An Overview of Humans and Autonomy for Military Environments: Safety, Types of Autonomy, Agents, and User Interfaces

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Abstract. The objective of this review is to extract design implications from multiyear US Army sponsored research investigating humans and autonomy. The programs covered diverse research paradigms: (a) effects of autonomy related to pedestrian safety during urban robotic missions, (b) supervision of multiple semi-autonomous robots assisted by an intelligent agent, (c) field investigations of advanced interfaces for hands- free and heads- up supervision of robots for dismounted missions and also investigations of telepresence, (d) effects of haptic control and stereovision for exploiting improvised explosive devices. Thirteen general design guidelines related to mixed initiative systems, pedestrian safety, telepresence, voice control and stereovision/haptic control are discussed.

Keywords: human-robot interaction, intelligent agent, military, autonomy.

1 Introduction

Modern combat is moving from the age of mechanized warfare, to the age of information, to the age of autonomy. Because of the increasing emphasis on the importance of using fewer operators to control multiple systems, some level of autonomy will be a necessity in future operations [1-3]. Autonomy covers a range of relationships between humans and intelligent systems - from systems that operate continuously without human intervention- to systems wherein specific behaviors can be performed without direct human control but humans must decide when to invoke the behaviors [4]. Autonomous systems planned for near-term military use are generally somewhere in between. The human maintains decision authority but there is only an occasional requirement for human intervention [1].

In this paper, we review human robot interaction (HRI) research funded by the Safe Operations for Unmanned Reconnaissance in Complex Environments

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(SOURCE) Army Technology Objective (ATO). The purpose of the HRI research was to understand the effects of advanced interfaces and autonomy on the safety of humans operating in the same area as autonomous systems as well as to understand how autonomy affects overall mission effectiveness. The first two programs investigated different paradigms of human interactions with autonomy. The University of Central Florida [6-10] studied the effects of varying levels of autonomy (LOA) on safety and the Army Research Laboratory (ARL) researchers in Orlando investigated mixed-initiative autonomy using an intelligent agent [3, 5]. Both programs shared a common research goal of finding the sweet spots between human control and autonomous control.

We also review two additional ARL programs that investigated advanced interface concepts to improve soldier safety for dismounted operations. Researchers at Ft. Benning focused on field experiments evaluating interfaces that improved situation awareness (SA) and reduced workload for both autonomous and teleoperated conditions. These evaluations measured Soldier performance during field experiments using voice control and telepresence as means of maintaining decision authority while reducing control requirements [11-14]. ARL researchers at Ft. Leonard Wood investigated the utility of using a combination of stereovision and haptic arm manipulators to improve Soldier safety for defeating improvised explosive devices (IED) [16].

2 Level of Autonomy (LOA) and Soldier Safety

The research team led by Jentsch and involving Fincannon and others at the University of Central Florida (UCF) has a long history of supporting Army HRI programs. Some of their earlier work investigated the number of persons required to conduct reconnaissance missions for semi-autonomous robots, crew size for supervising robot to robot interactions, mixed unmanned aerial and ground vehicle operations, individual differences and effects of different training regimens [6, 7]. The two experiments summarized here directly addressed the question of Soldier safety and mission effectiveness as a function of LOA.

The initial experiment varied automation and degree of human involvement during simulations in a 1/35th scaled Iraqi city with similarly scaled robotic vehicles [10]. The researchers decomposed the robots' task into three components: (a) detect a possible significant object and making a decision to stop the robot, (b) identify the type of object, and (c) 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; for 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. In contrast, in the *autonomy* condition, even though all tasks were automated, operators were given the option of overriding the autonomy for tasks b and c. Finally, in the *collaborative* condition, task b was performed by the operator and tasks a and c were automated.

The collaborative condition took advantage of both the obstacle detection strengths of state-of-art autonomy and the human operator's perceptual strengths for target identification. UCF researchers referred to the latter as *perception by proxy*.

The most dramatic differences were evinced in task a, detection of possible targets and stopping the robot: 37% accuracy for manual, and 67% and 58% accuracy for the autonomy and collaborative conditions. This implies that an operator controlling a robot manually would find 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 (task b and c), 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 experiment suggests that autonomy can enhance safety by detecting significant objects in the robot's path but that humans also can play an important role by being able to identify these objects (perception by proxy). However, choosing the correct ROE was best left to automation in this experiment. The results also suggest that the operator's role in overriding autonomy can be counter-productive and human intervention strategies for autonomy required further investigation.

The second experiment investigated LOAs in a similar tasking environment using the Mixed Initiative Experimental (MIX) computer simulation environment which allowed for more precise control of simulation parameters such as vehicular speed and pedestrian crossings [9]. Again the emphasis was on safety and LOA but the objective was to investigate the effectiveness of two operator intervention strategies. The test participants were told that pedestrians would transverse the robot's path under one of three LOAs conditions: fully autonomous (AU), management by consent (MBC) and management by exception (MBE) [2]. The AU system chose a response based on the ROEs (e.g., continue – intel suggests a dangerous situation) which were in turn based on the cover story for each simulated vignette. For the MBC conditions, the autonomy would always stop the robot and suggest a course of action based on the ROE which the operator had to consent to or change before executing. In contrast, in the MBE condition, participants could override the autonomous ROE but if they did not, then the autonomy-chosen ROE would be executed. The experimenters also varied autonomy reliability: either 60% correct or 90% correct ROEs, depending on 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 1 shows a significant interaction between reliability and LOA. MBE conditions allowed operators to take advantage of the accuracy of the AU conditions for high reliability conditions but also resulted in the operator being able to override 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 trust MBC conditions more than in AU ones, but their performance indicated that this trust was misplaced.

2.1 Design Implications

1. Autonomy can improve robotic safety by being able to respond to potentially dangerous situations better than humans in complex urban environments.
2. 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).
3. 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 ROE decisions than did low reliability autonomy, but MBE showed only a minimal loss of decision accuracy when compared to highly reliable autonomy.
4. Trust as measured by the UCF subjective scale [9], was a poor predictor of performance; MBC was trusted more than autonomy but overall human performance was poorer during MBC mission segments than for either the MBE or AU conditions.

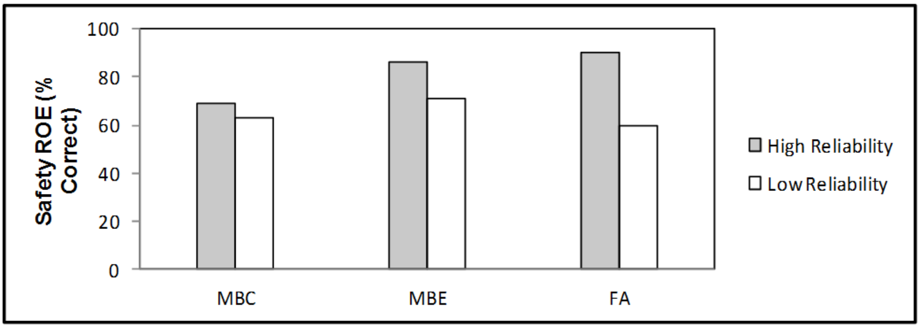

Fig. 1. Interaction between autonomy and reliability for predicting civilian safety; FA is same as AU in text and high is 90% and low is 60% reliability

3 Intelligent Agents for Supervisory Control: RoboLeader

Chen and colleagues simulated mounted combat situations wherein the operator was burdened with multitasking requirements as well as supervising multiple autonomous systems [3, 5]. 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 limits [2]. Chen and her colleagues introduced the concept of employing an intelligent agent (RoboLeader).The agent would 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 and RoboLeader would act as subordinate crew member whose focus was the current state of the robotic assets.

The first experiment was a proof of concept for RoboLeader [5]. Humans working with RoboLeader were able to successfully re-route 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 2 shows the MIX simulation environment with a map display for robot rerouting, small windows showing views from the robots, a larger window for target identification, instruments panels, and a text window for RoboLeader to communicate with operators. Previous research indicated that high FAP alerts were more deleterious to overall performance than were MP weighted [2] systems because the cry wolf effect caused operators to lose faith in FAP alerts.

sion routes to pass through the blue highlighted area on th-
e White Route.

1409 RoboLeader has received a Hostile Area Event Notification f-
or the Blue Route. Please Acknowledge and update mission ro-
utes to avoid passing through the red highlighted area on t-
he Blue Route.

Camera Position: Lat: 34.236628 Lon: -116.059933 Elev: 2337.0
Cursor Position: Lat: 34.236272 Lon: -116.052263 Elev: 579.8

Fig. 2. Simulation scene showing the robot location map, four windows of robot camera views, and a larger display of scene as viewed by robot number 4

To the contrary, in the second study [5], the FAP conditions resulted in better overall scanning performance compared to the MP agents. Because of the layout of the embedded map displays, the locations of the robots could be checked easily for FP alerts in their experiment as opposed to previous research [5]. This made compliance to FP alerts efficient because of the relative ease of attentional switching. 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 targeting displays. This conjuncture was supported by the SA measures indicating better performance on map related data for MP conditions again suggesting that operators focused on the map display to the detriment of their scanning performance. However, 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. Also, higher levels of spatial ability and gaming experience had positive effects on performance.

In the third experiment, RoboLeader used more sophisticated algorithms to direct four robots to entrap a moving vehicular target. LOA was varied as well the addition of a visualization aid [3]. The purpose of this experiment was to assess the effectiveness of the RoboLeader agent for a more dynamic combat environment in which both the targets and the pursuing robots were moving. There were four LOA conditions: manual, hybrid, hybrid w. visualization, and fully automated w. 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 showed how discrepant the robot's progress was from optimal solution to entrap the moving target. The full automation solution was correct 86% of the time whereas the hybrid solution (without visualization) was correct 96% of time, which although not statistically significant, suggested the possible advantages of human/autonomy collaboration found in the UCF studies. Visualization aiding had little impact on performance suggesting that even with partial autonomy, the raw data on the map display supplied sufficient information. Again, operators with higher levels of spatial abilities and more gaming experience showed improved performance. Both improved target acquisition while gamers were better at encapsulating the moving target [3, 5].

3.1 Design Implications

1. Intelligent agents acting as surrogate crewmembers are a potentially effective way of controlling multiple autonomous systems.
2. At a minimum, agent/human teams must have two characteristics (a) Operators must have final decision authority; (b) Agents must signal their intentions clearly.
3. Result in the above experiment [5] suggest that for agents that are not completely reliable, FAP (vs. MP) weighted alerts can be a relatively efficient means of alerting potential problems if the FA are easily checked and are not too numerous.
4. Individual differences in spatial abilities, attentional control, and gaming experience are important determinates of how well humans interact with autonomous systems.

4 Ft. Benning Field Experiments: Intuitive Interfaces

ARL researchers at Ft. Benning working closely with the Ft. Benning infantry school (and later the Maneuver Center of Excellence) evaluated dismounted HRI applications during realistic field experiments [11]. Their most recent research involved advanced interface designs to improve SA and free the soldier's hands and eyes for possible heads-up operations. Speech control of robotic assets has a number of distinct advantages. It is a natural way for Soldiers to interact with robots fostering a teaming relationship and it has the potential of hands- and eyes-free control. Redden and her colleagues conducted a number of studies evaluating the efficacy of voice for small robot control [12-13]. 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 3). The experiments were conducted using teleoperated robots but the results would transfers to operator interventions when necessary for semi-autonomous robots and for controlling miscellaneous functions such as menu selection. They found speech-based control exhibited the potential for benefits beyond controller size reduction. 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 speech control if they had to control the pan and tilt of the robotic arm because the voice commands were discrete and lacked the fluid precise movements evinced by manual controllers.

Fig. 3. Earpiece used as a microphone

In the second experiment [13], they investigated the potential for using speech for multipurpose functions such as having the robot photograph IEDs or having the operator choose items on 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 related to taking a picture of a potential IED (e.g., "enlarge a picture"), speech control was significantly faster than manual control. However, actually taking a photo by maneuvering the robot was more efficient using manual control because maneuvering the robot is a continuous process. Also, the ARL researchers investigated intuitive vocabularies for the various tasks that Soldiers were asked to perform and the researchers developed a user centered lexicon for the experiment.

In a totally different domain, Elliott and her Ft. Benning colleagues [14] collaborated with researchers from the TNO laboratories in the Netherlands to evaluate telepresence techniques that give the feeling of actually 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 an area of interest (AO) without putting the Soldier in harm's way. Augmenting robot video is particularly important because previous research indicated that video feed from robots gives an impoverished view of the AO [15]. The telepresence augmentations included stereovision and a head mounted camera that the operator could use to scan the remote area in a fashion emulating actually being in the AO. 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.

The second experiment contained more difficult detection tasks and the telepresence was augmented further using three-dimensional (3-D) audio cues to locate targets [14]. 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.

4.1 Design Implications

1. It is extremely important to tailor speech commands to the target audience. Tailoring allows better retention and more efficient operation.
2. Speech control is quicker than manual control in situations that require secondary task accomplishment and also in situations in which the items that need to be accessed are embedded in menus.
3. Manual control is more effective than speech control for non-discrete tasks such as turning.
4. Although not currently configured for efficient infantry uses, telepresence has great potential for remote sensing of combat environments using robotic assets.

5 Ft. Leonard Wood: Soldier safety and IED Exploitation

The objective of this study was to explore the effectiveness of stereovision displays and haptic feedback for IED exploitation [16]. IEDs have proven to be a particularly deadly and difficult to detect weapon of terror that is being used against coalition troops and indigenous civilians. What make them doubly dangerous are the risks that Soldiers must take to defeat IEDs. Polaris Sensor Technologies and Harris Corporations working with ARL and the non-profit Leonard Wood Institute evaluated an interface suite to improve Soldier safety using a Talon ® robot to find, manipulate and destroy IEDs. Previous work by ARL had demonstrated the effectiveness and acceptance of stereovision for both navigation and arm manipulation for small robots IED operations. The current study incorporated not only a stereovision display but also a Harris controller that gave haptic feedback to the operator (Figure 4).

The nine participants performed navigation, search and arm manipulations tasks for scenarios that were indicative of US Army engineering, military police, and biochemical missions. There were statistically significant latency effects of view (3-D vs. 2-D) and non-significant 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 both 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.

Fig. 4. Harris Corporation's haptic controller

5.1 Design Implications

A combination of haptic feedback and stereovision shows promise for safely manipulating and defusing explosive and chemical devices using small robots.

6 Conclusions

We reviewed four experimental programs sponsored by the ARL whose purpose was to develop design guidelines for human roles in autonomy focusing on safety issues. The programs varied in their military context from safe operations for robots in an urban environment, to supervising multiple robots with assistance from an intelligent agent, to advanced interface evaluations at Ft. Benning, to IED exploitation at Ft. Leonard Wood. Two overarching trends manifested themselves: (a) Mixed–initiative systems where autonomous and human decisions making were shared but decision authority always remained with the human were superior to either full autonomous or manual control systems; (b) Enhanced sensors and interfaces such as 3-D visual/ audio, voice, and haptic systems can combine to give the human operator a realistic sense of immersive control resulting in improved safety and mission performance.

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