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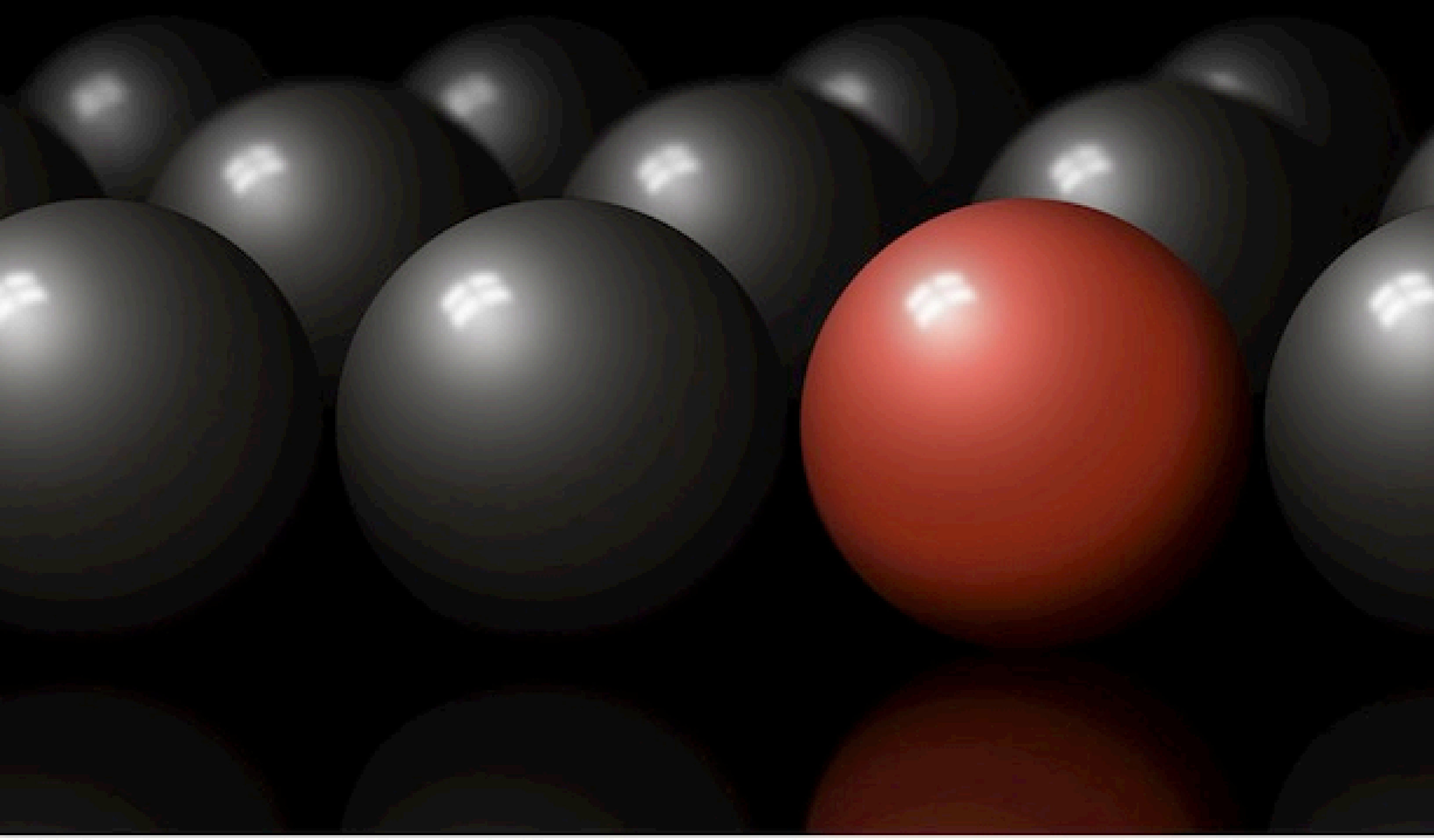

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Two Navy Virtual World Collaboration Applications: Rapid Prototyping and Concept of Operations Experimentation.

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Abstract

Traditionally, US Navy has had a number of Undersea Warfare applications which require rapid prototyping capabilities as well as the need to perform cost effective concept of operations exercises. Recent investigations into the use of virtual world technologies at the Naval Undersea Warfare Center (NUWC) have focused on confined physical spaces that are easily replicated in a virtual environment. For example, a command & control center is a physical environment in which people interact with each other and the space they are in (i.e., attack consoles, displays, etc.) to manage information flow and decision making. Being able to optimally configure and reconfigure such a space is a critical step in the design process to ensure the end meets the necessary mission requirements. Previously the Navy has deployed small scale physical models to visualize spatial relationships (though not allowing human interaction) or large full scale models at more substantial costs. Leveraging cutting-edge virtual world technologies, today's engineers can bring rapid prototyping to the next dimension. By transforming physical mock ups into virtual objects the costs of rapid prototyping can be drastically reduced. By extension, the designs evaluated inside the virtual worlds can then be tested under synthetic situations through concept of operations exercises.

Keywords: virtual world collaboration, virtual world technology, collaborative engineering, collaborative design, undersea warfare, virtual reality, rapid prototyping, Naval Undersea Warfare Center, virtual NUWC, virtual COOPEX

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Two Navy Virtual World Collaboration Applications: Rapid Prototyping and Concept of Operations Experimentation.

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Traditional Prototyping and Design Processes

Until the recent Virginia class of attack submarine, the Navy has deployed small scale physical models to visualize spatial command and control (C2) relationships (though not allowing human interaction) or larger full scale models at more substantial costs. In 1983 this was the one of the few means available to try out physical concepts before building to full scale. Even this process was costly and time consuming. Figure 1 shows a design team surrounding a small scale replica of a submarine attack center space and the subsequent full scale model allowing actual immersion into the prototyping space.

Figure 1. 1983 Submarine Attack Center Design Prototype Evaluation. Navy personnel and engineers collaborate using physical mockups before construction. These mockups were non-functional representations, but allowed for hands on evaluations for placement and workflow.

Using physical mockups, stakeholders typically identify recommended changes for alterations, and must depend on others for those changes to be executed accordingly since they required the coordination of graphics personnel, riggers, electricians, carpenters, safety inspectors and more to create. This process could take a considerable amount of time and money before changes were ready for reevaluation. Once the modifications are complete, stakeholders were then required to travel back to the staging location of the mock up for inspection. This iterative travel and review process is laborious and fiscally consumptive. Additionally, mockups are ultimately limited by the state-of-today technology and therefore have difficulty representing future mission requirements and capabilities. For example, one might extrapolate that flat panel technology will allow large curved or flexible surfaces 15 years from now but a representational mockup would have great difficulty simulating that functionality beyond a screen capture pasted to flexi-board.

Navy Requirements for a Virtual Rapid Prototyping Environment

Optimizing processes for faster and more accurate results by taking advantage of evolving technical capabilities is fundamental for cost savings. Collaborative virtual prototyping allows all the stake holders (i.e., the program managers, technical experts, and members of the fleet), to have the ability to remotely collaborate and contribute to a spiral design process that addresses everyone's needs and concerns. Having all stakeholders involved throughout the entire prototyping and design process ultimately produces a better end product while reducing risks. It also reduces the information learning costs at the end of the process since the customers are part of the process and not just receiving a finished design. Further, allowing them to participate remotely will decrease travel costs and afford more time for research and development.

The requirements for a virtual world rapid prototyping system are specific. Easy remote access must be provided to allow greatest participation while constrained to a given information classification level. A balance must be struck between security and connectivity. Any virtual world technology under consideration for the experiments described in this article must be capable of running behind a firewall and capable of accreditation for use on a military network. Fortunately, the experiments could be accomplished using stand-alone enclaved networks.

The virtual world must provide intuitive in-world build tools so that content can be quickly created and manipulated a priori and then modified in real-time by the design team participants. Related is the availability and efficiency of necessary training to interact in this environment. The virtual world must support enough fidelity to represent complex current and future capabilities in a 3-D environment while supporting a basic level of multi-media (for example streaming video onto display surfaces). And finally, the virtual world must allow user immersion into the 3-D modeled spaces with all necessary communication tools like voice and visual recognition so that the users are not only viewing the information but are part of the information space. This allows them to interact with the space as if it were real – determining line-of-sight, rehearsing information flow between participants, and identifying ergonomics factors. It must be noted that no one product or vendor could address all of the requirements simultaneously.

Virtual World Selection for Rapid Prototyping and Design Activities

The selection of a virtual world technology (VWT) to provide rapid prototyping capabilities must first identify the necessary basic functionalities. First, the user needs to be able to make virtual environment changes in real-time. Ideally, the ability to make these changes is provided to the users through in-world build tools (i.e., tools provided with the virtual world that can be accessed while he/she is in the virtual world itself) and the virtual world would support real time updates to changes made within the system. With usability in mind, these tools should be easy to use and not require specialized training.

Early efforts in NUWC's investigation were focused on finding a virtual environment that provided simple and intuitive in-world building and content modification tools so that non-skilled users could benefit from their use. These tools needed to be advanced enough for detailed modeling, and yet simple enough for use by a novice virtual worlds user. The ability to remotely collaborate in the creation of 3D models on-the-fly, import complex preexisting 3D wire mesh models, and import real-world images (textures, slides) were three crucial selection criteria. Another important selection criterion was the availability of in-world communications necessary so that users would be able to communicate with each other (as a team) in an intuitive manner.

Multiple virtual worlds were investigated including Second Life (by Linden Lab), Open Simulator (open-source), Wonderland (by Sun Microsystems), OLIVE (by Forterra) and Qwaq (by Qwaq, now Teleplace). The project was posed with a dilemma: all of the virtual worlds which allowed for users to create or import content either supported mesh model importing (and therefore could support content re-use) or supported in-world building and live design collaboration in a proprietary geometric primitive format. No virtual world could do both mesh import and in-world model modification at that time. For the identified rapid prototyping requirements, only one VWT emerged as a viable option: Second Life (SL). It was the only virtual world technology that provided sufficient in-world build tools and real time collaboration support to satisfy a collaborative engineering activity. While other VWTs were better equipped for importing complex wire mesh models, they lacked any type of in-world building and modification tools. This meant that any model developed would not be able to be modified in real time from within the virtual design space. Figure 2 shows an example of the Second Life build tools in action.

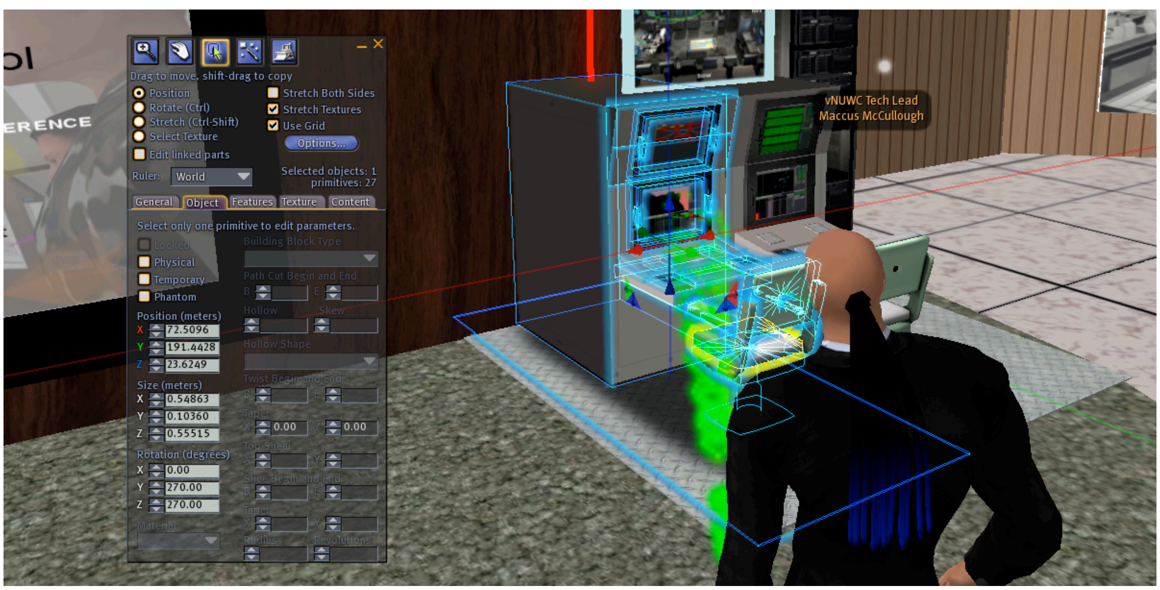

Figure 2. Second Life building tools being used to construct a submarine attack center console. Engineers, scientists, and fleet users have the ability to log in as avatars. The idea is to bring the end user of a product earlier into the design phase and possibly catch errors earlier, producing an overall improved output.

Since Second Life cannot accept CAD models, project personnel were tasked with learning the supplied build tools. Content inside of Second Life is relatively inexpensive and abundant due to a well established economy. We recognized early that we would be denied access to that economy when operating behind the firewall and disconnected from the public grids. It was therefore necessary to become self-sufficient builders and scripters. Additionally, due to copyright and intellectual property issues, most of the content we did purchase on the public side cannot be transferred to the secured side. As a consequence, almost all of the content on the Second Life Virtual NUWC campus is government developed, owned, and maintained. NUWC has engaged Linden Lab from the start and provides feedback in real time based on our experimentation and use. Linden Lab has addressed this issue with the announcement of the Second Life Marketplace to encourage the distribution of "behind the firewall" content as well as allowing NUWC to participate in a Mesh Import Beta testing program.

Future growth in virtual world technologies will allow easier transition from virtual prototypes generated in Second Life using primitive-based modeling to more general wire-mesh based models. In the near future, Second Life will be able to import external wire-mesh models (e.g., flat panel displays, consoles) that will allow on-the-fly relocation (though not supported by in-situ build tools). Furthermore, direct translation of primitive models to wire-mesh models are in discussion with Linden Lab as a future capability. Theoretically this would mean one could prototype in Second Life virtual space and export directly to a format that the ship builder contractor itself could use.

A notional Virginia class attack center was built on an OpenSimulator server. (OpenSimulator is an open-source clone of the Second Life server that was used as an internal alternative to the public SL servers because not all data is publicly releasable. In the context of this document, SL and OpenSimulator can be considered functionally equivalent). Initially, an image of a floor plan was uploaded, placed on the virtual land. From this floor plan, two employees spent less than 8 hours generating a virtual mock up of the attack center. Collaboratively they worked developing the same model at the same time. While intentionally built at a low level of fidelity (to ensure public releasibility), Second Life models can be accurate to the millimeter allowing for 3-D model representations rivaling professional CAD packages. A high fidelity Virginia attack center was built and deployed during the summer of 2009.

Virginia Attack Center Prototyping

In context of a larger spiral design process, development and refinement of the physical space represents only the first step. Since the command and control space is only as good as its ability to support a fleet team performing its missions, understanding the information flow within a submarine's attack center while its crew conducts various missions is and essential component to both baselining and improving the overall design (and hence the fleet's performance). It was determined that information flow starts at the data level and matures through information, knowledge, and finally a decision. The attack center's ability to support this evolution (and not hinder) is of critical importance. Likewise, information often follows a tactical string like the traditional kill-chain (contact detection, classification, promotion, situational awareness, weapons presetting and attack).

To expose the necessary elements of the decision process, first all information paths needed to be identified and visualized. At the theater of operations level these include ship and sensors streams; at the attack center level these include electronic (machine to displays), visual, audio and action paths; and at the operator level these include specific visual paths (individual display widgets). The analyst can then select a specific pre-recorded mission files that stimulate all elements providing playback of not only the tactical displays but the human interactions with each other an the physical space. Furthermore, filter queries are provided allowing the analyst to expose particular informational elements such as those real-time events leading up to firing a weapon on a particular hostile contact. Note the example in figure 3 depicts how information flows through a submarine watch team in an attack center. Specifically a fire control officer and chief are visually interrogating (green paths) a sonar display (orange path) while the chief is providing a tactical solution via voice (blue path) to the commanding officer (not shown).

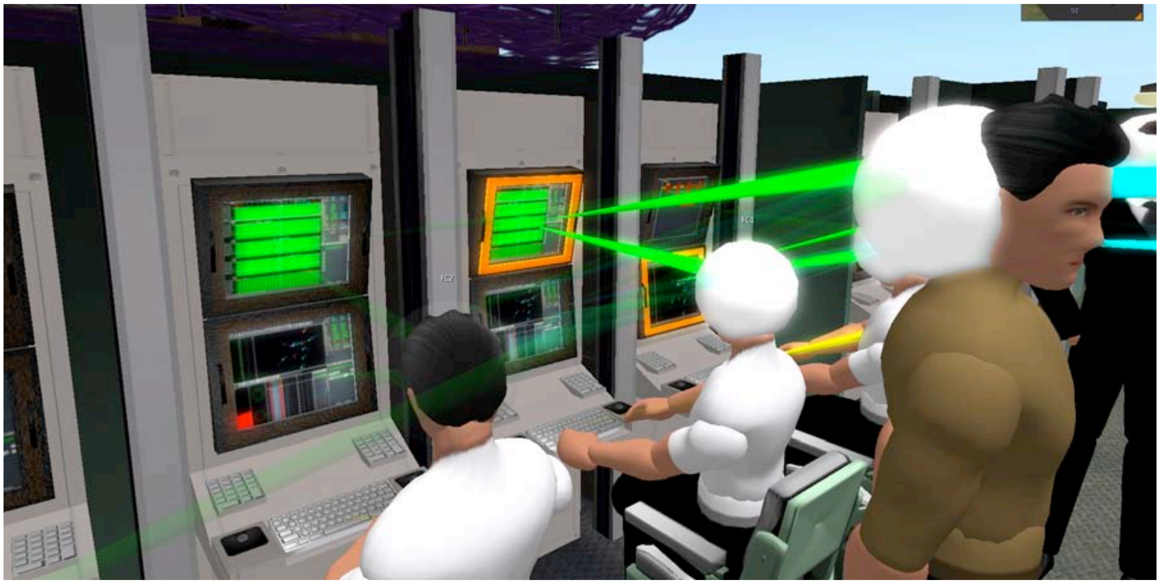

Figure 3. Information Flow inside the virtual USS Virginia Virtual Attack Center.

Navy Requirements for a Virtual Concept of Operations Exercise Environment

Currently, concept of operations experiments (COOPEX) are expensive and require a large number of personnel. Activities to support a COOPEX include the selection of a scenario, planning and coordination of personnel and material needed to play out the scenario (including construction and integration into tactical systems of an actual physical space), logistics to support the participants, data collection, and analysis. It is possible to envision a number of ways in which virtual world technologies can be applied to a COOPEX for the purposes of creating a more cost effective approach while still reaping the benefits of these exercises. Reducing travel by allowing for in-world design layout collaboration and evaluation activities, as described earlier, is an immediate application. Additionally, actual combat system software stimulated by real physics models and simulations will increase the accuracy and realism of the exercise.

The requirements for the selection of a virtual world technology which could support a virtual concept of operations exercise are challenging. The most important requirement in this case is the ability show live running combat system displays fed from combat system hardware located elsewhere on the network. A virtual world technology would need to support in-world interactive remote desktop sharing characteristics. The virtual NUWC team was able to find two possible candidates which supported this capability in the manner required to conduct a limited objective COOPEX demonstration - Sun's Wonderland and Qwaq/Teleplace. After further testing, it was determined Qwaq/Teleplace had the better performance characteristics and toolsets to support the experiment.

Virtual Target Motion Analysis Exercise

The objective of the virtual target motion analysis exercise was to create a virtual environment in which a team of distributed individuals could interactively and remotely operate a submarine combat control system. This is one of the first steps toward proving the viability of a virtual concept of operations exercise. On a technical level, this exercise provides for the evaluation of the infrastructure and support needed from a virtual environment to accomplish a successful target motion analysis task. This test helped to provide a basic "benchmark" of today's state of the art in virtual world technology for us to work from.

The approach to this test was broken down into three phases. Phase one was to identify a suitable mesh model of a Virginia Class combat and control center (CACC) and to import this model into the Qwaq/Teleplace Forums virtual world, figure 4. The source materials were models created from plans using the Maya 2008 modeling package. These models were converted to the virtual reality markup language (VRML 2.0) and imported into the virtual world. Qwaq/Teleplace provides basic model manipulation tools in-world and the environment was recreated without much difficulty.

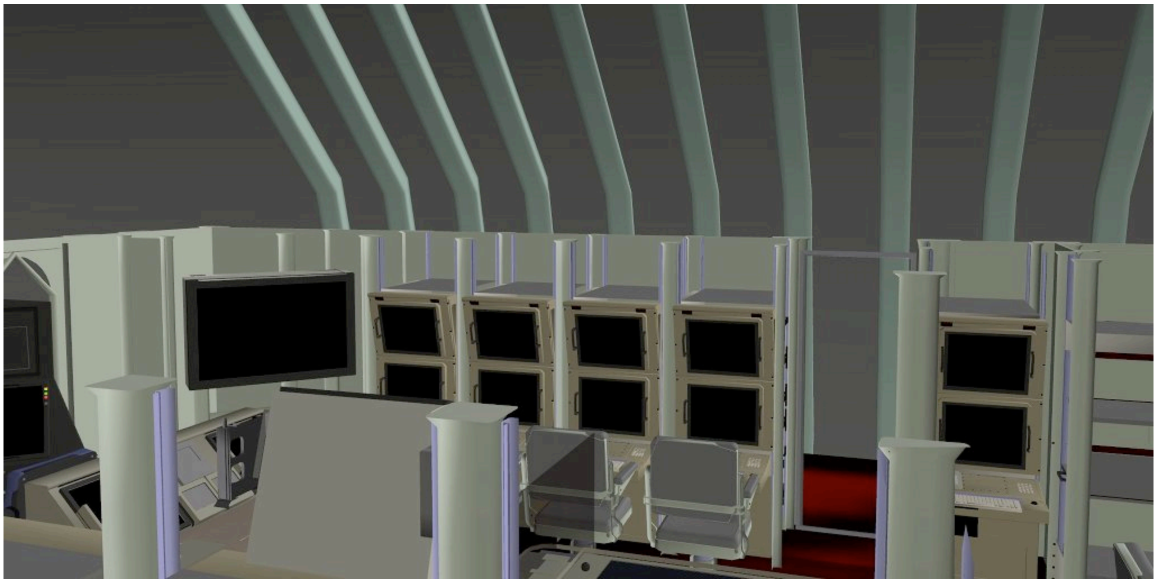

Figure 4. Virginia CACC inside the Qwaq/Teleplace Forums Virtual World.

Phase two involved the creation of a secured network between the combat system hardware and the virtual world server, each located in different buildings on the Naval Undersea Warfare Center campus in Newport, RI. The combat system software was run on functional equivalent hardware as to what is actually used in the fleet. The Qwaq/Teleplace server software was run on relatively modest HP Proliant DL380 G5 servers, which have one quad core Intel processor and 4Gb of main memory. The experimental clients where HP xw4600 workstations with quad core Intel processors, and 4Gb of main memory. The only specialized hardware in the loop was high end graphics in the client workstations, Nvidia Geforce GTX 285 cards with 1Gb of graphics memory. It is important to note the hardware requirements for this experiment were not high end and not cost prohibitive to replicate.

The network consisted of a fiber connection between the buildings. Combat system software would be shared between the buildings using virtual network computing (VNC). VNC is a graphical desktop sharing system used to remotely control another computer. It transmits the keyboard and mouse events from one computer to another, relaying the graphical screen updates back in the other direction, over a network. The media converters used to connect the category 5 lines from the network switches between the combat system hardware and the Qwaq/Teleplaces Server were 10/100 Base T. This will later turn out to be a bottleneck and affect performance.

Phase three involved providing a scenario for operators to work against and collecting user performance and feedback data. The purpose of this phase was to characterize the performance of individuals using a combat control system in the virtual environment by giving them actual tasking representative of operations in a real combat attack center. The experiment involved two teams of operators, with two operators in each team. The procedure for test was to have the teams complete a target motion analysis task on real representative combat system hardware, then complete another target motion analysis task while logged into the virtual world as avatars. Actual pre-recorded sea test data from the USS Ashville was used to stimulate the system via existing playback capabilities. In all cases, the participants are operating the same combat systems software. Figure 5 shows a screen capture of the virtual experiment in progress.

Figure 5. Two operators shown as avatars operating the BYG-1 Combat System. The operators were logged into the Qwaq/Teleplace Clients located in a different building as the combat system hardware. The system was effectively desktop sharing the combat system software allowing the participants to remotely operate the combat system and perform target motion analysis tasks.

Basic biographical data was collected and used to characterize the levels of knowledge and expertise of each team. The first team was considered novice combat system users and the second team was considered experts, with at least 5 years experience. The two teams were given both the real hardware and the virtual environment in which to perform the target motion analysis tasks.

More than one method of data collection was used to record the experiment. The Common Observation Recording Tool (CORT) was used by "real" observers in both the real test runs and the virtual world test runs. Additionally, direct observation using cognitive task analysis was performed as well as queries of confidence intervals. Lastly a post-task survey and questionnaire was provided.

Preliminary results indicated a number of surprising conclusions. While the number of participants in the study cannot be considered statistically relevant; the study has revealed a number of "lessons learned" when planning for a larger number of participants in future experiments. Based on observation and feedback from the operators, results indicate they performed equally well in both systems. Novice operators reported they found the virtual combat system experience facilitated better performance with the real system. Expert operators experience medium to high confidence levels in their decisions using both systems. Expert operators also indicated the first condition primed their performance in the second condition.

There are four key quotes gained from the post-task survey and questionnaires:

1. "The virtual experience was the same as the real (physical) experience."
2. "The virtual world operation was a good warm-up for the real operation."
3. "Being separate from the other watch stander makes the process more vocal."
4. "Working in a separate location than my secondary mate was not a hindrance."

A number of challenges were faced during this experiment. Although we could import combat system consoles, horizontal displays and other combat attack center models into the environment, options for modifying and adjusting the models were limited. Placement of the models in the scene to recreate the attack center layout was cumbersome. Additionally, the import of the models was not entirely straightforward and initially required assistance from the vendor. Subsequent releases of the client has addressed this issue based on NUWC feedback to

Teleplace, Inc.

During the course of the experimentation, it became apparent camera controls are important to the collaboration process. The environment had limited camera control ability after the avatar was seated in front of the consoles. Future experimental development will include feedback and changes made to the user interface.

The last major challenge encountered in these tests was performance. We discovered the mesh model import process was important. Some of the source models were very high quality and contained tens of thousands of vertices. After import into the Qwaq/Teleplace environment, the load on the system was unacceptable. The models needed to be decomposed (number of vertices reduced) in order to bring the frame rate to acceptable levels. Another factor impacting performance was the network. We were pushing two combat system console displays (four screens in total) across a 10/100 BaseT fiber network using VNC. Future tests will include the addition of more displays so upgrading the network to support end-to-end gigabit speeds is planned. Lastly, it is possible to leverage multiple fiber optic lines between the buildings to increase available bandwidth.

Recommendations for Government

In selecting a virtual world technology to provide rapid prototyping capabilities and virtual concept of operations exercises, certain basic functionalities were needed. In most cases, the primary capability needed was the ability for users to solicit real-time collaborative environment modifications and interactive desktop sharing. A technology that didn’t require extensive usage training or specialized skill sets was needed. Based on investigations to date by the NUWC virtual worlds team, Second Life is currently an appropriate technology for rapid collaborative virtual prototyping while Qwaq/Teleplace Forums is an appropriate technology for application and desktop sharing for virtual COOPEX.

The continued use of virtual world technology as a rapid prototyping tool is recommended. Likewise, the novel use of virtual worlds to expose elements such as information flow and decision making allows human interaction with those models to complete functionality to the point where they can be used to exercise and evaluate expected system performance. Additionally, great promise of cost savings for the COOPEX process has been demonstrated by the virtual target motion analysis experiments. The maturity and capability of the necessary features is at a level that it can supply immediate (and demonstrated) benefits across a number of prototyping applications. Discussions with a number of program sponsors indicate that virtual rapid prototyping is a capability that they can use immediately in support of specific program design requirements.

Government organizations are encouraged to continue the examination of virtual world technology. Experimentation has shown there is no one solution yet for the government, although there is great promise in significant increases in efficiency and cost savings. More experimentation and use cases are needed to prove and document the value of this technology.

Content management and information assurance are two areas where most project time and funding are devoted. Outside of the laboratory setting, the government must address these areas for realistic adoption. Information assurance rules and practices must be examined and updated to accommodate the needs of the virtual worlds. Feedback must be provided to the vendors so that they may respond to the needs of the government in an agile manner. A government content archive and standard must be created and agreed upon while the Google COLLADA model and online library of content shows promise.

Government users must be granted access to these technologies at their workspaces. One of the strengths of the virtual world is the online collaborative nature of the community. The Virtual NUWC team has made great progress in showing use cases for the technology, but could be even more effective if allowed to open the servers up to researchers at other government laboratories. Currently the process it technically possible although we have been unsuccessful thus far in our efforts to establish a multi-lab virtual world connection due to a lack of information assurance policy on virtual world technology. We are working with our local information assurance team and hope to be a model for secured and efficient operations. Efforts are ongoing and we expect a secret level Open Simulator deployment in the spring of 2010 to connect NUWC with our Air Force and Army partners. Lastly the technology itself must be light enough to run effectively on an average government desktop. It is the hope of this research staff that through a deliberate examination of the technology and feedback to vendors, these technological challenges may be solved.

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