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Robot-Assisted Medical Reachback: A Survey of How Medical Personnel Expect to Interact with Rescue Robots

Robin R. Murphy Dawn Riddle† Eric Rasmussen, MD, FACP‡
Center for Robot-Assisted Search and Rescue
University of South Florida, Tampa FL 33620, USA
†CHI Systems Orlando, FL
‡Naval Medical Center, San Diego, CA

***Abstract*— This paper introduces robot-assisted medical reachback, where a robot acts as a surrogate for medical personnel in situations such as urban search and rescue where a medical specialist cannot directly interact with a trapped victim. It presents findings of a survey of 28 medical specialists obtained after they operated rescue robots at Trauma Day 2003. The survey focused on how they would like to interact with a robot for critical care. The majority wanted to control the robot themselves over the internet, but also have the robot operator remain available for support. The responders wanted the robot operator to have medical training and be able to carry out some of the initial data collection procedures, as well as provide psychological comfort to the victim, during periods when the medical specialist was not available.**

I. INTRODUCTION

An important function of urban search and rescue (USAR) is to care for victims once they are found. The medical mission consists of three steps: finding the victim (victim localization), assessing whether the victim is dead or alive and general condition (life algorithms), and maintaining their life until they are extricated (victim management). Three factors make the USAR medical mission especially difficult. First, it takes place in *area denial* conditions, that is, in situations where the medical personnel are denied physical assess to the victim. In area denial conditions the point-of-care is not the same as the point-of-injury. Second, it is a critical care situation, where victims are in immediate danger. Third, doctors or medical specialists usually have no direct physical contact with the victim until about 20 minutes prior to final extrication, because the void space is too small and unsafe to permit the physical entry and interaction. Given the 10-18 hours to find a victim, and 4-10 hours for extrication [1], this means the victim has been without medical assistance for over 24 hours.

Rescue robots are one way to permit medical personnel access to the victim during the 4-10 hours of extrication. Man-packable robots have already been used in a real disaster, the World Trade Center [2] to locate victims, under the direction of the Center for Robot-Assisted Search and Rescue (CRASAR). CRASAR robots can carry out all the functions already being performed by medical personnel during area-denial scenarios but at deeper depths of 10 to 30 meters in the rubble. In addition, the robots may be able to move around in the rubble to provide additional viewpoints of the victim, and can be linked via the internet to medical experts, counselors, and even the victim's family. We dub the use of the rescue robot as a surrogate for the medical specialists as *robot-assisted medical reachback (RAMR)*.

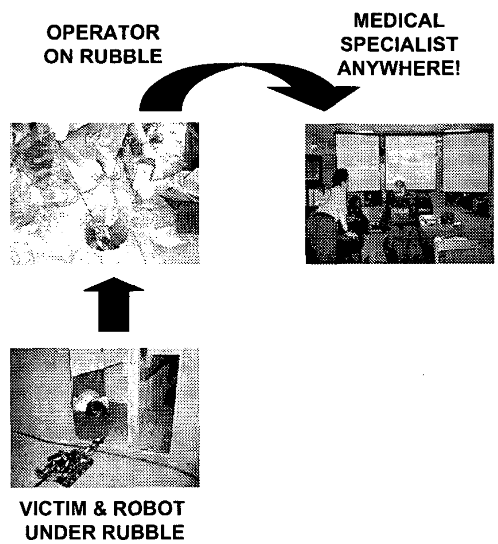

Fig. 1. Overview of human-robot interaction in robot-assisted medical reachback.

Because RAMR is a mechanism for moving the point-of-care to the point-of-injury via a robot, it is a particularly relevant venue for studying human-robot interaction. As shown in Fig. 1, it involves a wide spectrum of humans in different roles. The robot will interact with the victim and robot operators, while the operators and medical specialists will interact with the victim through robot mediation.

This paper defines what medical personnel expect in an interaction with a victim mediated by a robot. The paper identifies uses of robots for victim care, the level of control the medical personnel expect to have over the robot, their perceived role of the operator, and requisite modifications to the existing robots. The paper concludes with a list of five fundamental research issues in HRI for RAMR. The findings presented in this paper are not limited to USAR. USAR is similar to any medical operation under area denial. One example is battlefield medicine, where a medical specialist may be unable to go to a wounded soldier due to sniper fire. A robot can be used instead, but has limited mobility imposed by staying out of the sniper's line of fire.

II. Related and Previous Work

In terms of medical responses, RAMR functions are most closely associated with confined-space critical care activities. In these activities, the medical specialists have limited space to work in and limited options for moving or examining the victim. Also, the victim may be unfavorably presented for assessment or intervention. For example, the head and neck are good areas for collecting vital signs and providing medication, but there is no guarantee that those body regions would be reachable by the medical specialist. RAMR is more challenging than typical confined-space critical care scenarios described in [3] because the space is so confined that a human cannot enter it. This mandates the use of robots.

RAMR is related to, but quite different from, medical robot applications such as remote telesurgery, rehabilitation robotics, and nurse or therapy robots. Like remote telesurgery, the medical specialist may be hundreds or thousands of miles away and dependendent on communications. Unlike remote telesurgery, the point-of-care is not engineered to support medical activities. The void space is deconstructed and disordered, with major navigational obstacles for the robot leading to restricted viewpoints. Like rehabilitation and nurse or therapy robots, RAMR requires a robot to interact in close physical proximity to the victim. However, RAMR has a higher degree of urgency and may require a totally different set of interfaces and human-robot interaction.

The possibility of using mobile robots for medical assistance in area denial has been discussed for at least a decade. CRASAR has been working in the area of medical robotics for sub-human confined space critical care since 2001. A study was conducted with Florida Task Force 3 in July 2001 where search and rescue robots were used to evaluate the condition of a victim.[4] The robot did not have a specialized medical sensor payload. Instead, the rescuers used only the general purpose vision and FLIR sensors to determine the condition of a person acting as a victim. The rescuers also used the robot to make a physical challenge(nudging the victim to see if there is a response).

CRASAR coordinated the first known use of rescue robots, which was at the World Trade Center disaster. The robots were used to look for survivors, detect hazardous materials, and assess structural conditions. However, since no survivors were detected, the robots were not used for medical purposes.

Fig. 2. Standard rescue robot outfitted with a triage sensor co-developed by CRASAR and Radiance Technologies.

In August, 2002, CRASAR evaluated a set of experimental triage sensors and the fluid delivery system in the field at the USMC Chemical Biological Incident Response Force's Stump Neck facility in Indian Head, Maryland. A new sensor design emerged which is being commercialized by Radiance Technologies (see Fig. 2). In the interim, the prototype is now deployable and was evaluated in May, 2004, at the NASA Ames Disaster Assistance Response Team facilty, and training procedures are being developed.

In January, 2003, CRASAR also participated in Shadow-Bowl 2003, a simulated mass casualty exercise held in conjunction with the 2003 Super Bowl. CRASAR pre-deployed a robot team to San Diego for reachback to medical specialists in Tampa, over 4,000 km away. One of the biggest human-robot interaction problems that occurred was the lack of situation awareness. While the Tampa team had complete video and audio feeds from the robot and GPS location, they had no contextual or situational information. Often the Tampa team was unsure of what the robot was looking at.

The most similar work to RAMR has been the iRobot Bloodhound project which is geared for battlefield medicine.[5] The project uses a bigger robot, aproximately twice the length and width of robots used for search and rescue, and focuses on using a manipulator to interact with the victim. CRASAR efforts concentrate on sub-human confined space where robot access is highly limited and the size of the robot prohibits the attachment of a manipulator. It does not appear that the Bloodhound project has produced a system that has been put in use.

III. State of the Practice

In order to understand where robots fit into emergency medicine for area denial scenarios, it is helpful to review the standard operating procedures for basic life support for victims of a car accident, or other typical scenario, that can be done now by medical specialists without robots, and what rescue robots are currently capable of. While actual procedures depend on the context, victim interaction begins with the medical personnel attempting to assess the victim, then the generation and execution of a treatment plan (which may not be possible or severely limited for trapped victims), and psychological and mental reassurance of the victim during the extrication process.

A. Current Practice

When a victim is discovered, the first effort is an *audio challenge*, literally trying to talk to the victim to determine pain, level of consciousness, alertness, and generally try to communicate with victim to determin pain and then medical history, needs, and any other important information, especially a history of diabetes, asthma, or coronary artery disease. If the victim is unresponsive, a *physical challenge* (e.g., bumping the victim to provoke an involutary response) is then conducted. If the physical challenge is inconclusive and the specialist cannot determine if the victim is dead or alive, a *search for cardiopulmonary activity* (e.g., pulse, air movement) is conducted. If the victim is alive, the specialist would *take the vitals*: pulse, body temperature, respiration rate, assess airway-breathing-circulation state, and oxygen in the blood. If there is no evidence for life, either *aggressive resuscitation* would be initiated or in more limited or hurried mass casualty responses, the body would be tagged and the evaluation moves to the next victim.

In an area denial situation, triage of the victim relies typically on vision, video or thermal. The video imagery is provided by a camera on wand or boroscope which is usually limited in movement to seeing the same plane of presentation (e.g., straight ahead but never significantly to the side or behind the current view). Thermal imaging can be helpful to determine shallow breathing; if the nose is visible, the rhythmic cooling of the skin around the nose as the victim breathes out is apparent. Thermal imaging has also been proposed for locating wounds and general assessment of blood flow to the extremeties, etc.[6]

Victim management in area denial situations is limited. During the earthquake response in the 1999 Ismet, Turkey, earthquake, radios and small plastic IV tubes were inserted into the rubble pile to trapped victims. The tubes were hooked up to low velocity pumps, allowing water and fluids to be delivered to a conscious and cooperative victim. The victim and medical personnel communicated by radio and the victim was able to pinch the tube to control flow. Tubes can also be used to bring oxygen to victims, alleviating the inhalation distress.

B. Rescue Robot Abilities

CRASAR has inserted the first known medical payload for a search and rescue robot into an actual response team. (As of this time, no use of a medical payload for an actual robot-assisted rescue has been reported.) The payload consists of a fluid delivery mechanism and a triage sensor. Rescue robots can conduct an audio and physical challenge, carry sensors to attempt to triage unconscious victims, and carry tubes for fluids and oxygen.

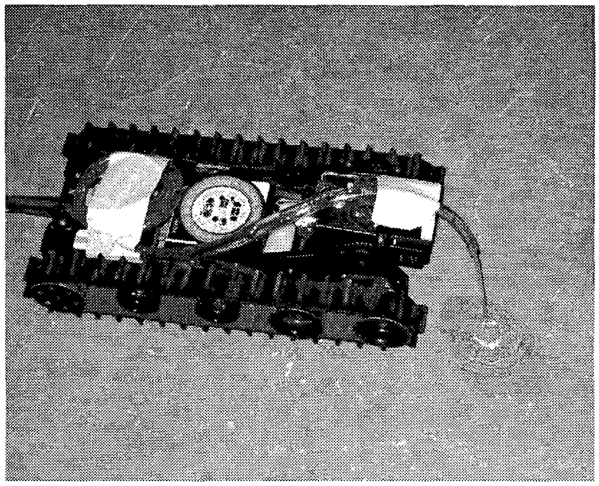

Fig. 3. Rescue robot with IV medical tubing delivering water.

All CRASAR fieldable robots are equipped with two-way audio. The robots, since they are situated with the victim, can perform a physical challenge. A new triage sensor being co-developed by CRASAR and Radiance Technologies can detect if a victim is breathing by analyzing the variances in the CO2 content in the air surrounding the victims, and can apply a pulse/blood oxygen meter to a victim if they are well presented. CDR Rasmussen's equipment for fluid and oxygen delivery has been adapted for use with the rescue robots (See Fig. 3). The equipment was available at the WTC, however, there were no survivors of the WTC disaster and the equipment was never used.

The mimimum system consists of a victim, robot, robot operator, and emergency medical professional. The robot is inserted into the denied area and directly controlled by a trained robot operator. The robot operator can be up to 300 feet away from the trapped victim. As of this time, limitations in establishing high-bandwidth communications requires the emergency medical professional to be physically co-located with robot operator so that they can both see the output of the sensors and to facilitate control. However, based on CRASAR's participation in the ShadowBowl exercise [7], communications at an incident may be sufficient to permit the medical professional to be located anywhere in the world.

IV. Survey of Emergency Medical Personnel

The primary source of information for this paper is a study of 28 medical personnel obtained following a robot-assisted search and rescue demonstration during Trauma Day 2003, an emergency medical specialist conference. The medical personnel did not have urban search and rescue experience, but represent the people who the robotics team would interface with. The study is also supplemented by the authors' personal

1) In what way could you use the robots to help you assess a victim?
2) Would you want to control the robot yourself? If you had to use the robots to diagnose a victim, what changes to the robots and interface would you like to see?
3) How would you see the robot helping you perform aspects of your job such as: Treatment prior to extrication? Planning / preparing appropriate care once extricated? Evaluating rescue activity impact on victim?
4) You are in the field during an emergency. A victim is located by the robot team. Your only contact with the victim is through the robot (with medical sensors) and the robot operator, please describe what you would ask the operator to do?
5) What specific knowledge or experience would be critical for the robot operator to have to facilitate effective victim care?
6) In emergency situations, what information do you need to most effectively assess victim status (for example, heart rate, and respiration)?
7) Currently how do you carry out this assessment (what questions do you ask? What procedures do you follow)?

Fig. 4. Questionnaire used for Trauma Day 2003 survey.

observations from working with emergency medical responders in field situations, both actual disasters and simulations such as the ShadowBowl 2003 medical reachback exercise [7].

Trauma Day 2003, held at the Caruth Health Education Center of the St. Petersburg College, St. Petersburg, Florida, provided an opportunity for local area healthcare providers to attend workshops and field demonstrations involving up-to-date emergency medical services. The Center for Robot-Assisted Search and Rescue (CRASAR) was invited to demonstrate the use of robots for Urban Search and Rescue (USAR).

Demonstrations consisted of four 20-30 minute presentations to small groups (7 to 10 healthcare providers per group) describing the use of robots at the World Trade Center disaster and providing hands-on demonstration of the robots.The respondents operated the robot and interacted with volunteer victims. Following the demonstration, participants were asked to complete a questionnaire (see Fig. 4) designed to obtain a medical personnel perspective on various issues related to the use of robots in urban search and rescue. Twenty-eight participants completed the questionnaire after viewing the demonstration. Although participants did not have USAR experience, they represented the local medical capabilities that would normally be tasked to handle a mass casualty incident. 16 were nurses (emergency room and other), 4 were EMT/paramedics, 5 were "other" (medical assistant, student, respiratory therapist, instructor, product manager), and 3 did not provide an occupation. Survey responses were reviewed and common themes were identified for each question.

The survey and discussions with medical specialists were intended to elicit responses to four questions. First, it is critical to get the medical profession's "desirements" on *what are the uses of robots for medical reachback?* in order to create realistic requirements specifications. It is impossible to design adequate human-robot scheme without understanding the application. *Who controls the robot, the medical specialist or the robot operator?* is a fundamental question in designing a successful human-robot interaction scheme. This has ramifications for the identification and prioritization of the design of distributed artificial intelligence components (is cognitive augmentation more important than robot autonomy?), adaptive interfaces (are different displays needed for each type of user?), and on training (how proficient do medical specialists have to be with robots and roboticists with emergency medicine in order to create an effective team?). Regardless of who is the primary controller of the robot, a field robot will require a robot operator that can initially place the robot in the restricted area and who can diagnose and repair problems. Given that such a person is available, an important question is *what is the role of the robot operator?* While this article focuses on the artificial intelligence needs for robot-assisted medical activities, a secondary issue is *what modifications to rescue robots to are necessary to tailor them for medical applications?* Understanding and cataloging the physical differences between "regular" rescue robots and medical rescue robots is necessary, not only to build usable platforms but to define the capabilities of a key team member.

A. *Uses of Robots for Medical Reachback*

The uses of robots for medical reachback was touched upon in Questions 1, 3, and 4. In order of importance, the uses of robots for medical reachback proposed by medical specialists were for: triage, remote deployment of sensors, establishment of communication, delivery of fluids and medicine, and treatment. This subsection serves as a *de facto* development scheme.

The first and second priority for RAMR is the use of robots for victim assessment, begining with simple triage (is the victim dead, unconscious, or viable?) and moving to more advanced information gathering from specialized sensors and the establishment of communication. Victim assessment is needed to determine whether an extrication should proceed (in practice, the extrication of dead bodies is deferred until there are no remaining trapped survivors), how urgent the extrication is (can this person wait while resources are devoted to extricating or caring for someone else?), and what is a treatment plan both for while the victim is trapped and immediately upon extrication.

The third priority cited was the use of robots for delivery of fluids and medication. If the patient is responsive, the robot can deliver a tube for drinking or oxygen, or ferry small packages to supplement care, such as dropping off a chemical light, a blanket, and a filter mask for reducing dust inhalation.

The fourth priority was treatment, where the robot must directly intervene. The two most commonly cited interventions were the *application of pressue to control bleeding* and to *stablize broken bones*. However, the ranking of these interventions may reflect the respondents experience and training for more traditional "hands-on" emergency medicine, and so should be taken with a grain of salt. Given the 10-18 hours for victim location, robots are unlikely to reach victims who are in danger of bleeding to death. Airway and breathing support, circulatory support, and pain control are the most commonly cited treatments for trapped victims. Stablization of broken bones becomes critical only as the extrication reaches the victim, although a crushed victim typically has poor tolerance of movement of the rubble in contact with him.

B. Who Controls the Robot?

Questions 2 and 7 touched on who should control the robot. A majority (60% of the survey respondents) indicated that they wanted to control the robot themselves, though no specific reasons were noted. This desire may be a reflection of lack of trust of the robot or automation in general, or even the uncertainties of working with an unknown operator, and merits further exploration. Medical specialists who work in distributed point-of-care systems (emergency medical technicians or paramedics communicating with emergency room physicians) note that they work best in teams where they know each each other, for example, a paramedic in the field communicating with a doctor back in the point of care facility. Of the 40% responding "no," reasons offered were: no relevant experience, my job is rescue and treatment; would prefer someone with more medical experience (than the respondent) to control the robot.

The positive responses seemed to be motivated in part by an assumption that changes to the interface and robot itself needed to make it easier to use without significant training would be easy to make. Most respondents commented unfavorably on the current interface. Specific suggestions were to provide "markers on sensor to help you visualize" similar to lines or grids often used in bomb-squad robot displays, and to display "the light and signal" separately.

C. Role of the Robot Operator

Questions 4, 5, 6, and 7 dealt with the expected role of the robot operator. While medical personnel appear to prefer being able to directly control the robot, none of the personnel respondents to the survey or participating in discussions want to eliminate the robot operator. It appears that they want the operator to remain both as a safety net to mitigate unanticipated problems with robot operation and to be their eyes and ears on the scene.

The respondents want the robot operator to do five major activities. One is to conduct the initial assessment of victim by collecting vitals data, assessing the cognitive state, and performing the audio and physical challenges. They also expected the operator to establish communication with the victim in order to provide reassurance, and to obtain information from victim as to their assessment of their self and their environment. The operator should also convey their own observations, especially as to the victim's location and environment. After the basic information had been extracted, it would be useful for the operator to determine the needs of the victim. In keeping with the operator's unique view of the interior of the rubble and also being situated in the overall response activity, the respondents expected the operator to provide recommendations as to what medical interventions would be possible, when and with what equipment.

The respondents expect the robot operator to be compentent in medical response, psychological support, and robotics. In terms of medical support, they want the robot operator to be have formal medical training in order to understand the basic procedures used in EMS, first aid, and paramedicine, understand medical terminology including basic anatomy and physiology, and have the ability to collect patient vitals data. They saw the operator as needing to act independently if communications were lost and also by being medically trained, the operator could streamline the initial briefing. The respondents thought the robot operators would be the major person talking with the victims, and thus needed training on how to provide psychological support via therapeutic communication with the victim They saw the robot operator's compentence in terms of the robot as providing technical proficiency, especially when something was working well, and to help interpret sensors.

More importantly from a human-robot interaction perspective, the respondents would like the operator to provide a general situation awareness of the rescue incident- something which the robot operator may not have but a software agent might. In particular, survey respondents indicated that the robot operator should provide recommendations on what medical equipment is needed, what supplies and hospital transportation options are available (or likely to become available), and the state of the extrication process (when direct access to the patient is likely to be available so that treatment can begin). The robot operator is unlikely to have access to logistics and planning information and is likely to be overwhelmed with the task of operating the robot, as noted studies before [4] and at the World Trade Center [2]. This type of mission-level information appears to be something that could be better delegated to a software agent (or human facilitator for the short term).

D. Modifications to Rescue Robots

The responders made several suggestions as to the robot themselves through their answers to Questions 3 and 6. They wanted the robots to be the current size (0.17 x 0.32 x 0.06 meters) or smaller, modified for closer inspection via extendable probes, be easily decontaminated since they will be most likely covered with bodily fluids, contain a delivery mechanism, and be durable and easily transported.

In keeping with their priorities, the respondents wished to see increased sensor capabilities, particularly heart beat measurements, rhythm interpretations, and chemical analysis of bodily fluids. Each of these sensing capabilities is difficult to perform in confined spaces without access to exposed clean skin in appropriate regions of the body. Victims trapped in rubble are not guaranteed to be favorably presented for such measurements. Furthermore, a rescue robot can only carry a light weight payload the size of a softball.

Regardless of the treatment goals, treatment, as well as assessment, may require radically different robot platforms. Up until this point, robots have been considered for non-invasive activities. More aggressive treatment schemes are invasive, ranging from shooting a dart or bone injection gun at a victim to a) collect and transmit biometric data to inserting and/or b) deliver medication.

V. Summary and Conclusions

Robots fielded by the Center for Robot-Assisted Search can duplicate what medical personnel currently can do in area-denial situations, but at greater depths in the rubble pile. Rescue robots will soon exceed traditional confined-space critical care capabilities by providing triage and additional victim managment sensing. However, the sucess of these robots will depend on human-robot interaction.

In order to begin to understand the HRI involved in RAMR, a suvery of 28 medical providers was conducted. The medical providers represented the type of person that would be locally available at a disaster, e.g., manning the ambulances and emergency rooms. A survey of 28 medical specialists after operating the rescue robots gives an indication of what will be expected. The medical specialists expect to use the robot for triage, remote deployment of sensors, establishment of communication for psychological comfort to the victim, delivery of fluids and medicine, and actual treatment. The specialists also expect to control the robot themselves, though with greatly improved interfaces. The role of the robot operator is to conduct some data collection procedures prior to the involvement of the medical specialist, comfort the victim, provide any additional information or observations that might not be obvious to the rescuers, and support the robot. Most importantly, the medical specialists expect the robot operator to be competent in medical response.

Based on our experiences, we believe there are at least four major issues in human-robot interaction for RAMR:

- How to divide responsibility between the human and robot team members? The analysis of operator performance at the World Trade Center response strongly indicated that the operators were overloaded; it is doubtful that they can handle an additional burden of the medical mission. Cognitive augmentation or expanding the team to include others, such as psychological counselors to work with the victim, is another possibility that should be explored.
- How can physically distributed teams work efficiently together? RAMR presents one of the most challenging scenarios for teamwork. Specialists who have never worked together and who are physically separated must cooperate during a highly stressful disaster. Communication may not be perfect or always at the desired bandwidth, and specialists involved may have conflicting goals. For example the medical specialist might want to robot to move to location X while the structural specialist might need to observe the void stability from location L. The robot operator is unlikely to be able to prioritize or facilitate negotiations.
- Will specialists trust the robot and the data coming from it? Will remote medical specialists trust their ability to control the robot over the internet? This raises the issue of whether RAMR should be engineered for RAMR specialists or for the general medical provider population.
- How should the robot interact with the victim? What motions, poses, behaviors should the robot show in order to be comforting and reassuring to the victim? Will these behaviors change when the operator or medical specialist changes? Some respondents strongly raised the need for the robot to be comforting to the victim and remarked on the overall "creepiness" of the platform.

Acknowledgments

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