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The Virtual Retinal Display: A Technology for Augmented Reality

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Abstract: Virtual Retinal Display (VRD) is an advanced technology for creating visual images. Dr. Thomas A. Furness III created it at the Human Interface Technology Laboratory (HIT Lab). Low power laser light is directly scanned onto the retina by the VRD to produce images. Bright, high-contrast, high-resolution photos are produced with this unique technique. It has been shown that all the technological advancements needed have been made in order for small, laser-scanned, virtual retinal displays to operate effectively. Since several years ago, military and commercial customers have received prototype devices with VGA resolutions (640 x 480 pixels), and Microvision's Virtual Retinal DisplayTM (VRDTM) is now ready for accelerated performance expansion. VRD images often use 300 nanowatts or less. Additionally, VRD images can be easily seen when placed on ambient room lighting.
Keywords: VRD, VGA, Virtual Reality, VRDTM

I. INTRODUCTION

The VRD display technology differs significantly from other, current display technologies. Without the need for displays, the VRD "paints" a high-resolution, full-motion, full-color image directly onto the retina of the viewer's eye using a modulated, low-power beam of light (in a raster scan pattern similar to that of a traditional television set). In some applications, an image is displayed in the viewer's field of vision as if the viewer were standing right next to a high-definition video screen. In other uses, the VRD can overlay an image on the viewer's field of vision (augmented vision), allowing the viewer to see data or other information in the context of his or her natural surroundings. The spectator sees a high-resolution, bright image regardless of how the VRD is used.

In 1991, the Human Interface Technology Lab (HIT) at the University of Washington developed the VRD. In November 1993, construction got underway. A full color, wide field of vision, high resolution, high brightness, and a reasonably priced virtual display was the goal. The sole license for commercializing VRD technology belongs to Microvision Inc. From head-mount displays (HMDs) for military and aerospace applications to the medical community, this technology offers a wide range of possible uses.

The VRD sends an electronically modulated light beam directly onto the retina of the eye, creating a rasterized image. The source image seems to the viewer to be visible from two feet away when seated in front of a 14-inch display. The retina of its eye, not a screen, is where the image is actually located. He or she is viewing an excellent-quality image with stereo vision, full color, a large field of view, and no flickering features.

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II. ARCHITECTURE OF VRD

Through the direct application of modulated light in a raster pattern to the retina of the viewer, the Virtual Retinal Display displays video data. The intensity of the light is varied as it passes over the eye. The VRD is made up of a light source, a modulator, vertical and horizontal scanners, and imaging optics at its most basic level, as depicted in the following picture (to focus the light beam and optically condition the scan).

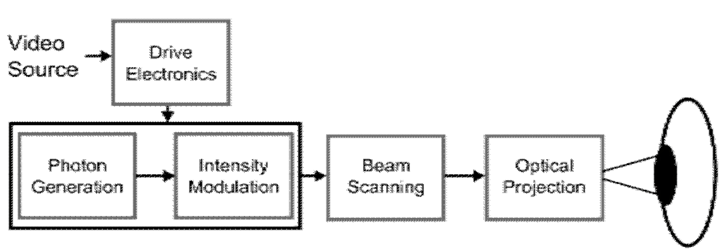

Figure 1: Architecture of VRD

The retinal image that is created as a result is interpreted as a wide-field of-view image coming from a certain viewing distance in space. The light raster on the retina and the resulting image that is viewed in space are shown in figure2.

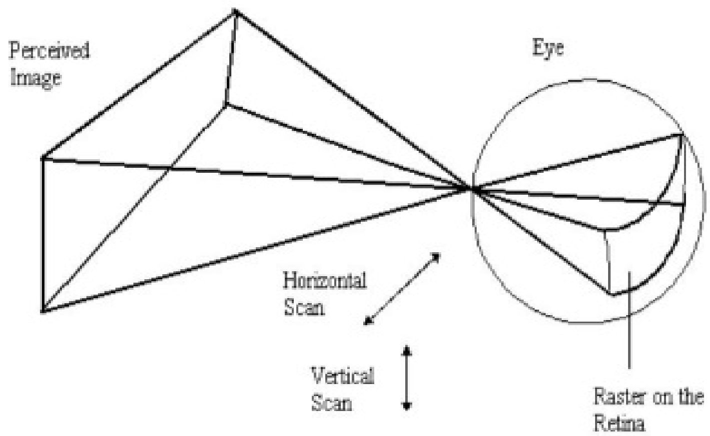

Figure 2. Illustration of light raster imaged onto the retina and the resultant perceived image.

A scanner generally scans an angled collimated light beam using magnifying optics. Each collimated beam is targeted upon a specific region of the retina. The location of the matching concentrated area moves across the retina as the scan's angle shifts over time. The raster image as it is seen in Fig:2 is made up of a series of intensity modulated spots.

III. WORKING TECHNOLOGY

A. Three Units Typically Comprise A VRD System

1) System Unit - Both a light source module and the driving electronics are part of the System Unit system.
2) A connecting cable- Between the System Unit and the Display Unit, the interconnect cable transports multiple electrical conductors as well as optical fibers.
3) Display Unit- The Display Unit can be worn on the head or on a helmet. It includes the viewer optics, the pupil expander, and the scanner assembly.

B. Five Major components in typical VRD System

1) *The System Drive Electronics:* The system drive electronics receive and process an incoming video signal, provide image compensation, and control image display.
2) *The Light Source Module:* The light source module includes a color combiner, light modulators, and a laser light source. Red, green, and blue (RGB) laser light sources are used alone or in combination. Each laser light source's light is modulated by the light modulators. Signals from the system drive electronics are used to modulate. The red, green, and blue modulated beams are individually combined by the color combiner to create a single white light beam.
3) *Scanner Assembly:* Two scanning mirrors are part of the scanner equipment. The laser light beam (from the light source module) is swept horizontally by one scanning mirror at a high frequency and in a raster pattern. The vertical laser light beam is swept by a second scanning mirror but at a considerably lower frequency. Both scanning mirrors are managed by synchronizing signals produced by the system drive electronics. The drive electronics get real-time information on the precise mirror position in the form of position feedback signals from both mirrors.
4) *Pupil Expander:* An exit pupil expander is an optical tool that broadens the field of vision for the observer. The pupil, expander, and viewer optics all pass through the raster image produced by the horizontal and vertical scanners, depending on the exact mirror location.
5) *Viewer Optics:* The user's oculars are fed the scanned raster image by the viewer optics.

IV. VRD FOR SYNTHETIC VISION INFORMATION SYSTEM

The emergence of cutting-edge image sensor and display technology supports the need to restructure digital synthetic/augmented vision systems. Under Instrument Meteorological Conditions, these systems' operating goal is to deliver range resolution and target recognition performances on par with or better than those attained with unaided human vision. A display for a synthetic vision system must do three tasks.

Firstly, the display must be built to provide the operator with the most information possible. As a result, a head- or helmet-mounted display (HMD) of low mass and great utility must be built to incorporate the picture properties of brightness, contrast (shades of grey), spatial resolution, and color. Color fully engages the human visual system, allowing it to detect and recognize targets, display false-color information from imaging sensors, facilitate color encoding of symbolic information, and improve the intelligibility of information displayed in comparison to ambient luminance.

Second, to align the real and virtual worlds, it is also necessary to track the operator's head's spatial orientation. There are many other technologies available, but because of their high accuracy, rapid update rate, and environmental robustness, a video metric approach is advised whenever it is practical.

Finally, eye-tracking capabilities are needed. Eye tracking enables a virtual world where the user's eye serves as a hands-free "mouse" for "look-to-activate" or "look-to-shoot" operations. The accuracy and update rate necessary are now becoming available using simple, affordable methods. In its visually-coupled HMD systems, Microvision will integrate COTS (commercial off-the-shelf) head- and eye-tracking technology.

V. APPLICATIONS OF VRD

The VRD has a wide range of application sectors, including manufacturing, communications, and classic virtual reality helmet mounted displays (HMDs). The VRD can be set up as inclusive (non-see-through) or see through, head mounted or hand held, and it offers high brightness and high resolution, making it suitable for a variety of applications. The sections that follow provide descriptions of some particular applications in the aforementioned industries.

1) *Radiology:* The fluoroscopic examination is one test that radiologists can perform. The radiologist uses live video x-rays to view the patient during a fluoroscopic examination. Until the patient is in the desired position, the radiologist must continuously reposition the patient and the examination table. The radiologist makes a film duplicate of the x-ray image after the patient is in the desired posture. Because the radiologist must simultaneously keep an eye on the patient, the video monitor, and the exam table, placement can be challenging and time-consuming. It is the perfect display to take the place of the large video monitor in a fluoroscopic examination room since the VRD can function in a see-through mode at high brightness levels. Through the x-ray monitor, the radiologist could see the patient as well. For this application, additional functionality like a display brightness adjustment or an on/off switch might be readily added
2) *Surgery*: Knowledge of the growth's location is necessary for surgery to remove a cancerous growth. It is possible to find a tumour inside a patient using magnetic resonance imaging or computed tomography. With head tracking and a high brightness see-through display, like the VRD, it may be possible to visibly locate a tumour within the human cavity. If a tumour, let's instance, is concealed behind an organ, the tumor's location and a depth indicator might be visually placed over the obstruction. Any display application in surgery would obviously need precise and dependable head tracking.
3) *Manufacturing:* High luminance and high resolution, which are the same qualities that make the VRD appropriate for medical applications, also make it very suitable for a production setting. A industrial worker can utilise a high brightness display and head tracking to acquire visual information on part or placement locations in a manner similar to surgery. If done electronically to a Virtual Retinal Display, plans and drawings might likewise be transferred to a production floor more readily (with the option of see through mode). Engineers and workers receive information about machines and processes through operator interface terminals on factory floors. A few examples of the types of data shown on operator interface terminals are valve positions, alerts, and thermocouple temperatures. Operator interface terminals might be replaced by eyeglass-style transparent Virtual Retinal Displays. Engineers and industrial workers would be more mobile on the factory floor with a high-brightness eyeglass display since they could be independent of the interface terminal position.
4) *Communications:* A mechanical resonant scanner (MRS) based VRD is a great display for one-on-one communication due to its small size and light weight. A portable monochrome VRD could be used as a video FAX or personal video pager. The display might be connected to a phone. A full-service personal communication gadget would include both video and telephone capabilities.

5) *Virtual Reality:* Virtual reality today includes the conventional helmet display as a key component. The VRD will be modified for this use. Then, it can be applied to virtual reality applications in education and architecture as well as long-distance virtual conference communications. In fact, it can be used in any virtual reality applications. It is a potential technique for the development of virtual reality head-mounted displays in the future because the theoretical limits of the display are simply the boundaries of the eye.
6) *Military Applications:* To support judgements that are time-sensitive (and frequently life-and-death), helicopter pilots need information. The effort of the pilot is reduced and visibility in poor visibility conditions can be improved if such information is given in a graphical and intuitive manner. To build a reliable pilot-data interface, a helmet-mounted display that can show full-color graphics throughout day and night flying operations has been needed. That finally might help to save both money and lives. With the ability to superimpose flight reference data, sensor imaging, and weapon iconography on [images from] the outside world, the Army has a potent vision. It is anticipated that having such a flexible display capability will significantly improve both the aircraft and the pilot's performance. It becomes even more effective when you can provide a pilot the ability to perceive the typically undetectable "bloom" of a radar signature, project a "road in the sky" in front of him, and superimpose wireframe or 3-D graphics into the environment. What you see depends on where you look is another idea incorporated into the Army's conceptualization of the virtual cockpit. Different targeting, navigational, or topographical overlays would display as the pilot looked up and outside the cockpit. Pilots may see "virtual" instruments projected onto their eyes when they look downward that literally replace many of the dials and multifunction displays used in modern cockpits.

VI. ADVANTAGES AND DISADVANTAGES

A. Advantages

1) *Size and Weight:* Unlike systems using LCD or CRT technology, the VRD does not demand an intermediary image on a screen. The photon source, preferably immediately modulatable, the scanners, and the optical projection system are the only necessary parts. One option is to utilize a laser diode or other small photon source. A simple mechanical resonant device created by the HITL can be used to scan. The front, reflecting surface of a pair of spectacles in a head mount configuration or a basic lens in a hand-held configuration could be integrated with the projection optics. With encouraging findings, HITL engineers have experimented with single-piece Fresnel lenses. The few components and lack of an intermediary screen will result in a system that can be held in the hand or put on the head with ease.
2) *Resolution:* The physical characteristics related to producing the LCDs or CRTs used to generate the image have a limit on the resolution of the current generation of head mounted and hand-held display devices. There is no such cap in the VRD. Diffraction and optical aberrations caused by the system's optical components, scanning frequency restrictions, and the photon source's modulation bandwidth are the VRD's limitations. A photon source with a modulation bandwidth large enough for displays with well over a million pixels is a laser diode. Multiple sources can be used if a higher resolution is needed. Displays with more than 1000 lines will be supported by already available scanners, enabling HDTV quality systems. Multiple sources that hit the scanning surface at various angles can be employed if higher resolutions are desired.
3) *Field of View:* The primary scanner's scan angle and the optical system's power determine the VRD's field of view. First-generation inclusive systems with horizontal fields of view more than 60 degrees have been demonstrated. It is possible to design inclusive systems with 100-degree fields of view. Fields of vision for see-through systems will be a little bit smaller. There have been examples of modern see-through systems with exceeding 40-degree horizontal fields of view.
4) *Color and Intensity Resolution:* Using three-photon sources—a red, a green, and a blue—a VRD will produce color. The three hues will be blended together so that they physically overlap. As opposed to the conventional practice of closely spacing a triad, this will produce a single spot color pixel, increasing spatial resolution. The viewer's perception of the VRD's intensity is directly correlated with the photon source's intensity. The amount of current that powers a photon source, such a laser diode, determines how powerful it is. More than 10 bits of intensity resolution per color will be possible with proper current regulation.
5) *Brightness:* The largest benefit of the VRD idea might be brightness. The most recent generations of personal displays struggle in settings with intense lighting. When a soldier is supposed to use the system outside or a doctor is supposed to use it in a well-lit operating room, this can lead to serious issues. The typical remedy is to obstruct out as much ambient light as you can. Unfortunately, when a see-through mode is needed, this does not perform effectively. By scanning a light source that is directly on the retina, the VRD produces a picture. Only the power of the light source can restrict the perceived brightness. It has been discovered through research that a brilliant image may be produced with less than one microwatt of laser light.

The few milliwatt range of laser diodes is typical. Because of this, laser diode source-based systems will function with low laser output levels or with severe beam attenuation.

6) *Power Consumption:* The VRD effectively transmits light to the retina. The system's exit pupil can be reduced, allowing the majority of the created light to reach the eye. Additionally, a resonant device that operates with a high figure of merit, or Q, and is also very efficient is used for scanning. As a result, the system requires relatively little electricity to run.
7) *Stereoscopic Display:* Different images are projected into each viewer's eye via the conventional head-mounted display used to produce three-dimensional views. A stereo pair is produced by producing each image from a slightly different vantage point. This approach results in a conflict but also permits the use of one significant depth cue. For the purpose of detecting depth, humans use a variety of clues. Along with stereo vision, accommodation is crucial for determining depth. The distance at which the eye is focused to see a distinct image is referred to as accommodation. The image is positioned at a convenient and fixed focal distance by the virtual imaging optics utilised in modern head-mounted displays. Since the image is coming from a flat screen, everything in the virtual image is situated at the same focal distance in terms of accommodation. As a result, the accommodation cue suggests that an object is located at a different distance than what is indicated by the stereo cues. It is theoretically feasible to create a more natural three-dimensional image with the VRD (this is still in the development stage). Each pixel in the VRD has a unique wavefront created for it. The curvature of the wavefronts can be changed.
8) *Inclusive And See Through:* Systems that function both inclusively and transparently have been developed. Most displays are not bright enough to operate in a see-through mode when utilised in an area with medium to high levels of illumination, where the luminance can reach 10,000 candela per metre squared, making the see-through mode a generally more challenging system to create. This is not a problem with the VRD, as was said before. In the VRD, a light source is modulated with image data either directly ('internally') or indirectly ('externally') via a modulator. The MRS and a galvanometer are the current x-y scanning systems that the light passes through. In current VRD systems, light from the scanner pair enters an optical system, creating an aerial image that is subsequently magnified and transmitted to infinity using an eyepiece.

B. Disadvantages

Additionally, there are a number of drawbacks to employing virtual retinal displays:

1) The distance between the light source and the eye is so close that damage to the eye is possible.
2) This technology can be utilized for military reasons and to increase harm, just like any other cutting-edge technology.
3) Interferences with actual things are a problem since they will be affected by the virtual image, which may destabilize them and divert attention away from potentially dangerous objects.

VII. CONCLUSION

With so much at risk, many critical agencies have already begun collaborating with the VRD, but it is difficult to get an update on their progress. However, we can state that right now, all of those engineers, fighter pilots, and people who are partially sighted who deal with VRD will be battling various aspects of the same issue. Studying resolution, contrast, and colour perception from scanned laser images, as well as how VRD images interact with images from the real world to improve augmented reality applications of the technology, are among the projects of interest in the field. Other projects include research on how partially sighted people perceive resolution and contrast from VRD images, the development of VRD light scanning paradigms to improve image resolution and contrast in low-vision subjects, and more.

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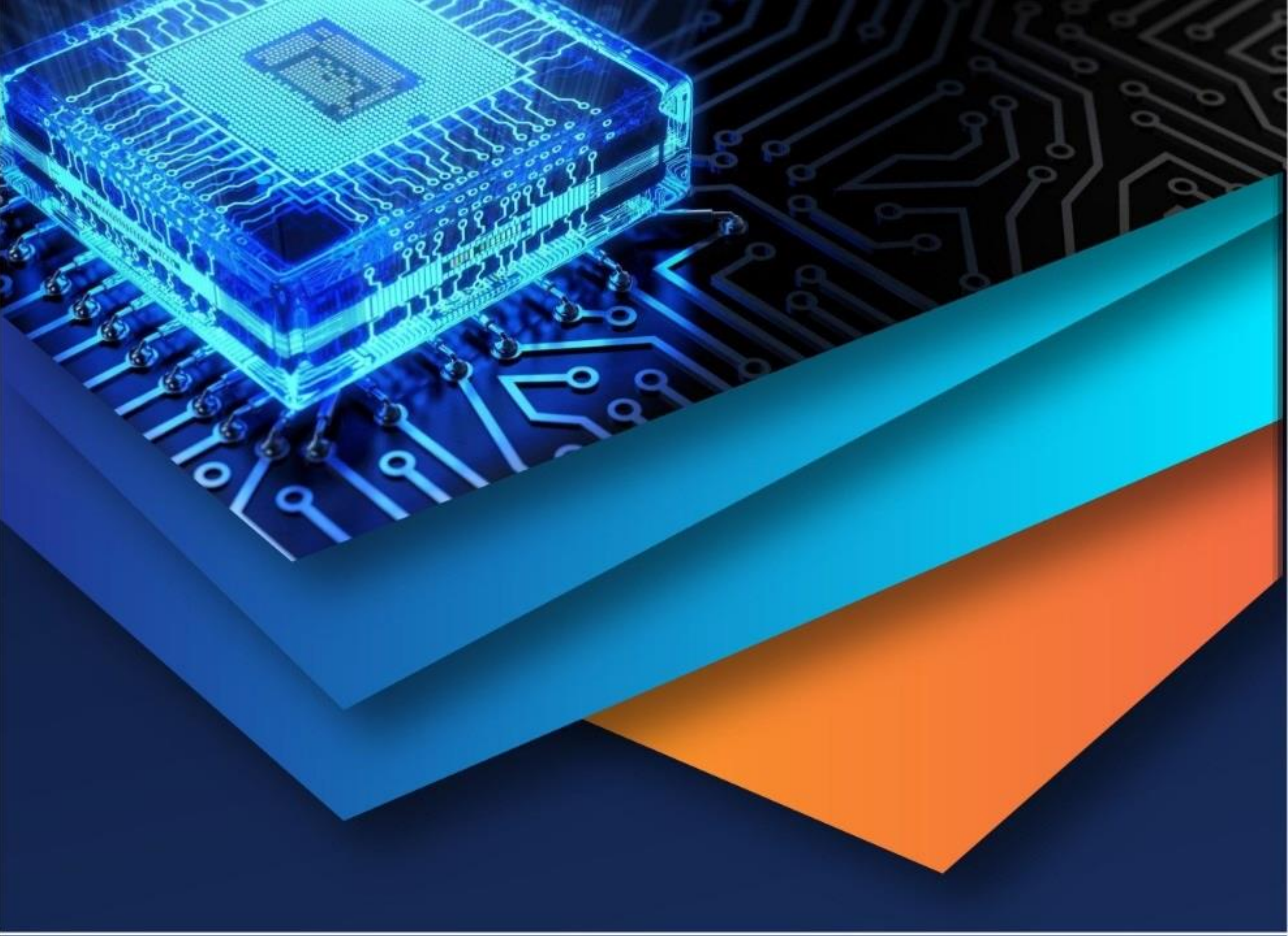

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