VISUAL DISPLAY RESEARCH TOOL
PERFORMANCE VS. DESIGN GOALS

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ABSTRACT

The Visual Display Research Tool (VDRT) is a visual simulation system comprising a two channel computer image generation (CIG) system, a head/eye attitude sensing system, and a helmet mounted laser projected dome display system. The VDRT was designed to provide an observer apparent wide field-of-view full color, high resolution, high detail density simulation of the out-of-the-cockpit visual environment.

The VDRT design approach takes advantage of the visual perception limitations of the man-in-the-loop through the use of an eye-coupled area-of-interest. The design of the VDRT was presented to the visual simulation community in 1981 at the IMAGE II Conference and the Third IITEC Conference. This paper will discuss the progress in developing the VDRT resulting from a contract between the Naval Training System Center (NAVTRASYSCEN) and American Airlines Training Corporation (AATC). AATC and their major sub-contractors Rediffusion Simulation Limited, General Electric and Polhemus Navigation Sciences (PNS) division of McDonnell Douglas Electronics Company have delivered the VDRT system components on-site at NAVTRASYSCEN in April 1985. In-plant test of system components have been completed and results will be reported. System integration and Government final inspection will have been completed by December 1985 and system performance relative to design goals will be reported.

INTRODUCTION

In a dome-type visual display it is ideal to have the pilot's eye point and the display projection exit pupil co-located at the center of the dome. The Visual Display Research Tool (VDRT) is an "eye-gaze slaved" area-of-interest visual system which essentially satisfies this goal and develops high visual acuity over a large field-of-view, in color, at a low cost. This paper will discuss the history of the VDRT leading up to and through the system design and development phase. In addition, system development decisions versus performance tradeoffs are analyzed. The paper concludes with the present status of the VDRT Program and when performance results can be expected.

BACKGROUND

Requirement

The Visual Display Research Tool (VDRT) development program addresses the need for cost-effectively providing an interactive extra-cockpit visual environment for the training of pilot/aircrew in a flight simulator. The characteristics of the extra-cockpit visual environment which drive the cost of a visual simulation system are the field-of-view, the resolution, and the scene complexity. High scene complexity is required for learning and exercising the visual skills necessary for performing missions where recognition and identification of objects or scene features in a visually cluttered environment is an important task element. Examples of such missions are air-to-surface (ASU) attack and visual navigation while flying at low level. High resolution is required for training mission tasks where detection, acquisition, recognition, and identification of objects and features at simulated ranges representative of real world ranges are important task elements. Resolution also impacts altitude and range judgements. Thus resolution is an important parameter for piloting navigation as well as both air and surface attack scenarios. The need for a large field of view arises mainly in air combat, confined area maneuvering, navigation, and ASU where the pilot utilizes visual cues throughout the entire field of view available through the aircraft canopy.

Canopy

Historically, visual simulation for pilot aircrew training has been provided by the brute force technique of surrounding the simulator cockpit with a relatively large number of display windows which are fixed relative to the simulator cockpit. This mosaic approach to providing wide angle simulation leads to complex, high cost systems, since each window must be relatively small if high resolution and high scene complexity is to be maintained throughout the entire field of view.

The VDRT represents an attempt to reduce the display system requirements and, consequently, total system cost by taking advantage of the pilot's visual perception system limitation. A characteristic of the human vision system is that high resolution is only possible over a relatively small field of view corresponding to central vision. The remaining peripheral field is seen at low resolution at any one time. Thus, the hypothesis is that a visual simulation system need only provide high resolution in the viewing direction of the observer and low resolution elsewhere in order for the observer to perceive a normal visual environment with the relatively large savings in cost of the image generator and display equipment. The approach taken by the VDRT progrm is to develop a display system which is based on efficiently matching the display parameters to the capabilities of the human eye. The specific design chosen for implementation of the eye-coupled display concept is based on helmet mounted projection of two full color laser rasters onto the interior surface of a spherical dome surrounding the cockpit.

Design Rationale

The choice of implementation resulted from a trade-off analysis taking into account system performance parameters and human interface considerations. These are summarized below:

Helmet Mounting

Helmet mounting conceptually eliminates many of the problems associated with conventional display systems. Some of the advantages of helmet mounting are: the display hardware moves with the head thus eliminating some mechanical/servo hardware; the close proximity of the display and viewing pupils minimizes geometric distortion (such as keystoning); the close proximity of pupils also allows efficient utilization of available light through the use of high gain, retro-reflective projection screen material; the use of retro-reflective screen combined with helmet mounted projection would allow multiple observers each seeing only his own display; problems due to obscuration and shadowing by the structure of the simulator cockpit are minimized; and the central location of the projector within the dome minimizes defocus problems. Helmet mounting does however generate a need to minimize the mass of hardware which is actually carried on the helmet.

Laser

Lasers were chosen as the light source in the VDRT for several reasons. The high spatial coherence of the laser allows efficient coupling with fiber optics for relaying the light to the helmet. Laser raster displays offered the capability to separate modulation and high speed scanning functions from low speed scanning functions which allows the low helmet mass requirement to be achieved through the use of lightweight fiber optic relays. Lasers can provide the three primary colors necessary for a full color display without the persistence associated with phosphors. The risks associated with laser display are; that laser systems do not have proven reliability in the simulator environment and possible display artifacts due to the laser's coherence.

Projection

Projection was chosen over virtual image displays for several reasons. A single optical projection lens is capable of providing a wide angle display whereas a virtual imaging system required two optical assemblies, for fields of view in excess of 90°. Since the projected image is only visible when reflected from the screen there is no need to track head position (in additon to attitude) and artificially blank the cockpit. Since both eyes view the same projected image there is no problem of binocular disparity. Projection does require a dome screen surrounding the simulator cockpit.

PERFORMANCE GOALS

Exploratory development efforts resulted in the definition of the performance goals listed in Table 1.

TABLE 1 SYSTEM PERFORMANCE GOALS

Apparent Field of View	Restricted only by Cockpit
Instantaneous Field of View	145° Diagonal
Area of Interest	36° Diagonal
Apparent Resolution (Limiting)	3.3 ARC MIN/TV Line Pair
Luminance	10 FLT (Highlight)
Color	Full
Contrast Ratio	30.1
Helmet Weight	3.5 lbs

SYSTEM DESCRIPTION

Figure 1 is a simplified block diagram of the visual system developed under the VDRT Program. Conceptually, the system functions in the following manner. A trainee wears a flight helmet which has a laser projector mounted on it. The exit pupil of the projector is located just above the trainee's mid eye point. Two rasters are projected from the helmet onto a retro-reflectively coated dome surface. A large field of view, low resolution raster (IFOV) serves to provide the trainer with peripheral vision cues while a smaller, high resolution raster (AOI), inset in the IFOV, develops the high visual acuity required by the foveal vision. A head and eye tracking system monitor the trainees line of sight for use by a visual processor in controlling the position of the rasters on the dome and directing the computation of the correct scene in the image generator. RGB laser light for both rasters is initially obtained from two lasers using seperation optics. Video modulation of the resulting six laser beams is effected using acousto-optic modulators. Combining optics form two modulated laser beams at a line scanner. The resulting set of laser scan lines are optically coupled to the helmet mounted projector via two fiber optic ribbons. Frame scanning and raster offsets are then accomplished using galvo driven mirrors located in the helmet projector. Both laser rasters are magnified by the output optics to produce the correct field of view to the trainee.

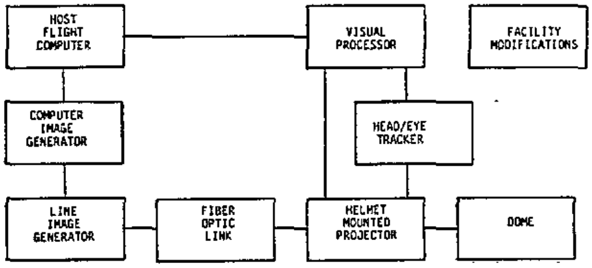

FIGURE 1 - VDRT BLOCK DIAGRAM

The visual processor mentioned above is the computational heart of the system. It interfaces with the head and eye tracker, galvo driver assembly, and the host flight computer to insure that the visual scene is stabilized at the screen and is closely synchronized with the trainee's eye-gaze position. The host computer in turn interfaces with the computer image generator to insure correct scene generation based on aircraft position and trainee look direction.

A description of each of the system components developed for VDRT along with their design and performance considerations is presented below.

Computer Image Generator

The CIG system used on VDRT is a General Electric system provided as government furnished equipment and modified to produce the required VDRT performance characteristics. The VDRT system requires a two channel image generator. One channel develops low resolution and low level of detail for use in the IFOV raster for peripheral vision cues. The second channel develops high visual acuity in the AOI raster for foveal vision cues.

Each channel provides system distortion and mapping corrections. In addition, smooth insetting of the AOI raster into the IFOV raster is also handled by the CIG. This technique involves cutting a 27.4° x 24° hole out of the center of the IFOV raster and providing a 5° blend zone just inside and around the cutout. A similiar blend zone is generated in the AOI raster. Each blend zone is divided into 16 transition areas to assure smooth insetting.

Each channel of the CIG also provides fiber optic compensation to correct for light transmission differences in each of the fiber optic links. This compensation is achieved by intensity modulating each pixel along the scanline to normalize the transmission of each fiber in the fiber optic bundle.

The CIG is also used to develop test patterns used in system test, calibration and maintenance.

Line Image Generator

Rediffusion Simulation Limited (RSL) designed and developed the line image generator whose main function is to generate two syncronized, video modulated, laser line scans for transmission to the helmet projector through the fiber optic links. A Coherent Innova 90 laser provides the green and blue laser beams at 514 nm and 476 nm respectively. A Copper LaserSonic Aurora 150 dye laser is used to produce red light at 610 nm.

Separation optics are used to develop two sets of RGB lines. Intra action ADM-70 acousto-optic modulators operated in conjunction with video processor units are used to video modulate the six laser lines. Combining optics form two laser beams which are directed into a 24 facet mirror located in the GFE line scanner. This mirror rotates at 76725 RPM to create two laser scanning beams operating at a 1023 line scan rate. The line scanner, developed by Speedring under a separate contract with NTEC, is a water cooled device with air bearings to achieve reliability and stability at the high rotational speed required. Post polygon optics transmit each laser beam to the fiber optic links and produce a finely focused line image on the fiber terminations on route to the helmet projector for AOI and IFOV raster development.

Fiber Optic Links

Galileo Electro Optic Corp, was contracted by RSL to develop the two fiber optic links used between the line image generator and helmet projector. Each link is required to contain 1000 usable 10 micron fibers in a row for transmitting the 1000 pixels of video information in each raster scan line. To insure a uniform transmission from each link, the CIG was designed to provide fiber optic compsensation for each fiber in both the AOI and IFOV channels. Currently, the system requirements on VDRT call for two, five foot, lightweight flexible cables having an overall transmission of at least 40%.

Helmet Mounted Projector

The AOI and IFOV laser line scans transmitted to the helmet via fiber optic links are converted into raster scans using galvanometer driven mirrors mounted inside the projector. One galvanomet develops horizontal offset for both line scans while two other galvanometers control AOI and IFOV frame scan development as well as vertical raster offsets. Galvanometer drive signals, developed in the visual processor, maintain control of all mirror operation through a galvo driver assembly. Inertia considerations in a large frame scan mirror have dictated a 2.5 millisecond fly back time resulting in 875 active raster lines per frame. General Scanning G-100 PD galvanometers were selected for use in this design by RSL who are responsible for the overall projector design.

The AOI and IFOV rasters are magnified in the output optics to create a 27.4° x 24° and a 140° x 100° scene on the retro-reflective dome surface as viewed from the pilot's eye point at the dome center.

In addition to obtaining the required optical performance, the emphasis on the projector design also included stability considerations as well as total helmet weight. Magnesium alloy, machined to tight tolerences, was used for the critical projector mounting plate as well as the telescope tube.

A lightweight flight helmet was manufactured by Gentex to support the projector. This helmet is designed to fit 95th percentile heads and is equipped with foam padding and an inflatible bladder to insure proper fit. A communication system is also included inside the helmet. The head tracker sensor is located on the lower back portion of the helmet. Overall helmet weight is within two pounds of the 3.5 pound specified goal. This excess is compensated by a single tensator arrangement attached directly to the projector.

Head Tracker

A SPASYN 14-bit Head Tracker system manufactured by Polhemus Navigation Sciences Division was selected for usage on VDRT based on its demonstrated high accuracy, resolution, and repeatability as well as large motion-box coverage. This system employs a three-axis magnetic radiator/sensor system to measure head position with respect to the cockpit. Helmet metal compensation has been designed into this system to reduce position errors introduced by metal projection components in the vicinity of the cockpit mounted radiator and helmet mounted sensor. The output of the head tracker interfaces with the visual processor through a de-multiplexer.

Eye Tracker

A PNSD designed oculometer working in conjunction with an Applied Science Laboratories (ASL) Eye View Monitor (EVM) system perform the eye tracking function on VDRT. The oculometer designed to be an easily calibrated lightweight unit, mounts directly to the telescope shaft of the helmet projector and contains an IR LED to illuminate the eye. A visor with an infrared reflecting coating is used to direct light from the illuminator into the eye and back to a NEC/VCI-B106 CCD camera. The EVM extracts the centroids of the pupil and corneal reflection from the video image of the subject's eye and computes the eye position with respect to the head. The output of the EVM interfaces through a de-multiplexer with the visual processor system.

Visual Processor

The Visual Processor, developed by RSL, contains a SEL 32/27 microcomputer and a de-multiplexer system to interface with the Head and Eye Tracker and the galvanometer drive system. An interface to the CIG is also provided via a High Speed Data Interface (HSDI) link to the SEL 32/77 host flight computer which talks directly to the CIG.

The main function of the visual processor is to compensate for system delays in image generation and raster positioning. A predictor-corrector technique using head and eye attitude information has been developed for this purpose. Resulting prediction data communicated to the CIG and helmet scan system is expected to reduce system delays to an acceptable level and produce realistic image stability.

Facility Modification

To accommodate the VDRT system several modifications to the existing facilities were required. The painted dome surface was sanded and cleaned and then coated using 3M 7610 retro-reflective screen material. The cockpit was raised to position the pilot's eye point near the dome center. Cooling water for the lasers and line scanner was plumbed into the dome along with line scanner vacuum and air pressure lines.

Adequate electrical power for the lasers and electronics was also provided inside the dome along with the video and sync interface to the CIG and HSDI link to the host computer. A boresight slide projector was located at the rear of the dome for use in calibration of head position.

Space was made available behind the cockpit and a mounting frame provided for installation of all the VDRT hardware including the line image generator, visual processor, head and eye tracker electronics as well as the video drive and galvanometer drive electronics.

SYSTEM PERFORMANCE

As with any visual system the basic parameters which define image quality, i.e. resolution, contrast, and brightness etc. are also of prime importance for VDRT. In addition, the requirements of "area of interest" place special demands on system dynamics in order to achieve satisfactory image stability and accurate location of the high resolution scene.

In the previous section some rationale for the unique system configuration of VDRT has been given. It is proposed that this system utilizing as it does, laser light sources, acousto-optic modulation, opto-mechanically scanned rasters, fiber optic flexible links, and a novel helmet-mounted projector will provide as good, or better image quality than more widely used display devices. Also it will be able to rapidly move the projected image to follow head and eye movements such that the observer will only be aware of viewing a well detailed scene over the complete field available from the cockpit.

It is therefore logical that we discuss the projector system design and its components in terms of performance expectation for the primary display parameters.

Field of View

As described earlier, the system generates two separate field, the Area of Interest (AOI) providing 27° Horizontally x 24° Vertically and the peripheral field (IFOV) 140° Horizontally x 100° Vertically. The AOI is always located at the center of the IFOV and is blended into it over a 5° band.

These field angles are defined within the helmet-mounted projector by the relay lenses, the galvanometer driven mirrors and telescope. The focal lengths of the two relay lenses have been selected to provide the required intermediate horizontal field angle on the beams emerging from the fibre optic terminations. For the IFOV beam the relay lens focal length is approximately 13mm for the 10mm line image providing a 44° horizontal field. For the AOI beam, the focal length is approximately 52mm providing a 11° horizontal field.

Similar angles in the vertical sense, for each field are generated by deflection of the AOI and IFOV frame scan mirrors. The telescope system then applies a magnification of about 2.5 times to the resulting AOI and IFOV rasters which are projected from a common pupil location.

However, as the FOV available is always presented to the observer throughout his total Field of Regard, the effective FOV should not be noticeably different from the real world.

Resolution

Given a CIG pixel rate of 40MHz and applying a Kell Factor of 0.7, useful display resolution should be sought within a video bandwidth of 14MHz. At higher frequencies CIG sampling effects would be expected to limit effective resolution. In any event the higher frequencies will be filtered out to limit possible moire interference effects between CIG pixels and optical fibers.

In general however, limiting resolution is not a reliable guide to image definition, contrast ratio at the lower frequencies being a much better criterion. NTEC have specified a contrast of 0.4 at 8 cycles/degree for the AOI and 1.7 cycles/degree for the IFOV corresponding to 8 and 9 MHz respectively.

In considering the line image generator, it is interesting to note that due to the use of Scophony illumination in the modulators, the resolution of a pattern in the line image is not limited by the dimensions of the beam at the modulator or by any aberrations in optics proceeding it, since the pattern is actually an image of the acoustic wave in the modulator. Therefore the resolution of this portion of the LIG is very largely determined by the response of the electro-acoustic transducer in the modulators. Amplitude modulation should be at least 0.95 at the given frequencies.

Regarding the scanner polygon and post-polygon optics, the aberration attributable to these is also small amounting to less than 1/10 wavelength giving 0.95 MTF at 9MHZ.

The sampling effect of the fiber optic array on the continuous line image will reduce the effective horizontal resolution of the projected image. Assuming 1000 fibers in the line, there will be 3 samples per cycle at 14MHz, producing an effective MTF factor of about 0.6. At 9 MHz the factor will be 0.8.

There is a very similar sampling effect due to raster lines, as line spacing is approximately equal to fiber spacing. Therefore contrast ratio for vertical resolution will be reduced to 0.6 at 14MHz and 0.8 at 9MHz.

The design target for the helmet-mounted projector optics was 0.6 contrast at 8 cycles/degree for the AOI and 1.7 cycles/degree for the IFOV measured over the complete field.

In practice this has been realized apart from the blue light performance in the AOI, without offset, where the average value obtained was approximately 0.5 and in the green channel with 30° of offset where an average value of 0.4 was measured.

The IFOV values were in fact well above the target in most cases.

The resolution performance for the complete optical system is obtained by multiplying the contrast ratio values which results in an overall ratio of 0.43 for the AOI and approximately 0.5 for the IFOV.

For most purposes these values will be reduced by some loss of contrast of incoming video from the image generator.

Also some loss of subjectively assessed resolution may be produced by laser speckle in a static scene.

However, in general, we should expect to obtain a resolution performance that is close to the specified values.

<u>Color</u>

VDRT will produce an image separately modulated in red, green and blue in both the AOI and IFOV field, hence the use of the six acousto-optic modulators.

The green and blue primary colors are dictated by the available emission lines of the argon laser. Green is supplied by the powerful 514nm line and blue by the combined use of the 476nm and other shorter wavelength lines. Intermediate wavelengths, in particular 496nm and 488 nm, are discarded in order to achieve an acceptable blue/green contrast.

Red is produced by pumping a dye laser with a second argon and is therefore tunable over the emission band of the dye which for R6G is typically 585nm to 620nm. The red wavelength which is likely to be used generally is 610nm as this provides a good compromise between color and luminosity.

It is worth noting that the chosen R, G, B wavelengths include a larger area of the standard chromaticity diagram than do the normal CRT phosphors.

A Standard Illuminant C white will be obtainable using R, G, B power in the ratio 0.9, 1.0, 1.0. This balance will be achieved by combining regulation of laser output power with video level control.

<u>Brightness and In-cockpit Visibility</u>

The specified peak-white brightness in the center of the field in the aircraft pointing direction is 10 foot lamberts minimum.

Although not usually addressed as a separate parameter it is also important that a simulator visual system does not too obviously effect the pilots ability to read the cockpit instrumentation or locate controls and switches. This has particular relevance to a helmet-mounted system, which may partially obscure the cockpit interior, or at least lower the contrast of panel lighting. Although the projected image from VDRT's helmet-mounted system will fall inside the cockpit when the helmet is pitched down, its very low brightness should ensure such problems are avoided.

System brightness is achieved through the use of the 3M's retroreflective screen and the small angle (0.9°) between exit pupil and eye point. Under these conditions the screen gain is approximately 90 as compared with less than 1 within cockpit.

The total laser power available from the emission lines selected to give the required color balance is 3.5 watts.

The transmission values for the system, shown in Table II, are all based on measured data with some rounding down applied to cover worst case situations.

TABLE II TRANSMISSION VALUES

LIG (excluding modulators)	0.6
Modulators	0.5
Line scan time averaging.	0.88
Fiber Optic	0.3
Helmet Mounted Projector (IFOV channel allowing blanking loss for inset).	0.45
Frame scan time averaging	0.91
Overall throughput efficiency	0.032
Time averaged power projected	0.113 watts
Time averaged luminous flux projected (using 271 lm/watt for Standard Illuminant C mix)	30.7 lumens
Effective luminosity with screen gain of 90	2768 lumens
Brightness of 140° x 100° field at 10 ft. radius.	20.4 fL

Even allowing for unforseen factors the conclusion is that the target brightness should be exceeded.

Image Geometry

The mapping of the projector telescope is such that an incident beam A off-axis emerges A' off-axis where sin A' = 2.5sin A. In effect, without correction the projected field would manifest fairly severe pincushion distortion.

In addition the geometry of projection from a small off-axis position into a spherical dome would produce significant errors.

The image generator will be programmed to effect correction for these errors by making a transformation of the image point co-ordinates with the original flat plane model so that the scene will be undistorted when viewed from the eye-point, provided that the pilot's head direction and look direction are straight ahead.

Corrections will be made using a function derived from measurement of telescope mapping errors.

Image Stability

In addressing the stability of the displayed image, fixed head and eye positions may be considered separately from effects due to head and eye movement.

In the static condition the raster stability is dictated primarily by the smoothness and repeatibility of the opto-mechanical scanning devices.

The mirror polygon line scanner rotating at approximately 76,000/rpm is sychronized at all positions in each revolution to an accuracy of 10 nanoseconds. With a pixel duration of approximately 40 nanoseconds no movement should be discernible due to this component.

Frame scanning is produced by the General Scanner PD-100 galvanometers which have a specified repeatibility of 0.05% and should ensure vertical stability within 1 scan line.

The greatest concern regarding general raster stability is that of possible noise and interference causing spurious vertical or horizontal deflections within any of the 3 projector galvanometers. The head and eye tracker devices are in themselves potential sources of such noise. If noise does prove present in these devices to any degree, it may be difficult to eliminate without jeopardising their dynamic response.

The overall objective is to control peak to peak movement of image points to within 1.5 arc minutes for the fixed projector case.

In normal use, head and eye movements, will of course, continuously deflect the projected image in a complex fashion. It is however, the performance of the head tracker and the computation of head position data that will primarily govern the accuracy and perceived stability of the projected scene. The eye tracker should simply allow the area of interest to be located at the point of gaze without effecting scene location.

The relatively long delay (80 millisecs.) for the image generator producing the required frame following the input of a new head position, would without correction probably cause unacceptable image lag. Head acceleration and velocity terms are employed to predict in advance where the head position will be before that position is reached. Movement beyond this position or any occurring duing the display of a particular frame will be nullified by a compensating deflection of the galvanometer driven mirrors.

The accuracy of predicted head position and consequently the image position will be related to the rate of movement. For head movements not exceeding 2Hz the phase error is expected to be less than 0.5°.

SUMMARY

VDRT, as discussed in the above paper, is one of the most intriguing visual system development undertaken in the last twenty years. State-of-the-art technology abounds in lasers, fiber optics, optical scanners, projection optics, computer image generation, and head and eye tracking and processing techniques. Currently this system is being installed and integrated at NTSC's Visual Technology Research Simulator facility in Orlando, Florida. System acceptance is scheduled for the 4th quarter of 1985. By that time, VDRT performance will be demonstrated and measured with results available for the visual flight simulation community.

ABOUT THE AUTHORS

Denis R. Breglia is a Physicist in the Simulation Technology Branch of the Advanced Simulation Concepts Division in the Research and Development Department of the Naval Training Systems Center. He has been the Project Engineer and Acquisition Director for the Visual Display Research Tool since its inception. Mr. Breglia has almost twenty years of professional experience and holds sixteen patents in visual simulation technology.

Dick Windyka obtained his BS and MS Degrees in Electrical Engineering from the University of Massachusetts and Northeastern University respectively. His twenty years of professional experience has been in the area of visual related systems including image generation, processing, and display. He is currently VDRT Program Manager for American Airlines Training Corporation.

Bruce Barber obtained his degree in Applied Physics when he was with the Royal Aircraft Establishment, Farnborough. He has worked in a variety of fields in industrial research and development. During his ten years with Rediffusion Simulation, he has been exclusively involved with the development of new display devices for visual simulation. Mr. Barber is Rediffusion's Program Manager for the Visual Display Research Tool.

ted at the point of gaze without effecting scene location.

The relatively long delay ($\sim$4 fields) for the image generator to produce the required frame following the input of azimuth/elevation information coupled with the approximately 4 field delay required to measure head and eye position and calculate the proper azimuth/elevation gaze angle would result in an unacceptable system response time of about 8 fields (133 milliseconds). However a prediction correction technique using head acceleration and velocity terms has been implemented to predict in advance where the head position will be before that position is reached. This prediction approach will reduce the system response time down to an acceptable period of about 4 fields. Movement beyond the predicted position or any occuring during the display of a particular frame will be nullified by a compensating deflection of the galvanometer driven positioning mirrors.

The accuracy of predicted head position and consequently the image position will be related to the rate of movement. For head movements not exceeding 2Hz the phase error is expected to be less than 0.5%.

SUMMARY

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