Human-Agent Teaming for Robot Management in Multitasking Environments

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***Abstract*—In the current experiment, we simulated a multitasking environment and evaluated the effects of an intelligent agent, RoboLeader, on the performance of human operators who had the responsibility of managing the plans/routes for three vehicles (their own manned ground vehicle, an aerial robotic vehicle, and a ground robotic vehicle) while maintaining proper awareness of their immediate environment (i.e., threat detection). Results showed that RoboLeader's level of autonomy had a significant impact on participants' concurrent target detection task. Participants detected more targets in the Semi-Auto and Full-Auto conditions than in the Manual condition. Participants reported significantly higher workload in the Manual condition than in the two RoboLeader conditions (Semi-Auto and Full-Auto). Operator spatial ability also had a significant impact on target detection and situation awareness performance measures.**

***Index Terms*—Human Robot Interaction, Simulation, Military, Individual Differences, Multitasking**

I. Introduction

Robots are being utilized more frequently in military operations, and the types of tasks they are being used for are evolving in complexity [1][2]. In the future battlefield, Soldiers may be given multiple tasks to perform concurrently, such as navigating a robot while conducting surveillance, maintaining local security and situation awareness (SA), and communicating with fellow team members. In recent years, several research efforts have developed intelligent software agents that can assist human operators in managing multiple robots in military tasking environments [3]-[5]. Indeed, a recent report on the Role of Autonomy in U.S. Department of Defense Systems recommended that ―increased autonomy can enable humans to delegate those tasks that are more effectively done by computer, including synchronizing activities between multiple unmanned systems, software agents and warfighters—thus freeing humans to focus on more complex decision making" (p. 1) [6].

II. RoboLeader

To achieve a better balance of enhancing autonomy and capability while simplifying human-robot interaction, an intelligent agent called RoboLeader, a robotic surrogate that could help the human operator coordinate a team of ground robots, was developed under the U.S. Army Research Laboratory's Director's Research Initiative Program [3][7][8]. In other words, instead of directly managing the robot team, the human operator only dealt with RoboLeader; consequently, the operator could better focus on the other tasks requiring attention. In typical mission situations, RoboLeader would recommend route revisions when encountering environmental events that require robots to be rerouted. The human operators, in turn, can accept the plan revisions or modify them as appropriate. RoboLeader, therefore, is a mixed-initiative system that consists of both human and machine decision-making components. It also possesses characteristics of hierarchical systems because it serves as the interface between the human supervisor and the less capable (in terms of decision authority) robots.

III. Current Study

In the current experiment, we simulated a multitasking environment and evaluated the effects of RoboLeader on the performance of human operators (i.e., vehicle commanders) who had the responsibility of supervising the plans/routes for three vehicles (their own manned ground vehicle [MGV], an unmanned aerial system [UAS], and an unmanned ground vehicle [UGV]) while maintaining proper 360° local security around their MGV (Fig. 1). The U.S. Army is currently developing 360° indirect-vision display capabilities to enable vehicle commanders to see their immediate environment via streaming video sent from cameras mounted outside the MGV. In the current experiment, the three simulated vehicles traveled in an urban environment as a convoy and the participants had to decide whether and how the routes for the convoy had to change based on environmental events (e.g., threats present, environmental hazards/obstacles) and/or intelligence reports. The paradigm followed Chen and Barnes [3][7] and there were three levels of autonomy (LOAs): the participants either performed the plan revisions manually (***Manual*** condition) or with the assistance from RoboLeader (***Semi-Auto*** condition: maintaining vehicle distance/separation only; ***Full Auto*** condition: vehicle separation + route planning). Concurrently, the participants monitored an indirect-vision display where the environment surrounding the MGV was visible. They were required to report any threats present in their immediate environment (i.e., target detection task).

Fig. 1. User interface of the convoy and 360 tasking environment.

Thirty-two individuals (22 males and 10 females, mean age 25 yrs) from the Orlando, FL area participated in the study. They were compensated $15/hr for their time. A modified version of the Mixed Initiative Experimental (MIX) Testbed was used as the simulator for this experiment [9]. The RoboLeader algorithm was implemented on the MIX testbed and it had the capability of collecting information from subordinate robots with limited autonomy (e.g., collision avoidance and self-guidance to reach target locations), making tactical decisions and coordinating the robots by issuing commands and waypoints etc. [8].

IV. Results

A mixed-model ANOVA (within-subject: LOA; between-subject: participants' spatial ability [SpA]) on Target Detection revealed a significant effect of LOA, $F(2, 29) = 10.4$, $p < .05$, $\eta^2_p = .42$. Post-hoc (LSD) comparisons show a significant increase in Target Detection scores between both Manual and Semi-Auto conditions and Manual and Full Auto conditions (p's < .05). There was no significant difference between Semi-Auto and Full Auto conditions. There was a significant interaction of LOA and SpA, $F(5.995, 55.954) = 2.4$, $p = .001$, $\eta^2_p = .20$ [3][7]. Target Detection was lowest in the Manual condition for participants in each SpA category; however, it was highest in Semi-Auto condition for Higher SpA individuals, and highest in RoboLeader condition for Lower SpA individuals (Fig. 2). The results suggest that all participants benefit in the Semi-Auto condition, and those with lower SpA benefit the most from Full-Auto RoboLeader. It is important to note that participants with higher SpA still show an improvement in the Full-Auto condition over their Manual condition scores; they simply do not show as dramatic an improvement as the lower SpA individuals.

A mixed-model ANOVA on Situation Awareness (SA) revealed a significant interaction of LOA and SpA, $F(5.373, 50.148) = 1.93$, p = .044, $\eta^2_p = .171$. Participants with lower SpA had increasingly higher SA as the LOA increased; however, those with higher SpA exhibited the opposite trend (Fig. 3). Tukey HSD post-hoc comparisons indicate Higher SpA individuals had significantly better SA than lower SpA individuals ($p < .05$). A mixed-model ANOVA revealed that there was a significant main effect of LOA on Perceived Workload (NASA-TLX), $F(2, 29) = 26.4$, $p < .0005$, $\eta^2_p = .645$. Post-hoc (LSD) comparisons showed that the differences between each pair were all significant (p's < .05), with Manual being the highest and RoboLeader being the lowest.

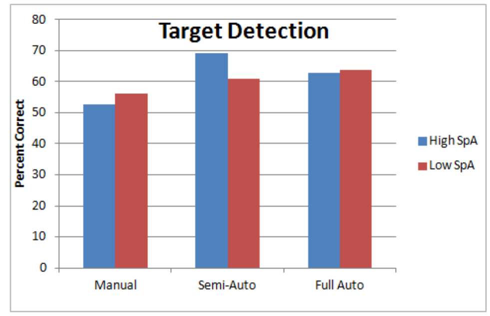

Fig. 2. Effects of spatial ability on target detection.

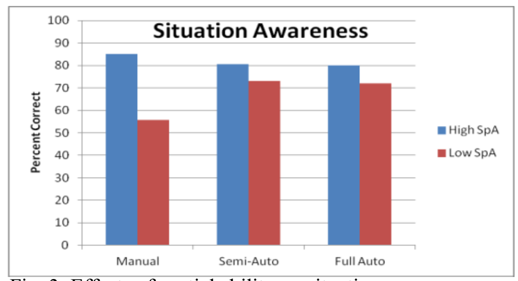

Fig. 3. Effects of spatial ability on situation awareness.

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