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Applied Virtual Reality Research And Applications at NASA/Marshall Space Flight Center

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A Virtual Reality (VR) applications program has been under development at NASA/Marshall Space Flight Center (MSFC) since 1989. The objectives of the MSFC VR Applications Program are to develop, assess, validate, and utilize VR in hardware development, operations development and support, mission operations training and science training. Before this technology can be utilized with confidence in these applications, it must be validated for each particular class of application. That is, the precision and reliability with which it maps onto real settings and scenarios, representative of a class, must be calculated and assessed. The approach of the MSFC 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. Specific validation studies for selected classes of applications have been completed or are currently underway. These include macro-ergonomic "control-room class" design analysis, Spacelab stowage reconfiguration training, a full-body micro-gravity functional reach simulator, and a gross anatomy teaching simulator. This paper describes the MSFC VR Applications Program and the validation studies.

1. INTRODUCTION

A Virtual Reality (VR) Applications Program has been under development at NASA's Marshall Space Flight Center (MSFC) since 1989. Its objectives are to develop, assess, validate, and utilize VR in hardware development, operations development and support, mission operations training and science training (Hale, 1993a). One of the 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 (Hale, 1993b).

The capability to perform specialized human factors analyses earlier in the hardware and operations development process can help refine requirements during the requirements definition phase. This leads to a more efficient design process where perturbations caused by late-occurring requirements changes are minimized. VR technologies and techniques currently provide some limited ergonomic analytical tools for consideration of operational, viewing, and reach envelope requirements in both one-gravity and micro-gravity environments. The use of VR in the macro-ergonomic analyses of work area topological design enables the consideration of the fields-of-view from a variety of eye reference points and can include operationally-driven components such as translation paths among the various worksites. Micro-ergonomics analyses for workstation spatial layout, combined with scalable user anthropometry, enables the consideration of the fields-of-view from a variety of eye reference points and the reach envelopes from a variety of shoulder and seat reference points and/or foot restraint locations, using a range of virtual anthropometric sizes.

Many human factors analyses that currently use full or part-scale "Fomecor" mockups, the KC-135 (providing approximately 30 seconds of weightlessness during each cycle of parabolic flight), or the Neutral Buoyancy Simulator (NBS) (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. Thus, for example, the first NBS dive of a four dive series could be replaced by a VR simulation to checkout and refine preliminary procedures, verify locations of foot restraints and translation aids, and modify worksite configurations. It could even be used to brief the dive support cadre and pre-determine desirable swim camera (video) and still photography views.

2. VALIDATION STUDIES

Before this technology can be utilized with confidence in these applications, it must be validated for each particular class of applications. That is, the precision and reliability with which it maps onto real settings and scenarios, representative of a class of applications, must be calculated and assessed. This process is necessary to calibrate and accurately determine the degree to which its use is appropriate for that class. The approach of the MSFC 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 are assessed, where possible, through empirical comparisons with existing, accepted tools and methodologies. Once validated, these 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. Specific validation studies for selected classes of applications have been completed or are currently underway.

2.1 Macro-Ergonomic "Control-Room Class" Design Analysis

One class of VR applications is as a human factors design analysis tool for work areas and other architectural spaces. The use of VR in the macro-ergonomic analyses of work area topological design enables the consideration of the fields-of-view from a variety of eye reference points and can include operationally-driven components such as translation paths among the various worksites. Examples of "spaces" include control rooms, space stations, and orbiting telescopes (Null and Jenkins, 1993).

A validation study for "control-room class" ergonomic applications was recently completed (Hale and Dittmar, 1994; Dittmar and Hale, 1994). Its objective was to investigate and characterize some of the possible distortions or filtering of relevant perceptions that might occur in a virtual world. Two existing control rooms and their corresponding virtual counterparts were used to collect subjects' qualitative and quantitative judgments on a variety of measures. The Spacelab Payload Control Room (PCR) and Simulation Control Room (SIM) were 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 PCR (VPCR) and Virtual SIM (VSIM) were developed that contain the basic elements (e.g., tables, monitors, printers, communication panels, etc.) and spatial layout of their real world counterparts.

A 2x2(x2x2) , full-factorial experimental design with 2 within subjects variables and 2 blocking variables was employed. In addition, two pairs of crossed two-level within subjects variables were nested in one of the "main" within subjects variables. The overall Independent Variables (IVs) were World (Real/Virtual) and Room (PCR/SIM) with Gender and World Order (Virtual-Real/Real-Virtual) as blocking variables. Nested within Room were range and relative range estimations. Range estimations were comprised of two IVs: 1) Item (Object/Surface) and 2) the Item's Range from the observer (Near/Far). The relative range estimations, where subjects were required to make a forced choice of which object of a pair of objects was closer, were also comprised of two IVs: 1) Field-of-View (FOV) (Same/Different, i.e., whether or not the subject can see both objects simultaneously in the same FOV) and 2) the objects' Distance from the observer (Close/Away). Range and relative range estimations, as well as elapsed time were collected as dependent variables. The Architectural Space Questionnaire (ASQ), 18 adjective pairs arrayed in a 7-point Likert scale format, was developed and employed in order to assess subjective perceptions of the four different environments.

Overall, there appears to be little difference between real and virtual worlds in one's ability to differentiate and estimate distances at approximately three and six feet. This is also true for discrimination of 2 in differentials at those distances with objects within the same FOV. For different FOVs, this discrimination ability starts to deteriorate in the real world and is lost in the virtual world. Thus, analyses using this technology that depend upon gross range estimations seem permissible, but those relying upon fine range perceptions should be approached with caution.

In terms of elapsed time, subjects took longer to make relative range choices for objects in the different FOVs and in all cases, subjects took longer to respond in the virtual world than in the real world. Part of the different FOV finding would be expected since subjects had to repeatedly turn their heads to compare the two object ranges. But overall, these findings suggest subjects had to gather and/or process more perceptual cues to make a determination. In the different FOVs, the pairs of objects lacked the shared occlusive and parallax attributes of the pairs of objects in the same FOV. As for the virtual world, it is not as rich in textures, shadows, and "clutter" as the real world. This very clear main effect of increased time to make judgments in the virtual world provides guidance as to when and when not to use this technology as an analytical tool. If task times, for example, are a critical component of the analysis, the use of this technology should be carefully considered.

However, these cautions will naturally be relaxed as the technology evolves. Texture mapping, a feature now generally available but not a part of this study's VR system, is an example of a technological advance that should modify these cautions and enlarge the set of VR application classes.

2.1.1 "Real World"

In a "real world" application, support was provided to the 30% design review of the late Space Station *Freedom* Payload Control Area (PCA). The PCA was to 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 VR.

Engineers, management, and the Public Affairs Office (PAO) utilized the system to immersively visualize the options. Engineers and management were able to focus on the operationally-driven design features, such as the team-based grouping and layout of the consoles. PAO evaluated the view from the Public Viewing Area, considering what a range of visitor sizes (e.g., 3.5 ft six year olds, 6.5 ft adults) might be able to see from a range of viewing area floor heights. PAO was also able to perform 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.

2.2 Spacelab Stowage Reconfiguration Trainer

There are frequent changes to the planned stowage locations of items on a Spacelab module during the last few months before launch. As the Mission Manager stowage "reserve" is released and item quantities are finalized, the flight stowage configuration is adjusted to maximize its utility. Early during training (12-4 months before launch) as stowage changes are made, the Spacelab training mockup at the MSFC Payload Crew Training Complex (PCTC) is updated. As the launch date approaches and access to the crew becomes more and more limited (particularly during the last three months when the crew is dedicated primarily to the Johnson Space Center (JSC)), the PCTC concurrently ramps down its effort to maintain a current stowage configuration.

It is assumed that providing the crew the opportunity to tour a Spacelab mock-up to "see" the latest stowage configuration will help to "internalize" the location of items within the Spacelab module. This is similar, for example, to one's ability to mentally walk-thru one's house or apartment to count the number of windows, doors, or closets. Memories contain a large number of images that can be retrieved and examined at will (Lindsay and Norman, 1972).

A Virtual Spacelab Module 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 JSC for the crew to "tour" on the JSC VR system. To further enhance this training application, using both the MSFC and JSC VR systems simultaneously, the users could enter and interact within the same VSLM at the same time, even though they are physically located in different states. This would permit, for example, a Mission Specialist at JSC to be accompanied by the stowage manager or a Payload Specialist at MSFC for the stowage "walk-thru."

The pathfinder Spacelab for this VR application is the second International Microgravity Lab (IML-2). A VSLM with two "stocked" lockers has been developed along with application-unique kinematic and object behavior attributes. These attributes were designed to minimize the "frustration points" and to facilitate task-specific user actions. Touching the locker door and the locker opens the door and makes the locker slide out, respectively. Running a hyper-extended hand through the locker turns the locker wire-frame, allowing the user to see the objects inside. Forming a grab gesture (a fist) below the locker allows the user to "pick-up" and manipulate the locker and its contents. The user's virtual hand appears approximately 1.5 meters from the user's point-of-view. This "stretched" virtual arm allows the user to manipulate the locker without the user's point-of-view appearing inside the locker. Objects within the locker can be "grabbed" by forming a one-finger point gesture, touching the object with the finger, and bending the thumb. Thus, the user can move the object to view beneath it or to manipulate the object to view it from all sides. Finally, the user can return the objet to its original location in the locker by touching it with a two-finger point and bending the thumb. The object "jumps" back to it origin. The simulator is currently being evaluated and refined. An analog study is also planned.

2.3 Full-Body Micro-Gravity Functional Reach Simulator

The objective of this project is to develop a methodology and capability to accurately and economically simulate a micro-gravity full-body functional reach envelope. (FB-FRE). In a one-gravity environment, one's side-to-side and front-to-back unrestrained full-body reach envelope is constrained to keeping one's center of mass over one's feet; otherwise you fall. In micro-gravity with the feet in foot restraints, one is able to sweep a "hemi-ellipsoid-ish" surface while pivoting about the feet, constrained only by the various joint ranges-of-motion. FB-FRE simulation can currently be accomplished aboard the KC-135 and in the NBS. Each is time consuming and costly. With the advent of more sophisticated computer anthropometric models and VR, an opportunity arises to develop, calibrate, and utilize these emerging technologies for this uniquely NASA-oriented application.

This project began with a review of the FB-FRE section (3.3.3.3.1 Functional Reach Design Requirements) in NASA-STD-3000, the Man-Systems Integration Standard (MSIS). After discovering that the data in the MSIS was insufficient to build the VR models, it was decided to employ a computer anthropometric model (Mannequin) to develop the data. The approach was, starting at the ankle and working upwards, to rotate a joint to the end of its range of motion (ROM), in the plane of rotation. Using a 95th percentile American male model, the figure was rotated through the X-Z and Y-Z planes while various measurements were made (e.g., fingertip, supersternum, angle of rotation). These data points were used to define curves that were then incorporated into a virtual world to give the egocentric perception of a full-body micro-gravity functional reach envelope. The Mannequin data is sufficient for developing implementation approaches and preliminary algorithms, but lacks really accurate, valid micro-gravity FB-FRE data. In order for the VR FB-FRE simulator to be used with confidence more "realistic" data is required.

This more accurate FB-FRE anthropometric data will be collected in the Neutral Buoyancy Simulator (NBS) utilizing a state-of-the-art 3-D underwater measurement system designed by Marquest Group under a NASA Small Business Innovative Research (SBIR) Phase II contract. This system has been designed to take up to six point measurements twice every second. Data collection requirements must address planes of rotation, ancillary test equipment, selection of anthropometric landmarks, placement of sensors, and anthropometric ranges (link lengths) of subjects. Once the data has been collected and reduced, it will be used to extend and enhance the existing VR simulation of micro-gravity FB-FRE; to assess and calibrate the computer anthropometric model's (Mannequin) FB-FRE; and to refine and extend the FB-FRE section in the MSIS.

The VR simulation task will refine the torso attitude algorithm and develop the virtual test environment. In the virtual environment, the user must be able to virtually rotate about the foot restraint while keeping both hands free to accomplish task-specific actions. The optimal method to accurately and intuitively command rotations will evolve as control algorithms mature and experience is gained in "hemi-spherical" FB-FRE. Body segment attitude is a significant contributor for FB-FRE. Of these the torso appears to be the most important. For this reason, refinement of the algorithm for modeling this segment is called out as a specific subtask. Finally, a virtual test environment will be created that provides the necessary functionality to accurately and completely assess the VR FB-FRE. As the NBS data are distributed, they will be "plugged into" the VR FB-FRE simulator and "exercised." FB-FRE and other relevant anthropometric data will be measured and compared with the NBS data. Deviations will be analyzed and their sources ascertained. The VR FB-FRE implementation approach will be refined to minimize deviations.

Assessment and calibration of Mannequin, in terms of micro-gravity FB-FRE starts with the selection and measurement of the NBS test subjects. The subjects' anthropometric link lengths will used to develop the Mannequin human models. These models will then be rotated through the same planes of rotation as defined for the NBS tests. FB-FRE and other relevant anthropometric data will be measured. These measurements will be compared with the NBS data as they become available. Deviations will be analyzed and their sources ascertained. The Mannequin FB-FRE implementation approach will be refined to minimize deviations and help calibrate the models. Mannequin, as with many other computer anthropometric models, was not developed with this particular application in mind. In addition to refining Mannequin's application, insights will be gained for the use of other computer anthropometric models for micro-gravity design.

2.4 Science Training

This project will assess the use of VR to help teach gross anatomy. A "virtual cadaver" with abdominopelvic organs has been developed along with application-unique kinematic and object behavior attributes. These attributes are based on those developed for the Spacelab Stowage Project described above. Users are able to turn the body wire-frame with a wave of the hand and touch, remove, and return individual organs with point gestures.

This fall, it will augment current teaching methods at a local college. Assessments will include whether the students learned faster, gained a deeper level of understanding, and/or had longer retention.

3. 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. 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.

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