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AREA OF INTEREST DISPLAYS IN VISUAL SIMULATION

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ABSTRACT

Visual simulation to provide effective training for airplane flight in a wide field of view, high detail environment presents problems of cost and adequate detail. Research and development to meet these problems is addressing various techniques for concentrating high image detail in an area of interest (AOI) which is set within a larger field of view of comparatively low resolution and detail. This paper reviews the various AOI techniques and suggests possible future benefits to visual simulation for the space program.

INTRODUCTION

Simulation of the pilot's view through the windows has been available for training and research over the last twenty years for airplanes, both civil and military, and for space vehicles. Visual simulation has presented some of the most difficult problems in simulation technology, and active research and development continues. In the space program, visual simulation systems have been built for the Mercury, Gemini, Apollo (Command Module and Lunar Excursion Module) and Shuttle programs.

The optical systems, built by the Farrand Optical Company, have utilized various techniques to generate and display the required imagery(1). Virtual images, located in the distance or at infinity as required, have been the rule, using the principle of reflection in a large concave mirror to collimate the image. Image generation techniques have included a black sphere covered with bright points to represent stars, a film strip to show the view of earth or moon during orbital flight and a cathode ray tube (CRT) showing the output of a television system viewing a model, to represent another spacecraft. The sole image generation technique used in the Shuttle Mission Simulator (SMS) is computer image generation (CIG)(2) and this is the technique now used universally by the airlines and almost exclusively for military simulation.

Visual Simulation for Airplanes

Visual simulation as used by the airlines is by now very well established. The maneuvers - with a strong emphasis on takeoff and landing - are satisfactorily simulated with CIG image generators and CRT displays with infinity image optics. For military fixed wing aircraft also, takeoff and landing simulation does not present a problem (although landing on an aircraft carrier presents a more exacting requirement). For air combat maneuvering (ACM), satisfactory results have been achieved on a few trainers over a period of more than two decades by projecting an image of a target aircraft onto the inside of a spherical screen surrounding the simulator cockpit. However, the simulation of a wide field of view of terrain in high detail as is needed in military simulation for low altitude flight, navigation, target acquisition, weapon delivery, threat avoidance and confined area maneuvering for both fixed wing aircraft and helicopters remains a difficult and expensive problem.

The best currently available approach to providing the required high resolution, wide field of view (FOV) display is to divide the FOV between a number of butted displays surrounding the pilot. Each display requires its own channel of computer image generation (CIG). The number of displays and CIG channels required depends on the total displayed FOV required, the resolution required and the number of picture elements (pixels) that can be displayed in each window. Television systems with 1023 scan lines are becoming more common (as compared with the broadcast system standard of 525 lines) so that approximately one million pixels per display are available. To cover a hemisphere with imagery with resolution of 2 arc minutes per pixel (a typical requirement), approximately 24 displays and 24 CIG channels would be needed. This is not practicable on the grounds of acquisition cost alone; the system would also pose problems in setting up and maintenance which would lead to high running cost. These practical considerations restrict a multiple projector system to five to eight channels, each covering about 70° and giving a resolution of 6-9 arc minutes per pixel. The cost of such a system is still approximately $20M.

As an alternative to generating and displaying imagery over the full FOV required by the pilot for carrying out the necessary maneuvers, imagery can be concentrated in those directions that are most useful to him, resulting in significant cost savings in both image generation and display hardware. This general concept is almost as old as visual simulation itself (one example being in ACM simulation as already described) but it can be implemented in many different ways and new approaches are being developed. It is time that these different approaches were compared and their limitations and advantages discussed. In the rest of this paper, any display in which at least part of the FOV is not fixed in direction relative to the aircraft windows will be referred to as an area of interest (AOI) display.

TYPES OF AOI DISPLAY

The movement of the FOV with respect to the aircraft windows to create an AOI display can be controlled in various ways. The FOV may move with or track:

a. a displayed target
b. the pilot's head
c. the pilot's eyes
d. a combination of the above.

Most of the systems have two fields of view, one set inside the other. To provide a common terminology, the larger FOV will be called the main FOV and the smaller the inset FOV.

Target Tracked Displays: Air-to-Air

In a target tracked system, the inset FOV is placed dynamically within the main FOV according to the computed position of the target with respect to the pilot's own aircraft. Most applications to date have been of the type described for ACM and gunnery where the target is another aircraft displayed on the inside of a spherical screen in high detail over an inset FOV of about 15°, using a servo directed television projector. The main FOV is provided typically by a wide angle gimbaled shadowgraph projector giving a low resolution, dim image of the horizon, sky and a suggestion of the terrain so that attitude (but not translation) cues are available.

The target aircraft image is superimposed on the sky background and always appears brighter than the sky; this is not usually in accordance with the real world, but is generally considered acceptable. Such a system is efficient in that high detail in the main FOV is not needed and is not provided. Improved aerodynamic simulation has led to several systems of this type being brought into use recently, to give effective training in high altitude ACM.

In the Navy, systems of this type include Device 2E6, the Air Combat Maneuvering trainer for the F-4 and F-14 and Device 2F112, two F-14 Weapon System Trainers (WST). The AOI image is generated using a television camera viewing a plane model mounted on gimbals.

The Navy's Visual Technology Research Simulator (VTRS), located at the Naval Training Equipment Center (NAVTRAEQUIPCEN), Orlando, Florida, has demonstrated the feasibility of applying CIG to an AOI display coupled with a background display on a spherical screen for military applications. Military tasks which have been demonstrated include carrier landing, formation and tactical formation flight, gunnery, air-to-ground weapon delivery and hostile environment maneuvering. Trainers in development which will apply this visual technology concept include the Navy's F-18 Weapon Tactics Trainer (WTT) and the Marine Corps AV-8B WTT. Examples of other target tracked displays include an early Air Force low cost formation flight trainer, which presented a 90° FOV of another aircraft, and the Northrop LASWAVS which presents a 60° FOV from a television camera viewing a modelboard.

Target Tracked Displays: Air-to-Ground

Where a target tracked inset is set against a main FOV the requirements are not particularly stringent, as long as the main FOV is relatively featureless, such as sky (in the case of a target aircraft), or sea (in the case of carrier landing). However, where air-to-ground tasks must be simulated, the ground target area, including the terrain immediately surrounding the target itself, is displayed as an inset at higher resolution than the main FOV (using either modelboard/television camera or CIG image generators), and the system requirements become more stringent in three respects. First, the computation and inset projector servo requirements are more exacting as the inset image has to register with the main image during all maneuvers, whereas air targets do not have a visual reference and small positioning errors are not seen. Second, the distortion of the image constituting the main FOV must be minimized so that when the inset takes up its correct position, the background imagery is also correct. Third, the mode of insetting needs consideration because straight-forward superimposition (as for air/air systems) may not be fully acceptable and it may be necessary to "cut a hole" in the background image to make way for the inset. These requirements are considered further in a later section.

Head and Eye Tracked Displays

Before discussing specific head and eye tracked systems, some background will be given on the relevant human characteristics. Figure 1(3) shows the visual field available for a given head pointing direction: binocular vision extends horizontally to ± 70° and vertically to + 50°, - 70°; monocular vision adds another 30° horizontally each side. Figure 2(4) gives the distribution of visual acuity across the retina, from which it can be seen that for an eye fixated on the center of a 40° diameter spot (and resolving 1 arc minute at the center), the resolution at the edges of the spot will be only about 10 arc minutes. Figure 3(5) is a collation of data from several sources on the range and velocity of head and eye movements encountered for various tasks. From the information in the three figures, it is possible to postulate various display systems that take advantage of human head and eye characteristics for various maneuvers.

Head Tracked Displays

Consider first a system with head tracking only, i.e., the displayed image is moved so as to keep its centroid always in line with the head pointing direction by monitoring the head attitude continuously with a head tracker and commanding the CIG image generator to compute its image with the appropriate viewing direction. With the eyes pointing straight ahead, a displayed FOV of 140° horizontally and 120° vertically would provide all necessary visual cues except for the peripheral monocular parts of the FOV. Deflection of the eyes by 20° (more than 20° only occurs 4% of the time) adds to these figures to give 180° horizontally and 160° vertically. So it may be said that if head tracking is adopted, there is no point in exceeding an FOV of 180° x 160°.

Actual figures for specific systems will, of course, depend on the training task and the cost effectiveness of providing as large an FOV as this. A head tracked display without any limitation in following head pointing direction, but with a small FOV of say 50° horizontally (a single fixed display of 50° horizontally by 36° vertically has been used for many years by the airlines for landing and takeoff) will enable some maneuvers to be carried out normally. For other maneuvers (see "Intense Visual Search" in Figure 3), an unnatural amount of head movement will be required and it may not be possible to carry out the task correctly. In any event, from some experimental work carried out at NAVTRAEQUIPCEN, a small head tracked FOV is made much more acceptable if the edges are softened, i.e., blended to black. Blending to midgrey is even better in removing the obtrusiveness of the edges of the FOV.

A very important consideration with head tracked displays is the CIG throughput delay. Assuming the head tracker response time is negligible, a change in head attitude will cause a demand for a new view and it is essential that the image presented to the pilot should not move in its apparent direction in space during this period, causing unnatural "swimming" of the image. Once the new image has been computed, it must be displayed in the correct direction. If the head tracked FOV is obtained from a television projector mounted in a fixed relationship to the cockpit structure, the displayed format direction may lag the head direction, but displayed objects must remain fixed in relation to the screen. For systems in which the display, such as one using cathode ray tubes, is mounted on the head, the displayed format moves with the head but compensation of image position is required to avoid "swimming." This point will be elaborated later when different systems under development are reviewed.

One interesting possibility with head tracked displays, if head position in relation to the cockpit is tracked as well as head attitude, is to obtain some of the effects of a collimated display in those systems where the image is viewed on a screen. Movements of the head are measured and fed to the CIG image generator to give a corresponding change in the computed viewpoint. The effect, particularly for sideways movements of the head, is that the objects viewed stay fixed in space with head movement, and this is a strong cue to the distance of objects. The results are similar to what is obtained with a collimated display. CIG throughput delay may be a problem with rapid head movements.

Eye Tracked Displays

Let us now turn to the consideration of eye-tracked displays in which the eye pointing direction of the pilot is monitored continuously and the CIG generates the visual information such that it is always concentrated in the eye pointing direction. From Figure 2, if a single field of view display were to be presented to the pilot in which the resolution decreased smoothly away from the center of vision, the central resolution would be available in all directions in which he could look, but the total amount of information required to be displayed would be very greatly decreased as compared with a system having everywhere a resolution equal to the central resolution. Smoothly varying resolution is difficult to implement but an approximation to the curve of Figure 2 can be made by having a high resolution inset FOV to provide for foveal vision inside a main FOV of lower resolution, with the main FOV image removed over the area of the inset.

In this context, it is necessary to distinguish between resolution and detail, where detail may be defined as density of CIG edges or average number of edges per unit solid angle of view. CIG data bases are modelled with a number of levels of detail, e.g., a house at the lowest level of detail is just a block (sufficiently detailed at a large range) but at a higher level it has doors and windows (necessary for close range). An inset may have either higher resolution or higher level of detail (LOD) than the main FOV, or both. For eye tracked systems, high resolution in the inset is necessary and it is uneconomic to provide it in the main FOV also where the eye cannot resolve it. Since the inset occupies only a small FOV, the edge density can be much higher than in the main FOV, although the inset CIG channel does not display more edges than the main FOV. This higher edge density requires a higher LOD from the data base and a higher display resolution. Thus, we arrive at a preferred system in which the inset has both higher resolution and higher LOD.

An important consideration in eye tracked systems is the boundary between the inset and the main FOV. A sharp edge is highly undesirable and a blend between the two over part of the inset area is necessary to avoid visibility of the boundary.

Another important consideration, as for head tracked displays, is the throughput delay of the CIG image generator. When the eye commences a rapid movement from one fixation direction to another, i.e., it commences a saccade, the eye tracker commands the CIG to generate a view appropriate to the new viewing direction. The time taken by the CIG to do this is around 80 msec and the system must be such that the inset is not visible until the image correct for the new direction is available. This means that the eye, if it moves fast enough, will be looking at part of the low resolution main FOV for some milliseconds before the high resolution of the inset appears. At NAVTRAEQUIPCEN, it was considered necessary to carry out an experiment to obtain some practical data on acceptable CIG time delay. Other factors, referred to above, which needed evaluation were the acceptable size for the inset and the width of the blend region in an eye tracked display.

Experiments were performed at NAVTRAEQUIPCEN(6) in which images were projected from a special slide projector to cover a spherically shaped screen surrounding the subject. A variable resolution mask, overlaying the slide, modified the image such that it had a central high resolution area surrounded by a low resolution area with a blend region between them. An eye tracker, using infrared light, measured the azimuthal pointing direction of one of the subject's eyes and drove a rapid servomotor attached to the mask. The subject, therefore, saw a high detail image in the center of his vision at all times. A variable time delay could be inserted between the eye tracker and the servo.

Various masks were used having different widths of blend region; a very small or nonexistent blend region was found to be highly objectionable and distracting to most observers. The experiments indicated that an inset width of 25° within which there is a 5° wide smoothly varying transition region combined with a delay of 80 msec and an eye tracker accuracy of ± 2.5° would cause noticeable, but not objectionable, perception of the borders of the inset.

This experiment does not provide exact simulation of the appearance of a working eye-tracked visual simulation display, although it gives useful guidelines on the design of such a system. In particular, it does not simulate the appearance of the different levels of detail of a CIG system; this will be discussed in a later section of this paper.

AOI DISPLAYS IN DEVELOPMENT

To advance the consideration of AOI displays, it is necessary to refer to systems currently in development. Table I lists the various Government funded systems; however, there is a great deal of additional activity on AOI systems by industry. Systems 1 and 2 have a target tracked inset FOV in a fixed main FOV for air-to-ground use; System 3 has a single head tracked FOV; System 4 has a head tracked main FOV with a head tracked inset; System 5 has a fixed main FOV with an eye tracked inset; and System 6 has a head tracked main FOV with an eye tracked inset. In referring to Table I and the following description, it has to be realized that these systems are in various stages of development and the performance data given are target figures for feasibility models only. Not all these systems will be developed to procurement of a fully engineered prototype, but a comparison of them in terms of fundamental advantages and limitations will be valuable in understanding the potential gains with AOI displays. All use displays with 1023 TV line capability.

System 1 in Table I refers to experimental work with VTRS at NAVTRAEQUIPCEN. The main FOV provides a low detail view of terrain from the background projector while the target projector provides an inset FOV of the target area with higher resolution. (Higher LOD for the inset FOV is in the process of being implemented.) The inset can show a group of buildings and part of a road or a group of tanks. Various maneuvers can be carried out, including strafing the target, without losing registration between the low and high resolution images.

To achieve this degree of dynamic registration, the servo response of the target projector had to be optimized. Its pointing accuracy was ± 1 arc minute under static conditions and ±1° at 50°/sec.

Another essential factor, permitting registration of the inset image with the main image, is correction of the distortion of the main image on the spherical screen. This distortion arises due to noncoincidence of the pilot's eyes and the projector exit pupil, the display optics and other factors. The correction is done in the CIG image generator(7) by breaking up long CIG edges into shorter edges and repositioning the vertices to map the scene onto the screen such that the distortion is less than 0.1% from the pilot's eye position. For the inset, the smaller FOV makes distortion correction less critical, but this is being implemented.

The method of adding the inset to the main FOV is simply to overlay the inset image on the background image, as for the target plane in air-to-air simulators. This means that the inset has to be brighter than the background and in fact appears as a fairly well defined bright disc. There is, therefore, no question of the pilot having to search for the target as in the real world; not only is it rendered in higher detail, but it is also brighter. However, once the pilot has acquired the target, the maneuvers he carries out should not be affected by its somewhat artificial appearance. Experimental work with pilots using the technique described will take place at VTRS during FY 83.

System 2 in Table I is the High Resolution Area (HRA) Dual Projector Display system(8) funded by the Army (Project Manager, Training Devices) and procured by the Human Resources Laboratory at Williams AFB. The Advanced Simulator for Pilot Training (ASPT) at Williams AFB has a visual system consisting of seven facets of a dodecahedron structure to provide a wide FOV display. Each facet contains a Farrand Pancake Window optical system and utilizes a large 36 inch diameter cathode ray tube as a display source. The optical elements of the Pancake Window produce an image of the CRT face at infinity.

The Dual Projector Display is an experimental replacement of the CRT by two 1023 line color television light valve projectors fitted with optics to project images onto a back projector screen of the size and shape of the CRT faceplate. One projector provides the main (70°) FOV covering the whole screen and the other, together with a servo driven mirror, gives an approximately 10° inset of high resolution. An important feature of this experimental system is the capability of (a) demonstrating the removal of the main image over the area of the inset (thus "cutting a hole" to leave room for the inset) and (b) demonstrating the effect of various blending functions for the region around the inset. This is a further development beyond simply superimposing the inset as has been demonstrated on VTRS.

The system had reached a certain stage of development in January 1982, and the inset could be moved around within the main FOV. A band of blending between the inset and the main FOV was generated by varying the gain of the video signals from the two projectors in a complementary manner, using eight steps of gain. This demonstration showed that more steps, or a smooth gain change, would be necessary to avoid high visibility in the blend region and also showed the sensitivity of the system to misalignment between inset and main FOV and to the variation of color which occurs across a light valve display (causing color mismatch for some positions of the inset). The experiment was valuable in its impact on future AOI systems.

System 3 of Table I is the Visually Coupled Airborne System Simulator (VCASS) which has been the subject of research by the Air Force Aerospace Medical Research Laboratory (AMRL) for many years. The primary purpose for its development is for aircraft display hardware and crew station configuration development. However, VCASS represents one of the important alternatives in the range of possible techniques for providing a pilot in a simulator with a view in any direction and so must be included here.

The principle of VCASS, as used for simulation, is to mount on the pilot's helmet two small CRTs on which CIG imagery representing the real world is displayed, and to present this imagery to the pilot using a miniature Farrand Pancake Window for each eye. Each Pancake Window presents an image of the corresponding CRT face at infinity over a FOV of 80° horizontally by 60° vertically. These fields can be overlapped to give a total horizontal FOV of between 140° and 100° (with corresponding horizontal overlap of between 20° and 60°). The system is head tracked, i.e., it uses a Polhemus Head Attitude Sensor, which uses a fixed magnetic field radiator, detected by a sensor on the pilot's helmet, to generate data representing the roll, pitch and yaw directions and translational position of the pilot's head. The CIG image generator is controlled by this data to produce the appropriate view for the instantaneous head attitude so that correct imagery is available at all times. To avoid the imagery representing the outside world appearing not only through the windows, but also superimposed on the instrument panel, a CIG model of the aircraft windows can be mapped into the viewing plane (the CRT faces) and used to blank out the image except where it occupies the window area, for the pilot's instantaneous head position and attitude.

The Pancake Windows have approximately 7% transmission for the direct view of the interior of the cockpit over a somewhat smaller FOV than the display. The CIG system currently in use is calligraphic.

As noted earlier, a head mounted AOI display has the characteristic that the slightest attitude change of the pilot's head immediately gives a corresponding change in the direction in space in which the imagery is seen. The CIG responds to the head tracker in computing the new view, but there is a momentary misalignment due to the throughput delay. Referring to the head velocity figures in Figure 3 and ignoring the highest velocities since vision deteriorates beyond about 30°/sec, a minimum figure of 30°/sec may be taken. For a throughput delay of 80 msec, the corresponding momentary angular error in the display is 2.4 degrees. Experimental work at NAVTRAEQUIPCEN (to be described under System 6 of Table I) has shown that the subjective effect of the resultant swimming of the image in a head mounted CRT display is disturbing and some form of correction should be applied. It is understood that improved head attitude sensing algorithms may be developed later for VCASS and no doubt this problem would be addressed at that time.

The concept of presenting an image separately to each eye in a helmet mounted configuration has important consequences. First of all, it makes possible a two-pilot system in which each of two pilots can be given his own independent view of the world (requiring a fair amount of duplication in the image generator). Second, it makes stereo viewing possible, which is being investigated on VCASS. However, a price must be paid in terms of complication: two CRTs and two sets of viewing optics are needed and this increases the weight. Furthermore, fairly exacting adjustments are needed to set up the display for any given pilot, in terms of interpupilary distance, shape of the pilot's head, etc. The concept is being further evolved and miniature color CRTs may be developed and a raster scan CIG may be used later to provide the imagery.

The VCASS system does not have a high resolution inset FOV; this is precluded by the resolution that can be obtained from a miniature CRT. An inset FOV is provided in the second Air Force system, described below, at the expense of greater complexity.

System 4, the Combat Mission Trainer (CMT) is being developed for the Human Resources Laboratory at Williams AFB by CAE of Canada. The display optics are the same as for the AMRL system (miniature Pancake Windows) but four light valve television projectors are used instead of helmet mounted CRTs, the images being relayed to the helmet through coherent fiber optic guides. Two projectors provide the main FOVs for the two eyes and a further pair, each with its own fiber optic guide, provides a slewable inset FOV to each eye.

The potential performance of this system compared with VCASS is greater, in that the high resolution inset (at present head tracked, but possibly, in the future, eye tracked) extends the possible range of use. Whether the performance can be realized depends on some difficult optical design problems. The problems center on the fiber optic guides and associated optics to couple them to the projectors; it is difficult to make coherent fiber optic guides of several million individual fibers without some broken fibers, giving black spots on the display, and such guides are fairly inflexible. By contrast, the VCASS system has only lightweight flexible cables connected to the helmet. The CMT has the same capability for two-pilot display and for stereo viewing. Color is, of course, readily available by using color projectors. Other comments made about the VCASS System are applicable on the problem of CIG throughput delay, the need to blank out imagery falling on the inside of the cockpit and the advantages and problems of presenting images separately to each eye.

System 5 of Table I is the Eye-slaved Display Integration and Test (EDIT) system.(9) The original concept was proposed and partially implemented by Singer Link for the Air Force Aeronautical Systems Division, Deputy for Simulators (ASD/YW), Project 2360, which included an advanced visual system for A-10 and F-16 training. The project was terminated, but some hardware and software became available for experimental use and further work is in progress by Singer Link, funded jointly by ASD/YW and NAVTRAEQUIPCEN, to complete the key components of the system and then integrate them with VTRS for test and evaluation. The data shown in Table I relates to this work and not to the original 2360 specification.

The concept calls for a fixed main FOV from one light valve projector (in a simulator for training the main FOV could be made to cover as large a FOV as desired by using several projectors) together with a "foveal projector" capable of rapid slewing in accordance with output data from an eye tracker and providing a small, eyetracked inset FOV. The foveal projector is mounted rigidly in relation to the cockpit structure in contrast to the helmet mounted arrangement for providing the inset FOV with System 4 (CMT).

This has several consequences. First, movement of the pilot's head does not automatically cause movement of the projected inset image with relation to the screen as is the case where the display is actually mounted on the helmet. The movement of the inset is controlled by the head tracker measuring head attitude change with respect to the cockpit and the eye tracker measuring eye attitude change with respect to the head, the two streams of data being combined to command the foveal projector servos to take up the new pointing direction. There is, therefore, no need to compensate for CIG throughput delay as far as head attitude is concerned. Second, the servo response must be extremely rapid to come near to matching eye movement rates (see Figure 3). Third, because the pilot's head and the foveal projector exit pupil are considerably separated, distortion of the inset image occurs and varies with position in the main FOV, which must be compensated, and the throw distance varies requiring servo control of the projector lens focus.

Finally, to add the inset to the main image, a hole is cut electronically in the main image and due to the variation of distortion with position, the hole shape has to be dynamically varied. A smooth blend is provided around the inset. Some indication has already been given of the possible problem in presenting the new inset image following a saccade, due to CIG throughput delay. Experiments carried out by Singer Link indicate that the phenomenon known as saccadic suppression, which causes the eye to be insensitive for some tens of milliseconds following a saccade, will allow time for the new image to be generated.

The EDIT project is a very interesting one as it aims at the greatest efficiency in generating and displaying imagery by employing eye tracking. Integration of the system into VTRS followed by pilot testing is at present planned to commence early in 1984.

The final system listed in Table I, System 6, Laser Helmet Mounted Display(10,11), has been developed at NAVTRAEQUIPCEN and a complete system is now being procured. Both head and eye tracking are used, the inset FOV being fixed in the center of the main FOV and the resulting combined FOV directed to follow the eye direction in space. The source of light to generate the image is a laser system giving red, green and blue primary colors and the display is viewed on a retroreflective spherical screen. The light is modulated by the video signals from the CIG and scanned in a line by a rotating mirror polygon. Three frame scanners are mounted on the helmet, one for the main FOV, one for the inset, and one for throughput delay compensation in the line scan direction. Two 1023 line rasters are produced. Fiber optic ribbons are used to transmit the light to the helmet; these are light and flexible compared with the full frame fiber optic guides required for System 4 (CMT).

The use of laser light, scanned optomechanically, has interesting implications. A system of this kind, unlike a light valve projector, can exhibit absolute uniformity in the intensity of the projected beam over the FOV and there do not appear to be any serious problems in matching the color and luminance of the inset image to the main FOV image.

To prove the concept as far as possible prior to procurement, a mockup was built omitting the eye tracked inset and using a 1023 line CIG signal, to give a head tracked FOV of approximately 25° on a 3 ft. radius spherical retroreflecting screen. Compensation for throughput delay was demonstrated, using the VTRS CIG image generator, by momentary deflection of the raster using offset signals to the line and frame scanners computed from the difference between current head attitude in pitch and yaw and the pitch and yaw attitudes used by the CIG to compute the current scene. The results of the experiment gave confidence that a helmet mounted laser display was feasible; in particular, CIG throughput delay was successfully compensated giving stable imagery. The fiber optic ribbons of 1000 fibers, made to NAVTRAEQUIPCEN specification, have not yet been satisfactory as to the presence of broken or distorted fibers. A ribbon is, however, much easier to make than a full frame guide.

As far as the eye tracked inset is concerned, the work previously discussed(6) gave confidence that, given quick response from the eye tracker, an acceptable result would be obtained. The procurement plan for the NAVTRAEQUIPCEN laser HMD system calls for integration with VTRS commencing part way through FY 85 followed by human factors evaluation during FY 86.

AOI Blending and "Popping"

Before attempting to sum up as to the advantages and disadvantages of the various AOI systems, the question of how well the inset merges with the main FOV for the systems that have an inset should be discussed. First, there is the question of whether the inset is simply superimposed on the main FOV image or a hole is cut in the main FOV image and the inset inserted. Experimental evidence to date favors cutting the hole and inserting the inset provided a blend region giving a smooth change between the two regions is used. However, this has not yet been implemented in a working prototype, and an optimum ratio of width of blend region to inset width needs additional experimentation.

Secondly, there is the question of "popping." As observed previously, an inset FOV has not only a higher resolution, but also should use a higher level of detail (LOD) from the CIG data base than does the main FOV, so that, for example, a runway may be featureless at the low LOD, but have stripes at the higher LOD. In CIG as normally implemented, a higher LOD is brought in as the range decreases and this can be done slowly so that, for example, the runway stripes gradually fade in on top of the previously blank runway. If the stripes occur in an AOI, but not in the main FOV, movement of the AOI may cause them to appear suddenly, and this has been referred to as popping.

For a target tracked system with a fixed ground target, popping cannot occur, although the appearance may be somewhat unrealistic owing to the target area standing out in higher resolution. For a target tracked system with a moving target, a fast target can cause popping, to a degree dependent on the data base.

Eye tracked systems, in which the inset moves within the main FOV, can exhibit popping also but the eye can never, by definition, look directly at the blend region and the eye is operating at lower resolution at the edge of the inset. With head tracked systems, in which an inset is fixed at the center of the FOV, the eye can look directly at the blend region.

The popping question has been considered sufficiently important at NTEC to lead to a decision to carry out some basic experiments simulating CIG objects by sinusoidal bar patterns of varying spatial frequency and amplitude. It is hoped that this work, to be accomplished during FY 83, will quantify the problem and provide guidelines to CIG modellers on minimizing the effect.

THE OUTLOOK FOR AOI

The trend towards AOI displays due to the excessive cost of implementing wide angle visual systems with multiple projector, multiple CIG channel techniques is likely to continue for a good many years to come. The eye tracked systems offer the greatest potential for high performance to cost ratio, with a resolution of 1 - 1 1/2 arc minutes per pixel in the eye pointing direction (and so effectively in any direction) with the need for only two CIG channels. A key question is whether an eye-directed inset can appear natural to the pilot and whether he will be able to perform with such a system without eyestrain or other physiological problems. It is certainly to be hoped that the funding identified to support the NAVTRAEQUIPCEN HMD and the ASD/YW/NAVTRAEQUIPCEN EDIT remains available as these two systems represent the two main alternatives - on-head mounting and off-head mounting - and only properly carried out integration and test will allow the best system to be chosen.

If eye tracked systems do not, in the end, prove to be practicable, or if they turn out to be more expensive than hoped, a head tracked system such as VCASS may perhaps be developed as a cost effective visual system with more restricted, but useful characteristics. McDonnell Douglas Electronics is working on a similar system, using a VITAL IV calligraphic CIG night scene image generator, giving a 40° circular FOV for each eye and a larger total field with partial overlap. Such systems do not, of course, have the effective resolution of the eye tracked systems.

The resolution may be increased in the center of the FOV to match that achievable with the eye tracked systems by using a system such as the CMT (System 4) in which both the main FOV and the inset FOV move with the head. With such a system it is necessary to turn the head to bring the high resolution area to bear on the object viewed, whereas in the real world situation the eyes move rapidly to acquire objects which are then seen with high resolution. It remains to be determined whether such a different viewing pattern will permit satisfactory training.

The target tracked systems, including the type of system demonstrated for air-to-ground use on VTRS using a target projector do provide an alternative to the eye tracking systems and certainly systems along the lines of VTRS could be implemented with little risk. The value of emphasizing a target by showing it with greater resolution will be explored this year on VTRS using pilots in human factors experiments. We shall have to wait three years for validation of the eye tracked systems.

Possible Application of AOI to the Space Program

The visual displays required for shuttle simulation share with those required for most military flight simulation the need for large field of view and high detail and resolution. The forward view of the earth available on the SMS is highly stylized due to the spreading out of the available CIG edges over a large field of view. Possible future earth resources tasks, for example, would need a very much more detailed view of the ground. The view of the cargo bay also is lacking in detail and some tasks, such as the release of satellites, require a very detailed view aft. Simulation of the view seen by an astronaut during extra vehicular activity has similar requirements for high detail and wide field of view. It may well be that, in the future, AOI techniques will prove valuable in increasing performance with reduced cost for a range of space vehicle requirements.

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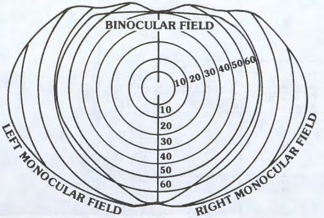

FIGURE 1 - MONOCULAR AND BINOCULAR VISUAL FIELDS

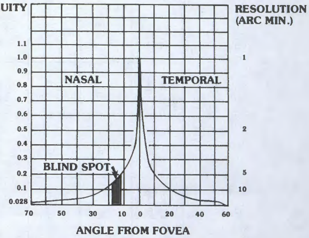

FIGURE 2 - DISTRIBUTION OF VISUAL ACUITY ACROSS THE RETINA EXPRESSED IN DEGREES FROM THE FOVEA

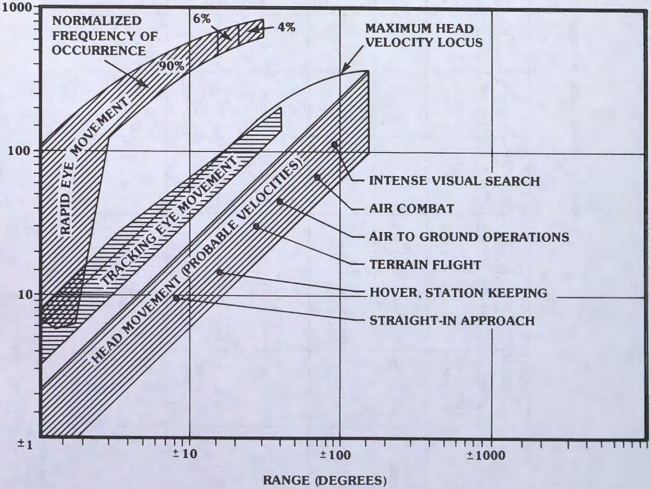

FIGURE 3 - RANGE AND VELOCITY OF HEAD AND EYE MOVEMENTS

TABLE I. AOI DISPLAYS IN DEVELOPMENT

System	Main FOV Size*, Resolution**		Inset FOV Size*, Resolution**			CIG Channels	Image Source	Image Presentation	2 Pilot Display	Stereo	Helmet Connections	Color
	Fixed	Head Tracked	Target Tracked	Head Tracked	Eye Tracked							
1. VTRS (NTEC) (experiment)	160° X 80° ~7 MIN	-	10° ~1 MIN	-	-	2	2 Light Valves	Spherical Screen	No	No	N/A	Yes
2. HRA Dual Projector (PM TRADE/HRL)	70° ~4.5 MIN	-	~10° ~1 MIN	-	-	2	2 Light Valves	Pancake Window	No	No	N/A	No
3. VCASS (AMRL)	-	140° X 60°+ ~4.8 MIN	-	-	-	2	2 CRT	2 Mini Pancake Windows	Potential	Yes	Electronic Cables Only	Potential
4. CMT (HRL)	-	140° X 60°+ ~4.8 MIN	-	25° X 25° or 37° X 37° ~1.5 MIN	Future?	4	4 Light Valves	2 Mini Pancake Windows	Potential	Yes	4 Full Frame Fiber Optic Cables	Yes
5. EDIT (ASD/YW/ NTEC)	160° X 80° 8.5 MIN	-	-	-	20° 1.4 MIN	2	2 Light Valves	Spherical Screen	No	No	Electronic Cables Only	Yes
6. Laser HMD (NTEC)	-	140° X 100° 8.4 MIN	-	-	27° X 24° 1.5 MIN	2	2 Laser Rasters	Retro-reflective Spherical Screen	Potential	Potential	2 Fiber Optic Ribbons + Electronic Cables	Yes

* Degrees, horizontally X vertically
** Arc minutes per pixel
\+ 80° X 60° each eye, partially overlapped