HUMAN-ROBOT INTERACTIONS: CREATING SYNERGISTIC CYBER FORCES

Jean C. Scholtz
National Institute of Standards and Technology
100 Bureau Drive, MS 8940
Gaithersburg, MD.
jean.scholtz@nist.gov

Abstract Human-robot interaction for mobile robots is still in its infancy. As robots increase in capabilities and are able to perform more tasks in an autonomous manner we need to think about the interactions that humans will have with robots and what software architecture and user interface designs can accommodate the human-in -the loop. This paper outlines a theory of human-robot interaction and proposes information needed for maintaining the user's situational awareness.

Keywords: Human-robot interaction, situational awareness, human-computer interaction

1. Introduction

The goal in synergistic cyber forces is to create teams of humans and robots that are efficient and effective and take advantage of the skills of each team member. A subgoal is to increase the number of robotic platforms that can be handled by one individual. In order to accomplish this goal we need to examine the types of interactions that will be needed between humans and robots, the information that humans and robots need to have desirable interchanges, and to develop the software architectures and interaction architectures to accommodate these needs.

Human-robot interaction is fundamentally different from typical human-computer interaction in several dimensions. First, I propose that there are three different levels of interaction possible from the human view point, each with different tasks and interactions. I call these levels supervisory interactions, peer interactions, and mechanic interactions. The second dimension is the physical nature of mobile robots. Robots need some awareness of the physical world in which they move and this model needs to be conveyed to the human to facilitate an understand of the decisions made by the robotic platform. A third dimension is the dynamic nature of the robot. Robots have physical sensors that may fail or degrade, affecting some of the platform's functionality, unlike the more static computer platforms. The final dimension is the environment in which interactions occur. Interaction devices and displays may have to function in harsh conditions and will have to support user mobility.

2. Situational Awareness

Situational Awareness has long been a metric for evaluating supervisory control interfaces and should be a good approach to developing metrics for HRI. However, each of the three levels of interaction will require a different set of information needs and hence different situational awareness.

Situational awareness (Endsley, 2000a) is the knowledge of what is going on around you. The implication in this definition is that you understand what information is important to attend to in order to acquire situational awareness. As you drive home in the evening there is much information you could attend to. You most likely do not notice if someone has painted their house a new color but you definitely notice if a car parked in front of that house starts to pull out in your path.

There are three levels of situational awareness (Endsley, 2000). Level One of situational awareness is the basic perception of cues. Failures to perceive information can result due to short comings of a system or they can be due to a user's cognitive failures. In studies of situational awareness in pilots, 76% of SA (Jones and Endsley, 1996) errors were traced to problems in perception of needed information. Level Two of situation awareness is the ability to comprehend or to integrate multiple pieces of information and determine the relevance to the goals the user wants to achieve. A person achieves the third level of situational awareness if she is able to forecast future situation events and dynamics based on her perception and comprehension of the present situation.

Performance and situational awareness, while related, are not directly correlated. It is entirely possible for a person to have achieved level three situational awareness but not perform well. A person can fail to perform correctly due to poorly designed systems or due to cognitive failures. The most common way to measure situational awareness is by direct experimentation using queries (Endsley, 2000). The task is frozen, questions are asked to determine the user's situational assessment at the time, then the task is resumed. The Situation Awareness Global Assessment

Technique (SAGAT) tool was developed as a measurement instrument for this methodology (Endsley, 1988). The SAGAT tool uses a goal-directed task analysis to construct a list of the situational awareness requirements for an entire domain or for particular goals and subgoals. Then it is necessary to construct the query in such a way that the operator's response is minimized, such as presenting choices for responses.

3. A Theory of Human-Robot Interaction

3.1 Level of Interaction Scenarios

To illustrate the three different levels of interaction, here are two different scenarios.

3.1.1 Scenario 1: Military Operations in an Urban Terrain. A number of soldiers and robots are approaching a small urban area. Their goal is to make sure that the area is secured - free of enemy forces. A team of heterogeneous robots will move in a coordinated fashion through congested areas to send back images to the soldiers. Robots will also be used to enter buildings that may be hiding places for enemy soldiers. A supervisor is overseeing the scouting mission from a remote location close to but not in the urban area. Ground troops are close behind the robots and individual robots are associated with a certain group of the soldiers. In each group one soldier is an expert in maintaining the robot (both physically and programmatically) associated with that group. The supervisor needs to know that all robots are doing their jobs and reassigns robots appropriately as the mission moves forward. If there is a problem the supervisor can either intervene or can alert the soldier mechanic.

The soldier functioning as the mechanic does what is necessary to get the robot back into an operational state. This could be as simple as identifying an image or as complicated as debugging hardware and software. The soldiers are also team members of the robot and may give the robot tasks to do such as obtaining another image at closer range. The robots will also encounter civilians in the urban environment. Some degree of social interaction will be necessary so that the civilians don't feel threatened by the robots.

3.1.2 Scenario 2: Elder Care. An elder care facility has deployed a number of robots to help in watching and caring for its' residents. The supervisor oversees the robots who are distributed throughout the facility and makes sure that the robots are properly functioning and that residents are either being watched or cared for — either by a robot or by a human caregiver. A number of human caregivers are experts in robot maintenance and assist as needed depending on their duties at the time. The caregiver robots can perform routine tasks such as helping with feeding, handing out supplies to residents, and assisting residents to move between locations in the facility. Watcher robots monitor residents and have the capability to send back continual video feeds but also to alert the supervisor or a nearby human caregiver to an emergency situation. Robots interact with the residents as well as visitors to the facility who may not be aware of their capabilities.

3.2 Scenario Generalizations

What can we learn from these two scenarios? First of all, the boundary between the three levels of interactions is fuzzy. The supervisor can take the mechanic role if it is more efficient than a handoff to the designated mechanic . The team members can command the robots. Peer interactions occur with team member and with bystanders who have little or no idea of the capabilities of the robot. All of the interaction levels can occur at the same time by the same or different people. Is it necessary and feasible to design adaptive interfaces that adjust as the user's role changes? What types of interaction technologies and feedback mechanisms are needed to support these interactions? What information is essential for users in each role?

3.3 The Supervisory Level

We assume that the supervisory interface is done from a remote location. Our hypothesis is that the supervisor needs the following information:

- an overview of the situation.
- the mission or task plan.
- current capabilities of any robotic platform and any deviation from "normal".
- other interactions with robots, including group robot behaviors.

A corresponding HCI domain is that of complex monitoring devices . Complex monitoring devices were originally based on displays of physical devices (Vincente, Roth, and Muman, 2001). The original devices were just lights and switches that corresponded to a sensor or actuator and were displayed on physical panels. Computer based displays were unable to hold all the information on a single display and so users had to sequence through a series of displays. This produced a keyhole effect—the notion that a problem was most likely occurring on a display that wasn't currently being viewed.

Another issue in complex monitoring devices is that of having an indication of what "normal" is. This is also true in human-robot interactions where physical capabilities of the system change and the supervisor needs to know the "normal" status of the robot at any given time. Another issue is that single devices may not be the problem but rather relationships between existing devices. Displays should support not only problem driven monitoring but knowledge driven monitoring when the supervisor actively seeks out information based on the current situation or task.

We suggest that lessons learned in producing displays for monitoring complex systems can be used as a starting point for supervisory interfaces for HRI. In addition, basic HRI research issues that are not addressed in complex systems include:

- what information is needed to give an overview of teams of robots?
- can a team world model be created and would it be useful?
- what (if any) views of individual robot world models are useful?
- how to give an awareness of other interaction roles occurring?
- what strategies and information needs are appropriate for handing off interventions to others? to others?

Situational awareness indicators will be developed based on a task-analysis of the supervisor's role in a number of scenarios (such as those described earlier in this paper). An initial hypothesis about possible indicators of situational awareness includes:

- which robots have other interactions going on.
- which robots are operating in a reduced capability.
- the type of task various robots are currently carrying out.
- the current status of the mission.

3.4 Peer to Peer Interactions

We make the assumption that these are face to face interactions. This is the most controversial type of interaction. Our use of the terms "peers" and "teammates" is not meant to suggest that humans and robots are equivalent but that each contributes skills to the team according to their ability. The ultimate control rests with the user—whether the team member or the supervisor. The issue is how the user (in this case, the peer) gets feedback from the robot concerning its understanding of the situation and actions being undertaken. In human-human teams this feedback occurs through communication and direct observation. Current research (Bruce, Nourbakhsh, and Simmons, 2001; Breazeal and Scassellati, 1999) looks at how robots should present information and feedback to users. Bruce et al. stress that regular people should be able to interpret the information that a robot is giving them and that robots have to behave in socially correct ways to interaction in a useful manner in society. Breazeal and Scassellati use perceptual inputs and classify these as social and non-social stimuli, using sets of behaviors to react to these stimuli.

Earlier work in service robots [Engelhardt and Edwards, 1992] looked at using command and control vocabularies for mobile, remote robots including natural language interfaces.They found that users needed to know what commands were possible at any one time. This will be challenging if we determine that it is not feasible to have a separate device that can be used as an interface to display additional status from the robots that would be difficult to display via robotic gestures.

We intend to investigate research results in mixed initiative spoken language systems as a basis for communicating an understanding of the robot to the user and vice versa. Our hypothesis about information that the user will need include:

- What other interactions are occurring.
- The current status of the robot.
- The robot's current world model.
- What actions the robot can currently carry out.

Other interesting challenges include the constraint on the distance between the robot and the team . We use other communication devices to operate human-human teams from a distance. What are the constraints and requirements for robot team members?

3.5 Mechanic Interaction

We make the assumption that this will be either a remote interaction or will occur in an environment in which any addition cognitive demands placed on the user are by the environment are light. We will also assume that the mechanic has an external device to use as an interface to the robot. The mechanic must be a skilled user, having knowledge of the robotic architecture and robotic programming. If the robot has teleoperation capabilities, the mechanic would be the user who would take over control. This is the most conventional role for HRI - however, one that has not been extremely well supported. Moreover, as the capabilities and roles of robots expand, this role has to be capable of supporting interaction in a more complex situation.

We hypothesize that the mechanic needs the following information:

- The robot's world model.
- The real-world situation (as much as can be obtained).
- The robot's plans.
- The current status of any robotic sensors.
- Other interactions currently occurring.
- Any other jobs that are currently vying for the mechanic's attention (assuming it is possible to service more than one robot).
- The effects of any adjustments on plans and other interactions.
- Mission overview and any timing constraints.

Murphy and Rogers (Murphy and Rogers, 1996) note three drawbacks to telesystems in general:

- The need for a high communication bandwidth for operator perception and intervention.
- Cognitive fatigue due to repetitive nature of tasks.
- Too much data and too many simultaneous activities to monitor.

Simulation and programming environments and computer games should be examined to determine the properties present in good examples of these that contribute to the user's situational awareness.

4. Summary

We propose that human-robot interactions are of three varieties, each needing different information and being used by different types of users. In our research we will develop a number of scenarios, do a task-based analysis of the three types of human-robot interactions suggested by each scenario. We will then develop both a baseline interface for each type of interaction and a situational assessment measurement tool. We propose to conduct a number of user experiments and make the results publicly available.

We have concentrated on the user and her information needs in this paper. However, to achieve a successful synergistic team, it will be necessary to furnish information about the user to the robot and to create a dialogue space for team communication. We will start by concentrating on the user aspects of the information but intent to expand our research to include capture and use of user information as well.

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