Understanding Soldier Robot Teams in Virtual Environments

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1 BACKGROUND

The Human Research and Engineering Directorate (HRED), U.S. Army Research Laboratory (ARL) 5-year Army Technology Objective (ATO) research program is addressing human robot interaction (HRI) and teaming for both aerial and ground robotic assets in conjunction with the U.S. Army Tank and Automotive Research and Development Engineering Center (TARDEC). The ATO has recently been enlarged to encompass intelligent collaboration among unmanned aerial systems (UAS) and renamed the Collaborative Robotics ATO. The purpose of the program is to understand HRI issues in order to develop and evaluate technologies to improve HRI battlefield performance for Future Combat Systems (FCS) and the Future Force Warrior (FFW). Soldier robot teams will be an important component of future battlespaces: creating a complex but potentially more survivable and effective combat force. The complexity of the battlefield of the future presents its own problems. The variety of robotic systems and the almost infinite number of possible Army missions create a dilemma for researchers who wish to predict HRI performance in future environments. Most of the FCS proposed systems are still in the conceptual stage and the nature of the environments that they are being designed for can only be approximated.

1.1 Statement of the Problem

The purpose of this paper is to demonstrate how current virtual technologies are being used to answer both very applied and more basic questions concerning how humans and robots interact and form teams to conduct missions in a variety of future combat situations. The general research philosophy is to conduct the research using virtual environments that are comparatively isomorphic to the functional requirements of future battlespaces. We argue that, in some cases, trying to capture the exact conditions of future conflict is self-

Barnes, M.J.; Cosenzo, K.A.; Jentsch, F.; Chen, J.Y.C.; McDermott, P. (2006) Understanding Soldier Robot Teams in Virtual Environments. In *Virtual Media for Military Applications* (pp. 10-1 – 10-14). Meeting Proceedings RTO-MP-HFM-136, Paper 10. Neuilly-sur-Seine, France: RTO. Available from: http://www.rto.nato.int/abstracts.asp.

defeating, because of the unpredictability of future events. Rather, we believe it is more efficient to sample a variety of future battlespaces and vary the functional requirements of both the robotic and the Soldier's tasking. Understanding the richness of possible HRI paradigms should allow us to develop general models of HRI and HR teaming performance in order to predict operational and design requirements before either the robotic systems or the future battle environments are fully articulated.

1.2 Summary of the Findings

A good example is the clever use of the "*Tom Clancy's Rainbow Six 3: Raven Shield*™[1]" gaming software by researchers from Micro Analysis & Design (MA&D) and HRED. The gaming software allowed the researchers to investigate Blackhawk Down type rescue missions using both aerial and ground robotic systems in an urban environment. They were able to ask generic questions about collaborative technologies to investigate different HRI teaming relationships using fairly realistic depictions of urban and desert environments while capturing the essence of a realistic combat mission.

Perhaps an even more realistic representation of an actual urban combat environment was created by Dr. Florian Jentsch and his colleagues at the University of Central Florida (UCF). They fabricated a 1/35 scale Iraqi city with toy buildings, Mosques, roads, and human figures in realistic Arab dress to emulate an urban reconnaissance mission conducted by robotic vehicles controlled remotely by military operators. The purpose of the UCF research is to understand teaming relationships between multiple operators and multiple robotic assets in an urban environment. The scaled city has proved to be very versatile allowing the experimenters to change the cityscape easily and conduct various missions without requiring software changes. Unbeknownst to the test participants, the scaled robots themselves are controlled by confederate researchers simulating semiautonomous Armed Robotic Vehicles (ARV). The surrogate operators plan the waypoints necessary to conduct their mission efficiently. The scaled urban environment is flexible and cost effective and yet has produced valuable data concerning the effectiveness of intelligence gathering under different experimental conditions.

Dr. Raja Parasuraman of George Mason University and Dr. Keryl Cosenzo of HRED have created simulation environments to investigate the effects automating various robotic tasks during multi-tasking mounted missions. One of their virtual environments represents a generic multi-tasking structure for a potential robotic non-commissioned officer (NCO) and the research focus is on how to best automate various functions when the operator must control or monitor multiple systems including UAS and unmanned ground vehicles (UGVs) during maneuver missions conducted over various types of terrain. Specifically, they are investigating the effects of adaptive processes, types of automated control, and adaptable planning. Of particular interest is the fact that they plan to use a number of inexpensive simulation environments in order to generalize their results.

Last, but not least, Dr. Jessie Chen from HRED and her colleagues conducted simulations at the U.S. Army Simulation Training Technology Center (STTC) in Orlando, FL. A mock-up of a generic crew station with mission software was constructed by UCF engineers to investigate workload demands of future robotic operators conducting realistic FCS reconnaissance missions with a limited crew size. The experimental question was whether the gunner in the crew station could conduct remote targeting using an ARV while concurrently performing his or her primary task of protecting the mounted system from local threats. The simulations required sophisticated software to emulate the different experimental conditions requiring the MCS to transverse software generated terrain. Aside from the crew interface, an ARL sponsored operator

[1] Raven Shield is a trademark of UbiSoft.

tactical control unit (TCU) that has been developed for actual robotic control was used to enhance the simulations real world validity.

Except for the last case, none of the research projects required expensive simulators and yet the experimenters were able to investigate a number of very sophisticated HRI missions. The remaining sections of the paper will examine results from the various efforts and reinforce our statement that it is possible to lay a solid foundation of HRI understanding for future design efforts using multiple virtual tools before either specific robotic systems or their intended environments are fully realized.

2 OFF-THE-SHELF GAMING SOFTWARE

2.1 Background and Purpose

This research investigated how teams can effectively use the visually rich information provided by unmanned vehicles (UVs). Robotic assets have vast potential to aid Soldiers by providing advance warning of enemy activities, precise location of targets, and a three-dimensional understanding of terrain including potential avenues of approach.

Two experiments were conducted to investigate real world issues surrounding the use of UVs and UV-provided information such as team configuration, the technologies used, and the information that was exchanged. The experiments provided insight into specific questions about the teaming arrangement between the person monitoring the UV (referred to as the Information Manager or IM) and the Soldiers in the field who are using the UV-provided information to complete a mission (referred to as the Rescue Mission player or RM).

- Can the IM be positioned rearward at a command center or should he or she be co-located with soldiers in the field? If the IM is in a command post he or she could better concentrate on monitoring the UV and determining how to use the information provided. However, this may come at a cost of degraded situation awareness (SA) and understanding of which information is most useful and timely.
- How useful are collaborative technologies? Does it help to have access to an electronic map that shows the dynamic location of the UV and the Soldiers in the field? Does the ability to share and discuss UV provided images or the electronic map improve performance?
- If being co-located is superior, what is it about being co-located that results in better performance? Is it visual contact between the team members coupled with the ability to communicate face to face (FF), the ability to share and discuss visual information, or the ability of the IM to see what the Soldiers in the field are experiencing?

2.2 Approach

Tom Clancy’s Raven Shield computer game by UbiSoft™ was used as a battlefield simulator. A pair of U.S. Marines worked as a team to conduct “Blackhawk Down” type missions. The RM navigated to a downed helicopter pilot as quickly as possible without being detected by enemy forces. The IM used a UV to gather information (such as the crash site, safe routes to the site, and enemy locations) and then relayed information to the RM. The IM used a traditional monitor (19’ screen) to watch the video from the UV, while the RM used a large 5’ by 7’ screen to increase immersion in the game.

The first experiment (McDermott, Luck, Allender, & Fisher, 2005) addressed the first two bulleted issues above. Researchers manipulated the location of the team members, the method of communication, and the type of UV asset used: air (UAV) or ground (UGV). In the co-located location, the IM and RM were in the same room and the IM could readily see the RMs view of the simulated world. In the remote location, the IM and RM were in different rooms. In the remote with map location, the IM could also toggle his or her screen to view an electronic map with the UV and RM locations. Communication was either verbal only (either FF or via radio, depending on the location) or verbal plus visual. When visual communication was allowed, the IM could “send” still images from the UV or the electronic map to the RM. This was done via a small monitor that was turned to face the RM when the IM wanted to transmit an image. Both UAVs and UGVs were simulated using the “ghost” function in Raven Shield (see Figure 1). This made the UV invisible and allowed them to fly. Because the ghost function also enabled the UV to fly through walls and underground, a confederate controlled the UV to ensure the UV behaved functioned in a realistic manor. The dependent variables included objective performance metrics: time, task completion, detections by the enemy, and the number of times each technology resource was used.

Figure 1: View of Enemy from UGV and View from UAV High above the Terrain.

Because the first study revealed performance advantages to being co-located, a second experiment was conducted to understand which aspects of being co-located were most beneficial (Luck, McDermott, Allender, & Fisher, 2006; Allender, McDermott, Luck, & Fisher, 2006). In this experiment, participants would communicate either FF or through a visual divider placed between them. Researchers also varied whether or not the IM could see the RMs screen and whether or not the IM could transmit visual images to the RM. This experiment environment was also improved by giving the IM two monitors so the IM could simultaneously see the real time UV information and the electronic map (see Figure 2), which was determined to be an issue in Experiment 1. In addition, instead of using the ghost function for the UV, we shrank a simulated player in the game (Figure 2) to act as a UGV, so that the UV was visible.

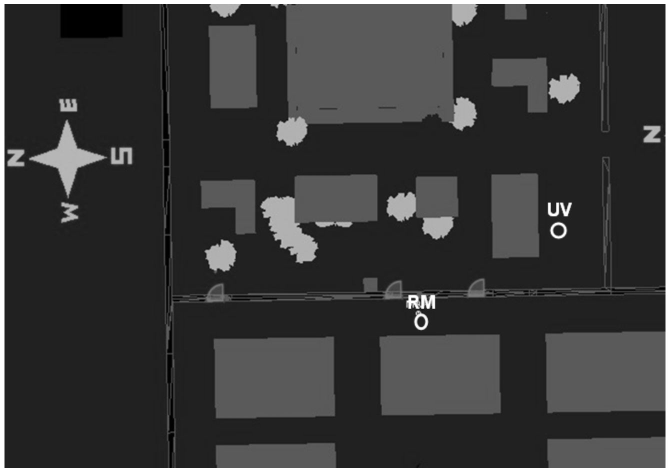


Figure 2: The RMs View with the UGV in the Middle of the Scene and the Electronic Map.

2.3 What Was Learned

The first experiment revealed several interesting findings. Soldiers were detected significantly less often when they were aided by a UV than when they completed the missions alone. However, this increased safety came at a price of higher mission times. Teams were faster and detected less often with the UGV than the UAV. Despite these performance benefits, participants preferred the flexibility of the UAV and its ability to provide the big picture. Teams were faster and detected less often with Verbal only communication than the Verbal plus Visual communication. This was mainly attributed to the fact that the transmitted images often confused the RM more than it helped because the RM did not have a good reference point for the image. Again, the preferences did not match performance. Participants ranked every *Verbal plus Visual* communication conditions higher than any *Verbal only* communication condition. Finally, there were some advantages to being co-located, as it resulted in fastest mission completion times and was preferred by participants. It did not, however, decrease the number of detections by the enemy.

In the second experiment, performance was faster when participants were FF. However, closer inspection revealed that this only held true when image transmission was not allowed. When image transmission was allowed, the extrapolated time was similar in FF and conditions with the divider (see Figure 3). The number of detections by the enemy followed a similar pattern. Therefore, being able to transmit images seemed to compensate for the fact that the team could not communicate FF. This increase in performance when transmitting images (compared to the first experiment where it degraded performance) is most likely explained by the fact that participants had more training in the appropriate use of images and provided a reference point for the RM location relative to the image.

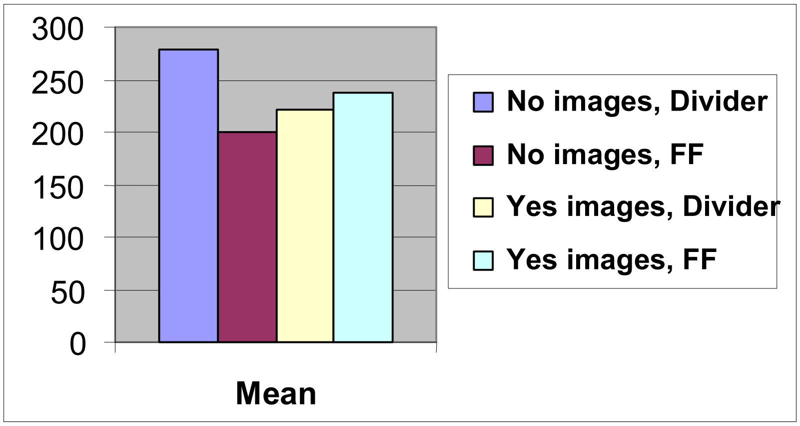


Figure 3: Interaction of Ability to Transmit Images by Communication.

2.4 Advantages and Disadvantages

Using the Raven Shield video game had both advantages and disadvantages. The "ghost" mode provided the flexibility to fly like a UAV or drive like a UGV. This simulated UV was relatively easy to operate using a mouse and keyboard with minimal training. When participants controlled the UGV in Experiment 2, they did not have to learn how to make complex maneuvers with a stick and throttle or fine motor inputs with a joystick. This allowed researchers to focus on communication issues, not control issues. In addition, the maps in Raven Shield were tailorable. A variety of maps were available on the Internet and a high level of programming was not needed to modify the location of terrorists and obstacles. Multiple forums and chatrooms exist on the Internet in which a developer can learn tricks of the trade and ask questions. Lastly, the Raven Shield software was inexpensive compared to high fidelity simulators and robots. The software itself was \$20-\$30 and the only other equipment required was upgraded video cards at approximately \$400 a computer.

One disadvantage was the number of workarounds required to get the game to work as intended. For example, the "compass" was actually a tracking device which tracked a dead player located in an extreme northern location. Therefore, the compass only showed where north was relative to the player's orientation instead of pointing north like an actual compass. It also took quite a bit of manipulation to simultaneously display both the electronic map and the UV feed to the IM. This was eventually accomplished by using another simulated player whose screen was used to show the map. Another workaround (discovered in a chatroom) was the "god" feature which prevented the RM from being killed when shot at by the enemy and prematurely ending the mission. The "god" feature also allowed the UV to be visible to the RM. All these workarounds provided the functionality needed but they made development more difficult and required more time to set up each scenario during the experiments. Other games provide more flexibility in authoring environments. Perhaps the biggest disadvantage was the fact that Raven Shield was not designed to collect that type of data needed. Raven Shield does provide statistics such as the number of rounds fired and the number of enemy killed but these were not part of our scenario objectives. Therefore, the researchers had to collect data manually by taking detailed notes and watching videotapes of the experiment. Despite these disadvantages, the researchers found Raven Shield to be a useful tool for understanding team communications in human robot interactions.

3 A 1/35-SCALE-MODEL MOUT ENVIRONMENT

3.1 Background and Purpose

A set of important questions in the area of HRI has been related to the way in which multiple operators interact with each other and with multiple robots. Although the goal of the robotics development is that a single soldier would have the ability to control a number of robotic assets at the same time, achieving operator-to-robot ratios at or below 1:1 has proven elusive. While controlling multiple robots may be a relatively easier task in the case of logistical missions (in which control of a lead vehicle can transfer to trailing vehicles in a caravan or convoy), more complicated missions, such as reconnaissance, require a great deal more attention from controllers in turn creating higher levels of workload. Further complications occur when multiple operators, each controlling one or several robots, must collaborate and coordinate. Researchers at UCF investigated these issues using a Scale Military Operations in Urban Terrain (MOUT) facility constructed on site at UCF.

3.2 Approach

A Scale (1:35) MOUT facility, representing a prototypical Middle Eastern urban and suburban environment, was constructed with the express purpose of conducting teaming and span-of-control research for UGVs. The MOUT facility has the capability to simulate the simultaneous use of two separate high mobility multi-wheeled vehicle-sized UGVs. For reconnaissance missions, the UGVs each have two independently controlled, radio-transmitter cameras providing images to remotely located controllers. The first of these cameras provides a fixed forward ‘driver’ view that always faces in the direction the vehicle faces and cannot be moved independent of the UGV. The second camera was in a top turret mounted unit which can be rotated independently of UGV movement to serve as a reconnaissance unit.

Using the facility, participants completed reconnaissance missions in teams of either one or two controllers using either one or two UGVs. In addition to these variables, a component of vehicle reliability (high vs. low) was added as a between subject variable and task difficulty (high vs. low) as a within subject variable creating a mixed model 2 x 2 x (2 x 2) design. Participants were initially shown a short training session that covered both UGV control and target identification (via BLUFOR and OPFOR handbooks) and then were to complete four 20-minute performance measure sessions. In between each session, workload measures were taken and various spatial tests were administered. Participants were measured on the number of correct identifications made of potential targets made during each of the four trials. Figure 4 provides an example of what controllers may have seen via the vehicle mounted cameras.

3.3 What Was Learned

Mentioned above was the hope that one soldier would be able to effectively control a number of UGVs in various military situations. Unfortunately, this does not appear to be the case. Teams consisting of two participants far out performed (by an average of 70%) teams consisting of one participant in terms of number of target items correctly identified. In the worst conditions, with unreliable vehicles performing in the most difficult task scenarios teams with two members performed 190% better than their individual counterparts. Indeed, the teams that consisted of one controller handling two UGVs showed the poorest performance of all the possible team configurations.

Figure 4: The Forward View UGV Camera Showing Insurgents in the Crowd with Weapons Aimed.

The addition of a second UGV had at best no impact on target identification performance and at worst actually produced a reduction in performance. For teams of two controllers, this lack of increased performance was likely due to the high use of an "overwatch" technique employed by the controllers. Using this technique, UGVs would simply leapfrog one another from waypoint to waypoint without utilizing the UGVs in different routes. An example of one of these routes can be seen in Figure 5. For teams with only one controller the addition of a second vehicle only reduced overall performance, sometimes by as much as 50%.

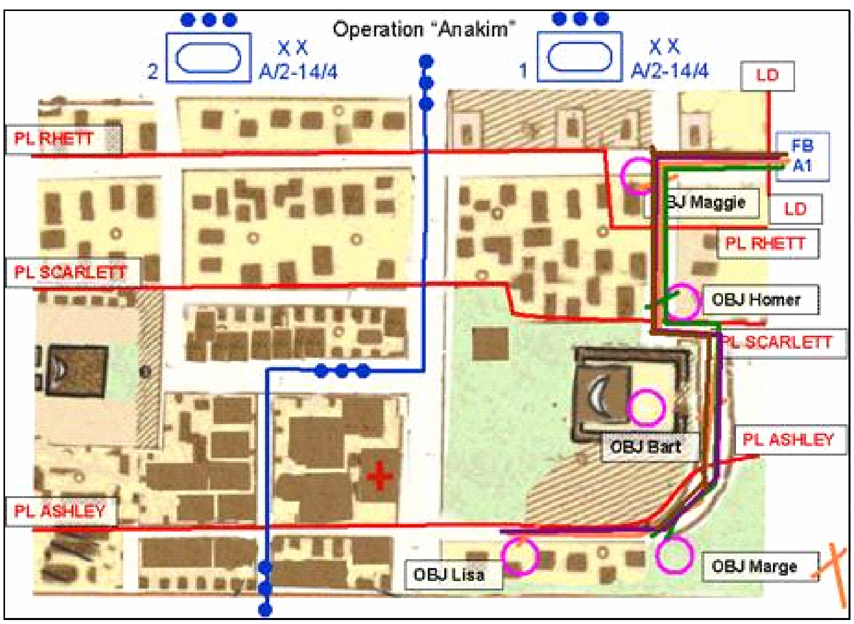


Figure 5: Example of 'Overwatch' Route Plan for Multiple UGVs. Notice both vehicle paths (the brown, purple, orange and green lines) follow exactly the same route.

Admittedly, participants in this study were naïve to the identification task, which surely contributed to the low overall identification rate (roughly 20% of possible targets). Studies are currently planned that will not only increase the levels of training for participants but also will utilize participants more familiar with the subject matter.

3.4 Advantages and Disadvantages

Use of the Scale MOUT facility carried with it several advantages. One of the largest of these advantages is the high fidelity environment provided to participants. The sense of realism created by having an actual physical environment, and not a computer simulated one, ensure that participants had a feeling of consequence to their actions. For example if a participant ran a vehicle into a building or person, real damage would take place and the UGV would not simply drive through the structure. This high level of fidelity meant that participants would control UGVs with more responsibility than they might have in a virtual environment, taking care to drive more slowly and be more conscious of their surroundings.

In addition, use of the Scale MOUT facility gave researchers flexibility in the environment which could be reconfigured quickly due to its component design. The entire facility is created by arranging 2' x 2' pallets with various building vehicles and figures on them that can quickly be rearranged to alter the environment.

The facility is not without its disadvantages, however. The use of a large number of radio transmission devices (vehicle remote controls, camera transmitters, etc.) means that interference can become an issue. UGV controls can lose signal and vehicle control can be lost as well as camera signal resulting in a scrambled image being transferred. While this is a real world problem that soldiers would likely have to deal with in actual military operations, it is not an ideal research condition, causing disruptions during experimental trials.

Finally, it should be noted that many people were required to run the Scale MOUT facility efficiently. For an example session, up to four experimental personnel are needed. The experimenter interacts with the participants, while up to two confederates simulate the automation of the UGVs. Finally, one research assistant is required as technical support help for any other issues (a role which in most cases, however, could also be fulfilled by one of the confederates).

4 A PURPOSE-BUILT SYNTHETIC TASK ENVIRONMENT

4.1 Background and Purpose

Robotic technology will be a vital component of future combat. The future Soldier will conduct 'traditional military tasks' such as scanning for threats, engaging targets, and conducting communications; additionally, the Soldier will have to control or monitor the unmanned system(s) and process information returned from the unmanned system(s). Robotic control will occur via an interface. Parasuraman and Cosenzo (Cosenzo, Parasuraman, Barnes, & Novak, 2006) developed simulations to evaluate human interactions with robotic systems particularly how Soldiers' multi-tasking requirements affect their ability to successfully complete their missions. More specifically, their goal is to investigate if and how adaptive automation should be implemented to support human control of multiple robotic systems from a single control unit.

4.2 Approach

ARL, HRED, in collaboration with George Mason University created a simulation testbed which emulates the essential robotic tasks (see Cosenzo et al., 2006 for details). The program, *Robotic NCO*, was based on an existing prototype operator control units (OCU) designed by MA&D and TARDEC. *Robotic NCO* allows control of both the task types and levels of automation available to the operator. *Robotic NCO* is a multi-task environment that requires participants to complete three tasks simultaneously: (a) Respond to targets encountered by a UAV by using the mouse, (b) respond to potential obstacles and waypoints encountered by a UGV via the mouse, and (c) respond to audio communications via the keyboard (Figure 6). The program was run using a Dell PC, keyboard, mouse, and monitor.

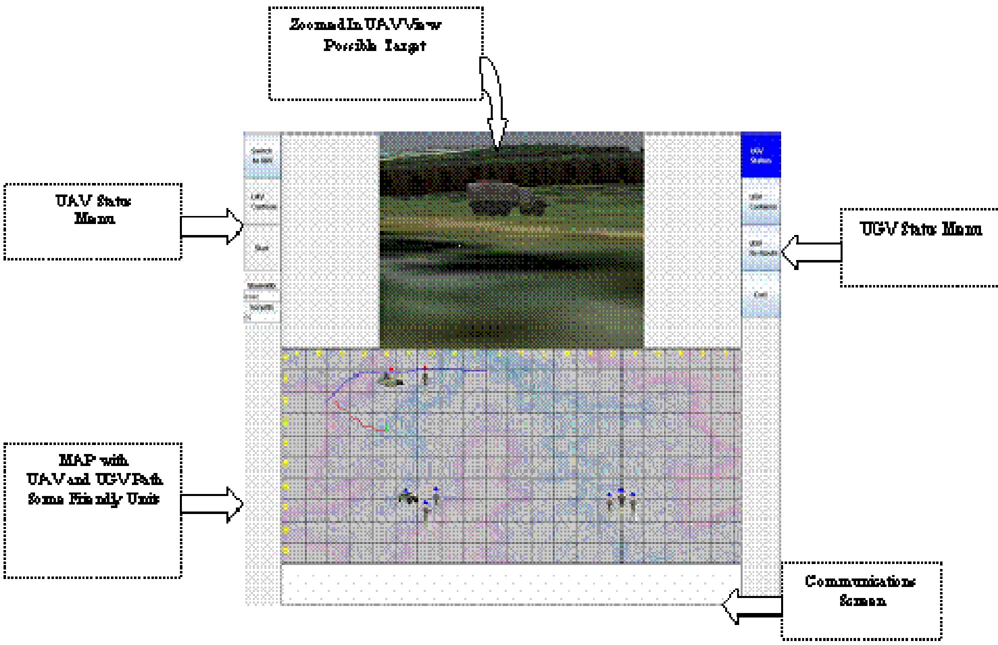


Figure 6: Screen Shot of the Robotic NCO Simulation.

4.3 What was Learned

The purpose of the first experiment with the *Robotic NCO* software program was to evaluate the effects of task difficulty on performance, workload, and SA. In the second experiment, enemy movement occurred at unpredictable times causing an icon on the SA map to change its location. The operator was required to report the change in enemy position. Preliminary results indicate that the change detection task was extremely sensitive to manipulation of multi-tasking difficulty. The simulation research has identified several possible automation tasks including SA aids, target identification, and robotic control. In future work, the researchers will be simulating automation strategies in the *Robotic NCO* and investigating their effects on alleviating workload and improving primary task performance. The series of experiments will help the researchers understand the generic tasking environment for mounted soldiers and will further their understanding of adaptive (dynamically changing) and static automation strategies for workload reduction during mounted scenarios. The advantage to *Robotic NCO* is that it will allow the initial studies to be tightly controlled resulting in efficient utilization of limited resources. As more is learned about Soldier performance, other simulation capabilities will be investigated. For example, the researchers intend to use a simulated TCU from an ongoing Army robotic program and eventually conduct field studies to validate and extend their initial findings with actual robotic systems.

5 COMBINING OFF-THE-SHELF WITH PURPOSE-BUILT SOFTWARE

5.1 Background and Purpose

The goal of this research was to examine if gunners in a U.S. Army FCS vehicle such as the MCS were able to effectively maintain local security (i.e., perform their gunner's tasks) while managing their unmanned assets and how individual difference factors such as attentional control and spatial ability impacted their performance (Chen & Joyner, 2006; Mitchell & Chen, 2006). Mitchell (2005) examined workload for possible crew configurations of MCS crew members using Improved Performance Research Integration Tool (IMPRINT) modeling, the gunner is the most viable option for controlling robotic assets compared to the other two positions (i.e., commander and driver). She found that the gunner had the fewest instances of overload and could assume control of the robotic tasks. However, she also discovered there were instances in the model when the gunner dropped his or her primary tasks of detecting and engaging targets to perform robotic control tasks, which could be catastrophic for the team and mission during a real operation.

This current research tried to verify the modeling project's analytical results and examined if the gunner could effectively detect targets in his or her immediate environment while operating robotic assets in a remote environment. Past research in dual task environments suggests performance decrements when both tasks involved focal vision as in detecting road hazards while operating in-vehicle-devices (Horrey & Wickens, 2004), when the number of the monitored displays increased (Murray, 1994), and as the size of the search set increased (Scanlan, 1977). In the current study, it was expected that performance would be worse in the concurrent task conditions because of the divided visual attention, and that the gunner's task performance would further degrade when the robotic tasks became more challenging (i.e., when more than mere monitoring was needed).

5.2 Approach

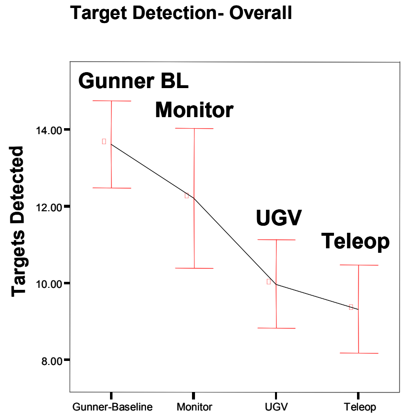
Chen and Joyner (2006) simulated a mounted environment that captured some of the generic capacities of future mounted systems and conducted an experiment to examine the workload and performance of the combined position of gunner and robotic operator. The experimental conditions included a gunner baseline (Gunner Baseline condition) and concurrent task conditions where participants simultaneously performed gunnery tasks and one of the following tasks: monitor a UGV via the video feed (Monitor condition), manage a semi-autonomous UGV (UGV condition), and teleoperate a UGV (Teleop condition). Participants also performed a tertiary communication task concurrently. The Simulation Integration Laboratory ([SIL] specifically the TCU developed by ARLs Robotics Collaborative Technology Alliance (RCTA), was used for the robotic tasks (this component has also been used at George Mason University in some of their studies). The gunnery component was implemented using an additional screen and controls to simulate the out-of-the-window view and firing capabilities (Figure 7).

Figure 7: TCU (left) and Gunnery Station (Gunner's Out-the-Window View) (right).

The main interface of the SIL is the TCU which is where the operator tasks and monitors the robotic asset. With the SIL various robotic assets can be simulated, large UGVs, UGSs, and UAVs. The simulation software is used to populate the reconnaissance area with multiple entities, friendly, enemy, or neutral. In a typical scenario, operators are asked to move assets from a start point through all checkpoints to the release point and to identify targets along the way. Subjects are first provided a map with waypoints and required to set up reconnaissance scans, which include the terrain inside areas of interests. In this environment, we plan to investigate the effects of number of robotic assets and reliability on performance in the SIL. The research will transition results obtained with the *Robotic NCO* simulation and validate those findings in the SIL, a higher fidelity environment.

5.3 What Was Learned

Results showed that gunner's target detection performance degraded significantly when he or she had to concurrently monitor, manage, or teleoperate a UGV compared to the baseline condition (gunnery task only). The gunner's performance was significantly better in the Monitor condition than the UGV condition, which in turn was significantly better than in the Teleop condition. For the robotic tasks, there were significant differences among the Monitor, UGV, and Teleop conditions in target detection performance, with the UGV being the lowest (only 53% were detected). Participants with higher perceived attentional control (PAC) (measured by a self-assessment survey) performed better on the tertiary communication task in the more challenging robotic task conditions, although they performed at a similar level on their gunnery and robotic control tasks as those with lower a PAC. Participants' perceived workload increased almost linearly in order from the Gunner Baseline, Monitor, UGV, and to the Teleop condition. Figure 8 shows participants' gunnery task performance and perceived workload.



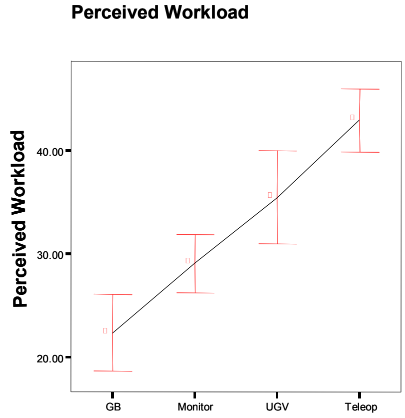


Figure 8: Gunnery Task Performance and Perceived Workload.

5.4 Advantages and Disadvantages

One advantage of this study was that an actual Army system (the TCU) was used and incorporated in a simulated MCS environment that was created by the researchers. By doing so, our results can be readily transferable to the FCS community. In fact, the designers of the MCS are currently evaluating the addition of the ARV to the MCS crew and have incorporated the ARL modeling and experimental data into their manning assessment for system functional review (Mitchell & Chen, 2006). In addition, the Army Unit of Action Main Battlelab has recognized that allocation of unmanned assets needs to be evaluated across all the crewmembers in the MCS Platoon (Mitchell & Chen, 2006). However, there were also some disadvantages associated with using an actual Army system that is still under development. The researchers were not able to obtain the source code for the TCU and, therefore, the manipulation of the robotic tasks and data collection efforts were limited.

6 GENERAL CONCLUSIONS

Modeling and simulation provide a cost effective means for training Soldiers, developing doctrine and tactics, and evaluating systems (National Research Council, 1997). More specifically, they can be used to train and test participants for a particular mission when access to the actual robotic systems is not feasible. Simulations can also be used as prototypes for future military systems. Immersive simulations can be developed that allow the participant to enter and navigate a particular environment increasing the realism of the participant's experience. A broad range of entities (e.g. tanks, aircraft, and people) can be represented in a simulation and their behaviors can be programmed and modified depending on the scenario.

The above examples indicate that the range of virtual environments in not constrained by their cost but rather by the creativity of the experimenters who create them. Even the most expensive of the above examples, was cost effective when compared to even limited field exercises (Barnes, Hunn & Pomranky, 2006). The versatility of the reviewed research paradigms also has the advantage of generalizing too many real world situations enhancing our ability to develop performance models that capture the essence of HRI behaviors. These models can be used to begin the process of developing Soldier-centered designs, tactics, and procedures for FCS aerial and ground robotic systems. Such models will never be perfect and they must be validated but they will be invaluable initial estimates.

In the future, we will develop increasingly realistic simulations as we understand the efficacy of adaptable or adaptive options in multi-tasking environments involving supervision and control of robotic assets. As the fidelity of the simulations improves, the ability to transition the human robotic technologies into fieldable systems becomes more likely as well.

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