Eyeglass-Based Systems For Wearable Computing

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ABSTRACT
This paper reports on progress in the area of hardware for wearable computing. Our specific interest is in reducing conventional head-mounted display systems to eyeglass scale. We report here the successful demonstration of an ergonomic eyeglasses-based display. We present some of the general considerations in the design of such eyeglasses and briefly review our approach and initial findings.

Keywords
Head-mounted display, computer display, eyeglass-mounted display, wearables.

INTRODUCTION

The development of ergonomic, useful visual interfaces for wearable computing is important for the future widespread success of wearable computers. Most work in this area has focused on head-mounted displays attached to a headband. Our view is that the displays of the next generation will be mounted within eyeglasses. Moreover, for widespread acceptance, such displays should be *concealed* within eyeglasses. Concealment of the display in a useful compact eyeglass frame presents a considerable technical challenge. We have termed such devices eyeglass-based systems (EBS) and we will discuss considerations in developing an EBS in this paper.

The technical challenges involved in the design of the EBS include the development of a suitable miniature display, miniature backlight (if needed) and development of an optical relay and eye piece capable of concealment in the eyeglasses. To this end, a number of concepts and inventions have been developed.[1-5] Recently we reviewed the difficulties inherent in building eyeglass displays.[6] In this paper, we report significant progress in a new approach to building eyeglasses using embedded optical elements within the lenses of conventional eyewear.

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AESTHETIC CONSIDERATIONS

A key consideration for the commercial success of the EBS is the design of aesthetically pleasing hardware. In our view, this means that the design should have two key features: (1) the EBS should look like and function as eyeglasses, (2) the EBS should permit others to see the user's eyes.

Look and Function of Eyeglasses

In our view, it is important that the EBS look as though it is conventional eyewear. Additionally, the EBS should *function* as eyewear, particularly when the display is turned off. Modern eyewear is free from extraneous lenses and other hardware in front of the frame or suspended near the user's face. Accordingly, the EBS must be free of such features. The display and its optics must be mounted behind the front of the eyeglasses frames so that the user's face appears unencumbered.

The EBS approach is distinct from more conventional approaches involving HMDs mounted in goggles or large sunglasses, which are designed to fit over eyeglasses, because the EBS approach replaces eyeglasses in form and function. The EBS may in many cases attain its greatest functionality if it is fit to the user by a trained vision care practitioner such as an optometrist. The EBS should include prescriptive vision correction when needed.

User's Eyes

The EBS should permit the user to have relatively un-occluded vision and should permit others to see the user's eyes. Therefore, the design must not rely on darkened surfaces to disguise the presence of a display, nor should it introduce significant occluding optical elements within the EBS eyepiece. (Designs utilizing non-occluding optics are sometimes usefully termed "see-through" systems.) Additionally, when the display is unpowered, the system should revert to ordinary eyeglasses, sun glasses, or safety glasses.

ERGONOMIC FACTORS

In order for the EBS to be used for prolonged periods the system must be comfortable. In our view, there are four principal areas to consider in the design of a comfortable and ergonomic EBS. These are mass and bulk issues, heat dissipation, and optical performance. (The considerations we describe below comprise our current view of the proper ranges of these factors; however, we should note that quantities stated here reflect our opinions and are not the result of a formal study of the problem.)

The system design should carefully consider mass and center of gravity. Loading on the ears and nose should be sufficiently low as to be tolerable by the users for several hours. We believe that the mass of the EBS should be in the range of 80 to 200 grams. Careful balancing and the use of a supporting strap may make it possible to increase the mass. For this range in mass, the distribution of the load between the ears, nose and head-strap may be important so as to minimize the torque produced by a poorly distributed load. However, straps and other supports should be avoided if possible. The size of the EBS should also be minimal, meaning that bulky appendages should also be avoided.

For comfort, heat dissipation should be minimal, particularly near the face and eyes. Of course for a wearable system, it is desirable for obvious reasons to minimize any waste of energy. However, if heat dissipation is unavoidable, it should be remote from the face.

The most important aspect of the EBS, if it is to be used for extended periods of time for reading text, is the optical performance. The image should be optically flat to better than ½ diopter so that accommodation during use is minimal. The image must be sufficiently large and the resolution great enough that text can be read without strain. Pupil-forming optical systems should have an exit pupil sufficiently large to accommodate some movement of the glasses; however, if the eye is relatively close to the lens, a small exit pupil may be tolerable (on the order of 5 to 10 mm).

APPROACH TO EBS DESIGN

We have developed an approach to the design of an EBS that meets many of the above requirements. Our approach moves the display behind the front of the eyeglasses frames, and uses a new type of eyeglass lens to convey the image to the user without adding significant optical elements in front of the frames.

Image Goal

Our objective is to provide a VGA (640x480) virtual image to the user positioned approximately 60 cm in front of the EBS. The desired width of the image is 28 cm and the height is 21 cm. This is nominally equivalent to a 35 cm diagonal (14 inches) desktop VGA monitor viewed at 60 cm (2 feet).

Miniature flat panel displays capable of delivering this image are now entering the market. Reflective and transmissive active matrix liquid crystal displays are available from a number of sources, and other technologies such as active matrix electroluminescent displays are also available. The size of the display is a key factor however. If we consider the largest practical magnification that can be attained from a single lens to be 20x, then we find that we require the display to be at least 18 mm in diagonal (0.7 in.) for our target VGA display. This display size is still too large for concealment in eyeglasses.

Partial or full concealment may be attained by utilizing smaller displays as they become available, in combination with a multi-lens system. If an optical relay is employed, the displays may be mounted behind the ears. The key requirement is then the development of an efficient relay system.

Embedded Optics

The image can be relayed to the eye through the lens by using embedded mirrors, as shown for example in Fig. 1. The display is viewed through an eye lens; the focal length of the eye lens is chosen such that the position of the virtual image is at a comfortable distance. Note that a single mirror can be used if the display is positioned at the edge of the lens. We have avoided the single mirror configuration for three reasons. First, the edges of the lens must be ground to fit in standard eyeglasses frames, meaning that edge-mounted components must be accommodated by a new non- standard edge grinding means. Second, the image will be mirrored, necessitating left-right reversal of the data. (This is only a consideration for displays in which the image cannot be easily reversed in the electronics.) Third, if the image is to be relayed from behind the ear, the second turning mirror is necessary.

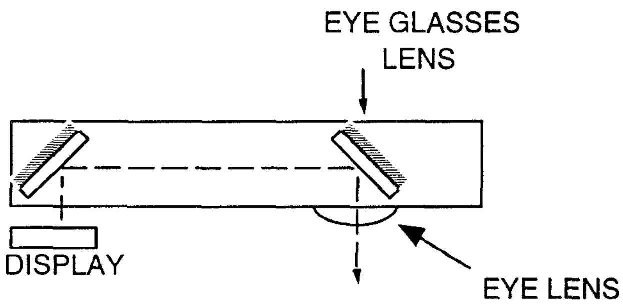

Figure 1. Illustration of embedded optics in an eyeglass lens.

Note that for a see-through design, the mirror in front of the eye may be partially silvered. Many variations on this approach are possible, but a full discussion would be beyond the scope of this paper.

For a see-through display, the design of the eye piece is a critical part of the eyeglass optics. One approach comprises use of a positive and negative lens, as shown in Fig. 2 below. Rays from the display pass only through the positive lens (thus magnifying the image). Rays from the ambient scene pass through a positive and negative lens designed for approximate cancellation of the powers of the two lenses.

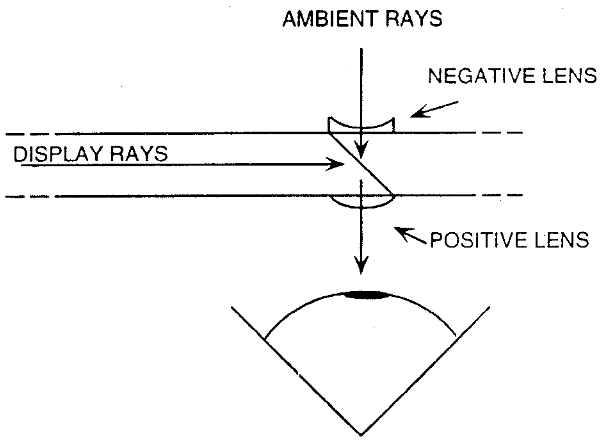

Figure 2. Illustration of One Possible Refractive Eyepiece Design

A key requirement in a design using the bulk material of the lens as part of the optical path in the imaging system is the effect of the lens thickness on field of view. This thickness introduces an aperture stop which can affect the position of the exit pupil and field of view. We believe that through careful design these factors are manageable, and we can support this contention with a convincing EBS demonstration. It is in general true, however, that if the lens is made thicker, the field of view increases.

Large displays that cannot be mounted close to the eyeglasses lens may be placed behind the ear. The most straightforward method of relaying images to the eyepiece is through the use of a tapered coherent fiber optic bundle, as illustrated in Fig. 4. Bundles are available with fiber pitch as low as 3 μm, meaning that high resolution imagery can be relayed in a compact bundle.

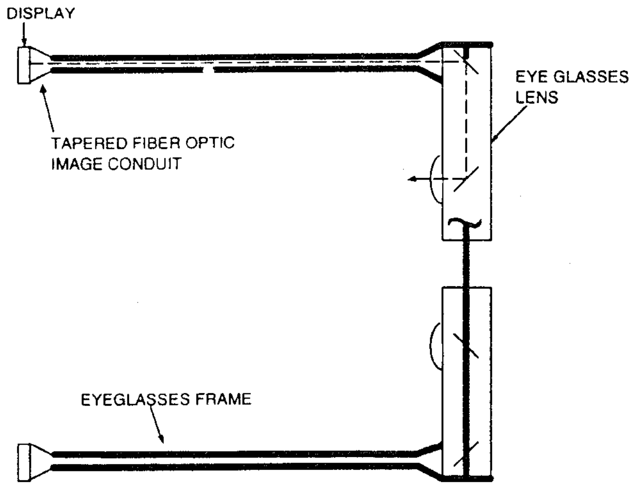

Figure 4. Eyeglass Displays Utilizing A Tapered Coherent Fiber Bundle Relay.

EBS DEMONSTRATION

We report here the first successful demonstration of an EBS. The glasses comprise a commercial eyeglass frame within which we have mounted a lens system similar to that shown in Fig. 2. A convex eye lens is paired with a concave lens mounted to the front of the eyeglasses lens, so that ambient scenery can be viewed through the eyepiece of the system. Our initial finding is that this optical approach works to a degree in the see-through mode, but that a small amount of distortion remains to be corrected. This further correction may require a third lens. The distortion however, has no effect on the displayed image.

The image in the EBS that we have built is provided by an active matrix liquid crystal display obtained from Kopin Corporation. The display and back-light are small and have a viewable area of approximately 5 mm by 5 mm. The overall thickness of the eyeglass lens is less than 6.5 mm, which fits well in the commercial eyeglass frame. The image source provides 320 by 240 pixels and is readable and useful in the demonstration optics system. Fig. 5 shows a photograph of the eyeglasses. The demonstration electronics, including EPROMs and microcontrollers, are contained in the black box mounted to the left temple. We have built a second set of glasses in which a thin cable connects the display to the drive electronics, so that the circuits may be carried in one's pocket or mounted within the wearable computer.

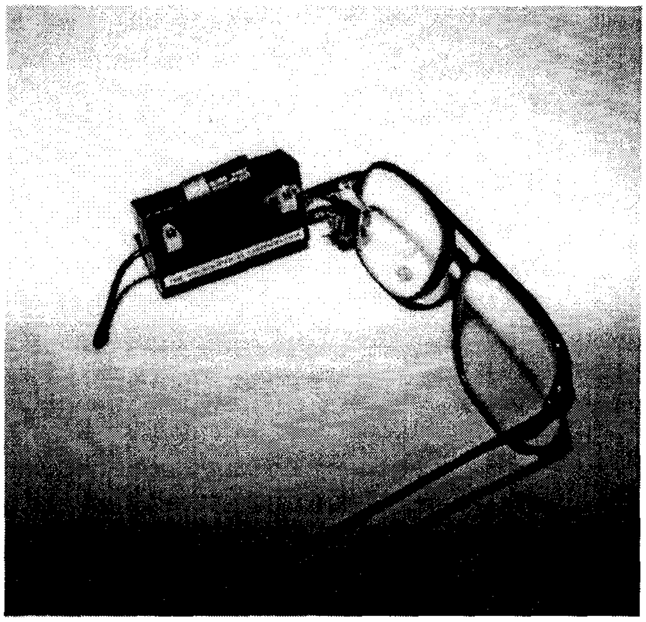

Figure 5. Photograph of MicroOptical's First Eyeglasses System

Based on this demonstration, we believe that the entire display and optics can be completely housed within the eyeglasses frame in a aesthetically appealing manner, and work is in progress to realize a fully concealed display system within eyeglasses.

SUMMARY

This paper has summarized the considerations involved in the design and development of an EBS. The factors suggested here have been employed in the design and demonstration of such a display. We believe that this approach shows the feasibility of new types of displays systems that can be mounted successfully in aesthetic, ergonomic eyeglasses systems.

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