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Simple 1-D image enhancement for head-mounted low vision aid

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Abstract High-contrast binary images (black and white without shades of gray) were demonstrated to improve face recognition performance by the visually impaired using static images (Peli et al., Invest Ophthalmol Vis Sci 1991;32:2337-2350). A binary head-mounted display device has now been adapted to present video in real time for testing as a low vision mobility aid (an electronic telescope). When used for text presentation (as a head-mounted CCTV), a single threshold produces satisfactory performance. However, binarization of a video signal through a single threshold results in high-contrast but extremely poor image detail. A more detailed binary image can be obtained by applying bandpass filtering prior to thresholding. The application of the adaptive 2-D enhancement technique used by the DigiVision device enables such live bandpass processing and provides substantial improvement. To reduce the cost, weight, and power consumption of a portable low vision aid, a one dimensional (1-D) analog video processing alternative has been designed and implemented. Since the processing is applied only across the horizontal dimension, it provides no enhancement of horizontal features in the image. However, in this head-mounted camera application the user can easily resolve such details by a slight tilt of the head. The 1-D enhancement alternative provides satisfactory quality, high-contrast binary imaging at substantial savings.

Key words Electronic aid; head-mounted display; image enhancement; visual prosthesis

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Introduction Reduced contrast sensitivity is often the result of diseases leading to low vision. This is especially true at high spatial frequencies.[1] Because of this loss of sensitivity, perception of fine detail is limited. This limitation can lead to an inability to distinguish faces and scenes, and severely limit reading speed. These restrictions are common complaints of low vision patients. The most common solution to this problem is the use of magnification. Magnification transfers image details to lower spatial frequencies, for which the patient has higher sensitivity, and thus renders them visible.

The use of image enhancement to aid perception in the low vision population was first proposed in 1984 by Peli and Peli.[1] Its use has since been evaluated in several domains, including face perception,[2] motion video perception,[3] and reading.[4,5] Enhancement of face images has been shown to improve recognition for many low vision observers.[2] Two types of enhancement were implemented in that study: adaptive enhancement,[6] which results in high-pass filtered gray tone images, and adaptive thresholding,[7] leading to a binary, high-contrast caricature of the original image. Improvement in face recognition performance using the two methods was similar. Massof[8] has demonstrated the value of binary caricature-like images using optical simulation. Until recently, however, testing of this technology was off-line and limited to static images.

Current technology allows us to apply the adaptive enhancement algorithm on-line to moving color video images.[9] Therefore, we are now able to directly evaluate the effectiveness of enhancing details in movies and moving text. Recent studies have evaluated the effects of adaptive image enhancement on the appreciation of details in moving scenes[3] and reading rate for text scrolled across a video monitor.[5]

It has been suggested that image enhancement could be implemented in a portable visual aid using a miniature camera and a head-mounted display.[10,11] The aim is to provide an electronic version of the commonly used head or spectacle-mounted telescopic aid (bioptic). The main advantage offered by the increased complexity of the electronic aid is the ability to provide image enhancement in addition to, or in place of, magnification. Although magnification in telescopic aids is very effective, it is inherently limited. The magnified image necessarily represents a smaller span in degrees of visual angle than can be otherwise viewed. Magnification causes image sway and motion which may result in difficulties in adaptation. Image enhancement has the potential to provide increased visibility without, or with reduced, magnification, thus providing a wider field of view and more flexibility. A special purpose head-mounted display for the visually impaired has been recently introduced commercially.[12] Although this system (LVES) does not provide digital image enhancement in its first generation device, it is intended for such use in the future.[13] Even in its current configuration, the LVES system provides an analog control of contrast as is available in many video systems.

In this paper, I describe initial experimentation aimed at modifying for low vision use the Private Eye™, a commercially available, low-cost, monocular head-mounted display.[11] The implementation required modifying the display, designed originally for static computer graphics, to process and present a live video signal from a camera. Since the display is binary, it could be adapted appropriately, using a single threshold, to the presentation of text when used as a portable electronic magnifier. For use as a mobility aid, where it will present gray-scale images of the continuous tone environment, I tested two different approaches to binarization, both of which approximate the adaptive thresholding used by Peli et al.[2] In one approach, the signal is processed in

2-D using the DigiVision™ adaptive enhancement device[9] followed by a fixed threshold. In the other, a low-cost analog filter is applied to the analog video signal directly to obtain 1-D band-pass filtering before thresholding. The 1-D processing may be sufficient in this application due to the ability of the user to quickly and easily examine other directions using small head tilts with the head-mounted camera.

The display unit The system is based on a miniature monocular head-mounted display (HMD) device called the Private Eye™, which was developed by Reflection Technology Inc. (Waltham, MA, USA)(described in ref. 11). The display is designed to operate as a monitor on any IBM compatible PC, and its aim is to provide a portable, private, inexpensive means of visual information communication. One such recent application is a portable Fax receiver for cellular phones. The Private Eye™ is also the display technology used in the binocular computer game device Virtual Boy™ by Nintendo.

The Private Eye™ combines semiconductor and electromechanical techniques to create a virtual image of a 12-inch monochrome monitor in a package of 2.8×3.0×8.1 cm (1.1×1.2×3.2 inches), weighing about 50 g. It is designed to be head-mounted in front of one eye, with the other eye's view of the environment unimpeded. The Private Eye™ provides high- resolution (720 (H)×280 (V) pixels) and a field of about 21°×14°. The displayed pixels are generated by red light-emitting diodes (LEDs) on a black background. The contrast ratio is quoted as 30:1 nominal, and the luminance is 7 cd/m^2 nominal. The display is refreshed at 50 frames per second (non-interlaced). The headset is configured to enable use with either the right or the left eye and can be located above, below, or directly in front of the wearer's line of sight.

Image data is sent as bit-mapped graphics from a host computer to the display unit. The bit-map information is loaded into a linear array of LEDs. A whole column is illuminated at once for about 6.25 μs. While the image is displayed column by column, the linear array is scanned horizontally by an oscillating mirror. The resulting scan is imaged by a lens system to form a virtual screen at 60 cm from the viewer's eye. A focusing knob allows correction for substantial levels of spherical refractive error, but the display can be used easily with spectacles when needed. The integrated technology enables production of the device at low cost. Even now, before mass production of these units begins, engineering development kits, including the display, the head mount, and all the electronic circuitry are being sold for $550.00. The Virtual Boy™ containing two such displays and considerable other electronics is mass-produced and sold for under $200.00.

The Private Eye™ in its standard configuration can display only computer-generated still graphics, or very slow animation using a small fraction (1/20th) of the field. Optelec Inc. (Westford, MA, USA) modified the device to provide the visually impaired with a portable electronic magnifier system (head-mounted CCTV) called the Bright Eye™. To operate as a CCTV, it had to be modified to display asynchronously live (video rate) images acquired from a CCD camera. The Bright Eye™ was designed to accept the input from scanned text (using a hand-held camera), and therefore the use of a single threshold was satisfactory. The core of the modified circuitry is a static RAM that replaces the original Private Eye™/Host Video Memory. The live video acquired from the camera is binarized using a single fixed threshold. The binarized data are stored in the RAM. Independent of the writing operation, the Private Eye™ display controller unit retrieves the data when it is ready for the next update at its own transfer rate. The production unit of the system could transfer images at 15 frames/second, while a prototype unit developed for lab purposes could operate at 25 frames/second using a PAL (European video standard) camera. We further modified the Bright Eye™ to permit display of gray-scale images on the binary display.

The bioptic design As an alternative to the binocular virtual environment aid proposed by Massof and Rickman[12] and implemented in LVES, I proposed an image enhancement aid implemented as a monocular bioptic device.[11,14] In that design, the HMD is placed above or below the line of sight to be used occasionally in the same way as the bioptic telescope. This design can combine the benefits of both magnification and image enhancement without the psychological and functional drawbacks of the limited field, virtual environment device.[14,15] The cost of this implementation can be reduced substantially because only one display and one camera are required. The display itself can be of a smaller field than the one required in the virtual environment, since the patient maintains his or her natural view of the environment (A larger field is required for safe navigation than is required for intermittent investigation of objects of interest with a bioptic mode). A smaller field display device may be implemented in a smaller, lighter, and cosmetically more acceptable aid.

2-D processing of gray tone video To test the concept of displaying a high-contrast binary version of a video image to the visually impaired, the Bright Eye™ was adapted first to present live video from a VCR. However, because the video signal in the unmodified Bright Eye™ is processed by a single threshold, even with optimal contrast and luminance adjustment we found that the resulting image was frequently of poor quality. If large portions of the image were dark, or light, all the details in these segments were missing from the binary image (Fig. 1a). Because there are many types of images in a typical movie, continuous adjustment of the parameters was required during viewing in order to obtain even minimal image quality as shown in Figure 1a.

A more detailed binary image was obtained by applying a 2-D bandpass filter prior to thresholding with a fixed threshold set at mid-video range. The resulting image is fairly similar in appearance to the binary images obtained using adaptive thresholding,[2] which where shown to be beneficial for the visually impaired. The application of the adaptive enhancement algorithm by the DigiVision™ device enables such live 2-D processing. In addition, the ability to control background luminance with this algorithm[1] could be used to partially maintain the average luminance relations at low frequencies. Such preprocessing of the video before the binary image is created resulted in binary images with

a

b

Fig. 1. Comparison of the appearance of the binarized video image threshold (a) without and (b) with 2-D enhancement.

many more visible details and much higher quality (Fig. 1b). The effectiveness of this process was demonstrated by playing a complete movie from a video tape through the binary display. Observers with normal vision could watch such a binary movie without any difficulty in following the story line and enjoyed the presentation.

It is important to note that the quality of the live video is much better than those depicted in static prints (Fig. 1b). The slight changes in illumination and shading associated with movement in the scene as well as camera movements tend to change the exact transitions in the binary images across frames. The visual system integrates the various details appearing over time into a more detailed and pleasing percept than any single frame would present. This effect is true for the unprocessed gray tone images as well, where the quality of a frozen frame on the display is usually perceived to be much inferior to the perceived quality of the live motion image. The improvement, however, is even larger for the binary images. Low vision patients with various pathologies watched the movie display as well. Most had no difficulty using the display and thus could watch the enhanced binary movie through the display. They reported better visibility of movie details with the binary high-contrast display, than with the standard video screen.

A small number of low vision observers, including two young careful observers (one with cone-rod dystrophy and one with Stargardt's disease), noted significant difficulty in using the display. They had the same difficulties using the display in the unmodified Bright Eye™ for text reading. These patients derived no benefit from the modified display. They attributed their difficulty to the red color. One of them was tested with a computer display which was set to display text in red letters on a black background. Despite the relative dimming of the computer display due to using the red gun only, he was able to comfortably read the red display. The question of threshold and perceived suprathreshold contrast in a red on black display will be tested in my laboratory in the future.

1-D, a simple and inexpensive alternative Complete 2-D processing, as performed by the DigiVision™ device, may be necessary for the processing of images taken from a video tape or broadcast or from a static surveillance camera. However, such processing is necessarily more expensive and consumes more battery power than simple 1-D processing applied to the video signal row by row. In the case of video tape imagery, such processing may be insufficient because it processes the image only across vertical features. Thus, important image features, such as edges, that happen to be horizontal are not processed and are not represented properly in the final binary image. Such horizontal features are abundant in the (man-made) environment and are needed for proper perception. In the case of the head-mounted camera, however, the user may change the camera orientation very easily by using slight head tilts. With such a head tilt, horizontal features become diagonal and are therefore processed, thus becoming visible in the thresholded binary image.

To test this idea, we implemented such analog processing using basic video amplifiers and filters (Fig. 2). The simple system separates the video signal from the timing signals and performs an analog high-pass filtering. To obtain results similar to those obtained with the adaptive enhancement algorithm, here too the filtration is obtained by low-pass filtering of the signal and then subtracting the low-pass version from the original. The high-pass filtered residual is then recombined with the timing signal, binarized, and fed into the display. The cost of the electronic components for the circuitry is under $50.

A miniaturized video camera (Pulnix TM-7X) was connected to the headband provided with the Private Eye™, using a lightweight adjustable arm. The camera was fitted with a (Tamron 31520 25 mm, 1:1.6) lens, which provided a field of view matched to the 21° field of view of the display (magnification of 1:1). The video signal from the camera was fed to a belt-mounted pack containing the electronics and operating on a single cordless drill battery (Fig. 3). The complete system weight is about 2.4 kg, with the head unit being 0.5 kg. The weight of

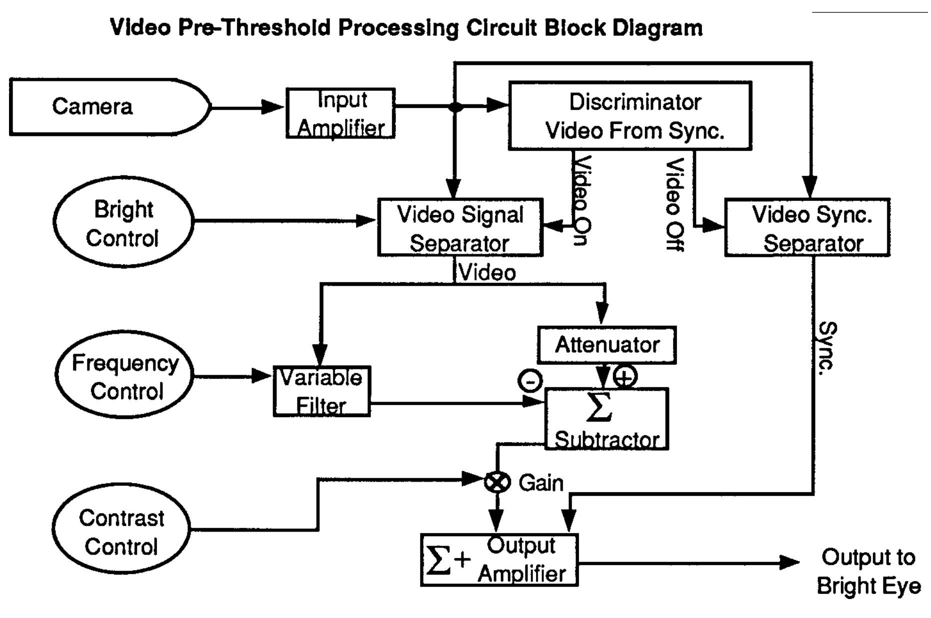


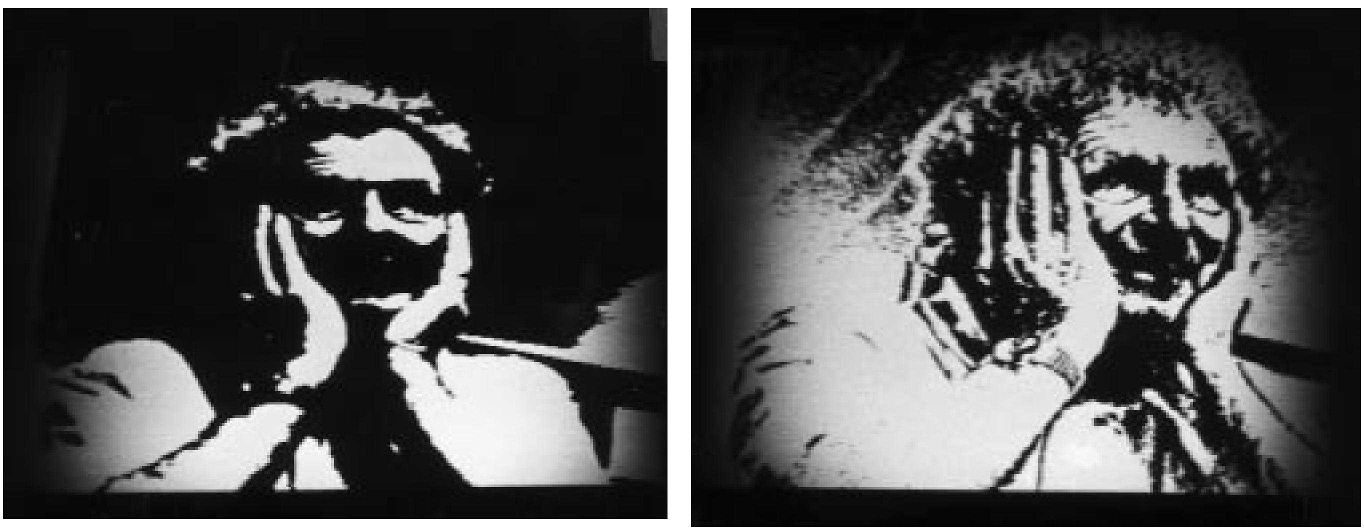
Fig. 2. Block diagram of the 1-D enhanced head-mounted system. The video signal from the camera is separated from the synchronization signals. The raw video is then low-pass filtered and subtracted from the attenuated raw video to obtain a high-pass filtered version. This is amplified by the contrast control and then recombined with the synchronization signals.

the head-mounted system can be further reduced by using a camera with a remote control unit in the belt pack rather than the integrated system we used in this prototype.

The validity of the 1-D processing concept is easily demonstrated with this system. The binary images seen in the display are an easily recognizable, highly detailed, high-contrast version of the video camera images. Many low-contrast details in the environment are highly enhanced in contrast and the image is nevertheless easily recognizable (Fig. 4). As expected, horizontal details in the environment are missed in the enhancement and thus frequently not represented in the binary image. However, a slight tilt of the user's head changes the orientation of such details in the coordinate frame of the camera and thus reveals the details in the binary image (Fig. 5). The slight head movements needed for such exploration are simple to perform and integration of the perception across these orientation changes is easy and natural.

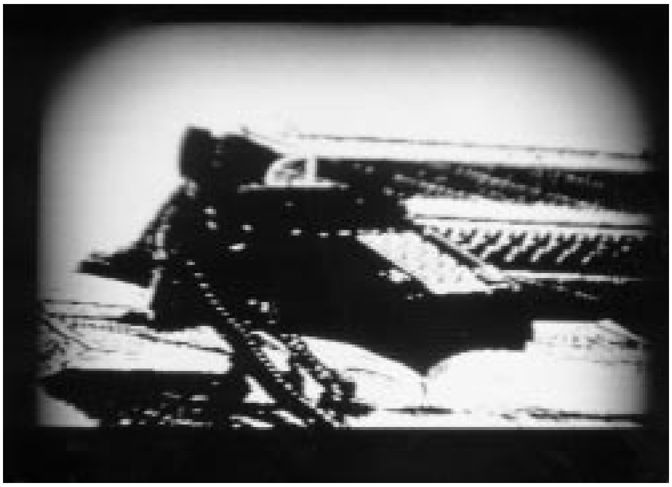
Fig. 3. A user wearing the prototype device is shown adjusting the monocular display while walking outside.

Conclusions We have previously shown that image enhancement provides significant improvement in the perception of still images[2] and moving scenes[3] displayed on a television monitor. If image enhancement is effective on a stationary video monitor, its benefits might be extended to a mobility aid using novel Virtual Reality (VR) technology-associated devices. The implementation of such devices in a full VR design[12] is now a reality (although without image enhancement capability yet). Preliminary results from patient testing with that commercial system are forthcoming and will indicate whether this approach is useful for the visually impaired. If a beneficial effect is demonstrated, then the approach presented here can be implemented inexpensively to provide the additional benefit of image enhancement to these devices, whether using the full VR aproach or the bioptic approach I proposed. The growth of the HMD technology should provide opportunities for adapting inexpensive products to this special purpose application while lowering cost.

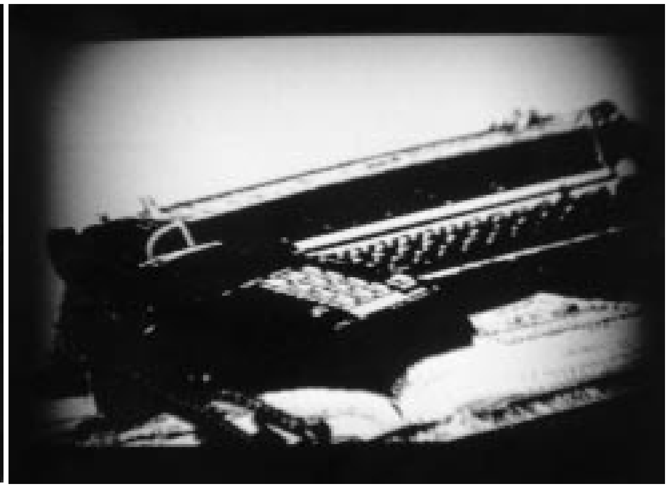


a b

Fig. 4. Comparison of the appearance of the binarized video image obtained from the head-mounted camera (a) without and (b) with the 1-D enhancement along the horizontal dimension only.



a



b

Fig. 5. Comparison of the appearance of the 1-D enhanced binary image at two camera angles: (a) upright and (b) slightly tilted. Note the appearance of many horizontal details in (b) which are not visible in (a), specifically the pages of the phone book and details of the typewriter.

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