SITUATION AWARENESS IN HRI WITH COLLABORATING REMOTELY PILOTED VEHICLES

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In future Army operations, soldiers may be required to remotely operate multiple robotic vehicles and participate in collaborative tasks with these systems. The ability to acquire and maintain situation awareness in tasking and controlling robots will be critical to human-robot interaction. Understanding the critical information requirements for robotics tasks will be important, particularly when operators must work with multiple systems across aerial and ground platforms, and must perform under what will likely be varying levels of system autonomy. Here, we examine SA needs in the context of a collaborative military task involving deployment of a single UAV that is coordinating with multiple UGVs to identify "safe lanes" for advancing troops. Cognitive task analysis was conducted for the task, along with an examination of potential function allocations that may require operator multi-tasking and frequent task switching. Issues in developing and maintaining situation awareness are discussed.

INTRODUCTION

Situation awareness (SA) is important to successful operations in complex, collaborative tasks involving human operators (Endsley, 1995; Salas et al., 1995). Each member of the team needs to have sufficient individual SA to meet his task goals. Team members must also be aware of shared information items as these items affect a team member's ability to coordinate with others. Acquiring SA, both individual and shared SA, can be challenging, though, in a complex task environment. The amount of information to be acquired, processed, and disseminated can be overwhelming. This can be compounded in team tasks that require close collaboration for joint decision making in system control, which is often required in military and civilian operations involving robotic assets. An issue in robotics contexts, though, is that the human understanding must also include awareness regarding what the robotic assets are doing, how they are meeting overall mission intent, and the status of each robot (Drury et al., 2003).

Robotics tasks today involve a human team working together to control and task robotic systems. For example, in robot-assisted urban search and rescue, a robot handler (controller) and an urban search expert (and sometimes a structural specialist) are teamed to locate victims in collapsed structures (Murphy, 2004). This team coordinates to determine where the robotic system should go and how its sensors and other tools will be utilized. They communicate frequently with regard to what they see and what their next action will be (e.g., continue search in current area, search new area, exit and regroup). Currently in these teams, and in many military teams that use robotic systems, the humans in the human-robotic interaction (HRI) outnumber the robots. A future operational goal, however, particularly in military operations, is to lower the operator-to-vehicle ratio and, also, to deploy the human-robotic team as an integrated battlefield element capable of multiple functions (e.g., reconnaissance, surveillance and target acquisition assignments, supporting combat by engaging targets, supporting troop sustainment by transporting troop supplies and equipment).

Increasing the number of robotic systems within human-robot teams will significantly impact performance and workload. The ability to acquire and maintain SA will be critical for completing operations. We examined some performance and SA issues in the context of collaborative HRI. The task involves coupling a single unmanned aerial vehicle (UAV) with multiple unmanned ground vehicles (UGVs) to expedite troop movement through a minefield (i.e., robot-assisted minefield breach).

THE TASK

The minefield breach task involves searching an area of operations to identify targets (mines or clusters of mines) that must be avoided when maneuvering troops through the terrain. The targets are identified and marked to reduce casualties. A single UAV is used to conduct a broad area search. Initial hazard areas are identified, followed by deployment of multiple UGVs that are used to search for and mark the hazards prior to troop movement.

We conducted a preliminary goal-directed task analysis for UGV control in the task. We decomposed the task and considered various function allocation schemes for completing the tasks. We were interested in identifying function allocation issues (e.g., required multi-tasking, task switching, and need for automated system behaviors), as well as SA issues that are a result of a collaborative, remotely-piloted vehicle operation. The potential roles for human operators in the collaborative task include vehicle controller, payload specialist (sensor specialist who interprets the sensor imagery from the remote platforms), and mission controller.

Goal-directed task analysis

Goal-directed task analysis (GDTA) was completed to identify the SA requirements for control and tasking the unmanned systems for this task. The GDTA reveals the major goals of the task, the operational decisions that must be made during performance (some of which are included in the graphic of the task decomposition), along with the specific information needed make the decisions and meet task goals (Endsley, 1993). The GDTA for UGV control was completed as a separate analysis from UAV control. That is, we considered the UAV operator and UGV operators, in this initial assessment to be different persons. The GDTA results provide the information needs for vehicle controllers and payload specialists (operators that interpret sensor data from robotic systems). The high level goals elicited from the GDTA for UGV control are provided below (Table 1). High level goals for UAV control are similar. The SA requirements for the two platforms are quite different, however, for similar goals.

<u>Table 1. GDTA for UGV control in robot-assisted military minefield breach.</u>

0.0 Expedite troop movement through hazardous area
1.0 Navigate vehicle through the environment
    1.1 Move in correct direction
    1.2 Avoid obstacles / collisions
    1.3 Localization of the robotic vehicle
2.0 Maintain working status of the robot
3.0 Communicate with team members
4.0 Identify safe lanes
    4.1 Locate targets
    4.2 Track progress on task (assess coverage)

Table 2 provides an example of SA requirements for goal 2.0 in the UGV analysis. The critical decisions associated with the goal are also listed.

<u>Table 2. Example SA requirements for a major goal in the UGV GDTA</u>

Goal 2.0 Maintain working status of the robot
What is the current robot status? Has there been a system failure? Should the robot be extracted from the task?

- Projected status of overall robotic system
    - Battery / fuel level
    - Overall status of motor system
    - Amperage / voltage level
    - Overall quality of communications
    - Camera
    - Body orientation
    - Body configuration
    - Orientation of tools
    - Sensors
    - Location of vehicle
    - Speed of vehicle
- Time in current position (location)
- Effects of terrain features
- Projected time to recovery

Task decomposition

The graphics in Figures 1 and 2 illustrate the steps of the task. The aim here was to decompose the high level tasks and break them down for illustrating task flow and the basic decision processes. The task decomposition, which allowed us to expand upon activities that must be performed with the UAV and UGVs, was complimentary to the GDTA and depicts where in the task flow critical information requirements (or environmental/system cues) are important to operational decision making. Though the deployment of the UAV and UGVs are depicted separately, the aerial and ground vehicles might be operating simultaneously. Thus, multiple decision points can be active at the same time.

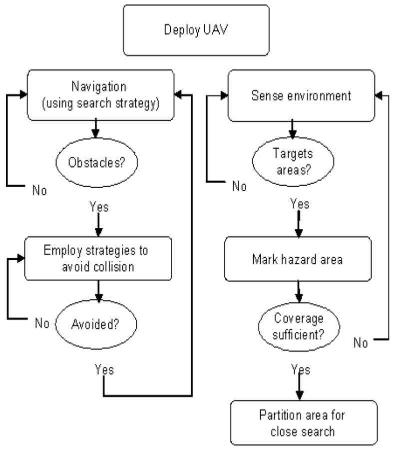

Figure 1. Decomposed UAV task.

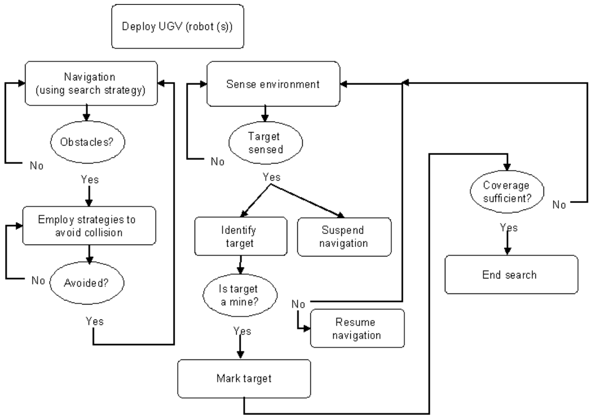

Figure 2. Decomposed UGV task.

Allocating functions across team members

The GDTA results and task decomposition were used to examine potential function allocations for the collaborative task. Recall the aforementioned potential roles for human operators (e.g., controller, payload specialist, etc.). We were interested in how the various robotic systems and components of the overall task could be allocated to various members of the human-robotic team. We began with the many-to-one allocation. That is, we looked at functions for each role with multiple operators assigned to a single robotic system. See Figure 3.

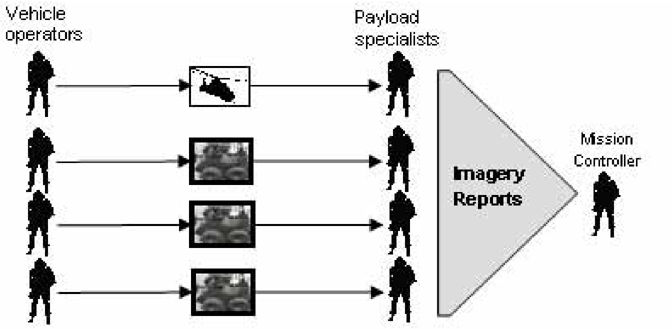

Figure 3. Many to one function allocation.

The vehicle operator. In this allocation scheme, the vehicle operator's goals are to navigate the vehicle and ensure system functionality. The environment poses many hazards. The controller is always concerned with avoiding obstacles and collisions, as well as steering clear of terrain over which the robot cannot traverse or be easily retrieved from. He or she must also perceive and integrate information from the status indicators to discern the overall health of the system.

The payload specialist. The payload specialist's goals are to identify the safe lanes (or hazards) and monitor progress on the search task. Detecting and identifying objects in the search task is highly taxing. The payload specialists (as well as the controllers) are often presented with grainy, soda-straw images of foreign environments that are presented from a point-of-view that is not natural for the human (at the robot's "eye" level). Object detection and identification is a visually demanding task under these viewing circumstances. Judging sizes and estimating distances from/between objects at this point-of-view is difficult.

The mission controller. The mission controller is tasked with assessing the adequacy of the demining process. This involves periodic evaluation of the human-robot teams' coverage of the area and determining the resultant degree of risk to advancing/retreating troops. The objective of maintaining global SA on the various vehicles, the operators, and overall state of task completion is a challenge. The mission controller must develop SA on multiple components of the task and on multiple role players in the scenario. Who and what the mission controller should be aware of at any point in time can change rapidly, as in military operation, any one of the soldiers or systems could be dropped from operations due to casualties or damage. This is important for the SA, performance, workload of the other team members as well, because situation can force one or more of the soldiers into multitasking and task switching.

Examining the many-to-one task allocation and considering the points above, help to make a case for the development of highly sophisticated robotic systems that can take over some of these functions. A future goal is to allocate functions across humans and automated components of robotic systems to reduce the number of operators required in the control/tasking of the vehicles. But what are the issues in function allocations that involve high degrees of autonomy in system control, autonomy that will be required to meet the goal depicted in Figure 4.

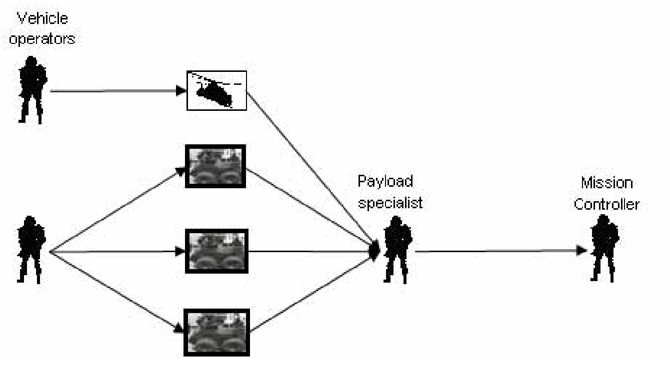

Figure 4. Reduced operator-to-robot ratio.

Figure 4 illustrates function allocation that suggests fewer operators: one for controlling the UAV and another for controlling multiple UGVs in the collaborative task. Also the number of payload specialists is reduced to one for all vehicles (and their associated sensor assets) across two platforms. This is just one example of function/system allocation across operators. (This particular scheme might be considered very challenging for a collaborative robotic task as we have described.) An alternative would be two payload specialists, one for each platform type (aerial versus ground). Other potential configurations can be considered. The important point to make is that some degree of highly reliable and intelligent autonomy will be required for reaching such ambition.

SYSTEM AUTONOMY

The question, "what should be automated", is an important issue in robotic tasks, particularly one with aspects as we described. Decisions need to be made regarding what tasks can/should be offloaded to autonomous components of the robot system to facilitate the few (humans) - to - many (robots) operational paradigm.

For the collaborative task, there are several stages of the task, or associated behaviors, which might be automated. For example,

1. navigation (and following search patterns)
2. vehicle localization
3. target detection / identification
4. observation behaviors
5. decision making with respect to degree of coverage (in search task)
6. recovery from system failures

Decisions regarding whether to automate some functions in this list seem straightforward. For example, automating navigation is certainly a feasible consideration. Ground systems in particular can be programmed to follow paths or search patterns, including avoiding collisions in an environment. Target detection and completing observation behaviors can also be handled autonomously. The case may be different, however, for tasks like vehicle localization, which involves comprehending where a vehicle is with respect to other vehicles, human operator locations, the control station or robotic base of operations, and other important landmarks. And what about decision making regarding the adequacy of the target detection task, which is the basis for assessing the risk to soldiers during advancement of troops? We must consider operator ability to maintain SA and make decisions in a collaborative, multiple unmanned vehicle control context where key functions are taken away. There must be means of supporting SA on individual robots, on the group of robots, and on the status of the overall task.

In such situations, it is important to consider the SA and control issues that might occur as a result of varying levels and approaches to autonomy. It is likely that many of the same automation issues observed in the application of automation to industrial settings will be observed in HRI (i.e. out-of-the-loop syndrome, mode awareness problems, vigilance decrements, etc.). Loss of SA could mean difficulties, and increased time required, in taking over during required interventions (e.g., extracting the robot from perilous situations). Research on the appropriate levels of autonomy for various robotics tasks is needed. Operator performance with robots may benefit from full automation of some tasks (e.g., target detection, prescribed observation behaviors), but be degraded by full automation of others e.g., navigation). Perhaps some tasks would benefit from lower levels of autonomy, like batch processing or blended decision making. That is, maybe SA and workload can be better managed by allowing operators to provide a series of commands to a mobile robotic system (or multiple robots) rather than reducing the operator interaction to supervision/observation of fully autonomous systems. This type of control has proved somewhat promising to traditional automation contexts and industrial robotics tasks (at least those that do not suffer from control lag).

MULTI-TASKING AND MULTIPLE ROBOT CONTROL

The multi-tasking and task switching that is required in a complex collaborative task may be detrimental to operator SA. The human operator of multiple unmanned vehicles will be required to manage allocation of attentional resources to maximize awareness on the robots and on the task, while hopefully minimizing idleness and workload. Research has pointed out that a human operator (particularly in teleoperation) may often focus on information relevant to a particular component of a robotic task (e.g., navigation) in the environment to the exclusion and detriment of other task component (e.g., victim detection and identification) (Draper et al., 1998). Allocation of resources to one element or stimulus in the environment may mean loss of SA on certain other relevant elements of the event. In multi-task situations, because an operator's cognition is distributed across multiple, and sometimes competing goals at the same time, the operator may develop SA on one goal or task component, singularly, or two or more goals or task components together. An operator's ability to develop good SA on multiple components of the overall task will be critically affected by his/her capability to divide attention to multiple environmental elements and/or activities. Acquisition and maintenance of SA under multitasking can also be affected by the design of the interface and its utility in supporting division of attention, in adequately directing the operator's attention to goal-specific items/elements, and/or in facilitating operator shifts between goal-driven and data-driven information processing at appropriate times.

What are system design features that will support SA when alternating between control of multiple vehicles? Operators need to know when it is okay to maintain current performance (e.g. with one robot system), but also when it is crucial to quickly switch attentions (e.g., to another system/task). Under such circumstances there is a need to provide mechanisms that support the user in maintaining or developing awareness of the current mode of operations for a particular system, the current goals and task state for a system, and the current operational status of a system.

HUMAN-HUMAN COLLABORATION

A collaborative task requires a means for collaborating with other operators. An important question is how to design for collaboration while also providing the multitude of information requirements that are key to mission performance. Control of multiple systems means more SA items to keep track of and to communicate to others. This kind of collaboration may be hindered by differences in information needs across different types of robot platforms. Both individual and shared SA will be important. Shared SA may be challenging when forced into distributed coordination with systems of variable capability, functionality, and control mechanisms. It will be important to design effective shared SA devices and facilitate effective shared SA methods/mechanisms.

A topic someone related to the above is the integration of operational data or output from multiple robotic sources. Various types and quality of sensor data can be provided from coordinating robot systems. Effective and meaningful ways of integrating or fusing, for example, imagery from UAVs and UGVs, will be needed. In order to develop ideas on how to integrate various kinds of data for decision making during operations, we must consider the task types, information types, and how the data might be used.

SUMMARY

These are just a few issues that will be important to HRI in collaborative tasks involving unmanned robotic systems. Other issues involve difficulty in providing the multitude of SA requirements on multiple systems via limited display space, potential needs for virtual controls rather than physical controls to support multiple robot tasking and control, the utility of augmented reality displays or overlays for improved high level SA (comprehensions and projections) during vehicle control, and the need to universal display and control mechanisms to support performance under varying tasks and system types/platforms. There are many research issues to consider in order making an effective transition from single-user-single-robot contexts to more complex multi-robot collaboration tasks.

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