A New Angle on Cheap LCDs: Making Positive Use of Optical Distortion

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ABSTRACT
Most LCD screens exhibit color distortions when viewed at oblique angles. Engineers have invested significant time and resources to alleviate this effect. However, the massive manufacturing base, as well as millions of in-the-wild monitors, means this effect will be common for many years to come. We take an opposite stance, embracing these optical peculiarities, and consider how they can be used in productive ways. This paper discusses how a special palette of colors can yield visual elements that are invisible when viewed straight-on, but visible at oblique angles. In essence, this allows conventional, unmodified LCD screens to output two images simultaneously – a feature normally only available in far more complex setups. We enumerate several applications that could take advantage of this ability.

ACM Classification: H.5.2 [Information interfaces and presentation]: User Interfaces - Graphical user interfaces, screen design. B.4.2 [Input/Output and Data Communications]: Input/Output Devices - Image Display.

General Terms: Human Factors.

Keywords: Displays, dual output, multiuser, privacy.

INTRODUCTION
When viewing LCD monitors from an oblique angle, it is not uncommon to witness a dramatic color shift. Occasionally, this can appear as a total color inversion. Although hues can shift, there are also complex interactions that affect saturation and luminance, causing, for example, light shades to become dark [2,7]. This is primarily caused by a polarization asymmetry, where light rays passing through the pixel matrix at oblique angles are influenced by the relative orientation of the liquid crystal (see Figure 1 and [7], chapter 6).

Engineers and designers have sought to reduce these effects for more than two decades. This effort has been further driven by the popularity of LCD televisions, which have viewers located at wider angles than seen in typical computing setups. This has led to the emergence of more advanced LCD technologies, such as In-Plane Switching (IPS) and Vertical Alignment (VA) screens, which have superior field of view [2]. However, this benefit comes with a higher price tag, slower refresh rate, and increased power consumption.

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Most of the LCD screens manufactured today are of the Twisted Nematic (TN) variety. Although more susceptible to color distortion, the technology has superior response times and is inexpensive. For most uses, the color distortion (and in general, poorer color reproduction) is acceptable to consumers. The installed manufacturing capacity is enormous, and is unlikely to evolve at a dramatic rate due to the huge costs in shifting production to a new technology.

CONCEPT
Rather than fight against the optical effects found in TN LCD screens, we embrace them. In particular, we take advantage of the fact that very light colors are almost indiscernible from white when viewed straight-on, but dramatically darken at oblique angles. This effect allows the LCD panel to output two images at once: one that is visible from conventional viewing angles (i.e., <30° from perpendicular) and another from oblique angles (>30° off perpendicular).

This ability has a similar flavor to that of much more advanced and expensive multi-output display technologies. These include lenticular and parallax barrier displays [9,11], shutter glasses [1,12], polarized glasses [10], switchable diffusers [5], retro-reflective surfaces [4], and highly engineered optical films [8,13]. An alternate approach is to use movable, spatially aware displays [3] to present different information depending on how the screen is positioned (e.g., a shared screen that can be tilted towards one user or another, and present different information accordingly [6]).

Without such special hardware to tightly control aspects, such as viewing angle and color reproduction, advanced techniques (e.g. stereoscopy) are not possible. However, with careful design, we believe there are numerous applications where the distortion can be put to productive use. These new abilities are essentially free, require no modification to LCD screens, and could be provided with little more than a software update.

AXIS OF USE
LCD screens tend to be viewed at more diverse angles along the horizontal axis; it is far less common to view screens from steep downward or upward angle. This is primarily because we sit or stand at fairly uniform heights, but our position in the room can change. When there are multiple viewers, as might be seen in a conference or living room, they also tend to be spread out along the horizontal axis. In response, LCD manufacturers have attempted to minimize color distortion primarily in the horizontal axis. High quality TN screens show almost no color variance from side to

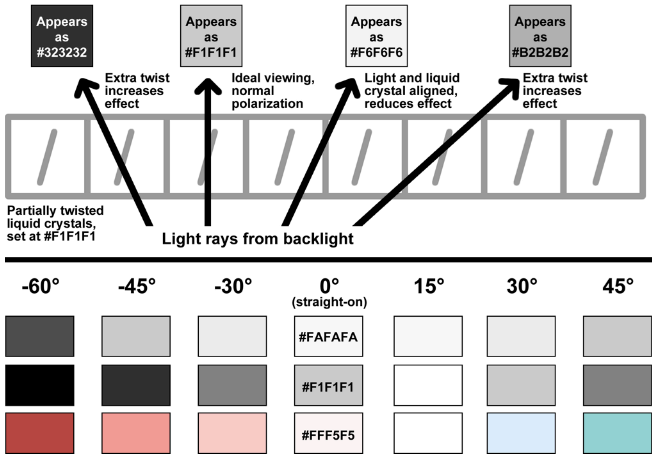

Figure 1. Colors are distorted when viewed off-axis.

side. However, even high quality screens show dramatic color effects in the vertical axis.

APPROACH

We employ a simple color palette to achieve our dual-output effect (partial set shown in Figure 1). This relies on three key phenomena: 1) white pixels remain white, even at oblique angles (though occasional inverting); 2) black pixels remain black, even at oblique angles; and 3) greys between pure white and pure black will darken at oblique angles (colors will also darken, and invert in one direction).

The effect seen in Figure 2 is achieved by rendering a very faint red box underneath pure white text. Both of these elements are imperceptible to the primary user. When viewed from the side, the red box darkens, allowing the pure white text (which remains white) to become readable. The same effect also causes the dark purple "print" and "return" buttons to darken to black. In Figure 3, light gray text is rendered underneath black text. When viewed from an angle, the black text remains black. However, the gray masking text becomes darker, fusing with the black text.

EXAMPLE APPLICATIONS

To help motivate our idea and illustrate the optical effect we employ, we devised a series of example applications. These were a built on a variety of monitors and brands, including Sony, Philips, and Samsung. As noted previously, TN LCD screen tend to have severe color distortion in one axis. Most of our examples assume secondary viewers in the horizontal plane, and thus, we place monitors in a portrait configuration (90° from typical use) to maximize the optical effect.

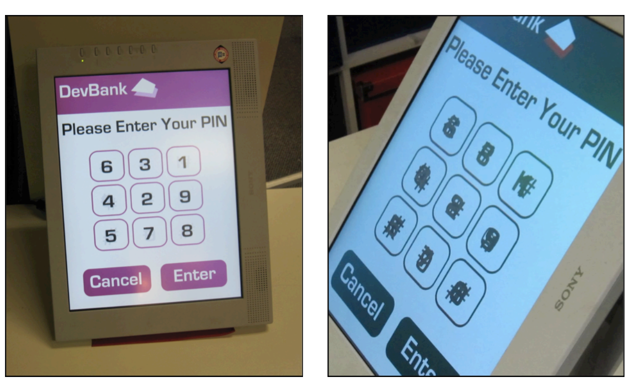

Figure 3. ATM PIN entry keypad with randomized digit locations. From side angles, the keypad buttons are masked, preventing onlookers from deducing the PIN.

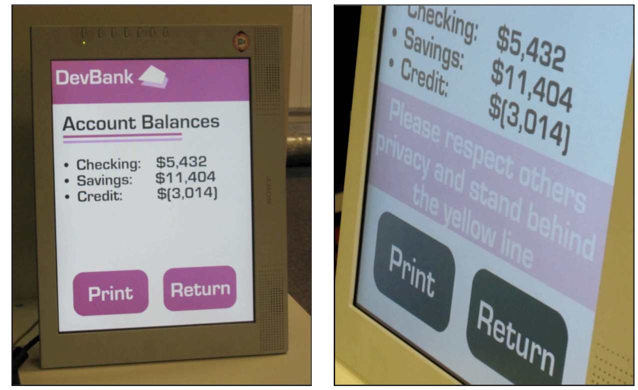

Figure 2. Warning messages could be displayed to people snooping behind and to the side of the ATM.

Note: Figures in this paper have not been graphically post-edited in any manner (e.g., contrast, white balance). The embedded photos are directly from the camera for maximum fidelity. The effect is more prominent in real life as human eyes have a superior dynamic range to that of a camera. All images were taken indoors with standard lighting to simulate realistic use. Please also view the Video Figure.

Privacy

One simple use of this phenomenon is for visual warnings for snooping onlookers. For example, while using an ATM, people floating behind and to the side of the user might see "please move back behind the yellow line" or "you are being filmed" on the screen in bold letters (Figure 1). The primary user, however, cannot see this text and goes about his or her banking business undisturbed.

It is also possible to mask sensitive information by employing a watermark. To the primary user, this is essentially invisible (very light grey text rendered behind black text). However, onlookers see the watermark rendered with a dark appearance. This visually fuses with the original text, making it difficult to read. Returning to our ATM example, this could be used to mask information such as account balance and credit card transactions.

This technique of masking elements could also be used for secure password entry. A simple approach could employ a

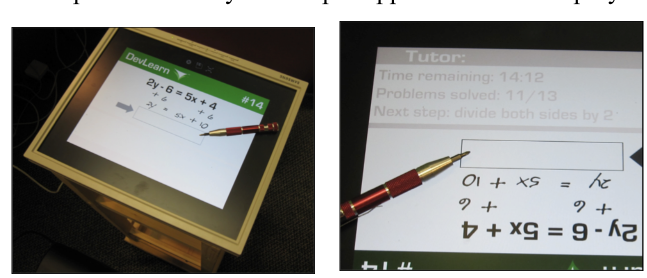

Figure 4. Left: a tutoring system displays a series of algebra problems to students. Right: the tutor, sitting opposite, can see additional information, such as time remaining.

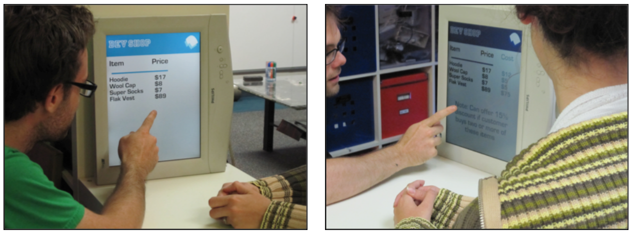

Figure 5. In a point of sale setup, customers could be shown inventory and prices, while the salesperson views additional, private information, such as cost or potential discounts.

touch screen number keypad with randomized digit locations (Figure 3). An off-angle onlooker could view the sequence of button presses, but would be unable to deduce the PIN without knowing the digit-to-button mapping (which is random and masked visually).

Multi-User

There are many situations where presenting differing information to two distinct parties is valuable [6,13]. For example, consider a tutor working closely with a student. A common computer and screen could be used to facilitate close interaction. However, it may be beneficial for the tutor to see the answer, problem difficulty, number of correct answers thus far, the next question, remaining time in the session, and so on. A LCD panel could be set up to provide this information to the tutor only, as depicted in Figure 4.

A similar setup could be deployed in point of sale applications, where, for example, prices could be shown to the customer, while costs are shown to the employee, who can then negotiate a final price. Stores, banks and similar facilities sometimes use privacy preserving grills to hide this information. Not only does this cost more in materials and retrofitting, but also comes at a total loss of information presentation ability to the consumer (Figure 5). A well-positioned LCD could achieve this effect for free.

A final example is that of the viewer peeking over a display from behind and above. This might happen if a teacher was walking around a classroom and checking on student progress by peeking over their laptop screens. This oblique angle opens the possibility to display information like that in the tutoring example. Alternatively, a parent could peek over their child's laptop to see what they have been working on and for how long.

Secondary Information Display

Screens with two viewing angles could also be used for primary and secondary information display to a single user. For example, when sitting in front of a screen, a user could see their email client as usual. However, when seated on a couch with an oblique and far view to the computer monitor, the screen could display "4 Unread Emails" in a large font (Figure 6). In this way, the monitor can serve an additional role as a naïve, context-sensitive ambient display, with no sensing, tracking or knowledge necessary.

There could also be opportunities to engage users on oblique approach trajectories, common with wall-mounted

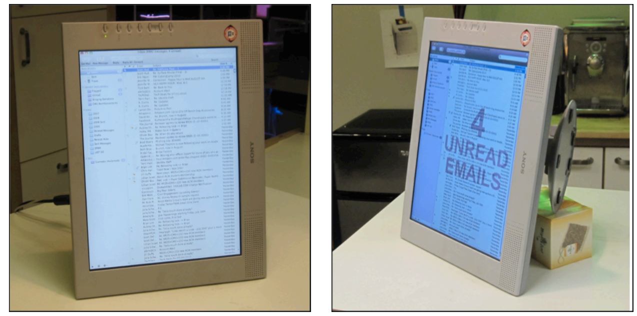

Figure 6. Typical email interface is visible when looking head on; when seated at or approaching from an oblique angle, the display could operate as an ambient display.

displays in hallways. Lastly, use in handheld displays, like those in mobile phones, could be fruitful. Tilting the device could reveal secondary information [6] or a control panel.

CONCLUSION

We have presented our novel use of the color distortion inherent in most LCD displays, especially prominent in the common Twisted Nematic variety. We discussed how our approach can be employed and articulate numerous example applications to help motivate our ideas. A meta-contribution of this work is to encourage researchers to reconsider what might at first glance be seen as a negative aspect or limitation of a technology, and instead, find ways to appropriate and make use of it.

REFERENCES

1. Agrawala, M., Beers, A.C., McDowall, I., Fröhlich, B., Bolas, M., and Hanrahan, P. The two-user Responsive Workbench: support for collaboration through individual views of a shared space. In *Proc. SIGGRAPH '97*. 327-332.
2. Baker, S. Panel Technologies - TN Film, MVA, PVA and IPS Explained. http://tftcentral.co.uk/articles/panel_technologies.htm. 7/25/11
3. Fitzmaurice, G.W. Situated Information Spaces and Spatially Aware Palmtop Computers. *Comm. of the ACM,* 36(7), '93. 38-49.
4. Hua H., Brown L.D., Gao C., Ahuja N. A new collaborative infrastructure: SCAPE. In *Proc. IEEE VR '03*. 171–179.
5. Izadi, S., Hodges, S., Taylor, S., Rosenfeld, D., Villar, N., Butler, A., and Westhues, J. Going beyond the display: a surface technology with an electronically switchable diffuser. *Proc. UIST '08*, 269–278.
6. Lee, J., and Hudson, S. Foldable Interactive Displays. In *Proc. UIST '08*. 287-290.
7. Lueder, E. (2010). *Liquid Crystal Displays: Addressing Schemes and Electro-Optical Effects* (2nd Ed). Wiley.
8. Matsushita, M., Iida, M., Ohguro, T., Shirai, Y., Kakehi, Y., and Naemura, T. Lumisight table: a face-to-face collaboration support system that optimizes direction of projected information to each stakeholder. In *Proc. CSCW '04*. 274-283.
9. Perlin, K., Paxia, S., and Kollin, J. An Autostereoscopic Display. In *Proc. SIGGRAPH '00*. 319-326.
10. Sakurai, S., Kitamura, Y., Subramanian, S., and Kishino, F. A visibility control system for collaborative digital table. *Personal Ubiquitous Computing.* 13, 8 (Nov. 2009), 619-632.
11. Schwerdtner, A. and Heidrich, H. Dresden 3D display (D4D). *Stereoscopic Display and V.R. Systems V*. SPIE Vol. 3295, 1998. 203-210.
12. Shoemaker, G.B. and Inkpen, K.M. Single display privacyware: augmenting public displays with private information. In *Proc. CHI '01*. 522-529.
13. Smith, R.T. and Piekarski, W. Public and private workspaces on tabletop displays. In *Proc. AUIC '08*. 51-54.