Augmented Vision for Central Scotoma and Peripheral Field Loss

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Abstract

Electronic aids for the visually impaired using head mounted display devices were proposed by many and a few attempts at implementation have even made it to the market. Existing products provided mostly magnification and standard video contrast control. These products had only limited success and are usually not recommended for use in mobility. Other prototype devices provided image enhancement and light amplification for night vision. The limited success of these approaches has been attributed to the limited field of view of most devices and to difficulties adapting to high magnification vision for constant use in mobility (visual vestibular conflict). I propose a novel concept of augmented vision, which is based on a new method of enhancement and the use of open peripheral-view, see-through display devices. This concept could be used for both enhancement for central scotoma and field expansion for peripheral loss.

Introduction

The visual system has evolved to provide us with a very wide field-of-view (about 180 deg.) at a very high resolution (about 1 min. of arc). Achieving a wide field and a high resolution instantaneously would require information transmission from the eye to the brain that far exceeds the capacity of the optic nerves. While the wide field of view is continuously monitored at a low resolution, it provides sufficient information for navigation and detection of targets of interest. The central high-resolution fovea (about 1 deg.) is scanning or sampling targets only at about 5 samples per second using saccadic eye movements. This spatio-temporal sampling approach combined with effective reconstruction algorithms provides us with an apparently high detail view over a wide field even though at any instant only a fraction of the field is seen in high resolution.

Most conditions that cause low vision impact only one of the components, the peripheral low-resolution wide field or the central high-resolution fovea. The loss of central vision is the hallmark of Age Related Maculopathy and also characterizes Diabetic Retinopathy, Optic Neuropathy, Central Retinal Vein Occlusions and other conditions. Peripheral field loss (tunnel vision) is a severe constriction of the peripheral field leaving only the central 5-10 deg. of the field functional. This condition is the result of Retinitis Pigmentosa and Glaucoma.

In all cases the loss of one of the system's components prevents the interplay of central and peripheral vision essential for the high performance discussed above. This leads to a loss of function and results in impairment and disability. Low vision rehabilitation has traditionally addressed these problems by attempting to replace or supplement the missing function. Magnification is used quite effectively (though with some limitations) in central field loss (CFL) to increase the effective resolution of the residual peripheral field, while minification has been attempted, with only limited success, to expanding the peripheral view in tunnel vision.

I contend that most of the limitations of current low vision devices are due to the concentration on the missing component, without sufficient attention to the need to also reconstruct the *interplay* of central and peripheral vision as well as the use of eye movements. Thus, devices that increase resolution in CFL through magnification, i.e. electronic head-mounted magnification devices such as the LVES (low vision enhancement system) and the V-MAX, completely rob the patient of his functional peripheral vision that is necessary for navigation and safe mobility. Similarly, minifying devices such as the Amorphic lens (a spectacle mounted cylindrical reversed telescope) have been used to increase the horizontal span of the field seen instantaneously by a patient with tunnel vision (Szlyk *et al.*, 1998). However, these devices prevent scanning eye movements over a wider field of view and at the same time reduce the resolution of the central field.

The proposed aids for both central scotomas and restricted fields are based on using see-through head mounted displays (HMDs) and image processing to derive a line drawing cartoon-like representation of the live camera input. In the case of central scotomas we call the superposition of the high contrast cartoon over the original wide-band enhanced image.

Wide-band Enhancement

Fig. 1. An illustration of the possible applications of wide-band enhancement. The original image (top left) was processed to obtain the bipolar representation of edges and bars (top right). Note that the processing applied here assigns arbitrary polarity to edges while veridical polarity is associated with bar features. In the augmented vision devices, only positive polarity can be reasonably used. The images on the bottom represent two options tested: using only the positive contours and disposing the negatives (left) and using both while inverting the polarity of the dark features (right). It appears that the latter gives better results.

Previous methods of enhancement increased the contrast over a narrow band of frequencies 1 to 2 octaves wide (Peli *et al*., 1991). This concept, band-pass enhancement, involves combining a narrow band of frequencies with the original image. The wide-band enhancement method identifies the main features in the image ("bar and edge" features), which if presented on their own, would create a recognizable caricature of the image (see an example in Fig. 1, top right). The contrast of these features is increased maximally and they are superimposed on the original image. Because they are sharp linear patterns, these feature images have a wide-band spatial frequency spectrum and increase the contrast over a wide range of frequencies, but only in critically localized areas in the image. In these locations the phase is congruent (Morrone and Burr, 1989; Ventatesh *et al*., 1995). If the wide-band enhanced image is band-pass filtered, it appears quite similar to the adaptive enhanced, or band enhanced images used previously, indicating that the wide-band enhancement is an expansion of those methods.

Spatial frequency considerations show that wide-band enhancement enables us to improve the visibility of critical image details over a wide range of image. It also provides a way to maximize the use of the limited dynamic range available on the display while causing minimal distortion to the appearance and color of the images. Further, basic studies (Bennett and Banks, 1987; Bennett and Banks, 1991) vs (Morrone and Burr, 1989) show that the peripheral retina performs better on various spatial tasks such as *phase discrimination* and *localization* (Hess and Hayes, 1994) using wide-band stimuli rather than narrow-band patterns. Thus, wide-band enhancement should provide better discrimination of feature polarity and better localization. This suggests that patients with central scotomas will do better with wide-band enhancement than with narrow-band enhancement, possibly without the need for individual tuning. Indeed, preliminary testing of this concept using static images proved promising as patients with CFL preferred the wide-band enhanced images and the preference increased as the severity of the visual loss increased (Peli, 1998). The same image processing technique used for enhancement in the case of central scotoma may be used for field expansion in cases of tunnel vision.

Minified Contours Augmented View for Tunnel Vision

The impact of field restriction on mobility is significant only when the loss is severe in both eyes, to the level of 10-deg. residual vision or less (Ferraro and Jose, 1983). Current methods of optical treatment include prisms and minifying telescopes. Prisms are ineffective in increasing the instantaneous field as they only shift the visible section of the world when the eye views through the prism. Furthermore, most commonly used and proposed prism systems (InWave, 1998) actually create optical scotomas at the spectacle lens (similar to the ring scotoma of telescopes). Patients using such systems have to use additional eye and head movements to avoid the scotoma created by the prism. Minifying systems are usually reversed Galilean telescopes. These are implemented as simple telescopes or more complex devices such the Amorphic lens (Szlyk *et al*., 1998), or the "fish eye" non-uniform minifier. The "fisheye" non-uniform minifier was implemented both as an optical device (door security peephole) and as electronic image remapper (Loshin and Juday, 1989). These devices do increase the instantaneous field of view but in all cases result in loss of spatial resolution and require scanning by head movements instead of eye movements. Most patients reject their minifiers, as the benefits (modest increase in the field of view, e.g. double) do not compensate for the reduced resolution and the need to scan using head movements rather than eye movements.

I propose a novel method that increases the instantaneous field of view without loss of central resolution and without restricting scanning eye movements. This would enable up to as much as 4X minification. This method is based on the principle of spatial multiplexing using an augmented-reality technique a with see-through HMD (mentioned on pg. 3). The system illustrated in Fig. 2 includes a see-through HMD with a typical horizontal field of view of about 25 deg. The patient can see the real world through the display without any reduction in resolution or limitations on scanning eye movements (scanning larger angles than available within the field of the display involves head movements even in natural situations). A miniature monochrome video camera mounted on the HMD has a field of view substantially wider than that of the display (a factor of 3 to 4 times wider). A portable processor provides real time (video rate) edge detection from the images captured by the camera. The detected edges are displayed on the see-through display as bright contours. The edges, which represent a very wide field-of-view (of 75 to 100 deg.) on a smaller field-of-view HMD, are minified. Thus the patient, with the severely restricted field of view illustrated by the elliptical shaded area in Fig. 2, can simultaneously see a full resolution view of the real world and the superimposed wider view represented by the edge contour map. The contour map, reduced in resolution, provides the patient with navigation information, which would otherwise be outside his view. Because the contours are minified, their movements (as a result of head movement) are slower and they are easily separated perceptually from the natural view of the world behind them. Because the contours occupy only a small fraction of the display area and are continuously moving, they rarely obscure any detail of the real-world view for any length of time. The proposed system provides the expanded scannable field of view while maintaining the all-important high-resolution of central vision.

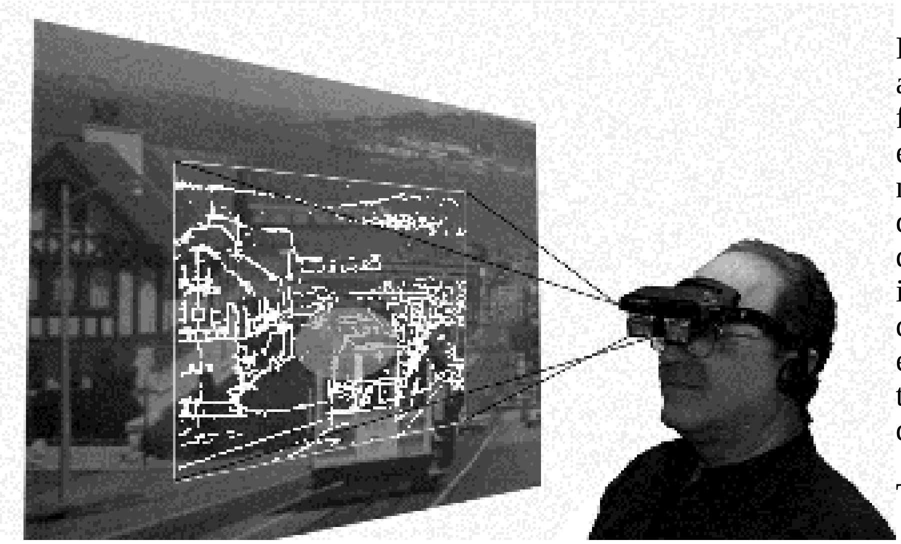

Fig. 2. An illustration of the concept of minified augmented view for patients with severely restricted field of view (illustrated as the small shaded elliptical area in the middle of the scene). The natural scene (gray scale image) is seen through the display. A wide-angle camera mounted on the same device obtains a wide-angle view, which is turned into contours and presented as white lines on the display. Thus the patient can see a wider part of the environment depicted in contours at each glimpse together with a normal resolution image through the display.

The wide-band enhancement, discussed

above, generates edges and bar features of the appropriate polarity. The use of black features in the see-through design will require a gray level background. Such a background will mask the contrast of the view through the display. Therefore, in this application only white features should be used. The bottom images in Fig. 1 illustrate two options for the generation of white-only features from the bipolar presentation. As can be seen both are satisfactory.

By using an edge detection algorithm that detects only edges of objects in motion (Castleman, 1979 pg. 106), the patient can control edges detected in a static environment by controlling the camera movements with slight head movements. While the head is stable only objects that move in the environment relative to the patient will be detected and displayed as edges. If the patient moves his head slightly, all edges in the environment will be detected and displayed. The patient thus can use slight head motion to temporally control the level of contour display available at any instant.

An InfraRed (IR) Camera rather than a standard video camera may be used in such a system to provide visibility at night for patients suffering from night blindness. The display may present the detected edges in red light, avoiding the light adaptation that would completely destroy the patient’s ability to view the outside dark environment if white light were used.

Wide-band Enhancement as Augmented Vision in HMD and for TV

Wide-band enhancement in the augmented vision situation with HMD for patients with CFL requires the same system as described above for the minified augmented view for patients with tunnel vision. The only difference is that in the case of the enhancement for patients with CFL, the contour image projected on the display has to be of the same size as the real world view seen through the display and exactly aligned with it.

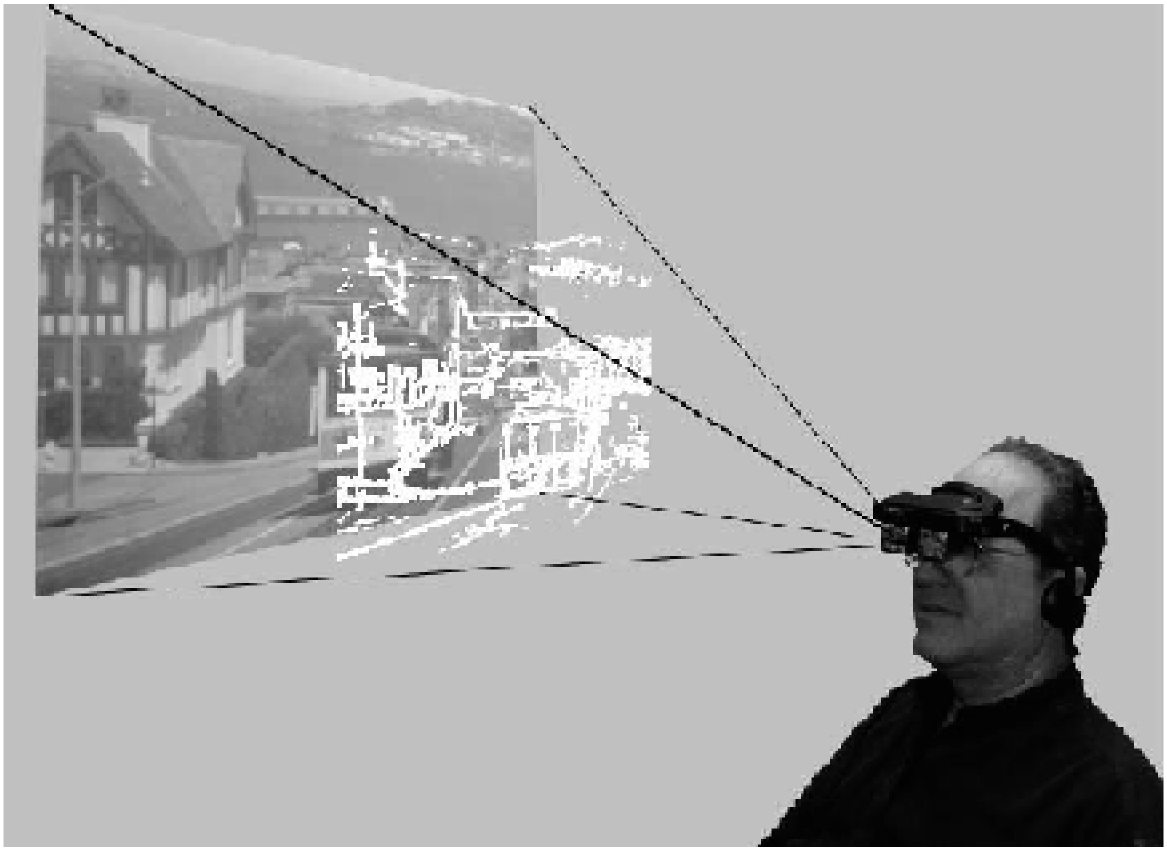

Fig. 3. An illustration of the concept of augmented vision using wide-band enhancement for patients with CFL. The edge map computed from a video of the see-through scene is superimposed on the display as bright contours. Here the visual field of the camera is identical to the angular span of the display and exact registration is required (unlike the system illustrated in Fig. 2). Assessing the feasibility of such alignment (which is expected to be less critical for patients with CFL than for people with normal vision) is one of the challenges of this proposal.

Fig. 3 is an illustration of the augmented vision system using wide-band enhancement for patients with CFL. The edge map computed from a video of the see-through scene is superimposed on the display as bright contours. The appearance to the patient in such a system is illustrated in the bottom row of Fig. 1. Here the visual field of the camera is identical to the angular span of the display and exact registration is required (unlike the system illustrated in Fig. 2). Assessing the feasibility of such a lignment (which is expected to be less critical for patients with CFL than for people with normal vision) is a challenge we are still facing. While exact alignment is a challenge in the case of a camera and HMD, the alignment is trivial if the enhancement contour is simply superimposed on the camera's view. This approach can provide wide-band enhancement using opaque HMDs and even more importantly in enhancing TV displays. Here, however, the motion edge detection is insufficient, as in many cases the camera will be static and motion edge detection will not provide sufficient edges to recognize the static scene. For this application therefore static edge enhancement will be required.

Dynamic control of magnified TV can be combined with wide-band enhancement. The full image is processed to obtain high contrast contour edges that are superimposed over the displayed image. If the image is magnified the contour edges may remain unmagnified. This hybrid presentation will provide the patient with increased resolution of the important details via magnification at the same time the contour outline will provide a wide field view of the original video frame compensating for the limited field of view inherent in the magnified view. Using the outline view the patient may choose when to reduce magnification for a larger field of view or when to override the frame centration and explore by manual control other parts of the video. This returns the situation to the spatial multiplexing discussed above. The only difference is that here the field restriction for which we correct is due to the magnification, not the patient’s visual system.

Conclusion

A novel approach for low vision aids designed to reconstruct the interplay of peripheral wide field of view with central high-resolution vision is described. In all cases the design permits continuous use of eye movements for scanning. Using see-through HMDs with on open design should be possible to provide such devices for both patients with central field loss and for patients with restricted fields. The main advantage of the approach is that the residual vision, whether central or peripheral, remains available and readily accessible to the patient when using these devices. Recent developments in HMD devices and in image processing technology are making the proposed devices a real possibility from both economic and technological perspectives.

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References.

Bennett, P. J. and Banks, M. S. (1987). Sensitivity loss in odd-symmetric mechanisms and phase anomalies in peripheral vision. *Nature* **326**, 873-876.

Bennett, P. J. and Banks, M. S. (1991). The effects of contrast, spatial scale, and orientation on foveal and peripheral phase discrimination. *Vision Research* **31**, 1759-1786.

Castleman, K. R. (1979). *Fourier Transforms in Digital Image processing*, Prentice-Hall, Englewood Cliffs, NJ.

Ferraro, J. and Jose, R. T. (1983). Training programs for individuals with restricted fields. In R. T. Jose (Ed.), *Understanding Low Vision*, American Foundation for the Blind, New York. Vol. 14, 363-376.

Hess, R. F. and Hayes, A. (1994). The coding of spatial position by the human visual system: Effects of spatial scale and retinal eccentricity. *Vision Research* **34**, 625-643.

InWave (1998). *Inwave Optics. Prescribing Guide*, InWave, Janesville, WI.

Loshin, D. S. and Juday, R. D. (1989). The programmable remapper: clinical applications for patients with field defects. *Optometry and Vision Science* **66**, 389-395.

Morrone, M. C. and Burr, D. C. (1989). Discrimination of spatial phase in central and peripheral vision. *Vision Research* **29**, 433-445.

Peli, E. (1998). Wide-band image enhancement for the visually impaired. *Invest. Ophthalmol. Vis. Sci. (ARVO Suppl.)* **39**, s398.

Peli, E., Goldstein, R. B., Young, G. M., Trempe, C. L. and Buzney, S. M. (1991). Image enhancement for the visually impaired: Simulations and experimental results. *Invest. Ophthalmol. Vis. Sci.* **32**, 2337-2350.

Szlyk, J. P., Seiple, W., Laderman, D. J., Kelsch, R., Ho, K. and McMahon, T. (1998). Use of bioptic amorphic lenses to expand the visual field in patients with peripheral loss. *Optometry and Vision Science* **75**, 518-524.

Ventatesh, S., Cooper, J. and White, B. (1995). Local energy and pre-envelope. *Pattern Recognition* **28**, 1127-1134.

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