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The Virtual Retinal Display: A New Technology for Virtual Reality and Augmented Vision in Medicine.

Erik Viirre M.D. Ph.D. Homer Pryor, Satoru Nagata M.D. Ph.D. and Thomas A. Furness III Ph.D.

Human Interface Technology Laboratory, University of Washington.
Box 352142 Seattle WA 98195-2142

Abstract

Introduction: The Virtual Retinal Display (VRD) is a new technology for creating visual images. It was developed at the Human Interface Technology Laboratory (HIT Lab) by Dr. Thomas A. Furness III. The VRD creates images by scanning low power laser light directly onto the retina. This special method results in images that are bright, high contrast and high resolution. In this paper, we describe how the VRD functions, the special consequences of its mechanism of action and potential medical applications of the VRD, including surgical displays and displays for people with low vision. A description of its safety analysis will also be included. In one set of tests we had a number of patients with partial loss of vision view images with the VRD. There were two groups of subjects: patients with macular degeneration, a degenerative disease of the retina and patients with keratoconus. Typical VRD images are on the order of 300 nanowatts. VRD images are also readily viewed superimposed on ambient room light. In our low vision test subjects, 5 out of 8 subjects with macular degeneration felt the VRD images were better and brighter than the CRT or paper images and they were able to reach the same or better level of resolution. All patients with Keratoconus were able to resolve lines of test several lines smaller with the VRD than with their own correction. Further, they all felt that the VRD images were sharper and easier to view. The VRD is a safe new display technology. The power levels recorded from the system are several orders below the power levels prescribed by the American National Standard. The VRD readily creates images that can be easily seen in ambient roomlight and it can create images that can be seen in ambient daylight. The combination of high brightness and contrast and high resolution make the VRD an ideal candidate for use in a surgical display. Further, tests show strong potential for the VRD to be a display technology for patients with low vision.

1. Introduction

The Virtual Retinal Display (VRD) is a new technology for creating visual images. It was developed at the Human Interface Technology Laboratory (HIT Lab) by Dr. Thomas A. Furness III. The VRD creates images by scanning low power laser light directly onto the retina. This special method results in images that are bright, high contrast and high resolution. Current prototypes of the system produce full color images at a true 640 by 480 resolution.

The technologies of virtual reality (VR) and augmented reality (AR) are the new paradigm for visual interaction with graphical environments. The features of VR are interactivity and immersion. To achieve these features, a visual display that is high resolution and wide field of view is necessary. For AR a visual display that allows ready viewing of the real world, with superimposition of the computer graphics is necessary. Current display technologies require compromises that prevent full implementation of VR and AR. A new display technology called the Virtual Retinal Display (VRD) has been created. The VRD has features that can be optimized for the human computer interfaces.

The VRD is a visual display device that uses scanned light beams. Instead of viewing a screen, the user has the image scanned directly into the eye. A very small spot is focused onto the retina and is swept over it in a raster pattern. The VRD uses very low power and yet can be very bright. The technology has been developed such that the scanning element will cost only a few dollars in mass production. Low cost light sources, optics and controllers will make up the rest of the system. Ultimately, the overall device should be very inexpensive yet it will be small enough to mount on a spectacle frame.

The development of this device has been driven by the need for a ubiquitious display that is lightweight, full color and high resolution. In particular, the demands for displays for virtual environments and augmented vision are most pressing. In the past, virtual environments displays have been very heavy, low resolution and have a small field of view. To create compelling virtual environments, the opposite is needed. The demands of displays for augmented reality, where the computer graphics image is superimposed on the real world, include a bright, high contrast image, and color that is appropriate. For example, an augmented vision display for a surgeon, which might provide him anatomic navigation information, would need to be unobtrusive during most of the procedure, produce bright enough images to be seen under the lights of the operating theatre and have color matched images that correspond to what the surgeon is seeing. The special characteristics of images from the VRD may make it very useful for people with partial loss of vision.

Figure 1 is a block diagram of the VRD. Laser sources are introduced into a fiber optic strand which brings light to the Mechanical Resonance Scanner (MRS) (patent pending). The MRS is the heart of the system. It is a lightweight device approximately 2 cm X 1 cm X 1cm in size and consists of a polished mirror on a mount. The mirror oscillates in response to pulsed magnetic fields produced by coils on the system mounting. It oscillates at 15 KHz and rotates through an angle of 12 degrees. The high frequency of scanning allows the fine resolution in the images produced. As the MRS mirror moves, the light is scanned in the horizontal direction. Because the mirror of the MRS oscillates sinusoidally, the scanning in the horizontal direction has been arranged for both the forward and reverse direction of the oscillation. The scanned light is then passed to a mirror galvanometer or second MRS which then scans the light in the vertical direction.The horizontally and vertically scanned light is then introduced to the eye. The light can be sent through a mirror/combiner to allow the user to view the scanned image superimposed on the real world.

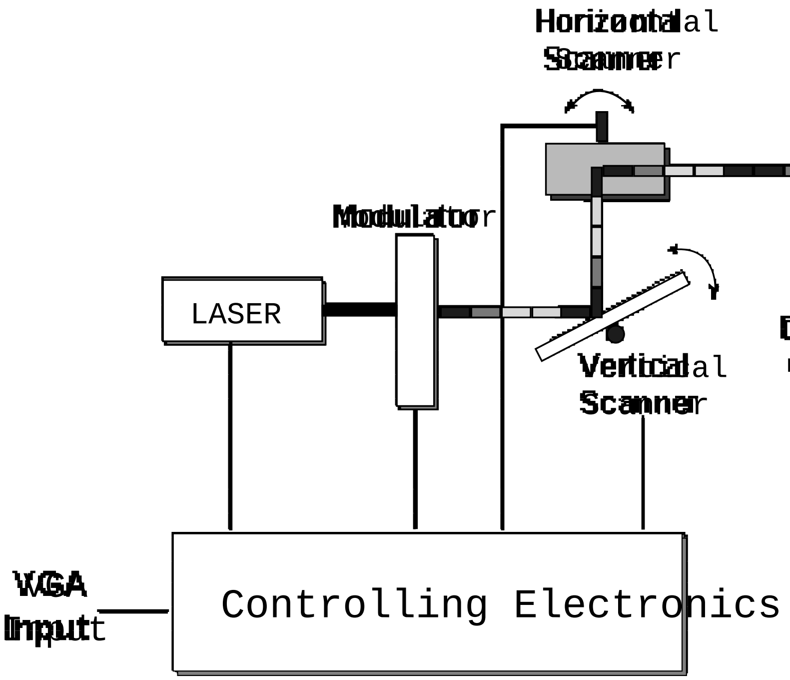

Figure 1. Block Diagram of VRD systems

VRD versus Pixel Based Displays

The mode of illumination of the retina by the VRD is quite different from conventional screens. The scanning mechanism rapidly sweeps a spot of light over the retina. The spot passes over the retinel (an area analogous to the retinal area where a pixel is focused). Thus the retinel is not illuminated uniformly in time. Further, the actual time of illumination is extremely brief (40 nanoseconds). There is only a brief spike of illumination of a portion of the retina for each refresh cycle of the display. The light from the VRD is coherent and very narrow band in wavelength. The VRD can be configured such that the spot actually overlaps retinels or is smaller than a retinal area. Table 1 summarizes the differences between the pixel based display and the VRD.

Table I

Pixel Based Display	VRD
Illumination constant over whole pixel	Light scanned across retina
persistent light emission	Short transient light emission
non coherent light	coherent light
broadband color	narrow band color
pixels separated by mask	Spot can overlap retinels in scans

Aids for the Partially Sighted: The Need

People with partial vision constitute approximately 2% of the population in King County according to an internal study by Seattle Community Services for the Blind and Partially Sighted. Other centers around the country find similar population numbers[1-3]. The partially sighted have several major needs. According to CSBPS, sufferers with low vision most often request aids to allow them to read text or watch television and they may also require aids for navigation or other activities of daily living. Current visual aids include simple glass magnifiers, video magnifiers and custom computer display enhancers. However current devices use old display technologies. The old displays have inherent limitations in resolution, brightness, contrast, and field of view[4-8]. Further, the older display technologies are generally not portable and have inherent characteristics that make them clumsy for use by the partially sighted.

In this paper, we will describe potential medical applications of the VRD, including displays for people with low vision and surgical displays. A description of its safety analysis will also be included.

2. Methods

For our safety analysis, we measured the light power output of the VRD when it was creating images. We had subjects adjust the brightness of the VRD images in a see through configuration that allowed them to see an image on a conventional CRT screen. The VRD image brightness was adjusted so that it appeared equal to the brightness of the CRT images.

The tables below show the results of some trial tests of low vision subjects with the VRD. In these tests subjects were brought in and gave informed consent. They were shown a series of vision test images on paper, a computer screen and with the VRD. Their visual acuity was tested with a standard office vision chart. For each display they were then shown test images to determine their resolving ability (acuity) and if any distortions were present (astigmatism or linear distortions on an Amsler grid) The performance on each medium was recorded and the subject's subjective impression of the visual image was also determined. The prototype VRD system was used for these tests.

In our pilot study we did a straightforward comparison of image quality of images from the VRD and a CRT and a images on paper. We controlled angular size of the images to be able to compare best visual acuity. Image intensity was not controlled.

Acuity measures: Landolt C's.

Image distortion Measures: Astigmatism stars and Amsler grids.

Subjective impressions of the images.

Subjects: Normal, Macular Degeneration, Keratoconus

3. Results

In our safety analysis, all subjects were readily able to match the VRD brightness to the bightness of the control images. Power output values of the VRD varied from 50 to 1200 nanowatts. Typical VRD images are on the order of 300 nanowatts. Typical VRD images are also readily viewed superimposed on ambient room light. Normal subjects are all able to see VRD images clearly. All 8 formally tested subjects were able to resolve VRD targets within one line of CRT or paper targets. 4 were able to resolve targets at the same resolution. 5 of 8 normal subjects reported VRD images to be "as sharp" or "sharper" than CRT or paper targets. There was no distortion detected with astigmatism stars or Amsler grids.

Macular Degeneration Subjects

MD subjects generally saw VRD targets as well subjectively and objectively as the CRT and paper targets. Macular degeneration is a degradation of the visual receptors in the central part of the retina resulting in a decreased ability to read or recognize objects such as faces.Their visual acuity was sharper with the VRD in some cases due to the pinhole effect on refractive error. Localization of the small pinhole was difficult for some subjects.

Keratoconus Subjects

Keratoconus is a distortion of the cornea. It results in blurred, defocussed images. All keratoconus subjects reported that they saw VRD images more sharply than any other visual targets and in any viewing condition: no correction, glasses correction or contact lens correction (which normally provides the best vision). All subjects had equal or higher visual acuity with the VRD targets, again even when wearing a gas permeable contact lens.

Subject	Visual Acuity		Vision Disorder	Paper		CRT		VRD	
	OS	OD		OD	OS	OD	OS	OD	OS
1	20/400	20/200	Macular Degeneration	1/2	4	2/3	3	2/3	4
2	20/200	20/400	Macular Degeneration	3/4	1	3/4	1	5/6	1/2
3	20/800	20/800	Optic Neuritis	1	3	1	3	1	2
4	20/200	20/80	Macular Degeneration	1	6	1	6	0	6
5	20/400	20/400	Keratoconus	1	1	1	1	6	7
6	20/400	20/400	Keratoconus	1	1	1	1	6	7
7	20/400	20/400	Keratoconus	1	1	1	1	7	7
8	20/20	20/20	Retinal Pigmentosa	6	6	6	6	6/7	6/7

Note:

Vision test accomplished using Landolt C charts.
Snellen Chart used to determine visual acuity.
Amsler grid and Astigmatism tests showed no difference between three conditions.

Legend	
1	20/400
2	20/200
3	20/160
4	20/120
5	20/80
6	20/40
7	20/30

Augmented Reality.

One of the leading applications for the VRD will be augmented vision and augmented reality. Because of the bright images that can be produced by the VRD it will be possible to use it in conditions as bright as ambient daylight. No current displays technology can produce a portable image this bright. In augmented reality applications, images from the display are overlaid on the real world for task enhancement. In augmented vision the images move with the subject's head. In augmented reality, the images are held in registration with the real world as the subject moves. For example, in an augmented reality application, a worker could see an instruction manual or diagram overlaid on a part that is being repaired. Another use would be for people working in environments with poor lighting conditions. The real world image could be enhanced electronically and presented for better viewing with the VRD. In the elderly, opacities in the optical media of the eyes increase glare as they view objects in sunlight or lighting conditions for night. The VRD could be used to image the world and then display it without the glare.

Understanding of how the perception of images from the VRD interact with images from the real world is crucial for these applications. The test set ups for the beam characterization studies and color perception studies will be ideal for augmented reality tests. In these tests the VRD will produce images that will be superimposed on real world textures and backgrounds in a series of lighting conditions. The same image quality tests acuity, contrast, color and saturation discrimination will be performed while viewing the images with various backgrounds. The beam intensity will be varied by the subject to maximize viewing quality. Beam characteristics and color sources will be reconfigured to maximize color contrast and hue matching with real world objects.

4. Conclusions

The VRD is a safe new display technology. The power levels recorded from the system are several orders below the power levels prescribed by the American National Standard. The VRD readily creates images that can be easily seen in ambient roomlight and it can create images that can be seen in ambient daylight. The combination of high brightness and contrast and high resolution make the VRD an ideal candidate for use in a surgical display. Further, tests show strong potential for the VRD to be a display technology for patients with low vision.

Our future projects are:

1.) Study the basic psychophysical processes of image perception from scanned lasers including resolution, contrast and color perception

2.) Study the interaction of VRD images with images from the real world to enhance the augmented reality applications of the technology.

3.) study VRD image perception in partially sighted users.

4.) design VRD light scanning paradigms to optimize image resolution, contrast in low vision subjects.

5.) Design text, image and computer icon representations for low vision users and test speed and accuracy of recognition of those representations in the Seattle low vision population.

5. Acknowledgements

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