

## **The Hunt for Situation Awareness: Human-Robot Interaction in Search and Rescue**

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### **Abstract**

Robots are gaining acceptance as team members in complex task completion, though they must be directed or closely supervised by human operators. Effective interaction between operators and robots is dependent upon the operator's ability to develop situation awareness on the robot and environment. In teleoperation this requires the effective distribution of attention between remote activities and the local controls and interfaces. Limitations in attentional resources can limit SA on one or the other place, resulting in overall decreased system performance. We present observations made at a robot-assisted search and rescue exercise to describe common SA problems in vehicle control. This paper focuses on human-robot interaction and the role of SA in search operations. Key SA concerns observed and discussed include difficulties in robot localization, inadequate support for team operations and shared SA, workload in the visually demanding task, and poor integration of data at the interface.

### **Introduction**

Robotic systems are more commonly being applied as task partners in domains where activities are not well-suited to insertion of human operators (e.g., hazardous search and rescue operations). In remote operations, the robot serves as an extension of the human operator. It is used to project the operator's presence and intent upon the environment. With advances in technologies, systems are acquiring autonomous capabilities. At present, however, human intervention is still needed in most domains to either manually control or closely supervise robot activity.

Effective interaction between human users and robotic systems is dependent upon sufficient operator awareness of the robot, task, and environment. The operator must understand what the robot is doing, how robot actions are meeting task goals, the current state of the robot, and how environmental factors influence task completion and the "health" of the system. In teleoperation, this requires the division of attention between remote activities and the local controls and interfaces. Limitations in available attentional resources can limit situation awareness (SA), and poor SA on either the task/robot activities taking place away from the user or on the control actions taken with local devices, can mean overall decreased system performance.

We present observations made at the 1<sup>st</sup> Summer Field Institute, developed by the Center for Robot-Assisted Search and Rescue (CRASAR) at USF, to describe the importance of SA in human-robot interaction (HRI). A goal of the institute was to embed scientist with urban search and rescue

(USAR) professionals and with robot operators as they completed deploy-search-clean cycles during a robot-assisted rescue training exercise. Scientists observed operations and noted common problems in the operations of vehicles, with respect to robot mobility, communications, and interaction. Our focus for participation in the study was on identification of HRI issues and the need to acquire/maintain SA for successful operations.

### **The Observation**

The observation process was structured similarly to a context inquiry. A major portion of the investigation involved direct observation of the robot controllers and USAR professionals utilizing robotic vehicles to support victim search and extraction in rescue missions. The observation can be described in three parts: the direct observation, the after action review/question session, and the post-institute review of training videos.

#### Direct observation

During direct observation, 3-4 scientists accompanied each USAR team (typically a robot controller/handler and USAR profession, sometimes including a mapper) on a rescue mission. Each mission was set up by Marines supporting the training session. For a mission the Marines placed "victims" (mannequins) inside the rubble of a collapsed building. Our goals for the direct observation were to:

1. make note of apparent interface/physical control issues;

2. note communications taking place across the team, including what they were talking about and how they were coordinating; and
3. identify other human factors or SA problems.

We were also interested in learning more about the characteristics of the task and environment, as they present challenges to ability to acquire and maintain SA and to overall SAR performance (e.g., clutter, lack of lighting, low visibility, time constraints, hazards, etc.).

Scientists did not get to directly observe all training scenarios. The majority of scientists were embedded with teams to observe 4-5 missions. There were very few opportunities during rescues to pose questions to team members, as they were training and receiving instruction to develop skills for actual operations.

#### After action review and interview

Questions were reserved for the after action review period. Participants were allowed a short time to question controllers and USAR professionals about the events of the rescue mission. Example questions include:

1. What information are you looking for during a victim search?
2. What are the limitations of the interface with respect to acquisition of information on the task (or environment or control response of the system)?
3. Are the difficulties experienced in this training mission common problems that occur during robot-assisted SAR?

In general our questions were aimed at gathering perceptions of the users/experts with respect to interface design and/or interaction problems that affect control performance. They were also aimed at identifying SA requirements and needs, as well as how system designs either support or fail to facilitate acquisition of SA.

#### Post-institute video analysis

The third part of the analysis occurred after the the Field Institute. Scientists were provided copies of video recordings of all of the rescue training missions. That is, participants were allowed to review missions that directly observed and watch those that they were not able to participate in. Video recordings included both night and day operations. The video analysis supported further identification of operational problems common to most missions, and provided data for summarizing the various interface, interaction, and control issues.

## **The Scenario**

Exercise participants were instructed that an earthquake, in a small town (Lebanon, IN), caused significant damage to the local library. The multistory building collapsed (see Figure 1). And several people were trapped inside the structure. Structural specialists and HAZMAT personnel are on hand, and the robot-assisted SAR team has been called in. Crews conduct operations to make initial identifications of where victims might be trapped deep within the rubble pile. They are buried too far in the ruins for rescuers to enter and safely pinpoint their locations. So, robots are needed to explore the voids and find a safe path for extraction. The vehicles are small, no larger than 1.5 feet long and 6 to 10 inches high. They are equipped with cameras, lights, and audio systems. Some are tethered and others are wireless. The robots will be the eyes and ears of the rescuers, the key link between SAR workers and the environment and victims that are found. (See Figure 2 for pictures of robots. The top robot is an Inuktun Micro VGTV and the bottom one is an iRobot Packbot.)



Figure 1. Collapsed library for rescue training.

## **The Search**

A victim is detected in the collapsed building and a rescue team is deployed with a robot for the search. One USAR member is dedicated to looking for cues on the victim. Another is tasked with developing a map of the explored space. The team is multitasking to complete the mission and trying to develop good individual SA. They employ a “leapfrog” technique for advancing through the collapsed building. The robot is sent ahead and SA is acquired through the interface. Once the team determines it is relatively safe to advance and that they have sufficiently searched an area, they move ahead to the robot’s location, and repeat the process. Thus, the team alternates between seeing the robot

during operations and non-line-of-sight teleoperation. The mission times for the training scenarios as part of the Institute varied in length depending upon the number and types of problems encountered during the training. On average the duration of a search for victims was about 1.5 hours.

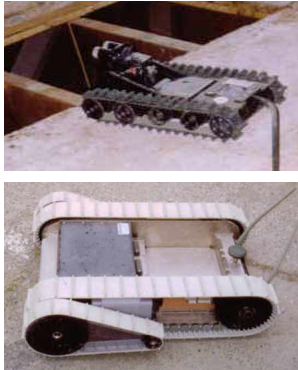


Figure 2. SAR robots used in training missions.

## Situation Awareness and Operational Issues

### Difficulties in robot localization

Disorientation in the environment is a major SA problem. This makes localization of the vehicle (a key SA element) difficult. During one search, immediate disorientation occurs upon insertion of the robot in a dark, smoke-filled void. Several minutes prior to navigation are spent in trying to orient/localize the vehicle. That is, the operator works to determine the direction of motion and orientation of the robot with respect to the insertion point (as it must return there for extraction) and to adjacent walls. This also occurs several times once a robot is out of the operator's line-of-sight.

Operators need to be aware of how the robot is situated with respect to their physical location/direction, entry points, and location of walls, openings and landmarks. They appear to expend considerable cognitive effort tracking control actions in order to figure out where the robot is and where it's been. Lapses in SA, on situatedness of the robot, result in lots of back-tracking for vehicle localization. In one scenario, the robot controller relies on the tether for navigating back to previous positions. Ultimately, if there a lack of SA on the situatedness of the robot, there may also be problems with directing rescuers to locations for extracting the victim.

### Lack of support for team and shared SA

A team effort is currently required for robot-assisted SAR. Robot operators are not experienced USAR workers, and USAR professionals are not proficient

in control of robots. Furthermore, search missions require multitasking across the team. Each member is building SA to meet task requirements and communicate with each other, for example, on where to look, where the robot can/can't go, robot status, and what to take closer look at. During training, teams shared a single display. They were often looking for different information or the same information to be used differently.

The robot operator uses the interface to control the direction of the vehicle and manipulate tools to drive over difficult areas. He watches the camera feed to assess the terrain and obstacles (size, distance), to determine where he can drive the robot, and identify areas he should avoid. He tracks his control actions (e.g., turned left, went straight) so that he comprehends the situatedness of the robot in the space. He also monitors the system status, assesses the approximate distance the robot has traveled and updates other team members on these SA items.

The USAR searcher uses the camera view and follows SAR tactics to instruct the robot operator on which direction to point the camera or in which direction to drive. He assesses colors, shape/form of objects, size and distance of objects, movement in the area, and environmental cues suggesting office areas, bathrooms, etc. where people may have been located. He is also noting environmental hazards and potential structural hazards that might hinder extraction.

The map developer is looking for structural and material hazards. He is identifying landmarks and unique features that can be pointed out to the extraction team and tracking operator control actions to determine the path to the victim. His map of the area will indicate areas that have been explored and those that may be too dangerous for entry.

The three people have difficulty sharing the display (on a laptop computer). This is a problem because ultimately, the individual SA of team members must come together to effectively convey information to other stake holders. For example, the extraction team will want information on how to get to the victim (what exact path to take), the victim's location (relative to the entry point), and the characteristics of the void. A medical team will ask about the status of victims (e.g., conscious, alive) and the type/urgency of treatment needed upon extraction.

The team primarily communicates on what each person is seeing, that is the individual perceptions of what's going on in the scene. Coordination focuses on things such as where to point the camera, where to drive the robot, what to look at next, how much farther the robot can travel ahead of the team. This is verbal communication that takes place face-to-face as the team cannot be separated (due to the use of a single display). On occasion operations become

somewhat hindered by the crowdedness in the smaller void areas. There is also the potential for conflict in this situation as the SAR expert concerned with victim search may not want to view the same items/areas and the SAR worker developing the map/layout of the area.

#### Needed support for visually demanding task

After the team has been searching for the victim over an hour, their SA and performance appear to be taxed by the environmental conditions and stress of the task. Poor lighting makes the search difficult in the dark void. The illumination provided by the robot is not sufficient and the team tries to compensate by adding a makeshift lighting fixture with tape and a flashlight. It works for a while, but the flashlight keeps falling off. The highly unstructured environment is frustrating and it is very hard to identify/recognize objects. Victim search is a very demanding visual perception task and object recognition is critical to success. The surrounding clutter, the dust and debris, etc. make scenes hard to interpret. This is severely compounded by soda-straw views and/or grainy images that are often provided with the camera. Operators also contend with the misleading viewpoint from the robots perspective. The robots are small and low to the ground, which means the size of objects (and distance to objects) can be greatly misjudged, leading to incorrect or total lack of object identification. Zooming in on objects with the camera (when possible) was not observed to be very helpful. Operators had to work to get the robotic systems very close to objects to make determinations, and then they often made joint decision regarding whether or not the items might be body parts of victims.

#### Low-level data overload and interface design

Beyond the difficult-to-interpret scenes, there is a lot of low level data on the robot presented through the interface. One interface observed in the exercise is divided into three major sections: the camera feed, the GPS screen, and the robot status information (see Figure 3). The interface shows status information on the pitch of flippers, flipper angle, heading, speed, brakes, battery level, radio level, main, boost, and flipper motors, etc. The data is provided at a low level. Little of the data is integrated or presented such that overall robot status can be ascertained relatively quickly. While navigating, the operator is also scanning the interface and cognitively integrating or fusing data to comprehend higher level SA elements like, the distance traveled based on speed and time on task, or the time until battery level is too low for operation, or if the overall motor system is within an acceptable temperature range

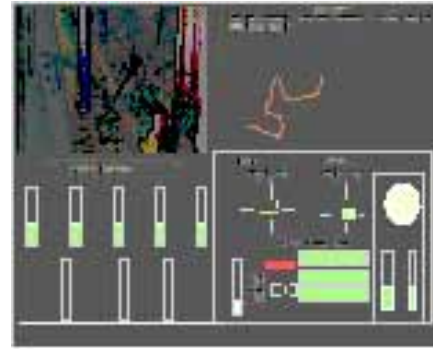


Figure 3. Graphic representation of robot interface.

Some of the data provided is not presented in an effective manner (i.e., it is not easily understood) and other SA requirements are just not available. During a search the team is watching the display and suddenly the robot fails to respond. The team is unsure of what has happened. They are not currently able to see the robot and struggle to assess and improve the quality of the communications link with the robot. On the interface there is a percentage value provided for the radio (communications) level. This is sometime hard to comprehend as the radio level effect on operations is not always the same for a given value. Without sight of the robot and clear understanding of how far it has traveled, it is hard to tell if the robot is actually having problems because of poor communications. It could be stuck - lodged against an object that can't be seen in the camera view or bogged down in terrain that it cannot traverse. There is no feedback, for example from any tactile sensors, through the interface (which operators have stated would be helpful information).

In another instance, the robot is deep in the rubble and though it's responding the operator is not sure what the robot is doing. There appears to be a problem with the controls. Ironically, the robot that has been deployed can navigate terrain both right- and wrong-side up. Because the team is out of visual range of the vehicle, the operator is not aware that the robot has flipped over (i.e., is operating wrong-side up). One might wonder why this cannot be determined from looking at the camera view. Shouldn't the view appear to be upside down? The problem in the wreckage is that void spaces often do not afford views of a ceiling, and the clutter above to robot inside the collapsed building looks just like the clutter below. So, there is no apparent difference in the view from the camera. And, the information provided at the interface on robot orientation does not support "at a glance" awareness of the upside-down state.

## Summary

The difficulties in developing and maintaining SA were observed in a highly realistic training effort and they are representative of real operational issues. In using human-robot teams for USAR, the hunt for SA drives the success of the search effort. Unfortunately, the problems of disorientation, interface design limitation, etc. discussed earlier resulted in failures to locate mannequins during training. There were also difficulties in using physical controls. The joysticks and buttons of the system were sometimes difficult to utilize given the protective equipment that rescuers must wear. Some of the issues can be addressed with basic improvements to lighting systems and available sensors and cameras for robots. Others are interface and interaction design concerns influencing SA and requiring investigation. An issue directly related to our research interests is the need for SA requirements analysis and data integration for interface designs that support team SA and performance, as well as single operator control.

The current state of robotic system/interface design is such that non-robotics experts are not able to adequately control robots for task completion. So a team search is required. As described above, the robot teams observed in the Institute, consisted of as many as three people. (One of these persons is a dedicated robot handler.) Because these multiple users are using a single display the potential for one or more of them to experience gaps in development of SA on the task, environment, or robotic system is high. Multiple displays might facilitate better team performance and allow some members of the team to be remote from others. It should be noted, however, that the multiple displays should be developed such that they support individual SA as well as team SA and coordination, not just multiple view of the same scene. Each team member will need to develop SA on items most critical to his/her responsibilities (mapping the environment and noting hazards, looking for cues on potential victims in the area, controlling the robotic system). Perhaps, the robotic system is equipped with multiple cameras that can be dedicated to a single user and/or traded-off across team members via the interface based upon current visual interest or SA needs. Displays might also allow users communicate through the interface, which can be particularly helpful if one or more of the team members is not collocated with the others.

Task analysis is needed for specific robot-assisted contexts to identify the SA requirements that support successful task completion. Work should focus on ideal information needs and how data is manipulated, fused, or integrated to make decisions

or perform in the given domain. SA requirements analysis can then be utilized as a basis for the design of user- or role-defined interfaces for various members of the team. In future a goal will be to merge task responsibilities and skills such that a single person is able to control the vehicle and complete the operational task (find victims, locate and identify targets). Interfaces must be easy to use however to meet this goal. SA requirements can be used to identify how roles can be combined to allow a single person to complete multiple responsibilities with a single robotic system.

We have completed some work on goal-directed task analysis for specific robotic contexts (e.g., robot-assisted military minefield breaching). The SA requirements derived from this work supported definition of concepts for SA-oriented interfaces to support team work and multitasking in mine clearance for troop maneuvers.

We are also investigating how interfaces can be designed to support a single operator in control of a robot while also completing other tasks (e.g., like the search for targets). We believe that effective designs can facilitate the use of robotic system by non-robotics experts. This will allow SAR experts to use robots without first having to become expert robot controllers. This work also has application to the future military where robots will become more common and soldiers must be able to quickly and easily learn to use them in operations.

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## References

- Casper, J. & Murphy, R. (2003). Human-robot interactions during the robot-assisted search and rescue response at the World Trade Center. *IEEE Transactions on Systems, Man and Cybernetics, Part B*, 33(3), 367-385.
- Endsley, M. R., Bolstad, C. A., Jones, D. G., & Riley, J. M. (2003). Situation awareness oriented design: from user's cognitive requirements to creating effective supporting technologies. *Proceedings of the Human Factors and Ergonomics Society 47th Annual meeting*.