Using Mobile Robots as a Shared Visual Presence in USAR Environments

Jennifer L. Burke and Robin R. Murphy

University of South Florida
Dept. of Computer Science & Engineering
4202 E. Fowler Avenue, ENB 342
Tampa, Florida 33620
jlburke4@csee.usf.edu, murphy@csee.usf.edu

Abstract

This paper presents mobile rescue robots as a way of augmenting communication in distributed teams through a shared remote visual presence consisting of the robot's eye view. Emergency/disaster management is a system composed of many (distributed) ad hoc teams; one of these is Urban Search and Rescue (USAR), itself a system organizationally structured as teams of teams. The use of mobile robots as a shared remote visual presence is presented specifically within the domain of USAR as a means of addressing the communication and coordination challenges posed for distributed team members onsite during an incident response, and also for others removed from the incident site. It is posited that the shared awareness (common ground) and mutual knowledge gained through the shared remote visual presence can enhance communication efficiency and coordination across teams, and improve team performance. Existing and potential applications in emergency management and response situations are discussed, along with an agenda for current and future research.

Introduction

This paper presents mobile rescue robots as a way of augmenting communication in distributed teams through a shared remote visual presence consisting of the robot's eye view. The question addressed in this paper is that of how AI technologies can facilitate information/knowledge sharing and semantic understanding while avoiding cognitive overload. We address this question within the purview of the Federal Emergency Management System, which became part of the U.S. Department of Homeland Security in March, 2003. FEMA's continuing mission within the new department is to lead the effort to prepare the nation for all hazards and effectively manage federal response and recovery efforts following any national incident. Emergency/disaster management is a system composed of many (distributed) ad hoc teams; one of these is Urban Search and Rescue (USAR). The use of robots as shared remote visual presence is presented specifically within the domain of USAR, though the potential applications have far-reaching implications for propagation throughout the emergency management system structure, encompassing all of the federal response and recovery efforts following any national incident. It is believed that using the remote presence provided by the robot as the basis for establishing mutual knowledge among distributed teams can increase communication efficiency in distributed teams by building shared awareness, or common ground. Communication efficiency has been shown to reduce workload and can result in better performance (MacMillan, Entin and Serfaty 2004). In this article we describe the characteristics of distributed teams in general, and of USAR teams specifically. The communication and coordination challenges posed by distributed teams are discussed, along with the additional hardships present in USAR environments. Current research on situation awareness and team process in USAR environments is presented as evidence of the need for shared awareness, or common ground. The use of mobile robots as a shared remote visual presence is posited as a means of addressing the communication and coordination challenges for distributed team members onsite during an incident response, and also for others removed from the incident site. Existing and potential applications in emergency management and response situations are discussed.

Distributed Teams

Distributed or virtual teams are those whose members are mediated by time, distance or technology (Driskell, Radtke and Salas 2003). Distributed teams are usually project or task-focused groups. The team membership may be stable (e.g., an established sales team) or change on a regular basis (e.g., in project teams). Members may come from the same organization, or from many different organizations. They can be co-located and work in the same physical space, but usually are thought of as working interdependently in remote, geographically separated workspaces. Moreover, they may work at different times, i.e. asynchronous work-cycles. Other factors can influence team processes in distributed teams, such as whether the teams are assembled for a single, time-limited project or on a long term basis, whether team members know each other and have worked with each other before, and whether they expect to have any interaction/shared work in the future. In summary, distributed teams work across temporal, geographical and technological boundaries. All of the characteristics of distributed teams described above are present in the USAR organizational structure, which consists of teams of teams.

Distributed Teams in USAR

Distributed teams in USAR are both project-and task-focused, in that they are created specifically to perform certain tasks in response to disaster incidents, and are mobilized as part of a larger emergency management effort, or project. Responders must go through a rigorous training and certification process to be eligible to serve on a regional or national USAR Task Force, and are often members of local fire rescue departments. Members of the same Task Force may have worked together before; however, in most responses that require activation of USAR functions, teams are drawn from all over the country, so it is very likely that rescue workers will be working alongside others from different teams for the single response incident. Teams work in 12-hour cycles, and though there is some overlap, they must coordinate their efforts with others as they enter or leave the Hot Zone (immediate disaster area). In the Hot Zone, team members operate in deconstructed, unfamiliar environments and rely heavily on radio communication as they work. The physical environment is dangerous and workers are required to wear heavy personal protective equipment, which exacerbates cognitive fatigue by making even the simplest tasks (breathing, walking) effortful. The work itself is highly stressful and time pressured, with serious (life-threatening) consequences for error. The primary tasks of technical search, victim rescue and extraction, medical care and patient transfer require close coordination of efforts with both co-located and remote team members, as well as prompt and accurate information transfer to incident command, local medical authorities, and others involved in the response. Situation awareness and team processes have been identified as important elements needed for effective communication and coordination of activities in robot-assisted USAR operations.

Communication and Coordination Challenges

Communication and coordination of activities pose significant challenges to distributed teams which can affect team performance. Communication in distributed teams can suffer from the loss of information gleaned through "back channels" such as physical gestures, body language, and interaction with artifacts in the environment. AI or computer-mediated technologies that do not support transmission of contextual information are impoverished and provide less visibility and feedback, both of which are needed for establishing and maintaining mutual knowledge, i.e. knowledge that team members share and know they share (Krauss and Fussell 1990). Computer-mediated communication's impact on mutual knowledge is likely to be greater for tasks where individual team members possess a large quantity of unique information, and where contextual information between remote sites differs. This problem is attenuated by high requirements for complexity, workload and interdependence, and can lead to confusion among team members and errors in performance (Cramton 2001).

Coordination of activities, which requires shared awareness, or *common ground*, is difficult when team members are distributed, and often requires more confirmatory communication, since many of the back channel types of awareness mentioned above are unavailable. Successful collaboration among distributed team members requires situation awareness – ongoing awareness of what each person is doing, status of task, and the environment (Endsley 1995) and conversational grounding – working with each other to ensure messages are being understood as intended (Clark and Marshall 1981). Three primary sources for common ground are common group membership (which presupposes a set of common knowledge), linguistic co-presence (hearing the same verbalizations), and physical co-presence (inhabiting the same physical setting). Physical co-presence provides multiple resources for building common ground, most prominently visual co-presence.

Shared Visual Presence as Common Ground

Research investigating the role of visual information in collaborative physical tasks decomposed the visual information available when people share physical co-presence into 4 categories: participants' heads and faces, participants' bodies and actions, task objects, and work environment/context (Kraut, Fussell and Siegel 2003). Each type of visual information offers certain benefits in various subtasks within the collaborative process of maintaining situation awareness and grounding conversation. Video conferencing systems usually focus on the participants' heads and upper bodies, which affords limited benefit in attaining situation awareness and common ground. Research on workspace-oriented video systems that provide input on task objects and work environment/context suggests it is likely to be more useful in supporting SA and conversational grounding (Fussell, Setlock and Kraut 2003; Fussell, Setlock and Parker 2003). In a study examining distributed participants performing a collaborative physical task (Kraut, Fussell and Siegel 2003), the use of head-mounted video did not seem to aid performance in terms of speed or accuracy. It did change the nature of communications between the participants, allowing for use of deictic references to task objects. However, the limitations of the field-of-vision provided by head-mounted video led to more queries designed to establish a shared field of view. They concluded that visual information was used both to maintain task awareness and to improve conversational efficiency and grounding. In a follow-up study comparing the effects of head-mounted video to workspace-oriented video (Fussell, Setlock and Kraut 2003), the scene oriented video was found to be superior in terms of task completion, communication efficiency and user ratings of work quality, suggesting that providing remote helpers with a wide-angle, static view of the workspace was most valuable (Fussell, Setlock and Kraut 2003). The researchers noted the difficulties in gaining the advantages of static cameras in mobile settings such as emergency telemedicine or remote repair. Finally, in a related "gaze" study using eye-tracking technology during a collaborative physical task (Fussell, Setlock and Parker 2003), results indicated that the remote helper's gaze was most directed at task (task objects, pieces/tools, and worker's hands), i.e. targets relevant to gathering information about steps to be completed and task status.

In each of these studies, one of the participants is operating in the task environment and the other is assisting remotely in the process. In robot-assisted search, both the robot operator and the tether manager are removed from the task environment—the robot serves as the remote presence in the environment for both of them. The robot operator teleoperates the robot using the Operator Control Unit (OCU), which provides audio-visual information from the robot's camera as the robot moves through the remote environment. The tether manager can manipulate the robot grossly through manuevering the tether, and can sometimes physically see the robot when it is first inserted into the void, but mostly relies on communication with the operator to participate in the task. Our interest is in how providing both team members with a common view of the remote work space may affect situation awareness and team processes in robot-assisted team tasks.

Figure 1. The Robot Operator teleoperates the robot from a point outside the voidspace using the robot's eye view provided in the Operator Control Unit (OCU).

Figure 2. The Tether Manager feeds the tether as the robot moves through the void space, and sometimes helps it move through debris and rubble by manipulating the tether.

Situation Awareness and Team Processes in Robot-Assisted Team Tasks

What we know about situation awareness (SA) and team processes from past studies is that SA is critical in robot-assisted team tasks, and that team processes, particularly communication between team members, contribute to the development of situation awareness. Results from three relevant studies are summarized below: two are field studies that were conducted in disaster response training exercises, and the third is a pilot study conducted at the Center for Robot-Assisted Search and Rescue.

Technical Search Field Studies. In two field studies (Burke and Murphy 2004a; Burke et al. 2004) conducted with 33 teams (robot operator-tether manager), communication analyses revealed that 50 – 60 % of operator communication during a technical search task was related to building and maintaining situation awareness. One of the challenges presented was the fact that the robot operator was cognitively overloaded; he couldn't drive and look at same time. Because the tether manager did not share the same viewpoint, the operator alone had to interpret the robot's eye view, and used talking with the tether manager (who might sometimes have an external view of the robot) to build common ground so that the tether manager could assist in the search process. Operators who reported to team members about the environment being searched by the robot and search strategy were rated as having better situation awareness (Burke and Murphy 2004b). In Burke and Murphy 2004a, team members created shared mental models (mutual knowledge) of the search space through talking about the environment, the robot's situatedness in that environment, and search strategy. If the tether manager or another distributed team member had access to the same robot's eye view, the effort required to establish mutual knowledge, or common ground, would be far less. This is important because analyses comparing the performance of operators rated as having good or poor situation awareness in a victim search scenario revealed that those with high SA were 9 times more likely to locate the victim.

Pilot Study on Medical Reachback. In a pilot study exploring the use of robots in remote victim assessment (medical reachback), a robot operator and medical provider (a physician or emergency medical technician) worked as a distributed team to assess a victim in a remote location (Riddle, Murphy and Burke 2004). During victim assessment, 52% of operator and provider image-related communications used the shared visual image to convey team member mental models or understanding of the situation. This reliance on the shared visual image to understand each other's perspective is critical for effective team coordination surrounding navigation and for efficient team communication. We examined the use of targeted and non-targeted communication to convey navigational expectations. Targeted communication references a concrete object in the image, providing the operator a discrete location to navigate toward (e.g., "I want to get a closer look at that object next to the victim's head"). Non-targeted communication provides general navigational directions, but does not identify specific objects in the image, (e.g., "go ahead and get in there"). During the orientation phase, the frequency with which providers used targeted and non-targeted directions was nearly equal (see Table 1). This may be misleading, however, because the use of targeted communication increases communication efficiency thereby reducing the need for frequent instructions. For example, using non-targeted communication, "turn the camera up … up…down ….down…," one provider needed multiple instructions to convey expectations regarding the desired image. Upon obtaining the desired image, the provider remarked, "yeah, that's what I want to look at, the bottom of the table." Following this reference to a specific object in the image, the operator scanned the bottom of the table without further direction from the provider. Upon switching to targeted communication, not only were expectations communicated more efficiently, but this example illustrated that provider-operator coordination was enhanced as well.

Table 1. Percentage of targeted and non-targeted statements made by medical providers.

	Targeted	Non-Targeted
Orientation	53%	47%
Victim Assessment	66%	33%

During victim assessment, providers demonstrated a two to one tendency to use targeted versus non-targeted navigational requests. Operators synchronized navigation in response to these statements. For example, in response to the medical provider's request to view the victim's head and neck, the operator moved the robot from the victim's feet toward the head. Understanding how teams use shared visual information to build common mental models and to coordinate activities is critical because the image is a fundamental component of robot-assisted tasks.

The results from the field studies and pilot study above suggest that using the robot's eye view as a shared visual presence can facilitate communication and coordination between team members in robot-assisted tasks.

Mobile Robots as Shared Visual Presence

We hypothesize that the shared visual presence provided by the robot's eye view can serve as common ground for the distributed team onsite, *and* for others removed from the site. Robot-assisted technical search presently requires a 2:1 human-to-robot ratio (Burke and Murphy 2004b). The robot operator bears the brunt of the cognitive load in teleoperating the robot and searching the remote environment; the tether manager can provide some physical assistance through manuevering the tether, but mostly relies on communication with the operator to participate in the cognitive aspects of the task. The tether manager can share the cognitive load by assisting with the search, but lacks the same point-of-view as the operator, since she is typically several meters away and cannot observe the visual image provided by the robot. The robot's eye view offers a medium for building a shared mental model of the remote search space, allowing for feedthrough of awareness information by positions, orientation and movement of both the robot and other artifacts in the visual environment (Gutwin and Greenberg 2004).

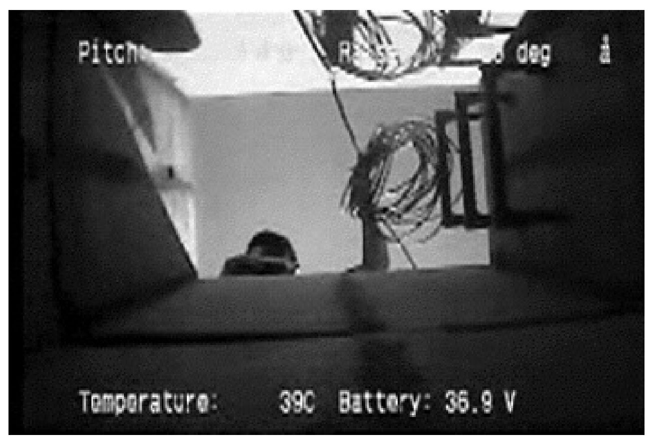

Figure 3. View from the robot's camera as the Tether Manager performs a vertical drop into a confined space void.

Shared visual presence in the remote environment can enhance team communication and coordination, serving as a source for conversational grounding (common ground), and facilitating the use of gaze awareness, deictic references and targeted communication, as well as providing a feedback source (visual evidence of understanding). Operators and tether managers currently utilize verbal communication to create team mental models of the search environment, and to support mutual knowledge of both the task and their respective roles and actions in performing the task. By providing the tether manager with the same remote visual presence experienced by the robot operator via an auxiliary monitor, more contextual information can be conveyed using targeted communication and deictic references toward artifacts in the environment. The robot operator can convey gaze awareness by camera manipulation or changes in the robot's configuration. Feedback between the two team members may be enriched by providing the visual channel as a conduit for confirmatory communication on an implicit level.

Figure 4. The Tether Manager uses an auxiliary video monitor linked to the Robot Operator's OCU, allowing both team members to observe the robot's eye view simultaneously as the robot moves through the void space.

Figure 5. Robot's eye view of the remote confine space void can be seen by both the Robot Operator and the Tether Manager. (This view shows the leg of a victim mannequin placed for a search task scenario.)

For example, the tether manager may suggest that the robot operator take a closer look at a particular artifact in the remote environment. When the robot operator focuses on the intended object, the tether manager has visual confirmation of the operator's understanding. In addition, using the visual image provided by the robot to build mutual knowledge may allow team members to anticipate each other's informational needs, and provide needed information without being asked. This simple switch from explicit to implicit coordination in teams can increase communication efficiency, and has been linked with effective team performance in high stress situations (Entin and Serfaty 1999). Therefore we expect the use of mobile robots as a shared visual presence in remote environments to lead to more effective team performance in robot-assisted technical search tasks in terms of task completion time, search accuracy, and coverage. We further posit that using the robot as a shared visual presence in remote environments can contribute to more effective team performance by providing increased visibility through multiple views or different sensor-mediated views (e.g., infrared), and by process feedthrough – sharing information about robot's actions (e.g., pose indicator, directional indicator), particularly as the robot's level of autonomy increases. Moreover, as wireless communication technology improves, this shared visual presence does not have to be limited to the distributed team onsite. A team member "looking over the shoulder" of the robot operator from a site well-removed from the Hot Zone can assist in the search task, offering a fresh pair of eyes that are not subject to the physical and cognitive stressors present onsite.

Shared Visual Presence Across USAR Operations. The use of mobile robots as a shared visual presence in USAR distributed teams allows for coordination of actions across operations - technical search and structural evaluation, rescue and victim extrication, medical reachback and victim management, safety monitoring, logistics and resource management. Many of these operations could be expanded to include offsite personnel, as tested in the pilot medical reachback study described earlier (Figure 6).

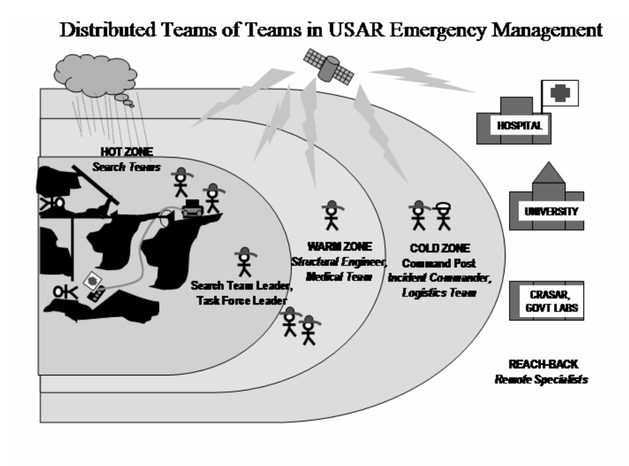

Figure 6. Distributed teams of teams in USAR operations.

Once a victim has been located, the rescue and extrication process can take from 4-10 hours. During the extrication process, a robot providing shared visual presence can be used as a communication channel not only for medical personnel, but also for a counselor or family member at a remote location to provide comfort/reassurance/encouragement to the victim during the prolonged extrication period. Safety monitoring is another potential domain application. USAR operations require the presence of a safety officer onsite during rescue operations. If a robot goes into a remote work area (deep into a void or confined space) with a rescue team, it can provide the rescue squad leader outside the void space with a visual image of the team during work process and the ongoing condition of the void, allowing an objective viewpoint (that is, not *in* the void) from which to monitor the work process and look for signs of fatigue, physical danger, or unnoticed errors. This simultaneously opens new opportunities for logistics and resource management during an emergency response. Having the robot with a rescue team in a remote, confined work space provides the rescue squad leader or incident commander with a more efficient communication channel than radio, as the robot's eye view can provide common ground for more implicit team coordination. For example, the leader may conduct an onsite assessment of the team's progress, estimated completion time of the task, and the team's ongoing logistical needs by observing the activities via the shared visual presence of the robot. In summary, mobile robots as a shared remote visual presence in USAR environments can serve as a conduit for the transfer of information horizontally (to other team members involved in common tasks), vertically to higher/lower levels (squad leaders, incident command, victims) and through diffusion to specialists (structural engineers, medical personnel) and others (family members, task force liaisons).

Current and Future Research Agenda

The Center for Robot-Assisted Search and Rescue is currently conducting research exploring the utility of robots as a shared visual presence in USAR operations in both remote and collocated teams. Approximately forty technical search teams are participating in a large scale, repeated measures field study. Each team will participate in two search task scenarios, one remote and one collocated, alternating between using the robot as a shared visual presence or not. Communication analysis using the RASAR-CS (Burke et al. 2004) and other measures of situation awareness, team process and task performance will be analyzed to determine the effects of mobile robots as a shared visual presence in robot-assisted tasks on team process and team performance. Future research should examine the extension of AI technology in mobile robots to help mitigate the enormous communication and coordination challenges presented by the occurrence of a large scale disaster.

References

MacMillan, J., Entin, E.E., and Serfaty, D. 2004. Communication Overhead: The Hidden Cost of Team Cognition. In E. Salas and S.M. Fiore, eds., *Team Cognition: Understanding the Factors That Drive Process and Performance.* Washington, D.C.: American Psychological Association.

Driskell, J. E., Radtke, P. H., and Salas, E. 2003. Virtual Teams: Effects of Technological Mediation on Team Performance. *Group Dynamics-Theory Research and Practice* 7:297-323.

Krauss, R. M. and Fussell, S. R. 1990. Mutual Knowledge and Communicative Effectiveness. In *Intellectual Teamwork: Social and Technical Bases of Collaborative Work*, J. Galegher, R. E. Kraut, and C. Egido, Eds. Hillsdale, NJ: Erlbaum.

Cramton, C. D. 2001. The Mutual Knowledge Problem and Its Consequences for Dispersed Collaboration. *Organization Science* 12: 346-371.

Endsley, M. R. 1995. Toward a Theory of Situation Awareness in Dynamic Systems. *Human Factors* 37: 32-64.

Clark, H. H. and Marshall, C. E. 1981. Definite Reference and Mutual Knowledge. In *Elements of Discourse Understanding*, A. K. Joshi, B. L. Webber, and I. A. Sag, Eds. 10-63. Cambridge: Cambridge University Press.

Kraut, R.E., Fussell, S.R., and Siegel, J. 2003. Visual Information as a Conversational Resource in Collaborative Physical Tasks. *Human-Computer Interaction* 18:13-49.

Fussell, S.R., Setlock, L.D., and Kraut, R.E. 2003. Effects of Head-Mounted and Scene-Oriented Video Systems on Remote Collaboration on Physical Tasks. In *Proceedings of the CHI 2003 Conference on Human Factors in Computing Systems*. New York: ACM.

Fussell, S.R., Setlock, L.D., and Parker, E.M. 2003. Where Do Helpers Look? Gaze Targets During Collaborative Physical Tasks. In *Proceedings of the CHI 2003 Conference on Human Factors in Computing Systems*. New York: ACM.

Burke, J. L. and Murphy, R. R. 2004a. *Situation Awareness and Task Performance in Robot-Assisted Technical Search: Bujold Goes to Bridgeport.* Forthcoming.

Burke, J. L. Murphy, R. R. Coovert, M. D. and Riddle, D. R. 2004. Moonlight in Miami: A Field Study of Human-Robot Interaction in the Context of an Urban Search and Rescue Disaster Response Training Exercise. *Human-Computer Interaction* 19, 85-116.

Burke, J. L. and Murphy, R. R. 2004b. Human-Robot Interaction in USAR Technical Search: Two Heads are Better Than One. In *Proceedings of the IEEE RO-MAN 13th International Workshop on Robot and Human Interactive Communication,* Kurashiki, Okayama, Japan.: IEEE.

Riddle, D.R., Murphy, R.R. and Burke, J.L. 2004. Medical Reachback: A New Kind of Technological Mediation. Technical Report, TR2004-24, Dept. of Computer Science and Engineering, University of South Florida.

Gutwin, C. and Greenberg, S. 2004. The Importance of Awareness for Team Cognition in Distributed Collaboration. In *Team Cognition: Understanding the Factors That Drive Process and Performance*, E. Salas and S. M. Fiore, Eds., 177-202. Washington, D.C.: American Psychological Association.

Entin, E.E. and Serfaty, D. 1999. Adaptive Team Coordination. *Human Factors* 41: 312-325.