MIRAGE - A NEW KIND OF VISUALIZATION TOOL

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ABSTRACT

A prototype of a new form of visualization system is described and its applications are discussed. “Mirage” is a 3D, stereoscopic, pseudo-holographic display system which generates an image that appears as a scale model resting on a horizontal table top in front of the viewer. The viewer may walk around the display, examining the image from various azimuths and altitudes or he may pan and zoom through the virtual space.

The system was developed at the Institute for Simulation and Training to be an "Ultra-Stealth" for viewing Distributed Interactive Simulation exercises but it could also be used to make sonar tracks, fluid flow patterns, logistics status, or other complex multidimensional data sets more easily understood. Of particular interest is the fusion of abstract data, such as graphical representation of network connectivity, battlefield graphical control measures, tactical communications links, and simulation management functions with the 3D representation of terrain and simulation entities. The unusual application of graphical transformations and projection algorithms is explained and promising application areas are discussed.

ABOUT THE AUTHORS

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The military commander approaches the glowing tabletop in the battalion's tactical operations center (TOC). Before him, his mechanized forces, arrayed over several kilometers of rugged terrain, appear as tiny scale models traveling slowly across the surface. Ahead of them lies the pass through the looming mountain range which seems to float a half meter above the table. The commander walks around the end of the table where the other side of the ridge is visible. Hundreds of small icons indicate that the enemy's forces are massing along a riverbank.

Outside, a small antenna links the TOC to distant JSTARS aircraft who supply the positions of the enemy forces as they assemble. A satellite downlink relays the positions of every friendly unit. The commander grasps a wandlike probe and circles his second heavy armored tank company. Its vehicles turn bright yellow in response. "Let's move these guys up here!" he says, pushing a button and selecting a message template from a menu that suddenly appears stretched across the nearby valley. Several minutes later he notices the lead elements of the yellow group moving slowly up a shallow wadi to an overlook where they will find a better field of fire.

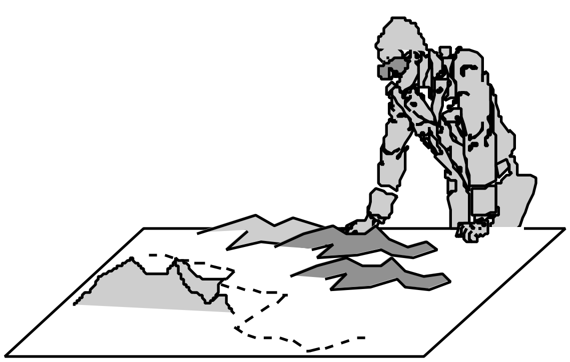

Figure 1. In the TOC

WHAT IS "MIRAGE"?

Mirage is a 3D, stereoscopic, pseudo-holographic display system which generates an image that appears as a scale model resting on a horizontal table top in front of the viewer. The viewer may walk around the display, examining the image from various azimuths and altitudes or he may pan and zoom through the virtual space. The display is not immersive in the way that a head mounted stereoscopic display can be. Instead, Mirage creates an inset of a piece of the virtual world and places it into the viewer's frame of reference. The rest of the viewer's environment around the display table remains visible.

The system was developed at IST [1] as an "Ultra-Stealth" to view Distributed Interactive Simulation exercises but it could also be used to make sonar tracks, fluid flow patterns, logistics status, or other complex multidimensional data sets more easily understood. Of particular interest to the authors is the fusion of abstract data, such as graphical representation of network connectivity, battlefield graphical control measures, tactical communications links, and Simulation Management functions with the 3D representation of simulation entities and terrain.

Mirage was developed with funding from the U.S. Army Simulation, Training, and Instrumentation Command, the Defense Modeling and Simulation Office, The U.S. Army Research Institute, and the University of Central Florida. The horizontal display was suggested by work done at the German National Research Center for Computer Science [2,3]. IST has further developed that concept and extended it into the domains of Distributed Interactive Simulation and Battlefield Visualization.

APPEARANCE

Mirage is a three dimensional display device. It produces real images which depict the spatial relationships of objects in the virtual world. Only the objects or portions of objects within the field of view are drawn. Foreground objects occult those farther away. Movement of the viewpoint results in differential shifting of the images of objects that are at different distances from the viewpoint. In this way the Mirage view is like the usual out-the-window images of most simulators.

Traditional displays are normally drawn on a vertical surface or on a head mounted pair of displays. In both cases the image is rendered assuming the viewer's line of sight will be perpendicular to the display surface. In Mirage the image is drawn on a horizontal tabletop display screen and the viewer's aspect angle is always oblique, usually between 30 and 80 degrees away from perpendicular.

As the user faces the table the image always shows what is in front of him. To change the view the user changes position with respect to the tabletop, walking around the display, examining the scene from various azimuths and altitudes. Moving closer or farther away does not change the apparent size of the objects in the scene, although it does change the angular field of view. The side of a building or tree that is hidden from one point of view becomes visible when the user walks to the opposite side of the table.

Being stereoscopic, Mirage presents each of the viewer's eyes with a different image, accounting for the different aspect angles, distances, and other characteristics of the image that is visible from those two locations. The viewer derives an understanding of the spatial relationships of objects within the scene from this additional cue when his brain fuses the two images.

Normal stereoscopic views of virtual worlds are usually attempts to generate realistic views so movement and separation of the right and left eye viewpoints are computed in the same scale that is used to define the virtual world. Objects one meter away from the viewer in the virtual world appear to be one meter away. Objects and features hundreds of meters away appear to be hundreds of meters away. Mirage uses stereo in a different way.

Mirage provides a view of the virtual world which appears to be that of a scale model placed on the table. A true scale model, such as an H.O. gauge train set, is small and very close to its operator (the viewer.) The distance between the viewer's eyes (typically 6 cm.) is a large enough fraction of the eyes' distance from the scene (typically 1.5 - 2.0 m.) that the parallax angle allows significant stereo separation and the objects "look" three-dimensional. Beyond five or six meters, however, stereoscopic vision is negligible and other cues (size, haze, etc.) are more useful indicators of distance. A "realistic" stereo view of a piece of terrain from a viewpoint hundreds or thousands of meters away appears "flat" with no more apparent relief than one sees when looking at the ground through the window of a high flying aircraft. An out-the-window view is not what was desired for Mirage.

The solution is to maintain the same ratio of virtual interocular spacing to virtual distance as is found in the "real" world. That "real" world consists of the viewer's eyes and the tabletop. Mirage provides a capability to "zoom" in and out, changing the size of the portion of the virtual world that fits on the tabletop. As the viewer moves out, his virtual interocular spacing is increased. The result is that the viewer is scaled up to be a sort of Brobdingnagian individual who is very large with respect to the hills, buildings, roads, and rivers (if those are being drawn.) In addition, as the viewer moves, the viewpoint is moved in this same scale so that a small apparent movement on the part of the viewer becomes a large movement in the virtual world. The effect of this is that the entire scene appears to be close to the viewer and objects in it appear to be small and located on the tabletop.

The Mirage image appears to float in space around the plane of the horizontal display screen.. Objects at higher elevations in the virtual world appear to float above the table. Objects at lower elevations appear to be depressed beneath the table surface (figure 2.)

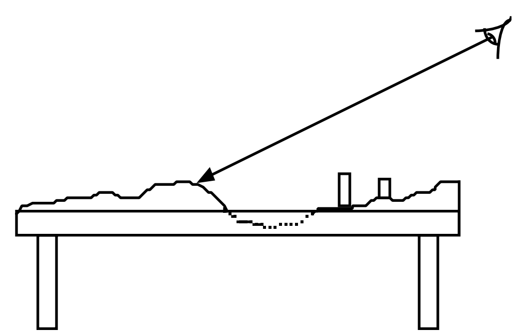

Figure 2. The Mirage image appears to float in space

Mirage is sometimes described as a "pseudo-holographic" display. This term was coined because the system provides the kind of visual illusion that people have long felt would be accomplished some day using holograms. In fact, holography is not used. The Mirage image is really just the result of a coordinated combination of stereo imagery, horizontal projection surface, and manipulation of the image to account for the viewer's position with respect to that surface.

Stereo projections and manipulation of viewpoints are readily accomplished using current computer image generation techniques. These allow rendering of dynamic images, with moving components, such as vehicles, clouds, and people. Through Distributed Interactive Simulation protocols, Mirage is linked to external sources of information about these dynamic components. In this way simulations may be viewed and, when the visual terrain databases correlate sufficiently with portions of the real world, the activities of real vehicles may be depicted in similar fashion.

Although movement of the viewer does not change the portion of the virtual world that is displayed, the user may pan through the virtual space with a joystick and this gives the impression that the terrain is scrolling across the tabletop.

IMPLEMENTATION

For the first prototype, IST chose a set of hardware and software components that seemed to offer the lowest risk and the shortest development time. The system was developed and integrated over a two month period between December 1995 and February 1996. A portable version was built several months later.

Hardware

The portable Mirage system comprises eight major hardware components.

Image Generator - The image generator is a Silicon Graphics Onyx computer (model CMN A011) with two 150 MHz. processors, 64 MB main memory, and one VTX graphics pipe. The image generator provides stereo output in the form of 60 right and 60 left eye images per second to avoid flicker.

Projector - The Projector is an Electrohome Marquee™ 8110 series model 38-P11075-95 with a short-persistence P43 green phosphor tube which can handle the 120 Hz. refresh rate.

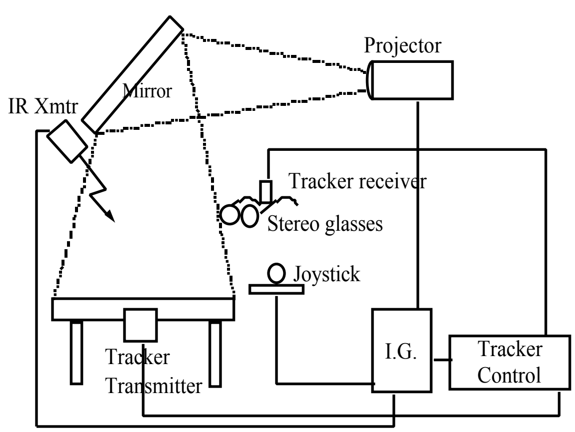

Figure 3. Mirage Physical Configuration

Head Tracker - The position of the viewer is determined using an Ascension Technology Corp. Flock of Birds™ magnetic position sensor with extended range transmitter and one receiver which is worn on a headband which positions it on the back of the viewer's head. The transmitter is suspended just below the center of the table. The receiver cable is suspended from the overhead frame to allow the user to walk around the table.

Stereo Eyeglasses - StereoGraphics Corporation CrystalEyes 2™ glasses are used to alternately occult each eye. These are field sequential electro-stereoscopic liquid crystal shutter devices which are synchronized using an extended range infrared transmitter driven by a serial port on the image generator. The image generator provides 60 pairs of left and right eye images per second from its output buffer, synchronized with the transmitter. When a right eye image is being drawn the glasses occult the viewer's left eye and vice versa. The transmitter is positioned to bounce its signal off the screen to viewer where it is detected by the sensor on the front of the shutter glasses between the eyepieces.

Control Inputs - Operator control is performed through a combination of the Onyx keyboard and mouse and a SpaceBall™ joystick. Panning the image is accomplished with the joystick. In the prototype, setup, scaling, and gross position adjustment is accomplished with mouse and keyboard. Other input devices are currently under investigation.

Network Interface -The Onyx communicates with other DIS systems at IST via 10-base2 Ethernet and FDDI network interfaces.

Mirror - The first prototype aimed the projector downward, taking advantage of the high ceilings at IST. In the second version, a trapezoidal mirror is suspended in front of the horizontally mounted projector to bend the optical path from horizontal to vertical. This reduced overall height while maintaining a large image size.

Projection table - The image is drawn on a low gain projector screen laid on a horizontal table. The table is constructed of wood to avoid distortion of the head tracker's magnetic fields.

Software

The software implementing the graphics, networking, and operator control and feedback functions forms the second component of the Mirage system.

Infrastructure - The Mirage software is based on an object-oriented library of interface and facilitating functions called the Virtual Environment Library (VEL). VEL was written at IST to support virtual reality research conducted for the Army Research Institute. It already contained drivers for the Flock of Birds^{tm}, SpaceBall^{tm}, and Crystal Eyes^{tm} so the Mirage work could focus on developing algorithms to relate user location to the characteristics of the viewing frustra. VEL and Mirage are written in C++. Loaders for Multigen Flight^{tm} and S-1000^{tm} databases are included.

Projection - For Mirage, an oblique projection is made onto the viewing surface that is horizontal and fixed with reference to the virtual world rather than with respect to the viewer. Because this was done using Silicon Graphics' Performer library it is accomplished by specifying asymmetrical viewing cones (or off-axis viewing frustra) in which the line connecting the center of projection with the eyepoint is not perpendicular to the projection plane.

We have defined what we call the "Look At Point" to be the location in the virtual world that is the center of interest for the image displayed on the table. The image is drawn so this point appears to be located at the center of the surface of the table top.

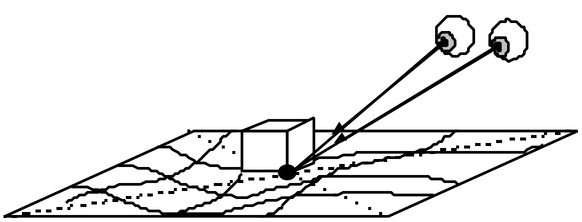

Figure 4. The "Look At Point"

Viewpoint - The viewer's location with respect to the center of the tabletop is obtained from the head tracker. A calibration sequence is used to draw a reticle at the center of the screen. When the tracker's receiver is placed on that symbol and a keystroke entered, the position is measured and an offset is generated which is saved in a configuration file and subsequently read on startup. If the geometry of the system changes this must be regenerated.

During operation, the receiver is worn on the back of the user's head and the assumption is made that the user is always facing the center of the screen. The location is scaled (by the current "zoom" factor) and added to the "Look At Point" to derive the virtual location of the viewer. A direction vector is then computed from this location to the center of the screen. A typical value for interocular spacing (6 cm.) is scaled up by the same amount and the locations of the right and left eyes are computed. Here we make another assumption; that the viewer's head is kept level. This makes it easy to keep the right and left projection planes coplanar with the tabletop.

Stereo - Once the locations of the right and left eyes' viewpoints have been calculated, direction vectors are calculated from each to the "Look At Point" and the asymmetrical viewing frustra can be specified.

In most other graphics applications the angular field of view remains constant. While using Mirage, however, the viewer may move closer to or farther from the projection screen. To keep the same scene content the field of view must be constantly updated to reflect the actual ratio of the table size and distance from the viewer. When the "zoom" factor is held constant, as the viewer moves closer to the center of the table the angular field of view must be increased.

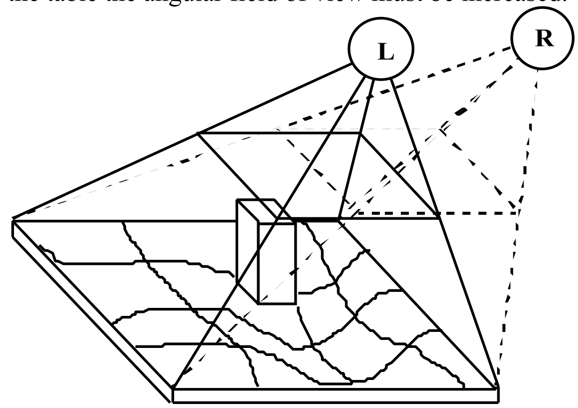

Figure 5. Viewing Frustra

Panning the Image - Independent of the viewer's movement, the virtual world may be moved with respect to the viewscreen by panning. A Spaceball^{tm} is currently used but other mechanisms could also be used. This is merely a horizontal shift of the Look At Point. A terrain following algorithm may be switched on or off. It is helpful when the viewer wants to concentrate on objects on the ground surface but it can make free-flight panning somewhat jumpy when the terrain is very uneven.

The Result

With the appropriate asymmetrical viewing frusta employed, the image is mathematically distorted to account for the oblique angle (pitch or elevation angle) and the viewer's position around the table (azimuth angle). The resulting image is "stretched" along a line between the viewer and the center of the display screen to adjust for the foreshortening the viewer would experience at increasingly low angles of pitch. The image is "rotated" to account for the direction between the viewer and the center of the viewscreen so that image appears "upright" to the viewer regardless of the azimuth angle

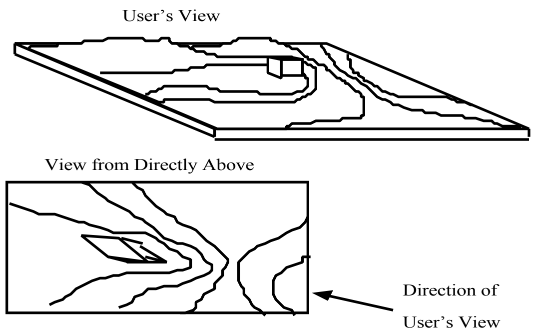

Figure 6. Distortion resulting from Oblique Projection

LIMITATIONS

Single Viewpoint

Mirage provides only one completely correct viewpoint which is located between the head tracker's receiver and the table center. The image may be viewed from other locations with a greater or lesser amount of distortion and understandability. Viewers within approximately 10 degrees azimuth of the receiver will see a view in which objects tend to lean left or right but occultation is correct and terrain looks natural. Viewing the scene from a point above the receiver results in an apparent exaggeration of the vertical dimension. When the viewer is located closer to 90 degrees off-azimuth the right and left eye images are no longer side by side and the stereo sense is lost. Finally, a viewer on the side of the table opposite the receiver will perceive an inversion of depth cues. Hills appear to be hollows and valleys become ridges.

Viewing Volume

Because the viewer is looking at a real image that is projected on the tabletop, objects in the scene which are outside the conical volume defined by the table edges and the viewpoint are clipped.

Viewing Angle

The viewing direction is constrained to angles above the horizontal. This could be changed by tilting the table to 45 degrees or so but the benefits of increased depth in the scene would have to be weighed against the usefulness of being able to walk completely around the table.

CURRENT APPLICATIONS

Visualization of Network Connectivity

Some experimentation has been done to fuse abstract data with the display of physical objects. One example shows the relationships between DIS simulation hosts and the entities that they generate. Each host is represented by a colored sphere floating several hundred meters above the terrain. A colored line is drawn from each sphere to each of the entities on the ground that is being generated by the corresponding host. The lines follow these entities as they move and each sphere maintains a location above the "center of gravity" of the entities it "generates". At a higher level, another sphere, representing the Local Area Network, is connected to its resident simulation hosts below.

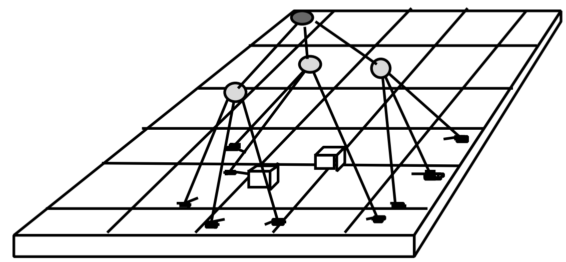

Figure 7. Fusing Network Topology with the Scenario

An exercise controller could use such a display to help manage a large number of assets. Other information could also be included, such as bandwidth usage and availability or location and remaining capacity of recording devices. Transfer of ownership could be graphically initiated by selecting an entity and dragging it from one host to another.

Command and Control Graphics

Flight corridors, no fly zones, no fire zones, assembly areas, and fire support coordination lines have been added in order to generate Mirage's version of a tactical map with overlays. Symbols of interest to ground oriented players are drawn as low fences. Air corridors are drawn as translucent polyhedra.

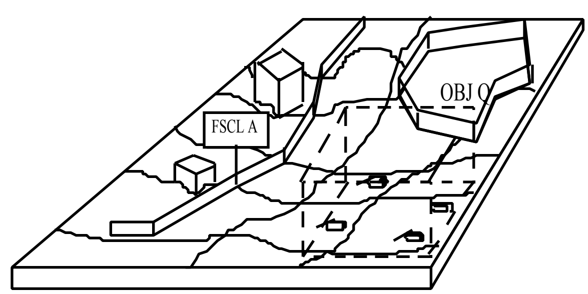

Figure 8. Graphics Overlays

POTENTIAL APPLICATIONS

Simulation /Exercise Management

As the size and complexity of distributed simulation events scale into the realm of tens of thousands of synthetic environment entities instantiated on hundreds of networked computer platforms at dozens of simulation support sites, the incorporation of novel visualization interfaces such as the Mirage in simulation management tools promises to enable the cost-effective management and control of these simulation events. Notions of dynamically representing simulation infrastructure components (such as host computers, gateways, or network linkages) as graphical metaphors in the virtual sandtable depiction of the exercise have been discussed. Exercise managers would be able to view pertinent exercise component information, such as host/site ownership of exercise entities or network utilization rates, on the consistent and intuitive user interface of the virtual sandtable.

Battlefield Visualization/Combat Management

The same features of virtual sandtable displays desirable for simulation management also apply to battlefield visualization/combat management systems. Of particular note is how the natural user interface (which is essentially the absence of a viewpoint control device) of the virtual sandtable promises to facilitate the shared and collaborative viewing and interaction of battlefield information. For these reasons, the notion of linking virtual sandtables at different sites via tactical nets and replacing the myriad of maps and overlays with these display devices has been promoted as a critical component of the Operations Center of the future.

Operations Analysis and Combat Development

While it is a given that visualization of operations and combat development information aids the understanding, analysis and discovery processes of these domains, the display of this information on a virtual sandtable promises to provide a more optimal user interface for such visualizations without the need for cumbersome display control devices. In other words, instead of using the constrained viewport of a graphics monitor under the control of a mouse or joystick, the virtual sandtable enabled analyst would simply walk around the table display to view the information.

Data Analysis

Given the trend in the modeling and simulation community to generate increasing amounts of simulation event data, either by inclusion of more entities and/or the production of more rich entity data, the use of novel visualization interfaces such as the Mirage virtual sandtable stands to enable the more cost-effective understanding and insight of this data. For example, graphical representations of very large data sets could be displayed on a virtual sandtable for manipulation and inspection by data analysts. Some candidates include engineering data, presented as mathematically derived surfaces, logistics data presented as 3D bar-graphs superimposed on schematic representations of transportation networks, and financial analyses presented as 3D spreadsheets with selected inputs controlled interactively.

After Action Review/Training Aids

Using the consistent and intuitive virtual sandtable graphical user interface, simulation training instructors could dramatically and effectively illustrate pertinent concepts or training event points of interest. As with traditional stealth displays, battlefield visualizations of training events could be augmented with graphical depictions of measures of effectiveness data, but the display of this information on a virtual sandtable would provide a more tangible 'big picture' view without the need for cumbersome display control devices.

IMPROVEMENTS

Experience with Mirage has uncovered a number of areas that would benefit from improved technology and other approaches.

This kind of application is natural for a large very high resolution flat panel display. The projector/table combination is bulky, heavy, and requires time consuming alignment and convergence each time it is moved. Field applications would benefit most.

The user is connected to the system by the tracker receiver's cable. Other methods involving optical or acoustic techniques might prove to be more convenient.

Some combinations of pointing, selecting, grasping, and moving operations will be required for most applications. Wands, gloves, and 3D cursors could supplement or replace joysticks but hands-free operation may eventually benefit even more from exploitation of voice recognition and recently marketed low cost brainwave monitoring control technologies.

The single most important improvement to Mirage would be the addition of multiple viewpoints. The current method, which time-multiplexes the right and left eye views, may be capable of extension, but probably not to more than two or three views. Other techniques are being sought. In the meantime, however, a combination of interlinked Mirages and Head mounted displays may prove most useful.

CONCLUSIONS

The intent of this paper has been to discuss the genesis, implementation, and potential future of the Mirage "pseudo-holographic" virtual sandtable display device. Based on preliminary experience with this operational prototype over the last few months, we feel that the virtual sandtable metaphor has strong potential to revolutionize the representation and collaborative interaction of a diversity of visualization domains.

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