

Designing for Humans in Autonomous Systems: Military Applications

**by Michael J. Barnes, Jessie Y. C. Chen, Florian Jentsch, Tal Oron-Gilad,
Elizabeth Redden, Linda Elliott, and Arthur W. Evans III**

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Designing for Humans in Autonomous Systems: Military Applications

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14. ABSTRACT The purpose of this report is to review U.S. Army Research Laboratory (ARL)-sponsored research on the human's role in future autonomous systems and to derive design guidelines to foster human/autonomy collaboration. The research was conducted as part of a larger Army program, Safe Operations for Unmanned systems for Reconnaissance in Complex Environments (SOURCE), that focused on developing safe autonomy for urban applications. The human-autonomy design research encompasses agent reliability, span of control, safety issues, individual differences, training, function allocation, and results from field experiments evaluating advanced interface solutions. The main sections of this report cover (1) autonomy and intelligent agents, (2) RoboLeader, (3) safety for autonomous systems, (4) naturalistic interfaces, and (5) situation understanding using unmanned vehicle imagery. After each section, implications of the results are summarized to develop design guidelines for incorporating humans into autonomous military systems.					
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1. Introduction

The possible applications of autonomy in the military are becoming ubiquitous for unmanned aerial, ground, naval, and underwater settings (Chen et al., 2011a). The advantages for military systems include reduced manpower, increased survivability, performance improvements, and tactics that would be impossible for manned systems to perform (Barnes and Evans, 2010). In the future, autonomous systems may be capable of travelling at speeds and operating under circumstances impossible for human-controlled systems. Currently, most unmanned systems still need human operators and thus do not have a significant effect on personnel reduction. For example, the Army's tactical unmanned aerial system (UAS) basic unit requires two ground stations with 22 personnel, including an officer and a warrant officer. In addition, maintenance is supplied by civilian contractors (Zapotoczny, 2007). Similarly, the Air Force also has significant manning issues when Airmen operate systems such as the long endurance UAS Global Hawk, and crew size is also a crucial issue for human control of unmanned ground vehicles (UGVs) (Barnes and Evans, 2010; Mitchell and Chen, 2006; Weiss, 2011). Improved autonomy is necessary to reduce personnel while maintaining acceptable performance and efficiency (Chen et al., 2011a). Because the capabilities of unmanned systems are improving rapidly, the performance gap between human-controlled systems and at least partially autonomous systems will tilt toward autonomy in the not too distant future (Chen and Barnes, in press; Weiss, 2011). The objective of this report is to investigate the human-related design implications as autonomy becomes a military reality (Barnes et al., 2011).

We focus on results from the human-robot interaction (HRI) program that supported a larger Army technology objective, Safe Operations for Unmanned systems for Reconnaissance in Complex Environments (SOURCE). SOURCE researchers successfully demonstrated improved autonomy for large UGVs navigating in urban terrain while avoiding pedestrians and other obstacles. In addition, this research also demonstrated the effectiveness of small UGVs (SUGVs) mapping interior spaces autonomously and the potential of coordinating small UGVs and UASs to surveil buildings for insurgency indicators. The human-related research focused on the design implications of autonomy and the utility of various advanced interface designs.

In this report, we examine various theoretical papers supporting the program as well as empirical results from in-house researchers from the U.S. Army Research Laboratory's (ARL's) Human Research and Engineering Directorate (HRED) and contracted research. The human-autonomy design research encompasses agent reliability, span of control, individual differences, training, function allocation, and results from field experiments evaluating advanced interface solutions. The five main sections of this report cover autonomy and intelligent agents, RoboLeader, safety for autonomous systems, naturalistic interfaces, and situation understanding using UV imagery.

After each section, implications of the results are summarized in order to develop design guidelines for incorporating humans into autonomous military systems.

2. Autonomy and Intelligent Agents

A number of theoretical and review papers were written to guide the empirical research and to develop guidelines that extend the boundaries of in-house research (Barnes and Chen, 2012; Chen and Barnes, in press; Chen et al., 2011a; 2011b). In these papers, Chen and colleagues discuss paradigm changes necessary to adjust to future military environments wherein hundreds of manned and unmanned combat vehicles will operate in concert. They concluded that as autonomy improved, the human's role will inevitably change to supervision of multiple unmanned systems, and that manual control will become a fallback mode used only in cases of emergencies (cf. Chen et al., 2007). Additionally, their conclusions stress the importance of developing new display concepts to improve situation awareness (SA) and to enhance trust because of the inherent complexity of modern combat entailing supervision of multiple autonomous systems. Specifically, direct supervisory control becomes inefficient as the number of assets to be controlled surpasses the human's attention span (Miller, 1956).

To address these issues, Chen developed concepts that are similar to executive supervision (cf. Barnes and Grossman, 1985; Chen and Barnes, 2012a; 2012b; in press). The analogy can best be described as the difference between the shop foremen and the executive. The foreman directly supervises the workers (who each have a specified degree of autonomy), and the executive works directly with the foreman to develop strategies and is the final decision maker for important changes. Chen and colleagues developed the theoretical rationale and empirical evidence for using software agents to allow a single operator to control multiple assets in a multitasking environment (Chen and Barnes, 2012a; 2012b; in press). An agent is defined as "an autonomous entity which observes and acts upon an environment and directs its activity towards achieving goals" (Russell and Norvig, 2009, p. 34). The advantage of an executive paradigm is that the human (executive) is freed to maintain overall SA and to make tactical decisions while the agent (intermediate supervisor) alerts the operator to possible problems and suggests courses of action to mitigate problems when semi-autonomous assets require intervention.

Chen's agents are an example of mixed-initiative systems wherein both the agent and the human can instigate decisions, but the latter has ultimate decision authority (Goodrich, 2010). They are contrasted with adaptive systems where control passes between operators and intelligent software under specified conditions and adjustable systems wherein the human decides which of the repertoire of autonomous behaviors to elicit (Barnes et al., 2006; Chen and Barnes, in press; Miller and Parasuraman, 2007).

In their most recent articles, Chen and Barnes (in press) concluded that a mixed-initiative architecture informed by a personal agent is the most flexible control structure for executive supervision. Such architectures allow the human to have ultimate control over multiple autonomous systems, while the agent acts as the interface between humans and more specialized autonomous systems. They developed the following guidelines based on a review of both the pertinent literature and in-house research:

- *Agent/human interaction needs to be flexible.* The user interface should support bidirectional communications and control structures to effect rapid change. The system should be able to adjust to operator workload and allow agents to act autonomously under operator-specified conditions.
- *The user interface must enable the operator's ultimate decision authority.* The mechanism for ensuring human authority needs to be embedded in the agent architecture (e.g., mixed-initiative systems).
- *Automation transparency is essential.* Lee and See's (2004) 3P's (purpose, process, and performance) as well as the *history* of the system's 3P's should be presented to the operator in a simplified form, such as integrated graphical displays. The user interface must support operator understanding of the agent's behavior and the mission environment as well as effective task resumption after interruptions.
- *Visualization and training techniques should act as enablers of human-agent collaboration.* Appropriate human-agent trust (Lee and See, 2004) can be reinforced by both training and visualization methods. Specific visualization techniques (e.g., augmented reality) have proven to be particularly useful in improving SA in the type of complex environments where agent technology is most beneficial. Operators should be trained to understand the system's 3P's.
- *Human individual differences must be part of the human/agent design process.* This guideline can be accomplished by interface design, selection, training, and/or designing agents that are sensitive to individual differences among humans.

3. RoboLeader and Control of Multiple Systems

Chen and colleagues simulated vehicular combat situations wherein the operator was burdened with multitasking requirements as well as supervising multiple autonomous systems (Chen, 2011; Chen and Barnes, 2012a; 2012b). Completely autonomous systems would not be practical in this environment because autonomy would limit tactical flexibility and pose safety risks, while supervisory control of multiple autonomous systems introduced its own problems, such as complacency effects and short-term memory limitations. Chen et al. (2011b) introduced the

concept of employing RoboLeader, an intelligent agent, to assess the current state of multiple systems, suggest algorithmic solutions, and execute them only when given permission by the operator. The advantage is that the operator could maintain SA and attend to other tasks while RoboLeader would act as a subordinate crew member focused on the current state of the robotic assets.

The first experiment was a proof-of-concept for RoboLeader (Chen and Barnes, 2012a). Humans working with RoboLeader were able to successfully reroute up to eight robots more rapidly than manual conditions when unexpected obstacles were encountered. In the second experiment, reliability of RoboLeader (60% and 90%) and type of errors (false alarm prone [FAP] and miss prone [MP]) were varied parametrically. Figure 1 shows the Mix Initiative Experimental (MIX) simulation environment that includes (1) a map display for robot rerouting, (2) small windows showing views from the robots, (3) a larger window for target identification, (4) instrument panels, and (5) a text window for RoboLeader to communicate with operators. Previous research (Wickens et al., 2010) indicated that high FAP alerts were more deleterious to overall performance than were MP-weighted systems because the “cry wolf effect” caused operators to lose faith in FAP alerts.

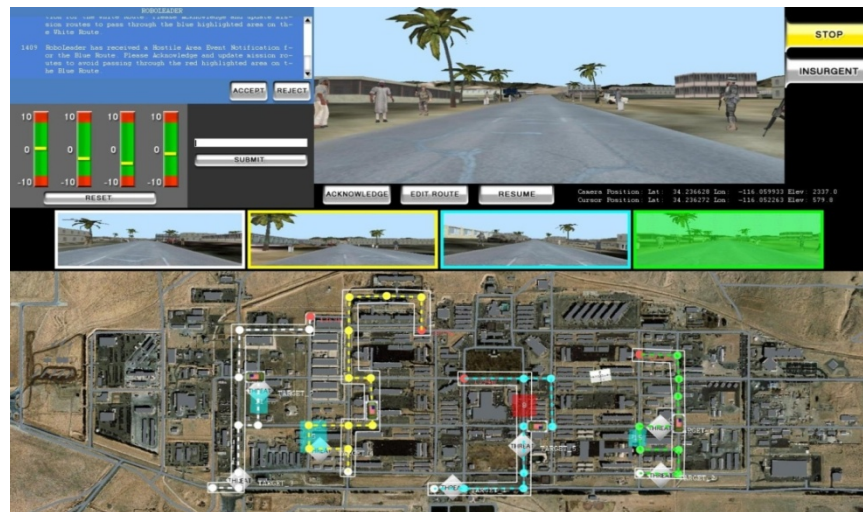


Figure 1. Simulation scene showing text window, robot instrument gauges, the robot location map, four windows of robot camera views, and a larger display of scene as viewed by Robot 4.

Conversely, in the second study (Chen and Barnes, 2012a) for agents with 80% average error rates, the FAP conditions resulted in better overall performance for both target acquisition and routing efficiency compared to the MP agents. In this study, the location of the robots could be checked easily for FAP alerts as opposed to previous research because of the layout of the embedded map display. As a result, this made compliance to FAP alerts efficient because of the relative ease of attention switching for target acquisition. By way of contrast, the MP agent interfered with the operator’s performance to a greater degree because participants in the MP

conditions had to continually check data on the map, thus drawing their attention away from the target displays. This conjuncture was supported by the SA measures indicating better performance on map-related data for MP conditions, suggesting that an operator's focus on the map display is detrimental to their scanning performance. Also, there were significant effects due to individual differences; for example, participants who were highly confident in their attentional control abilities had better overall MP performance, indicating their ability to shift their attentional resources. In the same vein, higher levels of spatial ability and gaming experience had positive effects on targeting performance.

In another experiment (Chen and Barnes, 2012b), RoboLeader used more sophisticated algorithms to direct four robots to entrap a moving vehicular target. Levels of autonomy (LOAs) were varied with the addition of a visualization aid. The purpose of this experiment was to assess the effectiveness of the RoboLeader agent in a more dynamic combat environment in which both the targets and the pursuing robots were moving. There were four LOA conditions: (1) manual, (2) hybrid, (3) hybrid with visualization, and (4) fully automated with visualization. For the hybrid condition, the human operator chose end points for the pursuing robots, and RoboLeader computed an optimal solution to entrap the moving target. The visualization aid displayed how discrepant the robot's progress was from the optimal solution to entrap the moving target. Overall, 86% of the participants successfully entrapped the target using the full automation solution, whereas 96% of the participants did so with the hybrid solution (without visualization), suggesting the possible advantages of human/autonomy collaboration found in the University of Central Florida (UCF) studies discussed in section 4. Visualization aiding had little impact on performance; even with partial autonomy, the raw data on the map display supplied sufficient information. Again, individual differences were important. Participants with higher spatial ability scores on the pretest had better target acquisition rates, whereas experienced gamers were better at encapsulating the moving target than their less experienced peers (Chen, 2011; 2012).

The design implications are as follows:

- Intelligent agents acting as surrogate intermediate supervisors are a potentially effective way of controlling multiple autonomous systems.
- At a minimum, agent/human teams must have two characteristics: operators must have final decision authority and agents must signal their intentions clearly.
- Results in the Chen and Barnes (2012b) experiment suggest that for agents with moderate error rates (approximately 80%), FAP (vs. MP) weighted alerts can be a relatively efficient means of alerting potential problems if the FA are easily checked.
- Individual differences in spatial abilities, attentional control, and gaming experience are important determinants of how well humans interact with agents supervising multiple assets.

4. Safety and Levels of Autonomy

As mentioned in the introduction, there were two main thrusts for the SOURCE program: enhancing autonomous capabilities and ensuring safety for humans in the vicinity of autonomous systems. UCF researchers focused on the effects of various LOA and how they influenced mission performance, operator workload, trust, SA, and, most important, how they affected human safety. The initial experiments were conducted in a miniature urban setting (1/35th scale) representing six square blocks of a typical Iraqi urban area (figure 2). The test participants were stationed in an isolated room with multiple television monitors that allowed them to view the ongoing experiments. They were unaware that the experimenters, in a separate room, actually teleoperated the miniaturized UVs based on the participants' inputs (Fincannon et al., 2011).



Figure 2. Views of Middle Eastern urban setting as viewed by operators in the control room.

The first two experiments investigated robot-to-robot autonomy (Jentsch et al., 2010; Phillips et al., 2010). The task was to coordinate four UVs to transverse one of five urban routes and engage a predetermined target by finding the optimal route based on communication traffic among the UVs. Jentsch et al. (2010) compared autonomy conditions (robots could automatically coordinate) with manual conditions (human operators viewed the communications information but made the coordination decisions). In both cases, the human made the final decision. In the former case it was a passive decision by affirming or denying the automated decisions, whereas in the latter case operators were actively involved in coordinating UVs. Communication among the UVs was either 100% or 80% reliable. Specifically, 80% reliability was accomplished by deliberately adding incorrect information during communications. Because participants did not have time or route constraints, the coordination task was only moderately difficult. For the less than perfectly reliable conditions, operators performed better when they made the coordination decision themselves. Thus, for the 80% reliability condition, having the operator actively involved in the decision process improved coordination performance.

In the second experiment task difficulty was increased by adding “no-go” areas and time limits. Under these conditions, autonomy was superior to manual operator coordination in both reliability conditions. This finding highlights the importance of the interaction between task difficulty and autonomy, as well as the limits of keeping the human in the loop. Thus, to optimize performance, the system designer needs to find the “sweet spot” between keeping the human in the decision loop and dependence on autonomous systems, particularly as task difficulty increases beyond the human’s ability to perform the task effectively. This is similar to findings in adaptive autonomy showing the efficiencies gained in having the human engage in manual control when task load is manageable and invoking autonomy under more difficult situations (cf. Barnes et al., 2006; Parasuraman et al., 2007).

A more recent UCF experiment varied automation and degree of human involvement during simulations in the 1/35th scale Iraqi facility (Fincannon et al., 2012). For this study, the researchers decomposed the robots’ tasks into three components: (1) detect a possible significant object and make a decision to stop the robot traveling at simulated speeds of approximately 5 mph, (2) identify the type of object, and (3) decide the type of action to be taken based on the current rules of engagement (ROEs). ROEs are command-issued rules that permit Soldiers to conduct their missions under permissible guidelines. In the experiment, the ROEs were developed by the researchers and given to the participants before each session. In the manual condition, all tasks were performed by the human operator, whereas in the autonomy condition, even though all tasks were automated, operators were given the option of overriding the autonomy for tasks 2 and 3. Finally, in the collaborative condition, task 2 was performed by the operator and tasks 1 and 3 were automated. The collaborative condition took advantage of both the obstacle detection strengths of autonomy and *perception by proxy*—that is, the human operator’s perceptual strengths for target identification.

The most dramatic differences were evinced in task-1 detection of possible targets and stopping the robot: 37% accuracy for manual, and 67% and 58% accuracy for the autonomy and collaborative conditions, respectively. This indicated that an operator controlling a robot manually found it very difficult to spot and react to unexpected events, and that even imperfectly automated systems are safer than relying solely on the operator for this task. However, for synthesizing information (tasks 2 and 3), a combined (collaborative) human and intelligent system decision was superior to either autonomous or manual control conditions except when the operator’s workload was high. Thus, the results suggest that autonomy can enhance safety by detecting significant objects in the robot’s path, but that humans can also play an important role by being able to identify these objects (*perception by proxy*). Therefore, human involvement is useful with the caveat that humans can become overwhelmed when the workload is too high.

The final experiment investigated LOAs using the MIX test bed similar to the RoboLeader studies described previously. Compared to the 1/35th scale world, the MIX computer simulation environment allowed for more precise control of simulation parameters, such as vehicular speed and pedestrian crossings (Jentsch et al., 2011; Sellers et al., 2012). Again, the emphasis was on

safety and LOA; however, the objective was to investigate the effectiveness of two operator intervention strategies. The participants were told that pedestrians would transverse the robot's path under one of three LOA conditions: (1) fully autonomous (AU), (2) management by consent (MBC), and (3) management by exception (MBE). The AU system chose a response based on the ROEs (e.g., continue—intelligence suggests a dangerous situation), which were, in turn, based on the cover story for each simulated vignette. For the MBC condition, the autonomy would always stop the robot and suggest a course of action; the operator had to consent to or change the AU decision before continuing. In contrast, in the MBE condition, participants could override the autonomous decision. In situations where participants did not choose to override the autonomous decision, the autonomy-chosen course of action would be executed. The experimenters also varied autonomy reliability (either 60% correct or 90% correct). Correctness was based on how well the AU followed the ROEs given to the operators for each vignette.

Overall, operators in the MBE conditions showed significantly superior performance (executing the correct ROE for safety) when compared to both AU and MBC. Figure 3 shows a significant interaction between reliability and LOA. The MBE condition allowed operators to take advantage of the accuracy of the AU condition in high reliability conditions but also resulted in the operator overriding poor AU decisions during low-reliability mission segments. MBC operators showed a greater tendency to incorrectly second-guess highly reliable autonomy. This interpretation is buttressed by the fact that operators tended to give higher trust scores to MBC conditions than to fully automated conditions. Thus for MBC, operators over-trusted their own decision compared to highly reliable autonomous ones. This could be in part because of the additional time they had to make decisions compared to MBE, making the operator more likely to second-guess even highly reliable autonomy (Beck et al., 2007). Although the studies by Jentsch and colleagues are complex, they suggest that full autonomy is only ideal when the operator's overall tasking performance level does not permit the operator to stay in the decision loop. The findings of these studies also suggest that trust per se is not the objective of HRI; instead, trust should be appropriately calibrated—knowing when to trust and when to override is the objective when designing for human calibration of autonomous systems (Chen et al., 2007; Lee and See, 2004). Especially in combat, humans will always be the final arbitrator of safety issues, and, as such, they must know when autonomy is safer than human intervention and vice-versa (Barnes and Evans, 2010; Chen and Barnes, under review; also see Goodrich and Blatter, 2012).

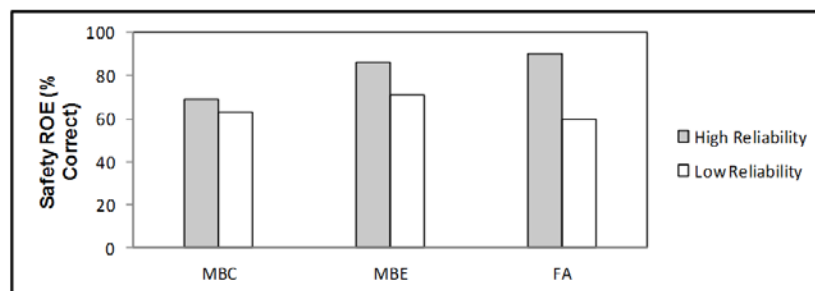


Figure 3. Interaction between reliability and LOA.

The design implications are as follows:

- The degree of human decision involvement in autonomous systems depends on two factors: the effectiveness of the automation and the human operator's tasking limitations. For example, even imperfect automation may be preferred to human involvement when the operator is fully engaged in multitasking.
- Adaptive automation (AA) wherein the human is re-engaged in the decision process for automated tasks during manageable mission segments is preferred to full automation. This is because AA keeps the operators aware of the state of the automated task but only engages them when the overall multitasking level is manageable.
- Autonomy can improve robotic safety by being able to respond to potentially dangerous situations more rapidly than humans can, such as the sudden appearance of a pedestrian in complex urban environments.
- A possible strategy for overcoming autonomy limitations is developing hybrid systems that allow humans to do what they do best, such as interpreting the significance of detected objects (perception by proxy).
- Overall, in the UCF studies, the MBE LOA that allowed humans to override autonomous decisions was the most effective strategy compared to AU and MBC. MBE resulted in safer decisions than did low reliability autonomy, but MBE showed a minimal loss of decision accuracy when compared to highly reliable autonomy.
- Trust, as measured by the UCF subjective scale, was a poor predictor of performance. For example, trust was higher in the MBC condition than the AU condition. However, overall human performance was poorer during MBC mission segments than for either the MBE or AU conditions.

5. Ft. Benning and Ft. Leonard Wood Field Experiments: Progressive Autonomy and Intuitive Interfaces

This section covers issues related to autonomy and intuitive interfaces for small robots. The researchers investigated a variety of interfaces for SUGV applications during exercises in field environments using active duty Soldiers as test participants. These interfaces either expedited supervisory functions, such as voice control, or enhanced the operator's ability to conduct SUGV missions remotely (telepresence and stereovision). The advantages and disadvantages of different degrees of small robot autonomy were explored as well.

HRED researchers worked with Navy researchers from the Space and Naval Warfare Systems Center (SPAWAR-Pacific) in San Diego, CA, to explore progressive autonomy for SUGVs in

field experiments at Ft. Benning. Full autonomy entails being able to respond to the environment in unexpected circumstances and to learn from past experience (Pettitt et al., 2010; Pettitt et al., 2012). Progressive autonomy assumes that autonomy will progress from manual control to different degrees of autonomy in a step-wise fashion. The team of Army and Navy researchers examined three levels: teleoperations, partial autonomy, and full autonomy (with a predictable environment and without machine learning). Thus, even the full autonomy condition was simplified in terms of a strict definition of full autonomy. The purpose of the experiment was to investigate the effects on mission and human performance as control became progressively more autonomous. Teleoperations required the operator to manually control the SPAWAR robot (figure 4) while performing secondary tasks (for some conditions). Partial autonomy consisted of autonomous obstacle avoidance in-route; however, the operator controlled the movement of the robot unless the partial autonomy overrode the operator to avoid obstacles. Full autonomy software automatically performed both robot movement to waypoints and obstacle avoidance.



Figure 4. SPAWAR robot.

In general, full autonomy resulted in zero driving errors (superior to the partial condition which, in turn, had significantly fewer errors than then the manual condition), faster course times, and fewer stops to conduct secondary tasks than both the partial and manual conditions. Partial autonomy was significantly slower than both the manual and full autonomy conditions and was also rated as more frustrating. The ability to identify potential targets and secondary task main effects was not significant. Secondary tasks affected mission time for manual and partially autonomous systems but had no effect on full autonomy. The superiority of the autonomous systems was to be expected, but it does indicate that some degree of autonomy is rapidly becoming state of the art even for the SUGV. The frustration for the partially autonomous conditions was understandable because in the partially autonomous condition the operators reported sometimes having to “fight” the software to find the correct way around obstacles. For

the same reasons, mission time was significantly longer for the partial condition than for either of the other two experimental conditions. However, even partial autonomy was superior to the manual condition for reducing driving errors and preventing unnecessary stops to conduct secondary tasks. Thus partial autonomy showed some advantages, but in general, it was less advantageous than full autonomy because partial autonomy can be frustrating and result in increased reaction times.

In another series of experiments, ARL researchers at Ft. Benning working with a private company (Think-A-Move^{*}) to evaluate voice interfaces during realistic dismounted field experiments. Their research objectives were to evaluate advanced interface designs to improve SA as well as free the Soldier's hands and eyes for head's up operations. Speech control of robotic assets has a number of distinct advantages: (1) it is a natural way for Soldiers to interact with robots, which in turn fosters a team relationship, and (2) it has the potential of hands- and eyes-free control as SUGVs become more autonomous. The HRED researches conducted a number of studies evaluating the efficacy of voice for small robot control (Petitt et al., 2012; Redden et al., 2013). Their goal was to show that speech control could reduce the size of the controller by replacing the manual controller with a lighter, smaller speech system (figure 4). The experiments were conducted using teleoperated robots, but the results could transfer to operator interventions when necessary for semi-autonomous robots and for controlling miscellaneous functions, such as menu selection. They found that speech-based control exhibited performance benefits beyond controller size reduction. Specifically, it decreased time and effort when performing multiple tasks simultaneously by allowing speech commands to be given for control of the robotic arm while at the same time maneuvering the robot using manual controls. However, the Soldiers had trouble with the speech-based control if they had to control the pan and tilt of the robotic arm because the voice commands were discrete and lacked the precise movements possible with manual control. Also, the ARL researchers investigated intuitive vocabularies for the various tasks that Soldiers were asked to perform, allowing the researchers to implement a user-centered lexicon for the experiment.

In the second speech experiment, Redden et al. (2013) investigated the potential for using speech for multipurpose functions, such as having the robot photograph improvised explosive devices (IEDs) or having the operator choose items on a menu. When the operator was required to perform a secondary task, speech control improved multitasking performance because of the efficiency of speech for shared cognition. Similarly, when the operator had to access a menu in order to take picture of a potential IED (e.g., "enlarge a picture"), speech control was significantly faster than manual control. However, taking a photo by maneuvering the robot was more efficient using manual control because maneuvering the robot is a continuous process.

In a different domain, Elliott and her Ft. Benning colleagues (Elliott et al., 2012; Jansen et al., 2012; Redden et al., 2013) collaborated with researchers from the TNO laboratories in the

^{*}Think-A-Move is a trademark of Think-A-Move Ltd.

Netherlands to evaluate telepresence techniques designed to artificially create the feeling of being in the area the robot is viewing. The obvious advantage of telepresence is that an autonomous robot would be able to gather information for a named area of interest (NAO) without putting the Soldier in harm's way. Augmenting a robot's video is particularly important because previous research indicated that video feed from robots gives an impoverished view of the NAO (Chen et al., 2007). The telepresence augmentations included stereovision and a head-mounted camera that the operator could use to scan the remote area emulating actually being in the area. In the first experiment, the tasking was relatively easy, and target detection, SA, or workload measurement differences were not significantly different from conventional interfaces. However, Soldier participants preferred telepresence, suggesting further research might be worthwhile. The second telepresence experiment contained more difficult detection tasks, and the telepresence was augmented further by using three-dimensional (3-D) audio cues to locate targets (Elliott et al., 2012). Telepresence was compared to a helmet-mounted display (HMD) and a joystick to locate targets in a remote location. In addition, there was sound associated with each target. The 3-D audio augmentation resulted in improved performance compared to the HMD and joystick for workload reduction, speed of responses, and target identification. On the negative side, the telepresence equipment was bulky and not ideally suited for infantry operations.

Another important issue related to SUGVs is their use for finding and defeating IEDs. IEDs have proved to be particularly deadly and difficult to detect. Progressive autonomy would make this task easier, but the most important issue involves manipulating the IED remotely to disarm it. Currently, the robots used to work with IEDs have a two-dimensional (2-D) view of the device, making the task more difficult than manually disarming an IED because the operator lacks the 3-D cues associated with normal human vision (Chen et al., 2007). A number of previous studies have identified the usefulness of stereovision for SUGV displays during related tasks (Barnes and Evans, 2010). More recent field experiments at Ft. Leonard Wood examined the combination of stereovision displays and haptic feedback for IED manipulations (Edmondson et al., 2012). Polaris Sensor Technologies and Harris Corporations working with ARL and the nonprofit Leonard Wood Institute evaluated an interface suite to improve Soldier safety using a Talon* robot to find, manipulate, and disarm IEDs. The current study incorporated not only a stereovision display but also a Harris controller† that gave haptic feedback to the operator (figure 5).

*Talon is a registered trademark of QuintQ_North America.

†Harris controller is a registered trademark of Harris Corporation.



Figure 5. The haptic manipulator used with stereovision for the Talon robot experiment.

Nine participants performed navigation, search, and arm manipulation tasks for scenarios that were indicative of U.S. Army engineering, military police, and biochemical missions. There were statistically significant latency effects of view (3-D vs. 2-D) and insignificant trends for controller conditions favoring the 3-D haptic combination. Similarly, there were significant effects for both these conditions for perceived workload reductions. The participants also endorsed haptic and stereovision components individually and as a combined unit. In summary, the results indicated user acceptance as well as performance improvements for stereovision and haptic controllers especially when combined in the same interface.

The design implications are as follows:

- Progressive autonomy research indicates that SUGVs with obstacle avoidance and autonomous movement to waypoints can perform simple search tasks more effectively than teleoperated SUGVs.
- Partial autonomy, such as obstacle avoidance, can introduce problems as well as increase effectiveness if they conflict with operators' control strategies.
- It is important to tailor speech commands to the target audience. Tailoring allows better retention and more efficient operation.
- Because of its lower cognitive demand, speech control is more rapid than manual control in situations that require multitasking.
- Manual control is more effective than speech control for nondiscrete tasks (e.g., turning); however, speech is more efficient for menu selection.

- Although not currently configured for efficient infantry uses, telepresence has great potential for remote sensing of combat environments using robotic assets.
 - A combination of haptic feedback and stereovision shows promise for safely manipulating and defusing explosive and chemical devices using small robots.
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6. Situation Understanding and Decision Support

Although we can expect autonomous systems to become more prevalent as the technology improves, certain functions such as situation understanding will remain predominantly human functions for the foreseeable future (Barnes and Evans, 2010). This is because situation understanding entails more than current SA but also involves ethical issues and consideration of the longer-term implications of the evolving situation (Chen and Barnes, in press). This is particularly true for intelligence gathering which may involve subtle cues and political nuances that change from day to day. Oron-Gilad and her associates from Ben-Gurion University (BGU) in Israel conducted a series of experiments to enhance the Soldier's ability to glean intelligence information from multiple unmanned systems (Oron-Gilad et al., 2011; Oron-Gilad, in preparation).

Oron-Gilad et al.'s (2011) initial experiments evaluated the utility of a physical device to portray the unmanned vehicle's (UV's) information to the dismounted Israel Defense Forces (IDF). The displays contained both a map and a video portion. The results depended on both the terrain type and the task. Specifically, for fine-grained analysis a larger display was required (video portion: 7.5-in diagonal), whereas for other tasks such as operations in a rural environment, a display with a video portion of 3.5-in diagonal was sufficient. Oron-Gilad et al., working with HRED personnel, conducted a subsequent experiment using U.S. active duty Soldiers at Ft. Benning. They examined three display types: a 12-in tablet (7.5-in video diagonal), a handheld display (HHD, 4.2-in video diagonal), and a monocular helmet-mounted display (HMD, 3.2 in). In this experiment, there was no difference between the tablet and HHD for reporting intelligence indicators (personnel, vehicles, and movement). However, the HMD resulted in significantly poorer performance than the other two devices. Participants also reported binocular rivalry and eyestrain for the HMD applications. The researchers also examined the relative effectiveness of UAS vs. UGV imagery for the intelligence-gathering task. Somewhat surprisingly, they found that the egocentric view (UGV) was superior to the exocentric UAS conditions. This may be scenario specific because other experiments indicated the opposite effect (Barnes and Evans, 2010).

In two experiments, Ophir-Arbelle et al. (2013) evaluated interfaces that showed both UAS and UGV imagery. These interfaces displayed multiple views of the area of operations. Because they

assumed that UAS would be the default mode for IDF operations, they examined two conditions: UAS alone and combined UAS/UGV (figure 6). The video for both UVs was urban feeds with targets related to Soldiers or vehicular movement. The tasks were to identify the randomly appearing targets and to perform an orientation task requiring coordinating video movements with the map orientation. Not surprisingly, considering the aforementioned findings, the addition of the UGV imagery improved identification.



Figure 6. Ben-Gurion University combined view display.

More interesting was the improvement in the orientation task in their first study because based on prior research, Orphir et al. predicted that UGVs would not be useful in aligning the videos with the map locations. The second study verified the combined-views advantage for target identification but did not replicate the orientation finding. The two experiments demonstrated the benefits of combining the “out-of-window” UGVs’ view with the “god’s eye” view of UASs.

Further research showed that the efficacy of combining views depended on three factors: the mix of imagery, the participant population and, the simplicity of the displays (Oron-Gilad et al., in preparation). U.S. infantry Soldiers in a field study at Ft. Benning made targeting and orientation decisions with a display with a center view of UGV imagery and inserts with additional views of the scene. There were three imagery-feed conditions for inserts: additional UGV views, UAS views, and combined views with separate inserts of UGV and UAS inserts. Format was a separate condition and involved eight formats with various schemes for presenting the inserts, including toggling between views. The eight formats compared individually did not affect performance; however, image availability had significant effects on both targeting and orientation decisions. Thus for indentifying targets, display configurations that had multiple

UGV (“out of the window”) views improved performance. However, for inserts that displayed multiple UGV and UAS views, the plethora of choices actually degraded performance. Similar results were evident for orientation decisions in that UGV-only conditions were significantly better than all conditions with UAS availability. To summarize, when the surveillance was in a stationary area of an operations scenario (compared to Ophir-Arbelle et al., 2013, more dynamic scenarios), having more imagery choices than the minimal necessary to complete the tasks degraded performance. Thus, U.S. Soldiers preferred and did best with all UGV ground views and less well when they had to focus their attention on both UAS and multiple UGV imagery simultaneously.

A subset of Oron-Gilad et al.’s study (in preparation) was rerun with BGU students who actually had more combat arms experience (3+ years) than the Ft. Benning participants (1.9 years). The BGU study only examined conditions where they could choose among additional ground and/or UAS views with the UGV center view always available. In general, they did better than the Ft. Benning participants for these same conditions. BGU participants toggled to the UAS views approximately 75% of the time and thus were able to extract better information from the same UAS views than the less experienced Ft. Benning Soldiers. Oron-Gilad et al. suggest that this is due to the IDF giving more extensive training and hands-on experience with aerial maps during their military service. Thus, the four variables that influenced performance were experience, training, imagery, and type of task (compared to Ophir et al.’s studies). Differences between these series of experiments and the Ophir-Arbelle et al. (2013) studies should be noted. Ophir-Arbelle et al., also using BGU students, showed a definite advantage for having both UGV and UAS imagery compared to UAS imagery alone, whereas in the Oron-Gilad et al. BGU study, the focus was predominantly on how to present additional imagery if the UGV imagery was available on the center display.

The difference in utility of feeds seems to be due to the more dynamic quality of Ophir-Arbelle et al.’s (2013) study. In that study, the observers had to locate a moving target over a larger area rather than surveil a specific location. Also, most of Oron-Gilad et al.’s (in preparation) eight formats were more complicated with the possibility of up to three UGV windows and a single UAS window with various toggling schemes and insert sizes. The Ophir-Arbelle study used two windows, neither of which required toggling (figure 6). Oron-Gilad (in preparation) verified that toggling between UGV and UAV views (even with the advantage of a larger display surface) had a deleterious effect on target identification for the Ophir-Arbelle paradigm. The implication of these studies is to keep it simple when using both types of imagery. Moreover, the design of the main displays should be large enough so that the operator can focus on either or both types of imagery, depending on the mission. Also, having both types of imagery is particularly useful for dynamic situations wherein one imagery type or another is at a disadvantage because of obstructions or other factors as the UVs move (Ophir-Arbelle et al., 2012).

Another use of situation understanding imagery was explored by Evans (2012) and coresearchers at the DCS Corporation. They examined the utility of using overlays superimposed on the

autonomous UGV imagery. The overlays (figure 7) were generated by the autonomous navigation system (ANS) indicating a short-term prediction (a few seconds ahead) and a long-term prediction (a few minutes) of the UGV's future path. The first experiment was conducted in ARL and DCS laboratories wherein the imagery was generated by the Modeling and Simulation Environment (MODSIM). MODSIM is a physics-based simulation that ARL used to simulate in real time the ANS and sensors developed for autonomous UGV. In some conditions, obstacle overlays generated by the laser ranger finder were represented as red and green areas shown as the "out-of-the-window" view in figure 7.

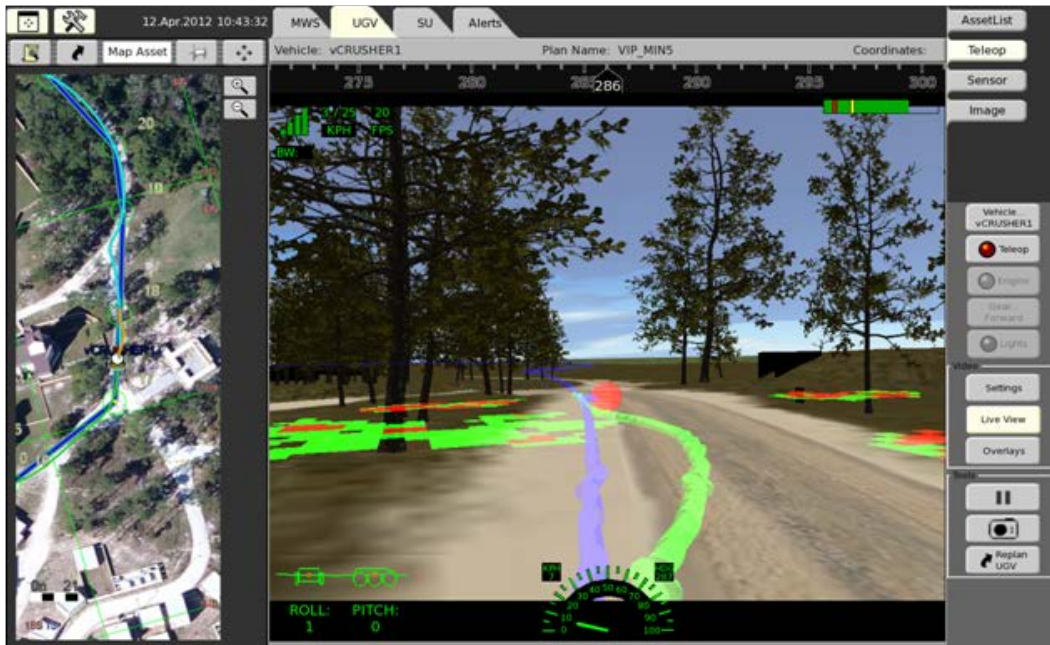


Figure 7. An example of the Warfighter machine interface (WMI) showing both the short-term (green) and long-term (blue) operator aids.

Combinations of obstacle and prediction overlays did not affect the operator's ability to identify potential targets, total mission time, route deviations, or the number of times the operator switched from the ANS to teleoperations. Whereas the 17 participants' supervisory-control-related scores were not affected by the overlays, the operator's subjective ratings and workload estimates both supported the visualization's effectiveness (i.e., better ratings and lower workload scores). The failure to show significant performance differences could be attributed to a variety of causes, including a brief practice session. Evans (2012) argues that the most likely causes were the ease of the particular missions chosen for the simulations. Specifically, the targets were easily spotted (e.g., smiley faces) and obstacles, for the most part, were equally obvious.

For his second study, Evans (under review) developed a more militarily relevant mission environment with realistic targets and more difficult obstacle decisions, such as whether to drive over grass. It was conducted at Camp Lejeune, a Marine training base where the capstone experiment for SOURCE was being held at the Military Operations in Urban Terrain site. Nine

Soldiers participated in the field experiment using the same MODSIM environment as in the laboratory experiment. The field study was more realistic in a variety of ways: the travel planner (TP) previewed the vehicular path from a few seconds to several minutes ahead depending on the terrain, which gave the Soldiers visual views of the predicted path of the autonomous vehicle similar to those shown in figure 7. There was also an obstacle map and a rerouting alert that warned of navigation changes. The SA probes queried the operators concerning more realistic objects resembling IEDs, and the obstacle map showed grass areas that were more difficult for the operator to discern compared to the more obvious barrel obstacles in the previous experiment. The dependent measures relating to the operator reducing his or her reliance on teleoperations showed significant effects of the TP alone, TP + alert, and TP + obstacle map. The operators' greater reliance on autonomy when they had TP overlays both alone and in concert with other aids shows the advantage of these aids in improving appropriate trust (Lee and See, 2004). That is, they relied on autonomy more often when they had visual augmentation previewing the projected autonomous route.

The design implications are as follows:

- The requirement for video display size varied depending on the mission, terrain, clutter, and task. Video displays of 7.5 in were required for fine-grain analysis especially in urban areas. However, 3.5-in video displays were sufficient in less demanding environments.
- In two experiments, Ben-Gurion University using Israeli participants with at least 3-years military experience found that a combination of UAS and UGV imagery improved their surveillance performance.
- U.S. Soldiers at Ft. Benning preferred UGV imagery to UAS imagery and actually showed degraded performance with too many UGV and UAS imagery inserts, indicating that too much imagery was detrimental.
- Israeli participants with more extensive experience with aerial views preferred UAS imagery. Toggling back and forth between UAV and UGV views also lead to poorer target identification.
- The general conclusion was that two heterogeneous sources of imagery were better than one, especially for dynamic surveillance. Preferences depended on previous experience with UV imagery; the best performance was obtained for the simplest display configurations.
- Augmented interfaces that showed the predicted path of the autonomous UV, alerted the operator to navigational changes, and indicated locations of obstacles improved the operator's trust. The augmented aids significantly reduced the number times and the durations of the instances that the operator switched from the autonomous to the teleop mode.

7. Conclusions and Future Research

Multiple sources indicate a future in which autonomy will become an important part of our lives as well as an important component of modern warfare (Barnes and Chen, 2012; Barnes and Evans, 2010; Chen et al., 2011b; Chen and Barnes, in press; Weiss, 2011). However, the human role will not diminish but will become more executive-like, setting longer-term goals and intervening for safety, autonomy malfunctions, or because of changing objectives (Barnes and Evans, 2010; Chen et al., 2007). For the foreseeable future, the human's meta-knowledge and ethical responsibilities will require that autonomous systems defer to human decision authority when lives are at risk (Chen and Barnes, in press).

This report covered findings in a variety of experimental paradigms pertaining to the central issue of autonomy: how much intervention is necessary and under what conditions should humans trust the autonomy and not intervene. Although the findings were complex, Jentsch and colleagues (2012) reported that, in general, having the human in the loop was positive either for improved SA or because the humans performed a specific function better than the autonomous entity (perception by proxy). However, there were conditions in which human intervention was counterproductive, either because of time constraints or because the workload requirements negatively affected the human's ability to intervene. Unfortunately, there is also evidence that in dangerous situations, humans over-trust automation because of complacency or neglect, resulting in catastrophic accidents (Parasuraman and Riley, 1997). Adaptive control was suggested as a possible remedy because it allowed the human to be in the loop under moderate workload, and it allowed automated control when multitasking difficulty impeded human performance (Barnes et al., 2006).

The RoboLeader research suggests that intelligent agents are possible solutions to the emerging problem of having a single operator supervise multiple semi-autonomous systems. The RoboLeader agent is an intermediate supervisor that controls less capable semi-autonomous systems and is in turn under the supervision of the human operator. When something is amiss, the agent informs the operator of the issue and executes a solution with the operator's permission. This allows the operator to multitask during high-workload missions and still maintain decision authority; however, decision authority can be delegated to agents under specified conditions, such as a time-critical emergency (Chen and Barnes, in press). The experimental results suggest that using an agent as an intermediary is an efficient way to control multiple robots, especially under difficult tasking situations (and even under conditions in which the agent is less than perfectly reliable) (Chen and Barnes, 2012a; 2012b). Of particular interest is the finding that operators' individual differences are an important determinate of human-agent performance (Chen, 2011).

The report also examined advanced interfaces for small robots for both autonomous and teleoperated conditions during field experiments at Ft. Benning. The purpose of the field studies was to investigate interfaces that freed the operator's hands, increased SA, and improved mission safety. Autonomous SUGVs were able to move from point A to point B more rapidly with fewer errors while navigating around intermediate objectives and avoiding obstacles. Partial autonomy proved frustrating and not nearly advantageous as full autonomy. Other research indicates that voice control shows promise but still requires control augmentation in order to make continuous course corrections efficiently, whereas telepresence research indicates an advantage for operators using 3-D audio cues for target detection during remote viewing. Similarly, field experiments at Ft. Leonard Wood demonstrated the utility of combining SUGV stereovision with a haptic arm manipulator for IED missions.

Finally, our Israeli colleagues working with Ft. Benning researchers investigated the Soldier's ability to use multiple UVs to conduct surveillance and reconnaissance missions. The findings were complex, indicating that mission dynamics, military experience, and display characteristics all contributed to successful surveillance missions. The most general findings are that UAS and UGV imagery can be combined synergistically as long as the display configuration is simple, and the imagery is congruent with the operators' military experience. This research was important because one of the most promising uses of autonomous systems is persistent surveillance with multiple sources of imagery being broadcast to a safe location. Also, our in-house research indicates that augmented status information, such as the projected path of the autonomous vehicle, increases the Soldier's trust in the sense that he or she is less likely to interfere with autonomy when the system is performing effectively.

There are two major thrusts for future research. UV interfaces are becoming more naturalistic, thus emulating the Soldier's interaction with other Soldiers. The future Soldier will be able to work more naturally with autonomous systems using 3-D audio and visual telepresence information from remote UVs. Also, future Soldiers will be able to redirect UVs using gesture, haptic, and voice interfaces. Our research objectives will be to enable Soldiers to effortlessly combine these technologies without adding to the weight already carried or interfering with other mission requirements. The promise of naturalistic interfaces is a hands-free and eyes-forward control of multiple systems during the heat of combat.

The second thrust involves intelligent agents. Most of the intelligent systems involved in SOURCE incorporated sensors and algorithms to perform behaviors autonomously, such as rerouting or pedestrian avoidance necessary to conduct circumscribed missions. True intelligence is broader and involves adapting to new environments, inferring intent, and communicating with other intelligent entities (Chen and Barnes, in press). This will require agents that have at least limited intelligence that mimics their human counterparts. Our research efforts (working with other ARL-sponsored and Department of Defense research teams) will focus on two aspects of human-agent interaction: agent transparency and bidirectional communication. The first objective will be to develop transparency principles and prototype displays that enhance the

operator's ability to understand the agent's current state, predict future agent states, and infer the intent of the agent's behavior. Bidirectionality implies that the agent can communicate with humans concerning the human's intent, possible changes in the military environment, and clarifications. Bidirectionality will entail graphical, annotated imagery, gestures, and verbal communication between humans and agents. Intelligent agents and unmanned systems with greater autonomy will change the military landscape. However, it will not make the Soldier's task easier; it will only change the type of tasks and problems he or she will face (Chen and Barnes, in press).

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List of Symbols, Abbreviations, and Acronyms

2-D	two dimensional
3-D	three dimensional
AA	adaptive automation
ANS	autonomous navigation system
ARL	U.S. Army Research Laboratory
AU	autonomous
BGU	Ben-Gurion University
FAP	false alarm prone
HHD	handheld display
HMD	helmet-mounted display
HRED	Human Research and Engineering Directorate
HRI	human-robot interaction
IDF	Israel Defense Forces
IED	improvised explosive device
LOA	level of autonomy
MBC	management by consent
MBE	management by exception
MIX	Mix Initiative Experimental
MODSIM	Modeling and Simulation Environment
MP	miss prone
NAO	named area of interest

ROE	rules of engagement
SA	situation awareness
SOURCE	Safe Operations for Unmanned systems for Reconnaissance in Complex Environments
SPAWAR	Space and Naval Warfare Systems Center
SUGV	small unmanned ground vehicle
TP	travel planner
UAS	unmanned aerial system
UCF	University of Central Florida
UGV	unmanned ground vehicle
UV	unmanned vehicle

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