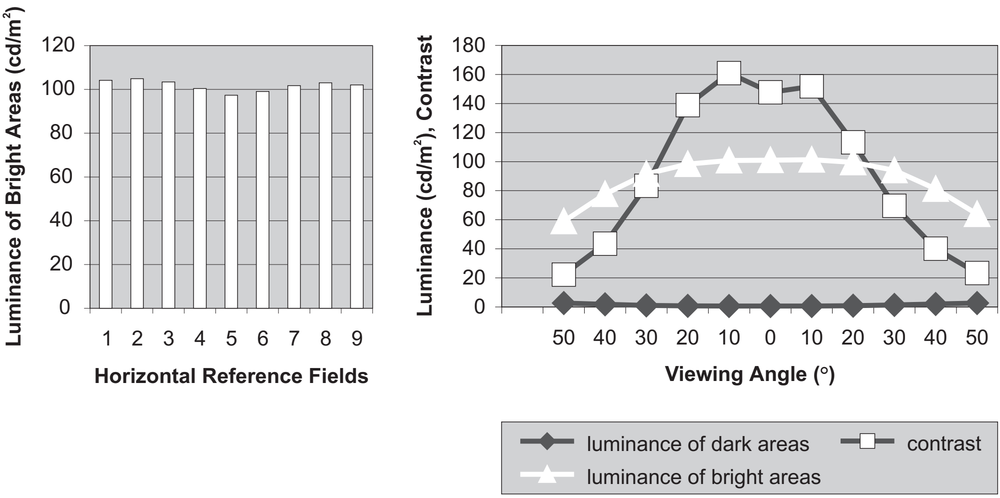

Figure 4. Left: A standard view the 63 luminance values (averaged over vertical rows). Right: A bystander view with luminance values (dark-bright) and contrast due to different viewing angles.

And this was exactly found using the bystander view (Figure 4, right). As can be seen there, there is a distinct drop within luminance of bright areas as well as contrast (dropping to only 1:20 at 50° off-axis).

2.4. Experimental Task

As an experimental task, quadratic Landolt Cs (with the gap oriented upwards, downwards, left, and right) were displayed randomly on all 63 screen fields (Figure 5). Participants had to detect the orientation of the gap and to indicate it by pressing an appropriate key on a pad specifically built for experimental purposes. The target's height and width subtended 8 pixels (2.4 mm), the stroke width 1 pixel (0.3 mm), and the gap 2 pixels (0.6 mm). Participants were instructed to work fast and accurate.

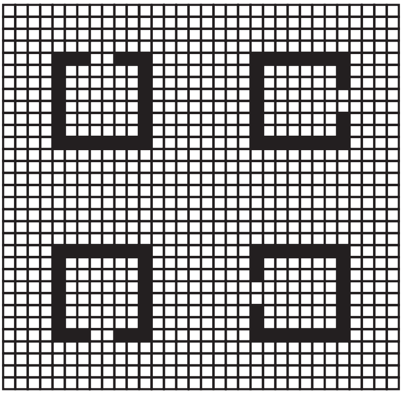

Figure 5. Quadratic Landolt Cs with the gaps in the four different orientations.

2.5. Participants

Twenty-four participants (14 male and 10 female students of different academic fields) took part in the experiment. Participants were between 20 and 29 years (*M* = 23), with above-average visual acuity (*m* = 1.28, checked with a TITMUS, USA, tester).

2.6. Procedure

The factor viewing position was treated as a between subject variable, thus 12 participants looked onto the screen from the right and another 12 from the left side off-axis, though all completed the task in the central condition (0°). The factors viewing angle and ambient lighting were within subject variables, thus all accomplished the three viewing angles in a dark and a bright room. In total, 1512 trials (randomly assigned) were completed. In the beginning, 50 training trials were carried out to familiarize participants with the procedure.

3. RESULTS

Results were analyzed via analyses of variances for repeated measurements. The level of significance was set at $p < .05$. As only very few errors occurred at all (mean accuracy was at 99.62%), only correct responses were considered for further analyzing. In the following, the results for reaction times were described with respect to the three independent variables.

Viewing position. No significant effect on reaction times was found due to viewers' position. Independently from which side they were looking at the screen, reaction times were equal.

Ambient lighting. No difference in reaction times was found depending on whether the room was illuminated (300 lx) or remained dark. A closer look into photometric outcomes (Table 1) shows why.

TABLE 1. Luminance and Contrast Depending on Room Lighting and Viewing Angle

	Viewing Angle					
	0°		30°		50°	
Luminance and Contrast	Dark	Bright	Dark	Bright	Dark	Bright
Luminance of bright areas (cd/m^2)	100.4	101.1	92.2	93.2	66.5	67.7
Luminance of dark areas (cd/m^2)	0.99	1.5	1.7	2.6	3.3	4.2
Contrast	101	67	54	36	20	17

Notes. dark—dark ambient lighting, bright—bright ambient lighting.

As can be seen from Table 1, ambient lighting did not affect luminance values of the bright, but of the dark areas. Relatively, characters are less dark in a bright surrounding. The contrast, the ratio out of the two, is analogically decreased by ambient lighting. Apparently, performance does not follow the contrast, but the background luminance.

Viewing angle. As expected, the viewing angle significantly increased, $F(2, 46) = 10.33$, $p < .05$, reaction times (Figure 6). Whereas participants needed on average about 430 ms to detect the gap's orientation in the Landolt C, it took 460 ms at a viewing angle of 50° off-axis.

Hence, visual performance decreased with increasing viewing angle. What can be also seen is the close accordance of background luminance and detection performance. The less bright the background, the higher are reaction times.

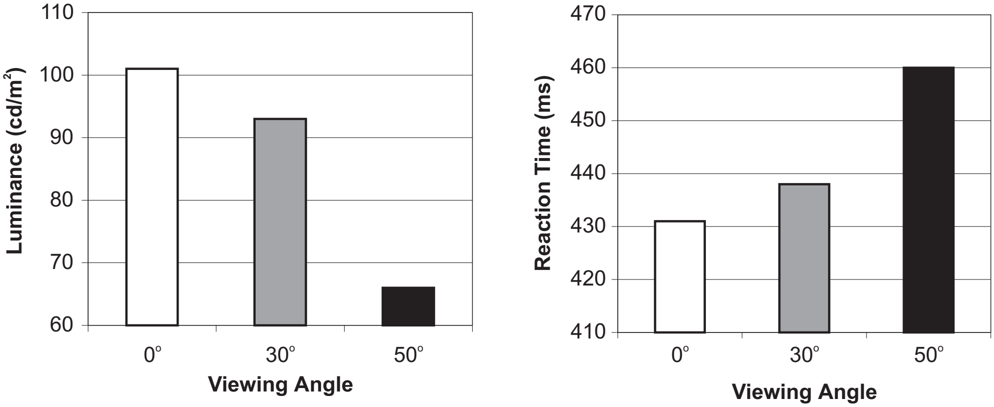

Figure 6. Left: Luminance of bright areas (background). Right: Detection performance (reaction times) due to viewing angle.

4. DISCUSSION

This study aimed at examining TFT's anisotropy on detection performance. In order to determine the correspondence of photometry and visual performance, the fluctuation of the luminance of bright and dark areas as well as contrasts over the screen surface were measured in detail. Then, visual performance was quantified by using three viewing angles of different extent. The task was performed in a dark and in an illuminated surrounding proving if ambient lighting interacts with anisotropic effects by changing photometric variables.

The outcomes can be comprised as follows. First, anisotropic effects are not only present at extended viewing angles of 60°, as was already shown by Hollands et al. (2000, 2001), they are also present at smaller viewing angles (30, 50°) as examined here. Thus, the change of photometric measures has shown to significantly decrease visual performance. However, anisotropy is not only present in off-axis conditions. In a very recent study (Groeger et al., 2003), effects of anisotropy were also measurable if no extended viewing angle was adopted, but if users turned their view towards the screen edges, as they usually do if information, displayed at all possible locations on the screen, is looked at.

A second point relates to the question which of the photometric measures accounts for the performance drop. In general, different standpoints are possible. On the one hand the contrast can be regarded as the most powerful photometric source. However, the contrast, always a ratio out of two luminance values, does not reflect absolute levels of luminance. On the other hand, the luminance of the background can be regarded as the critical factor as it accounts for an optimization of the eyes adaptation level (e.g., Johnson, & Casson, 1995). The present results suggest the latter assumption to be correct, as detection performance was shown to be in close accordance with the luminance of bright areas and not with the contrast. This outcome replicates results previously found: Groeger et al. (2003) showed the photometric measures to be significantly correlated only with the luminance of the background (bright areas). Neither the contrast nor character luminance accounted for performance differences.

What conclusion can be drawn from these findings? On the basis of the present results, anisotropy must be regarded as a major handicap of the TFT-LCD technology. The fluctuations of light depending on different viewing angles were shown to negatively affect visual performance. Thus, in working environments in which a fast and accurate visual detection performance is of vital importance, the suitability of this new display technology seems to be limited.

Future studies will have to enlighten additional visual factors possibly interacting with anisotropic effects. It will have to be proven, if negative screen polarities or specific color combinations of characters and screen backgrounds may reduce anisotropic effects. Moreover, more cognitive and less visual demanding tasks than used here will have to be applied. Further on, anisotropic effects should be examined with older users representing the real situation in the workforce.

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