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The Enigmatic Display

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The monocular head-up display is the most distinctive component of many wearable computers. Yet people often misunderstand how and why this style of display is used. In this issue, I examine the most common questions on wearable displays and point to new research on their use.

WHY USE A HEAD-WORN DISPLAY?

In many industries, workers need to access information but have both hands occupied. For example, a surgeon might perform an intricate microscopic procedure while watching a magnified view of his actions on a head-up display. An overlay of the patient's vital signs might give the surgeon vital information during the procedure.

Similarly, a network technician might use a head-up display to monitor packet transmission while using his hands to physically reconfigure a router. In Europe, BMW recently demonstrated an augmented reality system for automobile technicians; the technicians used the head-up display to overlay 3D graphics on a BMW engine, which helped guide them for each required step in the engine's service.

Monocular head-up displays show potential in consumer products as well as in industry. A growing number of individuals have adopted these displays (and the corresponding wearables) as part of everyday life. My display gives me a quick way to access my calendar, refer to notes while teaching class, inconspicuously take notes on a conversation, or even read the next paragraph of an article while walking to my next appointment. I have even used a head-up display to read in bed; holding books over my head for extended periods of time leads to arm and back cramps. And because the display is self-illuminating, I do not have to turn on the light.

WHAT DOES IT LOOK LIKE? WHAT CAN YOU DO WITH IT?

Figure 1a shows a simulation of using the MicroOptical SV-3 monocular display; Figure 1b shows the display when worn. The SV-3 is a color VGA display with 640 × 480 resolution and a 16-degree horizontal field of view (19 degrees diagonal). In practice, the computer's image seems to float in space, overlaid on the real world. Because of a trick of the human eye, most users perceive "seeing through" the display even though it is opaque.

You can see a similar effect by holding your thumb a couple of inches in front of one eye while focusing on something distant with the other. The thumb is blurry, of course, but you perceive both it and the distant object, even if your thumb at first seems to obscure the object. Closing first one eye, then the other, demonstrates how different the images are to each eye. Opaque head-up displays exploit this effect to create the illusion of overlay. Additionally, they use optics (much like a microscope's) so both the display and the distant object are in focus simultaneously.

Because you can drive many of these units from a standard VGA port, they can display information just like a normal desktop computer. Generally, anyone with normal vision—corrected or uncorrected—can use monocular dis-

Figure 1. The MicroOptical SV-3 monocular display: (a) a simulation of the display's overlay effect; (b) the display mounted magnetically to the author's eyeglasses for quick donning and doffing.

WEARABLE COMPUTING

USEFUL URLS

Prio: www.prio.com/consumers/problem.shtml
Bausch & Lomb: www.bausch.com/us/vision/products/magnifiers/cvs.jsp
ETH Wearable Computing Laboratory: www.wearable.ethz.ch/projects/research/vrd.html

plays. Some displays clip to eyeglasses (or sunglasses if the user does not wear eyeglasses). Others are mounted on a type of headband and sit far enough from the forehead that the user can wear eyeglasses underneath. While these headband mounts have improved, I have found many of them to be uncomfortable owing to temple pressure.

WHAT ARE ITS ADVANTAGES?

Head-worn displays have several advantages over PDA displays, including

- Size and weight
- Speed of access
- Less vulnerability to damage
- No need for hand support
- Less strain and fatigue for back, neck, and hands
- Adjustable focus
- Less power
- Virtual overlay on physical world
- Privacy
- Less intrusiveness
- Potential for large virtual image

UPCOMING CONFERENCES

Percom: www.percom.org
March 23–26, 2003 in Fort Worth, TX

CHI (computer-human interaction): www.chi2003.org
April 5–10, 2003 in Fort Lauderdale, FL

MobiSys 2003: www.usenix.org/events/mobisys03
May 5–8, 2003 in San Francisco, CA

International Symposium on Wearable Computers: submission deadline May 2003
Conference in October 2003 in New York

Compared to a laptop or PDA display, modern head-worn monocular displays have a distinct size and weight advantage. For example, the part of my SV-3 mounted on my eyeglasses weighs 35 grams (slightly over an ounce). Although the display also requires a small box to convert the VGA signal to a format appropriate to its liquid crystal display, you can store the converter box away from the head. When not wearing my display, I store it in my shirt pocket. These days, most people assume that the wire to my shirt pocket belongs to a cellular phone or MP3 player earphone. However, when I need it, I can still access the display very quickly. I have placed small magnets on both the display and my eyeglasses so that the display easily latches in place without fumbling.

The display's access speed is another significant advantage. PDA users must reach into their pockets or briefcases, uncase the PDA, boot it, pull out the stylus, and access the right application. With a head-up display and a fast-mounting system, you can access your system in as little as one-tenth of a PDA user's time (2 seconds for a head-up display; 20 seconds for a PDA[1]). Such accessibility lets you frequently use the display and wearable computer for quick reference and note taking.

Because a head-worn display is small and mounted near the face, it is naturally more protected than a PDA or laptop screen. PDA screens are relatively large and theoretically vulnerable surfaces in a mobile environment. A user might store the PDA in a pocket, which can subject its screen to large forces if the user sits on it or places a large object on his or her lap.

Another problem with PDA-sized screens is that a hand must support them. In fact, most PDA interfaces require using both hands (one for support and one for the stylus) and both eyes. If users attempt to use the PDA interface when walking, they will have to devote much of their attention to compensating for the movement's mechanical shock. So, the PDA could consume both users' physical resources and concentration. In contrast, a wearable with a head-up display demands much less of a mobile user.

A head-worn display can also be better ergonomically than a desktop, PDA, or laptop screen. Instead of having to sit upright with their hands, necks, and backs in the proper location, head-worn display users have much more freedom. For example, I often lie on my office sofa to write my papers. (An unfortunate side effect, however, is that visitors sometimes come to my office for an appointment and initially think I'm asleep.) Such freedom can release sufferers of back, neck, and hand injuries from occupational pain.

Another ergonomic benefit of several modern head-worn displays is their adjustable focus. Frequent desktop and laptop users are vulnerable to *computer vision syndrome* caused by forcing the eye to focus at a close distance for extended time periods. Symptoms include headaches, loss of focus, burning or tired eyes, double or blurred vision, and neck and shoulder pain. Some optometrists even believe such computer use increases the risk of myopia (near-sightedness) in children. According to two CVS equipment makers, Prio and Bausch & Lomb (see the "Useful URLs" sidebar), the syndrome is due to the difference in the *resting point of accommodation*—the default distance at which the eyes focus (around 76 cm)—and the distance where users must focus to read a computer screen. With an adjustable-focus screen, head-worn display users can vary their focus from a near depth to the RPA to an

Figure 2. A head-worn display emulating a high-resolution display wrapped around the user's body.[2]

effective infinite depth depending on what is most comfortable.

Head-worn displays also require less power than PDAs. To use a PDA, you must be able to view it from different angles, even if the perceived image subtends the same amount of effective visual arc as a head-up display. However, a head-worn display is mounted so that its light is relatively focused into the eye. Thus, head-worn displays naturally require less power than PDA screens. To illustrate, you can think of the PDA as a flashlight that casts its light over a wide area to catch as many eyes as possible, whereas you can envision the head-worn display as a laser beam that tries to provide a brilliant image for one user in a limited area.

Head-worn displays offer some unique features over PDA and laptop screens. Because the user wears the display close to the eye, spying on the user's screen without his or her knowledge is nearly impossible. You can use head-worn screens combined with appropriate sensing to create a real-time graphic overlay onto the physical world (that is, augmented reality). Additionally, you can use accelerometers or a magnetic compass to create a virtual head-up display; while you rotate your head, the display image pans through a virtual image rendered in a ring around your body (see Figure 2).[2]

Head-worn displays can also be less socially obtrusive than many alternatives. For example, a cellular phone call can be announced discretely with caller ID in the user's display instead of with an insistent and uninformative ring. As another example, instead of needing to look away from his interviewee to put pen to paper, a reporter can maintain eye contact while typing notes to his display. Such subtlety can help avoid derailing the discussion because artifacts of the interviewer's note taking (notepad, pencil, writing, and so on) are no longer visible.

MARKET ACCEPTANCE

Although head-worn displays go back to the earliest efforts in computer graphics,[3] only recently have researchers developed small, mobile computers that can exploit the appropriate communications infrastructure. Additionally, developing the display technology and starting a new market have given manufacturers difficulties.

Not long ago, head-up displays were relatively large (see Figure 3), and many potential users avoided them because of perceived social awkwardness. However, displays such as the SV-3 in Figure 1 and the one built into my eyeglasses (which you can see in the header to this department) are now unobtrusive enough to interest nontechnical users. In a recent trip to Europe, I found that businessmen were almost as likely as computer specialists to show interest in the SV-3. Perhaps in addition to the smaller displays, mobile technology's maturation and widespread adoption has increased the general population's awareness of a mobile computer's potential uses. With short message service technology, game playing, and photography on cellular phones becoming increasingly popular, a greater impetus to adapt head-worn displays for the more general market exists. Additionally, wide-area wireless Internet access is becoming reliable, and the public should begin to embrace the idea that you don't have to be constrained to the office to access full-scale computing support.

Even so, microdisplay manufacturers still face difficult challenges. For example, only recently have prices approached US$1,000 for a 640 × 480 color display (previous VGA displays typically cost $2,500 to $5,000). Volume pricing requires volume purchasing, and vice versa, leading to the familiar chicken-and-egg syndrome of many beginning markets. Technical and human perceptual limitations also continue to affect current display manufacturing. For example, manufacturers must balance the display's field of view against the amount of visual area its support hardware occludes. Cost, brightness, contrast, power, resolution, social obtrusiveness, and clarity are only some of the factors that must be balanced in a product.

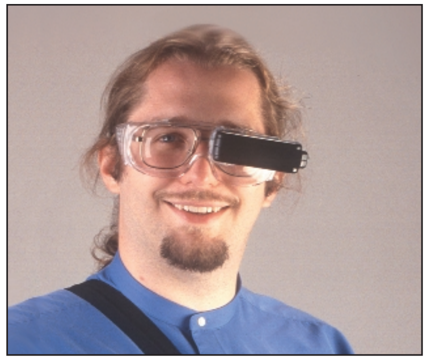

Figure 3. The Private Eye display, which is relatively large compared to today's head-worn displays.

Figure 4. Microvision's virtual retina display, the Nomad.

WEARABLE COMPUTING

TESTING HEAD-WORN DISPLAYS

Recently, researchers began testing modern head-worn displays in various situations. In the *Journal of Optometry and Vision Science*, James Sheedy and Neil Bergstrom report that users performed similarly on paragraph reading, letter counting, and word-search tasks using a monocular 800- x 600-resolution display (e-case by InViso) versus a 15-inch flat-panel display or hard copy.[1] In previous experiments by other researchers, older head-worn displays did not perform as well as desktop monitors or hard copy. The authors attribute the favorable results to improved display resolution, partial instead of full immersion, and several other effects.

While Sheedy and Bergstrom's experiment shows the promise of newer wearable displays' image quality, Robert Laramee and Colin Ware have been exploring the effects of various backgrounds on task speeds when using a monocular display.[2] In their paper, Laramee and Ware experiment with both a see-through monocular display and an opaque monocular display. Given a question such as "What is the price of lettuce?", users had to scan through a table of items and prices and use a mouse to click on a specified price. While performing this task, the users either saw a bookshelf or a television playing a movie in the background.

The authors found statistically significant evidence for both binocular rivalry (what one eye sees affects the other) and interference (the background in a see-through display conflicts with what the user is doing). However, the effects were not as strong as the authors expected, especially in the case with the static background. Many of the experiment's aspects can be explored further: adjusting brightness, contrast, and transparency levels; using higher resolution than the 450 x 266 IO Display Systems i-glasses in the experiment; exploring focus effects with the TV background; exploring other user tasks; and so on. However, the experiment shows the need for examining more complex tasks with head-worn displays. The research community must conduct more such experiments to help display manufacturers and wearable software providers tune their products and overcome limitations to head-worn display use.

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FOR FURTHER READING

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Yet even with the current poor economy, manufacturers continue to improve their products. Recent studies suggest that monocular head-up displays can be as good as hard copy or flat panels for reading tasks (see the "Testing Head-Worn Displays" sidebar), and future technology promises more choices in displays. In 2002, for example, Microvision released a commercial version of its 800- × 600-resolution laser scanning monochrome display, the Nomad (see Figure 4), and announced that it built a miniature color version of the display. Such virtual retinal displays are exciting because of their potential high brightness, sharpness, depth of field, and power efficiency. Academics also continue to push the technology forward; researchers at the Swiss Federal Institute of Technology in Zurich are investigating variants of virtual retinal displays without the need for scanning.[4]

Although many industry watchers are interested in head-up display technology, it's difficult to predict when, and in what form, the market will develop. One reason is that many markets and mechanisms might lead to success. Perhaps early market adoption will be similar to that of cellular phones and pagers, with high-income, high-pressure professionals such as doctors and lawyers leading the way. Or perhaps computer system administrators, some of the earliest telecommuters, will create a new wearable lifestyle long before the rest of the population. With luck, someone will develop a product with mass appeal like the Palm Pilot, and head-up display adoption will be fast for both horizontal and vertical markets. In any case, the market forces in mobile computing and communication will make the next two years exciting for display manufacturers. For more on head-worn displays, see the "Further Reading" sidebar.

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