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Using Virtual Environment Technology for Preadapting Astronauts to the Novel Sensory Conditions of Microgravity

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ABSTRACT

A unique training device is being developed at the Johnson Space Center Neurosciences Laboratory to help reduce or eliminate Space Motion Sickness (SMS) and spatial orientation disturbances that occur during spaceflight. The Device for Orientation and Motion Environments Preflight Adaptation Trainer (DOME PAT) uses virtual reality technology to simulate some sensory rearrangements experienced by astronauts in microgravity. By exposing a crew member to this novel environment preflight, it is expected that he/she will become partially adapted, and thereby suffer fewer symptoms inflight.

The DOME PAT is a 3.7 m spherical dome, within which a 170° by 100° field of view computer-generated visual database is projected. The visual database currently in use depicts the interior of a Shuttle spacelab. The trainee uses a six degree-of-freedom, isometric force hand controller to navigate through the virtual environment. Alternatively, the trainee can be 'moved' about within the virtual environment by the instructor, or can look about within the environment by wearing a restraint that controls scene motion in response to head movements.

The computer system is comprised of four personal computers that provide the real time control and user interface, and two Silicon Graphics computers that generate the graphical images. The image generator computers use custom algorithms to compensate for spherical image distortion, while maintaining a video update rate of 30 Hz.

The DOME PAT is the first known such system to employ virtual reality technology to reduce the untoward effects of the sensory rearrangement associated with exposure to microgravity, and it does so in a very cost-effective manner.

INTRODUCTION

In the weightless environment of space flight, the absence of a gravity stimulus to the gravity receptors in the vestibular, proprioceptive and somatosensory systems alters the relationship among sensory inputs. The altered sensory stimulus conditions are responsible for space motion sickness, spatial orientation and motion perception disturbances experienced by many astronauts and cosmonauts. Two devices have been designed to partially simulate the sensory conditions present in microgravity in order to help astronauts more quickly adapt to these conditions during a Shuttle mission. The DOME PAT is designed to achieve graviceptor stabilization to simulate the absence of gravity information. In this system, the trainee can move about the virtual environment in six degrees of freedom (X, Y, Z, roll, pitch, yaw) without a change in the gravity vector. Actual head rotation about an earth-vertical axis keeps the trainee's orientation fixed with respect to the gravity vector while preserving the normal relationships between rotation of the visual field (in one plane at a time) and semicircular canal outputs. Actual head rotation about non-vertical axes is prevented, although virtual rotation may be enabled about any axis. By helping astronauts become comfortable with rotations in all body axes without a tilting gravity vector, the DOME PAT should facilitate crew members' performance and sense of well being in microgravity.

MECHANICS

The DOME PAT is a 12 ft (3.7 m) diameter spherical dome. The inner surface is painted white and serves as a projection surface for two video projectors with custom wide angle optics. The field of view for the trainee is 170° horizontally by 100° vertically. The projectors, along with an adjustable trainee restraint assembly, are mounted on a 6 ft (1.8 m) diameter rotating base in the bottom of the dome. The base rides on a 92 cm diameter bearing, and is gear driven by a servomotor to allow computer-controlled rotation of the trainee and the projectors about a vertical axis. This single degree of freedom of rotation is the only real movement allowed by the system.

The trainee restraint adjusts for three different trainee positions: 1) sitting upright, 2) lying on left or right side, or 3) lying supine looking up at the top of the dome. For the upright and on-side positions, the projectors' optical axes are approximately horizontal, and for the supine position the projector assembly is tilted back so that images are projected on the top of the dome.

CONTROLS

A computer generated virtual environment is projected on the inside of the spherical dome. The trainee uses a six degree-of-freedom isometric force hand controller to move through the virtual environment. Joystick or forceplate emulation for the hand controller is configured with a software switch. There are three different motions that the hand controller can simulate: position, velocity or acceleration. It is generally configured as a forceplate in the acceleration mode with no damping; however, there is a deceleration factor to provide fast cancellation of motion in each degree of freedom. The instructor has an identical controller and may 'move' the trainee to provide instruction or demonstrate passive motion. The trainee also wears a head restraint that is mounted in the center of the dome. This head restraint contains position and force transducers which sense actual and attempted head movements. The only actual head movement allowed is about an earth-vertical axis in order to keep the trainee's orientation fixed with respect to the gravity vector. Attempted off vertical head movements can drive virtual rotation allowing the trainee to 'experience' the rotation without actually changing their orientation with respect to the gravity vector.

COMPUTERS

The DOME PAT computer system consists of four AST personal computers (PCs) and two Silicon Graphics computers (SGIs) networked together. Refer to Figure 1. The four PCs are networked using Arcnet and Novell Netware software. The SGIs use ethernet and NCSA Telnet software to communication with each other and with one of the PCs.

The Real Time Positioning System (RTPS) gets the raw signals from the hand controller and the head transducers and calculates a delta position vector (DPV). It sends the DPV to the Real Time Controller (RTC). The RTPS also drives the servomotor when actual rotation is enabled. The RTC takes the DPV from the RTPS, calculates the current eyepoint and sends it to the SGIs. The RTC also performs collision detection to prevent the trainee from moving "outside" the virtual environment. The SGIs function as a two channel computer image generator. They draw the next frame of the scene based on the current eyepoint and send RS343 video signals to the projectors at a rate of 30 Hz to display the virtual environment with a resolution of 960 X 1280 pixels for each channel.

Paradigm Simulation, Inc. of Dallas provided the image generation software which is based on their commercially available product, VisionWorks™, with some custom code for special functions and tools. Due to our spherical dome configuration with the very wide viewing area, in addition to the standard image generator functions (3-D to 2-D mapping, clipping, drawing, etc.), the SGIs must perform some special functions such as spherical distortion compensation, edge tessellation, and edge blending. The distortion correction is also required because the projectors are not located at the same position as the trainee's eyes.

There is a distortion map for each channel and each orientation (left upright, left supine, right upright and right supine). Paradigm built a nice interactive tool that is used to build and modify the distortion maps. Basically the distortion map takes each vertex of the polygons to be displayed and remaps it from flat space to a new "warped" location so that the projected image appears with the correct perspective on the curved surface of the dome. This vertex remapping approach had a potential impact on our visual database design, because any line or polygon edge that was "too" long would not get distorted properly. And this brought up another issue: How long is "too" long? The answer is: it depends! It depends on what percent of the viewing area the line or polygon is taking up. For example, if you are only several centimeters from a "small" polygon, it will appear very large in the viewing area.

One way to resolve this problem is to use visual databases consisting of many very small polygons. However, since we are limited to a finite number of polygons that can be processed and still maintain the 30 Hz update rate, an extremely complex database (one with many polygons) is not feasible. Another approach is tessellation or breaking up large polygons into smaller ones. Ideally, once a polygon crosses a threshold of "largeness" in the viewing area, it could be broken into smaller polygons in real-time. However, due to real-time processing limitations, it is not possible to do this across our entire viewing area. Therefore, since it is crucial to maintain proper distortion along the edges especially in the center of the field of view where the left and right projections meet (the "seam"), a special function known as edge tessellation was implemented. This automatically breaks up polygons that intersect with the edges into small polygons, allowing them to be properly distorted which creates smooth projection edges. This facilitates a smooth seam down the middle.

To smooth the seam between the two projections even more, particularly since the colors between the two projectors are not perfectly matched, another special function blends the colors along the center seam. This is called edge blending. The two projections are slightly overlapped. Using translucent edge matching polygons, the intensity of the overlap portion from each projection fades out toward the center edge. Therefore, the colors from the two projections are blended down the center seam where they overlap. The width of the blending band and the intensity function can be adjusted offline to achieve the desired effect.

FUTURE

There are a number things we would like to do in the future to improve the DOME PAT trainer. First, we would like to upgrade the image generator hardware to the Silicon Graphics reality engine in order to increase processing speed and power capability. With the increased processing power, a different approach for distortion compensation could be implemented. More accurate distortion compensation than our current technique could be achieved by remapping each pixel instead of just remapping each polygon vertex. This would eliminate any anomalies that currently occur if a polygon is too long to be properly distorted. Also, it would eliminate the anomalies that occur since the polygon warping look up table is not a one-to-one map. Some points are remapped to the same location, while other locations are blank because no point is mapped there. With the extra processing capabilities and new distortion approach, texture could also be incorporated. Texture would increase the realism of the virtual environment and reduce the number of polygons in the visual databases.

Second, we would like to combine the functions of all of the DOME PAT PCs onto one machine. This would simply the operation for the user. It would also reduce maintenance costs by eliminating of some of the non-standard hardware and software (special graphics boards and their FORTRAN library, 386 co-processor board inside one of the 286 machines and the special software for shared memory and communications.)

Finally, we plan to add more visual databases such as the mid-deck, flight-deck, payload bay with doors open, etc. This would allow us to present different virtual environments, or perhaps combine them (flight-deck, mid-deck, with either the spacelab or the payload bay with open doors) for a large virtual environment with different areas to explore.

CONCLUSIONS

In conclusion, the DOME PAT meets some complex scientific requirements for (1) holding vestibular graviceptor signals constant, (2) allowing 6 degrees-of-freedom of full virtual motion, and (3) allowing active trainee interaction with the novel sensory environment. This is accomplished in a very cost-effective manner using commercially available hardware and software with some custom software. Our image generators provide real-time distortion correction for a wide angle spherical display. Other simulators use analogous systems which employ multi-million dollar computer image generator systems. Our hardware and maintenance costs are greatly reduced by using standard computers, and system upgrades are simplified.

The DOME PAT is currently being used in an actual training environment. It is being used to demonstrate perceptual illusory phenomena to astronauts and to teach them to describe their perceptual experiences. Anecdotal reports from several crew members suggest that a number of perceptual experiences produced by the DOME PAT system are similar to those experienced inflight, during entry, or immediately postflight.

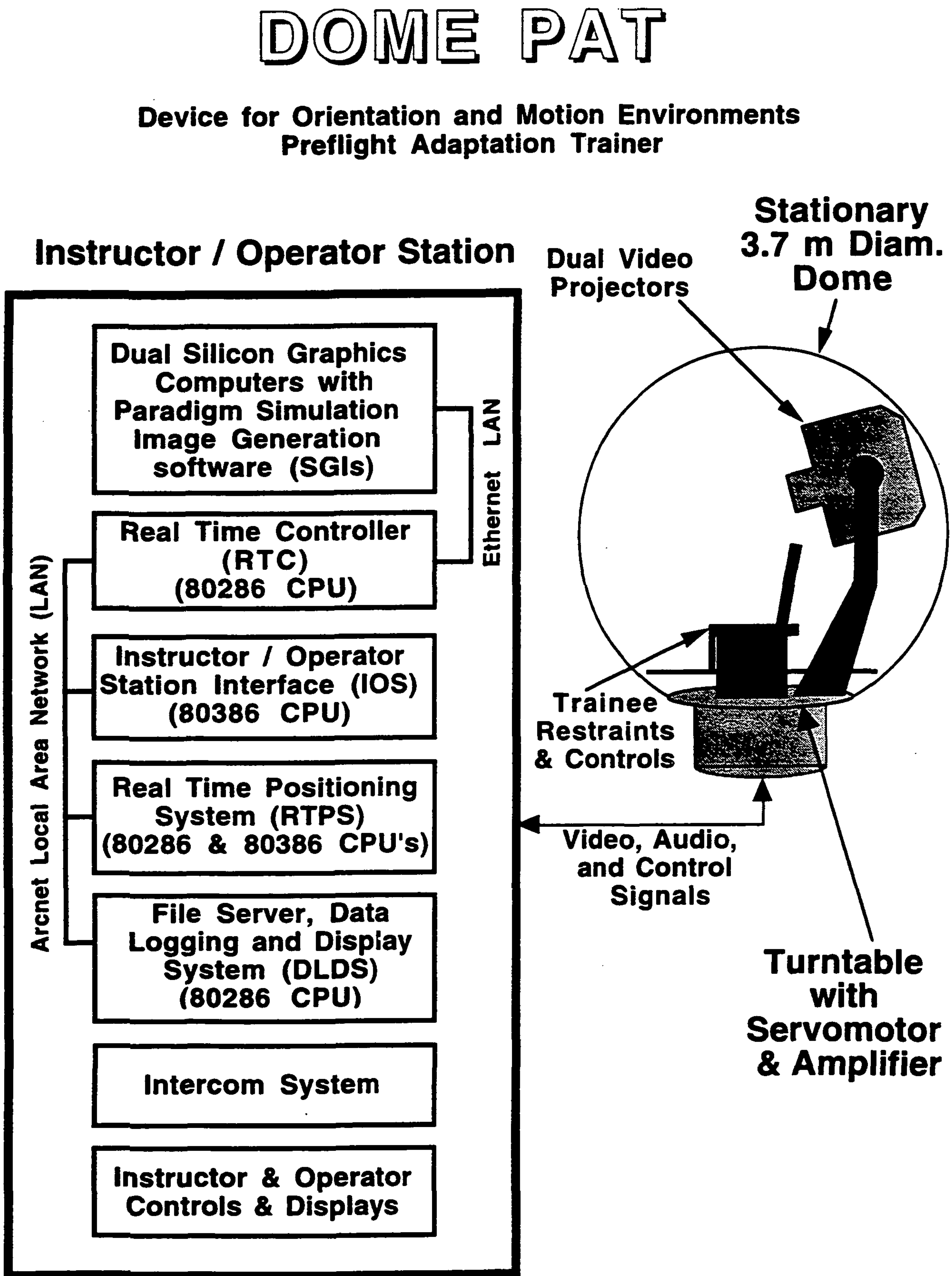

Figure 1 Block diagram of the DOME PAT system.