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US NAVY AND MARINE CORPS REQUIREMENTS AND CHALLENGES: VIRTUAL ENVIRONMENT AND COMPONENT TECHNOLOGIES

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The US Navy and Marine Corps have clear requirements for virtual environment (VE) systems and related component technologies for both training and operations. VE systems have been defined broadly to include any computer-based representation of an artificial or real world regardless of the medium of display. A more restricted definition includes only those systems that rely on some form of immersive display where the user experiences and interacts directly with the virtual world as if they were part of the simulation. This paper addresses requirements and technical issues related to the latter category of immersive VE systems. Discussion will be limited to land, sea and subsurface applications without in-depth treatment of aviation and targeting requirements.

Immersive VE systems are characterized by multiple sensory modalities and direct interaction. VE displays can include head-mounted visual displays, which are yoked to head position producing the illusion of fully immersive 360-degree immersion. Head-mounted visual displays can be monocular or "see-through" permitting the observer to integrate real surroundings with virtual objects and displays. Another version of visual immersion uses projection displays on a small enclosed space allowing free head movements and natural exploration of the surrounding virtual space. The sense of physical presence created by immersive visual displays may be augmented by spatialized (3-D) audio, which can simulate the acoustic filtering of the head, pinnae and facial features as well as virtual room acoustics. Spatialized audio creates the perception of sound sources well-localized outside the head rather than between the ears as is usually the case with headphone presentation of sound. This expansion of the perceived workspace of the operator takes advantage of the human ability to attend to multiple spatially discrete information sources. As we shall see later, both virtual visual and audio have the potential for greatly increasing the personal or shared workspace of individual operators.

In addition to the better known visual and auditory virtual displays, there have been significant advances in the rendering and display of virtual haptic representations (Tan, Durlach, Beauregard, & Srinivasan, 1995; Srinivasan and Durlach; http://touchlab.mit.edu/). Haptic perception combines tactile (touch) and force-feedback (proprioceptive) and is usually associated with active motor exploration of the objects being explored. Haptic displays can be used as direct manipulation interfaces and together with automatic speech recognition help to make interactions with immersive VEs truly direct and natural. Immersive VEs can be defined by any or all of these features but most commonly are associated with temporally synchronized and spatially registered virtual visual and auditory displays.

VE systems should be considered as potentially augmenting or replacing dedicated simulator technology, especially with respect to training applications. Conventional simulators are dedicated hardware and software systems, often costing millions of dollars to acquire and maintain and requiring large spaces to house the systems physically. These size and cost constraints often limit the number of available systems and can only provide limited accessibility for a broad range of users. While these systems are often magnificent in their fidelity and potential effectiveness, more affordable and accessible simulation-based training systems are required to reach a larger training market. Reconfigurable computer-based training systems including VE are available to a larger market because of their low cost and inherent deployability. Such lower fidelity systems can be used to optimize limited time spent in more expensive dedicated simulators and may, in some cases, actually be as capable or more capable in terms of training effectiveness. Rapid advances in VE display technologies and computing power coupled with decreasing system costs will continue to improve the fidelity and usability of interactive VE systems.

VE systems have many advantages over conventional simulator systems for training and mission rehearsal. Unlike conventional dedicated simulators, most immersive virtual environment systems are compact and have the potential to be reconfigurable in software. This means that a single virtual environment interface could be used for multiple training domains as diverse as shiphandling, maintenance and flight operations.

This reconfigurability makes VE an affordable alternative. Both the compactness and inherent affordability of VE systems makes larger production runs possible and increases the potential for large-scale deployment in the classroom and in the field. The resultant increase in availability of VE systems makes training systems more accessible to more

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potential students and could optimize the limited training time spent in conventional and dedicated simulators. Technical challenges to field and shipboard deployment of immersive VE training systems must be addressed quickly as there is a groundswell of requests to deploy these systems as quickly as possible.

Operational uses for immersive VE systems outside of training and mission rehearsal are a longer-term developmental challenge. There seems to be some potential for VE as a control system for remotely-operated vehicles (ROVs) among other teleoperation applications which require a sense of remote spatial situation awareness and maneuvering skills. Performance aids have been discovered as training approaches for pilots of undersea ROVs where close-in maneuvering is a critical control feature and where current control interfaces are not well designed from a human usability perspective. Non-immersive volumetric displays such as the Virtual Reality Responsive Workbench (Rosenblum, Naval Research Laboratory) show great promise as a medium for operational planning and distributed coordination and could be augmented or replaced by personal head-mounted immersive VE technologies.

More near term operational opportunities are VE component technologies that together provide immersive VE experiences. Spatialized audio and heads-up or monocular displays have immediate value to the design of optimal human-computer interfaces by increasing the potential display real estate available to the designer and the user. We shall see later that these component technologies are already making inroads into operational Navy systems such as the advanced multi-modal watchstations and distributed integrated command environment (ICE) concepts in the SC21 ship design program (21st Century Surface Combatant; http://sc21.crane.navy.mil).

SIMULATION-BASED TRAINING: A SEAMLESS CONTINUUM

Current Navy and Marine Corps training doctrine is to "train as we fight." This philosophy leads to a scenario-based training approach that lets our warfighters experience some measure of the chaos and unpredictability of combat before they are thrown into the real thing. Scenario-based training allows a full range of experience to the warfighter from mundane to high-pressured mission rehearsal and allows the user to experience dangerous situations and attempt potentially high-risk solutions and strategies that would not be feasible in real-life training exercises.

Another implication of the "train as we fight" approach is that it is better to train in the actual operational environment with the same people and the same equipment than to train in some remote location on mockups or other degraded facsimile of the operational environment. According to this reasoning, the farther away the training experience is from the actual operational experience, the less effective will be the transfer of training to the real operational world.

These considerations have lead the Navy to emphasize embedded training systems for almost all manned shipboard systems. Onboard scenario-based embedded training systems are well placed to provide training in an operational context that facilitates training transfer. Because of their inherently deployable nature, embedded training systems can also provide just-in-time refresher training or mission rehearsal as needed driven by emerging mission requirements. Embedded training systems must also be designed to diagnose training needs of individuals and teams through computer-based monitoring. This information has the dual advantage of providing feedback to shipboard instructors as well as forming the quantitative foundation for a performance-based measure of personnel readiness required in a reduced manning force. Timely information about operational skills is absolutely essential for intelligent management and optimization of limited personnel resources. Shipboard embedded training systems do have the potential to greatly reduce the shore-based training infrastructure and may provide some long-term affordability benefits.

Embedded training approaches do have a potential downside. Operational requirements and training requirements can often conflict restricting the availability of training opportunities. This restricted availability is compounded when the training exercises require multiple team members, making it even less likely that everybody will be available without taking the operational systems off-line. Shore-based training resources are being reduced to save money and to streamline the training pipeline. Given this trend, additional stand-alone training capabilities are required to augment and support the increasing dependence on embedded training systems. More pierside and shipboard training opportunities are needed.

Stand-alone simulation-based training systems can complete a seamless training continuum from shore-based schoolhouse and pierside training to onboard systems including stand-alone and embedded systems. Simulation-based systems can emulate the operational environment including both equipment and virtual team members and adversaries. To the extent they are successful at emulating operational systems in terms of functional and physical fidelity, they will have similar benefits to embedded systems. Hypothetically, it should not matter to a student fully immersed in a stand-alone training system whether the system is deployed in the schoolhouse, pierside or onboard. Stand-alone onboard systems will have the additional advantage of allowing accessible just-in-time training tailored to the needs of the individual without conflicting with the operational requirements of the ship.

Stand-alone simulation-based training can be delivered at multiple levels of physical and functional fidelity, from interactive courseware on CD-ROM to fully immersive virtual environments. These computer-based systems have the advantage of being reconfigurable in software so that a single delivery system can serve a broad range of training domains. Critical task analyses and studies of training effectiveness must focus on the conditions under which a specific training delivery approach is warranted and cost effective. As display and interaction technology improves and costs decrease, fully immersive VE displays will become commonplace and affordable. It is important to begin to define the acceptable boundary conditions for use of immersive VE systems deployed ashore and afloat. Critical factors to consider include effects of platform motion, field of view, update delays and duration of immersion on physical symptoms of sensorimotor adaptation.

NAVAL SHIPHANDLING REQUIREMENTS

The US Naval Air Warfare Center, Training Systems Division (NAWC-TSD), with the sponsorship of the Office of Naval Research (ONR) has been addressing the needs of the surface and subsurface Navy in shiphandling and harbor piloting with immersive VE training systems. In the submarine community, harbor piloting is an infrequent but critical mission function with few training opportunities. While there is an existing below-decks team trainer (Submarine Piloting and Navigation or SPAN), conventional simulator technology was considered too expensive to provide an immersive visualization capability for the critical leader of the submarine navigation team, the officer of the deck (OOD). The ONR-supported 6.2 exploratory development program in virtual environment training technology (VETT) produced a prototype submarine shiphandling trainer that has transitioned to the 6.3 VESUB program (Hays) and is currently in its third year of funding.

This successful development of a VE training approach to submarine shiphandling has led the Office of Naval Research, NAWC-TSD and the Surface Warfare Officers School (SWOS) to evaluate the related training requirements of the surface warfare community. SWOS has identified the need to augment or replace existing dedicated simulator training capability that costs the Navy in excess of $2M/year to maintain and suffers from the drawbacks in availability outlined above. The possibility of compact and deployable VE systems is consistent with SWOS' vision of a seamless training continuum that could include other shore-base facilities where a stand-alone system could help sailors maintain their shiphandling skills while on extended shore duty or during sea-going deployments. Department Head training at SWOS has been identified as the primary target of the new VE shiphandling systems. Critical task analyses and experiments are underway at SWOS, NAWC-TSD, MIT and elsewhere to define specific training objectives, curriculum and instructional approaches that enhance the training effectiveness and usability of proposed simulation-based systems. Operational challenges being addressed in the near term include underway replenishment (UNREP), plane guard and harbor transit. Technical challenges include understanding "seaman's eye" at a perceptual and cognitive level, ship hydrodynamics and interactions as well as the human-computer interaction (HCI) design guidelines for the development of usable VE systems. Of particular interest is the value added of immersive VE interaction versus more conventional desktop approaches.

URBAN WARFARE REQUIREMENTS

The US Marine Corps has identified training for urban warfare as their highest priority. Urban warfare is the bloodiest, most casualty-intensive warfighting challenge facing our military services today and training the high-level skills required to be effective in these difficult combat scenarios is of critical importance. The Marines are strong proponents of the simulation-based approach to combat training and have instituted a series of large scale distributed training exercises (Hunter Warrior, Urban Warrior and Capable Warrior) to evaluate new methods of distributed team training and operations, with a special focus on small unit operations.

One example of distributed urban warfare training is a Marine Corps project being developed at NAWC-TSD called Small Unit Tactical Training (SUTT). Training objectives and HCI technical challenges of this effort include marksmanship, house-to-house search, person-to-person nonverbal communications and global spatial situation awareness of individuals and team members for immediate search planning and execution. Ultimately these training modules will allow distributed team training across sites that are widely distributed geographically. The Marines would like to see this capability developed for shipboard mission rehearsal while underway on combat deployment. Similar training and mission rehearsal capability would be useful for Special Operations forces.

The current SUTT simulation approach uses a single screen back projection technique with no head-mounted display and a relatively artificial locomotion interface and speech input system. One advantage of this system is that it allows the integration of marksmanship to the urban warfare training objectives. Potential drawbacks to this approach are that spatial situation awareness must be reconstructed in a very unnatural way that could impede the development of individual and team tactical skills. With the single screen projection approach, the user can only see into the virtual world through a single screen like a picture window in front of the viewer. In order to look to the side, users must artificially swing the world around to the front by turning their head and body more than 45 degrees to the desired

viewing direction. This unnatural and perhaps maladaptive motor behavior conflicts with basic proprioceptive and vestibular sensory input and creates an inconsistent mapping of the local virtual environment orientation with the global coordinates of the real world the user can still see and feel around him. At minimum, the control and display interface is a distraction and additional information overhead for the user. At worst, such a display interface will disrupt the very spatial orientation and situation awareness that the system is meant to train.

There are a number of possible technical approaches to the SUTT spatial situation awareness training objectives. Immersive visual displays including head-mounted displays (HMDs) and immersive room environments (e.g., CAVE) would provide a complete 360 degree perspective that would not produce conflicting spatial awareness cues to the user. The HMD solution has the added benefit of compactness and deployability but presents a further technical challenge when the marksmanship requirement is added to the training requirements. The immersive room environment potentially could address the marksmanship requirement as well and new technologies could be developed to reduce the footprint of the immersive room. In addition, researchers at the US Naval Research Laboratory in Washington, DC, are developing and evaluating a more natural and easy to use locomotion interface that would reduce the information overhead required to use all of the simulation-based training concepts described above (Templeman).

REMOTELY OPERATED VEHICLE REQUIREMENTS

Remotely Operated Vehicles (ROVs) are unmanned air, land or sea vehicles that are teleoperated by human users at a remote location. The primary benefit of teleoperation is the projection of human skill or intelligence into a potentially hazardous remote environment. Some technical challenges for ROV operation are developing a spatial awareness of the remote environment of the vehicle and developing a vehicle control capability that includes maneuvering and, in some cases, telemanipulation. Virtual environment simulation for teleoperation can provide a seamless 360 degree reconstruction of the remote environment that could actually be an improvement over having a human observer directly at the site. For example, undersea ROVs are often used at extreme pressures in cold, dark, silty ocean environments that would be extremely hazardous or impossible for human divers. Multi-sensor fusion (visual, IR, sonar, force feedback) can support reconstruction of the remote scene that would be better that the limited visual inputs of a diver on the site.

Undersea ROVs address military requirements in mine countermeasures and submarine rescue as well as commercial and military needs in search, salvage and inspection (hulls, undersea oil rigs and pipelines, etc.). There is a scarcity of experienced Navy ROV pilots and a large turnover of competent pilots makes ROV pilot training a major training requirement for this community.

A consortium of industry and academia researchers (Imetrix Inc., Boeing, GTE, and MIT) supported by ONR is addressing this requirement in the TRANSoM (Training in Remote Sensing and Manipulation) project. The TRANSoM team has developed a stand-alone maneuvering skills trainer for pilots of undersea ROVs using on-line intelligent coaching that tailors instruction to fit the needs of individual students. Current efforts are looking at extending the training to spatial situation awareness (including tether management) and the relative value added of immersive versus conventional desktop displays.

VE COMPONENT TECHNOLOGIES

Many of the technologies developed for immersive VE systems will find near term application as non-immersive augmentations to existing or planned operational environments. As discussed earlier, head-mounted visual and audio displays can greatly extend the perceived workspace of an operator, taking advantage of the human capability to attend to multiple information sources that are spatially distinct. This expanded display space can be used in the design of consoles that optimize information management and workload. Volumetric information displays can improve global spatial awareness and might be valuable to provide a common picture for distributed interactions among geographically separated team members, reducing the communications overhead of team interactions. Personal portable displays can provide decision support where and when it is most needed. For example, "see-through" or monocular display approaches might be able to superimpose technical schematics on a specific mechanical system during routine maintenance, diagnosis and repair.

One example of VE component technology aiding operational design is in the advanced multi-modal watchstation being developed by Dr. Glenn Osga and colleagues for the ONR-funded SC21 Manning Affordability initiative. One objective of this program is to reduce AEGIS Combat Information Center manning by at least 50% through the use of human-centered design principles. The SC21 program office has conservatively estimated that success in this program objective will reduce at least 23 billets per ship providing a cost avoidance of more than $1.3B over the expected life cycle of the ship class. Osga and colleagues plan on exploiting head-worn displays and spatialized audio to expand the perceived workspace of the combat systems decision-makers. The multi-modal watchstation design can be used for

other knowledge domains across the ship including damage control and maintenance decision-making and in the design of human-machine interfaces for other ship classes using similar human-centered design principles and VE component technologies.

A larger vision for VE component technologies is found in the DD21 Integrated Command Environments of the SC21 program office (http://sc21.crane.navy.mil). In this vision of cooperative distributed decision-making, multiple individual decision-makers will communicate with the use of personal display systems similar to the advanced multi-modal watchstation. It remains to be seen whether fully immersive virtual reality simulations will ultimately play a role in recreating a shared decision-making environment across geographically distributed teams.

SUMMARY

Current military requirements for simulation-based training and optimized personal displays provide a compelling opportunity for implementation of virtual environment technologies. Near term applications for VE include land, sea and air training systems that will ultimately be used in a geographically distributed fashion for team training, mission planning and mission rehearsal. Stand-alone training systems will complete a seamless simulation-based training continuum from the schoolhouse to pierside and shipboard, augmenting the current Navy and Marine Corps emphasis on embedded training in operational systems. Virtual environment training systems have the great advantages of compactness, deployability, software reconfigurability and affordability when compared to conventional dedicated simulator systems. These advantages will lead to more widespread and available training capability. Careful task analyses, human-centered design principles and methods and better performance metrics will be needed in order to meet these emerging requirements. A continuing challenge for VE training systems is to demonstrate the value added of immersive versus more conventional desktop delivery systems. Further work needs to be done to evaluate the potential for shipboard VE systems and safety guidelines for their use. However, with the rapid advances in display technologies and computing power in industry today, we can expect VE technologies to continue to grow in value and availability as we enter the next century.

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