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Marshall Space Flight Center's Virtual Reality Applications Program 1993

Joseph P. Hale, II
Crew Systems Engineering Branch/EO23
Marshall Space Flight Center
MSFC, AL 35812
(205) 544-2193

INTRODUCTION

A Virtual Reality (VR) applications program has been under development at the Marshall Space Flight Center (MSFC) since 1989. Other NASA Centers, most notably Ames Research Center (ARC), have contributed to the development of the VR enabling technologies and VR systems. This VR technology development has now reached a level of maturity where specific applications of VR as a tool can be considered.

The objectives of the MSFC VR Applications Program are to develop, validate, and utilize VR as a Human Factors design and operations analysis tool and to assess and evaluate VR as a tool in other applications (e.g., training, operations development, mission support, teleoperations planning, etc.). The long-term goals of this technology program is to enable specialized Human Factors analyses earlier in the hardware and operations development process and develop more effective training and mission support systems.

The capability to perform specialized Human Factors analyses earlier in the hardware and operations development process is required to better refine and validate requirements during the requirements definition phase. This leads to a more efficient design process where perturbations caused by late-occurring requirements changes are minimized. A validated set of VR analytical tools must be developed to enable a more efficient process for the design and development of space systems and operations. Similarly, training and mission support systems must exploit state-of-the-art computer-based technologies to maximize training effectiveness and enhance mission support.

The approach of the VR Applications Program is to develop and validate appropriate virtual environments and associated object kinematic and behavior attributes for specific classes of applications. These application-specific environments and associated simulations will be validated, where possible, through empirical comparisons with existing, accepted tools and methodologies. These validated VR analytical tools will then be available for use in the design and development of space systems and operations and in training and mission support systems.

MSFC VR SYSTEM CONFIGURATION AND DEVELOPMENT

The MSFC VR systems reside in the Computer Applications and Virtual Environments (CAVE) Lab in Building 4610. System components consist of VPL Research, Inc. Eyephones (Model 1 and LX), DataGloves, and software (Swivel 3D, Body Electric, and ISAAC), Polhemus Isotrak and Fastrak spatial tracking systems, two Macintosh IIfx computers and two Silicon Graphics Inc. graphics computers (4D/310VGX and 4D/320VGXB). Two single-person configurations are possible. These are the Eyephone Model 1 (stereo views) with one DataGlove and the Eyephone LX (stereo views) with one or two DataGloves (i.e., both right and left hands, simultaneously). A two-person configuration is possible and consists of both Eyephones (monocular views) with one DataGlove associated with the Eyephone Model 1, and up to two DataGloves associated with the Eyephone LX. In the two-person configuration, both people are in the same Virtual World (VW) simultaneously and each is able to see and interact with the computer-generated image of the other.

Several VR development activities are underway at MSFC and with the Johnson Space Center (JSC). EXOS, Inc. is under contract to develop a Sensing And Force-Reflecting Exoskeleton (SAFiRE) for the hand. This device will provide force-reflecting feedback to the fingers and hand as the user touches and grabs virtual objects.

Tomorrowtools is under contract to develop a 30 sensor spatial tracking system. Using ultra-sonics to determine the location of each of the sensors and infrared to transmit data to the base units, this system provides an untethered method to track up to 30 body points and/or other objects simultaneously. This will be particularly useful in dynamic work envelope analyses. In-house, work is underway to broadcast the video signals to the Eyephones, removing the video cable to the user. Integration of the two latter activities' products will free the user from existing I/O cables.

MSFC is cooperating with JSC in their efforts to develop a "long distance" two-person capability using their in-house-developed VR system. This means allowing two people to see and interact with the computer-generated image of the other in the same Virtual World, simultaneously, with one person at JSC and the other at MSFC! Basic capabilities have already been demonstrated. As VR technology evolves, this virtual link between, and eventually among, the NASA Centers will provide major foreseeable and unanticipated benefits.

COMPUTATIONAL HUMAN FACTORS

Human Factors issues and considerations in hardware and operations development present a large class of potential VR applications. VR technologies and techniques currently provide some limited macro- and micro-ergonomic analytical tools for consideration of operational, viewing and reach envelope requirements, in both one-gravity and micro-gravity environments.

Macro-ergonomics analyses for the topological design of work areas can consider what one is able to see from a variety of eye reference points. These analyses can also include operationally-driven components such as translation paths among the various worksites.

Combined with scaleable user anthropometry attributes, micro-ergonomics analyses for the spatial layout of workstations can consider what one is able to see from a variety of eye reference points and what one is able to touch from a variety of shoulder and seat reference points and/or foot restraint locations, using a range of virtual anthropometric sizes.

Many analyses that use "Fomecor" mockups, the KC-135 (provides approximately 30 seconds of weightlessness during each cycle of parabolic flight), or the Neutral Buoyancy Simulator (underwater facility for simulating weightlessness) are candidates for VR. It is not that VR would completely replace these other technologies and techniques, but it adds another tool to the analytical toolkit.

In some instances, VR might be considered for use in an analysis that would have otherwise not be undertaken. Resources (time, people, materials, etc.) required for a "standard" simulation or mock-up analysis may be greater than the expected return. In this case VR, due to its relatively low utilization costs, would surpass the cost/benefit ratio threshold and enable an analysis that would have otherwise been forgone.

Similarly, VR can enhance and enable more effective utilization of standard simulations and mock-up analyses. By preceding these analyses with preliminary VR analyses, both the hardware and operations can be refined so that the return from the standard analyses is increased. This is accomplished by either reducing the magnitude or number of standard analyses and/or improving the fidelity of those analyses with a more mature design.

Because the VWs are nothing more than computer files, design changes can be done more quickly and more candidate configurations can be subsequently analyzed than is currently possible with existing, "standard" Human Factor tools (e.g., Fomecor mockups).

VALIDATION STUDIES

Several VR applications validation studies are underway at MSFC. The selected applications are those that can utilize existing VR technology and capabilities. Before VR can be used with confidence in a particular application, VR must be validated for that class of applications. For that reason, a specific validation study has been proposed for classes of applications. The validation approach is to compare the results from the VR analyses or application with a specific past or present analysis, design, and/or actual flight experience.

Early applications utilizing the VR system currently in place at MSFC fall primarily into viewing analyses (including visualization of spatial layouts) and reach envelope analyses. Three studies are underway to begin validating VR for these classes of applications.

The objectives of the first study are to develop, assess, and validate VR as a macro-ergonomics analysis tool for the topological design of work areas. Two existing control rooms and their corresponding virtual counterparts will be used to collect subjects' qualitative and quantitative judgments on a variety of measures. The Spacelab Payload Operations Control Center (POCC) and the Data Control Room (DCR) have been selected, based on their apparent separation on a variety of continua (e.g., large/small, spacious/cramped, aesthetically well/poorly designed, etc.). A corresponding Virtual POCC (VPOCC) and Virtual DCR (VDCR) have been developed that contain the basic elements (e.g., tables, monitors, printers, communication panels, etc.) and spatial layout of their real world counterparts.

Forty-eight subjects (twenty-four males and twenty-four females) will participate in a within-subjects design study. Overall Independent Variables (IVs) include World (Real/Virtual) and Design (Good/Poor) with Gender as a blocking variable. Nested within the Design variable, the subjects will either estimate the range to items (Range Estimation) or choose (forced) which of a pair of objects is closer (Relative Range). The Range Estimation IVs are Item (Object/Surface) and the Item's Range from the observer (Near/Far). The Relative Range IVs are Field-of-View (FOV) (Same/Different, i.e., whether or not the subject can see both objects simultaneously in the same FOV) and the objects' Range from the observer (Close/Away). Adjective pair Likert scales, range estimation, relative range forced choice, and elapsed time to answer range questions will be collected as dependent variables.

The second VR validation study involves a proposed redesign of the Crew Interface Coordinator (CIC) console. The CIC console is part of the POCC. The CIC position is analogous to the Mission Control Center's "Capcom" position, communicating directly with the Spacelab payload crew about payload operations issues. In this study, the objective is to develop, assess, and validate VR as a micro-ergonomics analysis tool for considering operational, viewing, and reach envelope requirements in the spatial layout of workstations and worksites and to develop, assess, and validate scaleable user anthropometry attributes. It compares the proposed redesigned CIC console with a Virtual Crew Interface Coordinator (VCIC) console.

An algorithm has been developed to rescale user anthropometric attributes to any desired virtual anthropometry. Thus, a 95th percentile male could view and reach as a virtual 5th percentile female and vice-versa.

Test scenarios will be performed on both a "Fomecor" mock-up of the CIC console and the VCIC console and their results compared to ascertain what, if any, distortions arise in a VW. The test scenarios focus on what one can see from a variety of eye reference points and on what one can touch from a variety of shoulder reference points using a range of real and virtual anthropometric sizes. Results of these analyses are also compared to determine the relative merits of VR vis-a-vis an existing, "standard" Human Factor's tool (i.e., "Fomecor" mock-up).

The objectives of the third study are to develop, assess, and validate VR as a Human Factors design analysis tool for considering operational, viewing and reach envelope requirements in a micro-gravity environment and provide some of the various advantages and disadvantages of reaching and maneuvering in micro-gravity. It compares the results from a "virtual analysis" with a previously conducted analysis relating to the operation of the Electromagnetic Processing Facility (TEMPUS), an experiment to fly on the Second International Micro-gravity Laboratory (IML-2) Spacelab mission.

TEMPUS is a levitation melting facility for processing of metallic samples in an ultra-clean environment. Sample positioning and heating can be controlled separately by two independent RF oscillating circuits. The issue driving the previously conducted analysis was whether a crewmember could adequately control the position of a sample in the facility with controls located in the right half of Rack 10 while monitoring the results on a CRT in the right half of Rack 8. The CRT was co-planar with the rack faces and 42 inches away from the controls. A full-scale part-task "Fomecor" mock-up of both racks was fabricated to determine the crewmembers ability to view the CRT while touching the controls.

A virtual mock-up of racks 8 and 10 has been developed and placed inside of a virtual Spacelab module. A method to enable the various advantages and disadvantages of reaching and maneuvering in a micro-gravity environment has been developed, within existing VR technology capabilities and limitations. In particular, the user can manipulate the attitude of the Spacelab, as a whole, while "grabbing" a handrail, giving the egocentric perception of micro-gravity mobility. Viewing and reach envelope analyses are conducted and the results compared with the previously conducted "Fomecor study." This study also includes the scaleable user anthropometry, developed and assessed in the VCIC study.

MSFC VR APPLICATIONS

Current Applications

The MSFC VR capability has already be utilized in a couple of activities. Both primarily involved immersive visualization of architectural spaces. One supported the recent move of the CAVE Lab into its new quarters. Two different lab layouts were developed and modeled in Swivel 3D. Several of the lab staff then "entered" the virtual labs and evaluated the configurations as both users and visitors. Layouts were modified near real-time and re-evaluated. Based upon these evaluations, one modified layout was chosen and implemented.

In a second activity, support was provided to the 30% design review of the Space Station *Freedom* Payload Control Area (PCA). The PCA will be the payload operations control room, analogous to the Spacelab POCC. Several configurations of the console floor plan layout, large video screens, and Public Viewing Area were modeled in Swivel 3D. Designers, management, and the Public Affairs Office (PAO) utilized the system to immersively visualize the options. PAO evaluated the view from the Public Viewing Area, at various raised floor heights, and performed a preliminary camera viewing analysis, "flying" to various possible camera locations to inspect the composition of the possible camera fields-of-view. The ability to pan and tilt and change "lens" (i.e., narrow to wide angle fields-of-view) in real-time was especially useful.

Proposed Training Applications

Two Spacelab training applications are proposed. The extent to which they are possible using the existing VR technology capabilities and limitations will be determined largely by the earlier validation studies. The implementation of these applications is, therefore, somewhat tentative and will be modified by the results of the validation studies. These proposed applications require a translation capability to translate existing Spacelab Computer-Aided Design (CAD) data files into VR compatible formats.

The first proposed application is related to initial crew and POCC cadre training. As a new crew or cadre member is assigned to a Spacelab mission there is a familiarization phase for both mission independent Spacelab systems and capabilities, and mission dependent payload systems and capabilities.

Early in the mission planning and development process, this training is accomplished in the classroom, and through Spacelab systems and mission documentation. The full-scale Payload Crew Training Complex (PCTC) training mock-up and simulators are not yet available. For personnel assigned later, the PCTC training mock-up may be in place, but access may be limited due to simulator development and other training activities.

In either case, there is a period during which the newcomer must quickly assimilate a large amount of information into his or her concurrently evolving schema or mental model of Spacelab. A tour through a virtual Spacelab may initialize the newcomer <u>and</u> provide insights into system functionality and capabilities. If successful, this could provide a basis for a more accelerated training program and a better integrated understanding of Spacelab systems and payloads.

The essential feature of this application is one or more Virtual Spacelab Modules (VSLMs). Depending on the focus of the "lesson", there may be several VSLMs, each configured to support that lesson objective. For example, Spacelab Program Overview may use standard Spacelab systems in both the long and short modules and perhaps even the "pallets only" configuration. Mission specific training could use a Spacelab systems-only VSLM and/or an integrated systems/payload VSLM. In addition, each system and payload could be "exploded" to permit visualization of its constituent components and their interrelationships.

The second proposed Spacelab training application, utilizing existing VR technology capabilities, involves using VSLMs during the last nine-to-six months before launch. There are always late changes to on-board stowage. As changes are made, the PCTC Training mock-up is updated. It is desirable to allow the crew the opportunity to tour the mock-up to "see" the latest stowage configuration. This helps to "internalize" the location of items within the Spacelab module. Unfortunately, as the launch date approaches, access to the crew becomes more and more limited, particularly during the last three months.

A VSLM with the updated stowage configuration would enable a more convenient, even remote, method to "visualize" changes in stowage locations. Updated VSLM files could even be electronically transmitted to the JSC for the crew to "tour" on the JSC VR system. Validation of this application, like the previous real-world application, will be based primarily upon subjective data gathered through questionnaires.

This ability to electronically transfer VWs further enhances the familiarization/ initialization training application discussed above. Using both the MSFC and JSC VR systems simultaneously, the users could enter and interact within the same VSLM. This would permit, for example, a "tour guide" for the Spacelab Program Overview or a Mission Specialist accompanied by the stowage manager or a Payload Specialist for the stowage "walk-thru."

Future Applications

A demanding and comprehensive application for VR is support of unplanned Inflight Maintenance (IFM). That is, subsets of the features and VR capabilities required to support this application are used in a variety of other applications. Support to unplanned IFM requires Human Factors analyses (e.g., viewing, reach, and dynamic work envelope analyses), operations development, training, mission support, and even simultaneous participation by physically separated users in the same virtual environment.

An example of an unplanned IFM occurred on Spacelab 3. This actual Spacelab mission experience will also be used for comparison in the validation of this application. The goal would be to actually recreate the IFM environment and operation, then compare this virtual IFM experience with the actual flight experience. This would include reference to video and audio recordings of the on-board operation, written logs, and participation of the actual Spacelab crew involved in the IFM operation.

During Spacelab 3, the Drop Dynamics Module (DDM) developed a problem with a power supply module. One of the three DDM AC power supplies had failed. No procedures or plans had been developed pre-mission for this particularly malfunction. No spare power supplies were stowed. It was decided to cut the wires from the failed power supply and re-route them to one of the other power supplies that could handle the extra load. Procedures had to be developed and validated on the ground and approved by both MSFC and JSC before uplink to the crew. The procedure required removal of the rack front panel before the Payload Specialist (PS) entered head first. Only his legs remained visible outside of the rack. Inside the cramped rack interior, the PS successfully re-wired the power supply modules and continuation of the science objectives resumed.

It is anticipated that enhanced VR would have been capable of supporting many of the activities and analyses that occurred on the ground in support of this unplanned IFM. Viewing analyses, reach envelope analyses, and, with an incorporated anthropometric model, dynamic work envelope analyses can be achieved concurrently with procedure development. Although much of this can be done in an engineering mock-up, VR offers several unique capabilities.

First, VR could provide a timely and safe method to enable the various advantages and disadvantages of reaching and maneuvering in a micro-gravity environment. This includes body attitudes and positions difficult to recreate in a one-G environment. This would be superior to existing methods for simulating micro-gravity because existing methods can not be used in a timely manner and are of limited duration (KC-135) or require ancillary equipment (Neutral Buoyancy Simulator) that can interfere with operations in restricted volumes. Second, VR would permit anthropometric sizing to reflect the dimensions of the on-board crew. This is particularly useful for operations being planned in relatively tight spaces.

Since a payload IFM procedure has to be approved by MSFC and JSC before it can be implemented, VR would offer the mission and payload managers the ability to visualize the procedure and environment to gain a faster and more in-depth understanding of the operation. This could be accomplished while the managers are sitting at their consoles in the control center. Further, managers at both centers could enter the VW simultaneously to review and discuss the operation. This capability for direct mission support would be unprecedented, though the possibilities are not limited to unplanned IFMs.

Pre-mission operations development and validation could also be carried out in the same manner, even though the rapid turn-around capability of VR is not necessarily a requirement. Pre-mission crew training could use the same VWs developed to support procedure development. This would prove particularly beneficial for operations where the various advantages and disadvantages of reaching and maneuvering in a micro-gravity environment make a difference.

Enhanced VR technologies and techniques could also provide unique capabilities not presently possible with current simulation technologies. Currently, there is no way to practice the logistics of handling multiple, mobile objects in a simulated micro-gravity environment. The duration of the micro-gravity periods on the KC-135 are too short (approximately 30 seconds) and the viscous drag and motion-induced turbulence in water makes neutral buoyant methods unsuitable. VR, with suitable tactile and force-reflective feedback and a physics properties simulator reflecting physical laws concerning motion and collisions, could prove to be a valuable operations development and training tool for applications requiring dexterous, fine-motor movements.

SUMMARY

This paper has described the VR Applications Program at MSFC, including objectives and approaches. Current and planned applications and associated validation approaches were presented.

The three validation studies described above can be started with the current MSFC VR Applications Program resources and capability. The two "real-world" proposed applications will require augmenting current capabilities with commercially available products

Viewing analyses, reach envelope analyses, and dynamic work envelope analyses can be achieved concurrently with procedure development. VR can provide a timely and safe method to enable the various advantages and disadvantages of reaching and maneuvering in a micro-gravity environment. This would be superior to existing methods for simulating micro-gravity because existing methods can not be used in a timely manner and are of limited duration. Even where the KC-135 and/or the Neutral Buoyancy Simulator are appropriate, prior utilization of virtual mockups can result in more efficient use of these micro-gravity simulators. Hardware and operations design can be more mature, resulting in fewer and/or more productive simulator sessions.

Utilizing VR in initial Spacelab crew and POCC cadre training can provide a basis for a more accelerated training program and a better integrated understanding of Spacelab systems and payloads. A virtual Spacelab with an updated stowage configuration can enable a more convenient, even remote, method to "visualize" changes in stowage locations.

Pre-mission and mission operations development, validation, and support can utilize VR. This would prove particularly beneficial for operations where the various advantages and disadvantages of reaching and maneuvering in a micro-gravity environment make a difference.