Interacting with Trapped Victims Using Robots

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***Abstract*—The paper reports on a discovery field exercise used to examine how disaster responders can use an audio and video equipped robot to interact with a trapped victim. In the exercise, a small robot with two-way video and audio communication was inserted into a physically simulated building collapse next to a trapped victim, and was provided to a team of trained responders as a means for performing remote triage and victim monitoring. The interaction between the responders and the victim was examined, with emphasis on how the responders adapted to different video and audio capabilities, and how they might have responded to different populations and injuries that may limit communication. The ad hoc interaction protocols used by the responders were observed in the field exercise, and four interaction schemes were identified: *Two-way Video with Two-way Audio*, *One-way Video (from Robot to Responders) with Two-way Audio*, *Two-way Video with no Audio*, and *One-way Video (from Robot to Responders) with no audio*. The interaction schemes are defined according to the minimum capabilities of the robot and victim, the requirements of the responders, and preliminary protocols required for each interaction scheme. From observations made about the exercise, the paper identifies *minimalistic interfaces* and *transparency of robot state* as key areas for improving a robot-mediated interaction between responders and victims.**

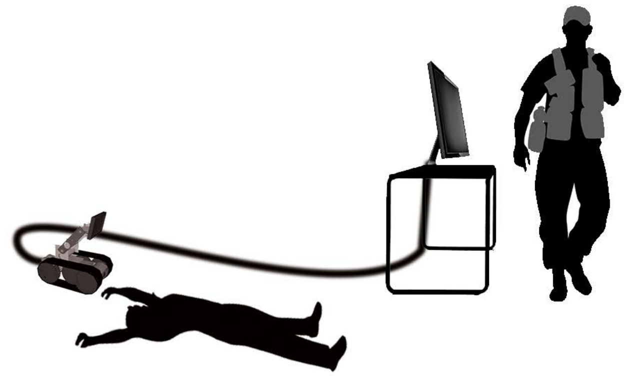

Fig. 1. A diagram of the interaction between a trapped victim and a responder using a robot, showing their relative positions. The responder works a computer console connected via tether to the robot, which is located in front of the victim.

I. Introduction

At a disaster such as a building collapse, it can take responders four to ten hours to safely extricate a trapped victim from the time they are discovered. In order to improve survivability, it is valuable to responders and medical personnel to be able to monitor the victim's condition during this time, as well as comfort the victim and keep them calm. Remote monitoring and communication with the victim requires an interaction means, preferably including two-way audio and video.

A small robot able to enter the void in which the victim is located and equipped with two-way audio and video can act as the means for such an interaction (see Figure 1), and if viable, could revolutionize medical care for trapped victims. The concept is that medical specialists could use the robot for the initial phase of assessment and stabilization of the victim after the victim was found, then other responders would step in to provide emotional support and health monitoring during the maintenance phase - that is, the waiting period until the extrication can be completed. The robot could assist medical specialists in assessing a victim's condition and provide hope and comfort to the victim during the time before extrication.

This paper reports on a discovery field experiment that examined how robots can be used by responders to interact with trapped victims during a building collapse, using four interaction schemes. The exercise used the Survivor Buddy robot - a multi-media monitor motorized with four degrees of freedom mimicking human head movements - mounted on a iRobot SUGV base to add two-way audio and video capabilities to a search robot. Four medical specialists from Texas Task Force 1 and two volunteer victims participated in the discovery experiment on February 16, 2013, in a rubble pile at TEEX Disaster City®.

The discovery experiment was conducted to determine if and how medical responders would use robots for victim triage and management, and to uncover systems-level issues and help formulate future formal hypothesis testing. The experiment identified four victim-robot communication schemes for interaction with responders through the robot. The ideal interaction scheme is two-way audio and video, in which responders and victims can see and hear each other. In two-way audio with one-way video from the robot, the robot is essentially a two-way radio with a camera. Two-way video without audio is an option when responders and victims can see each other but victim may be deaf, temporarily deaf from a blast, or speaks a different language. Finally, one-way video with no audio is a fallback default for a search robot (all of which have video as standard) with no added audio capabilities.

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From observations made in this exercise, design recommendations are made in two areas: the medical responders' interface, and the victim's interface. Pending these recommendations, the exercise strongly suggests that telemedicine and victim support through a search and rescue robot will be beneficial, and that operational protocols should be developed immediately.

II. Related Work

The role of robots in interacting with trapped victims has been explored from four perspectives: the robot, medical specialist, victim, and system. This paper extends the understanding of the medical specialist and victim perspectives, leading to better protocols and recommendations for improving the system. The majority of the literature on the use of robots for the management of trapped victims has been from the robot's perspective, concentrating on mechanisms for the physical interaction between the robot and the victim: such as detecting a victim [1], [2], removing a victim [3]–[5] protecting from crush syndrome [6], attaching robotic sensors to a victim [7], and expressing engagement with the victim [8]. Research from the medical specialist perspective has concentrated on what triage and reachback procedures would be used if a robot found a victim [9], [10] and possibly what mobile apps might be helpful [11]. More recent research has considered the victim's perspective of how a robot's behavior influences the victim's affective state [12]. The systems viewpoint of how the medical specialist, robot, and victim interact is captured in [13], [14], and [15] and describes how emergency management can be reorganized to support tactical emergency medical services, such as those offered by a robot.

III. Exercise

Fig. 2. The simulated disaster site used for the exercise.

The purpose of this exercise was to examine the use of different interaction schemes by responders in a disaster response scenario. The different interaction schemes were highlighted by medical responders' use of a rescue robot in a simulated disaster setting. This section describes the scenario for the exercise and the details of the robotic platform and participants.

A team of four medical specialists, shown in Figure 3, communicated through a rescue robot with two volunteer participants, who took turns being placed in a rubble pile, normally used for training canine search teams. Each participant was given a different "backstory" as to what disaster had just occurred and what injuries they had. The participant entered the rubble and waited until the robot located them. The participant, shown in Figure 4 was then able to interact with the responders through the robot.

Fig. 3. The medical specialists interacting remotely with the victim.

Fig. 4. A "Trapped victim" interacting with the medical specialists via the Survivor Buddy robot.

An iRobot SUGV robot coupled with a Survivor Buddy [8] affective head robot, were used in the simulated response. Survivor Buddy is an affective head attachment which has four degrees of freedom, a compact footprint of 14cm X 9.5cm, and a weight of 1.72 kg. It is easily attachable to other robot bases. Survivor Buddy's "head" is a small, 7-inch MIMO 740 touchscreen monitor, which also contains a webcam and microphone. A speaker system is mounted in Survivor Buddy's neck. The platform, shown in Figure 5, was capable of locomotion via the iRobot SUGV base and communication using two-way audio and two-way video via the Survivor Buddy head. This enabled four unique communication schemes: two-way video with two-way audio, two-way audio with one-way video, two-way video alone, and one-way video alone. A typical rescue robot would have a camera and a microphone, and would be limited to two schemes of interaction, one-way video from the robot with two-way audio, and one-way video from the robot. The iRobot SUGV robot and Survivor Buddy were controlled by the responders. In addition to video and audio, the robot

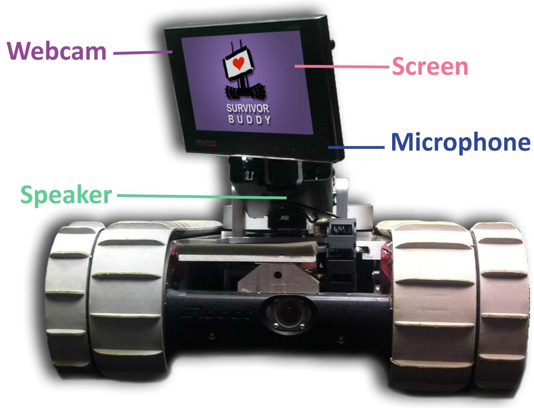

Fig. 5. The robotic platform used by the medical responders to interact with participants.

	Interaction Scheme	Situation
1	Two-way Video, Two-way Audio	Ideally suited for all search and rescue scenarios.
2	One-way Video (from Robot), Two-way Audio	1) Robot does not have the capability for two-way video. 2) Failure in the communication equipment.
3	Two-way Video, No Audio	1) The victim is unresponsive, deaf, temporarily deaf from a blast, speaks a different language. 2) Failure in the communication equipment.
4	One-way Video (from Robot)	Robot does not have the capability for two-way video.

Fig. 6. The situations in which each interaction scheme can be used.

was also capable of generating synthetic speech.

The responders attempted to assess the participant's condition using only the robot's capabilities. The robot had intermittent audio and video communications failures, leading the responders to explore protocols with limited audio and video capabilities, as might be seen in other robots, and with different populations or types of injuries which might prohibit certain forms of communication.

All responders and participants involved in the exercise were healthy adult males above the age of 18. This population was selected because a) the medical specialists had extensive experience with triage and interacting with dependent trapped victims as a part of their duties with Texas Task Force 1, and b) the volunteers who played the role of a trapped "victim" had prior experience with confinement for long periods of time in a physically simulated disaster scenario. Two exercises occurred, each with a different participant, but the same medical response team. Prior to the exercise, participants were provided simple background information about their condition. Participant 1 was informed that he was trapped in a building collapse as a result of a earthquake and had limited lower body movement due to injuries to the leg. Participant 1 encountered the two-way video but no audio interaction scheme. Participant 2 was told that the he was trapped in a building collapse as a result of a terrorist event and had limited lower and upper body movement as a result of extensive injuries to the leg, torso, and hands. The responders interacted with Participant 2 using one-way video from the robot.

IV. Interaction Schemes

The discovery exercise identified four victim-robot interaction schemes for interaction through the robot: two-way video with two-way audio, two-way video but no audio, one-way video from the robot to the responders with two-way audio, and one-way video from the robot to the responders. The situations in which each of the interaction schemes are applicable are summarized in Figure 6. The following subsections detail the robot's required capabilities, the victim's required abilities, resources the responder needs, communication steps, and advantages and disadvantages of each interaction scheme.

A. Two-way Video with Two-way Audio

The two-way video with two-way audio is an interaction scheme, in which responders and victims can see and hear each other.

The robot's minimum needed capability for two-way video with two-way audio interaction is a screen, microphone, speakers, and a webcam. The screen must be located in at a point that it is visible to the victim, while the speakers and microphone must be powerful enough to facilitate auditory communication. Since disaster environments can be harsh and irregular, additional lighting may also be required to allow the webcam to capture the victim.

The victim needs to be cognitively responsive, should have functional hearing, speak a language that is understood by the responders, and have a cultural understanding of remote presence devices. Responders may contribute to the victim's abilities by explaining and framing the situation through the robot.

Responders in this interaction scheme should be sensitive to the nuances of telepresence communication. The responder should use both visual and auditory cues when possible, making gestures slowly and clearly pronouncing words. The responder should be prepared to repeat statements and should obtain confirmation on all information provided by the victim. This is necessary as fluctuations in connectivity can cause segments of audio or video to be lost or distorted. In general, this interaction scheme allows the most natural and flexible communication of all the schemes. The recommended steps for this type of interaction scheme are:

1) Display video feed on robot's screen, use two-way audio to initiate contact.
2) Confirm that the victim can see and hear responders.
3) If the victim is unable to see or unable to hear, switch to a more appropriate protocol.
4) Use the audio and video feeds to conduct triage, collect information about the victim, and provide assistance.

Two-way Video and Audio is ideal for search and rescue, as it allows the first responders to immediately assess the situation using both the auditory and visual channels. Responders can call out to victims "If anyone can hear my voice, come here", visually identify hidden and unresponsive victims, and ask

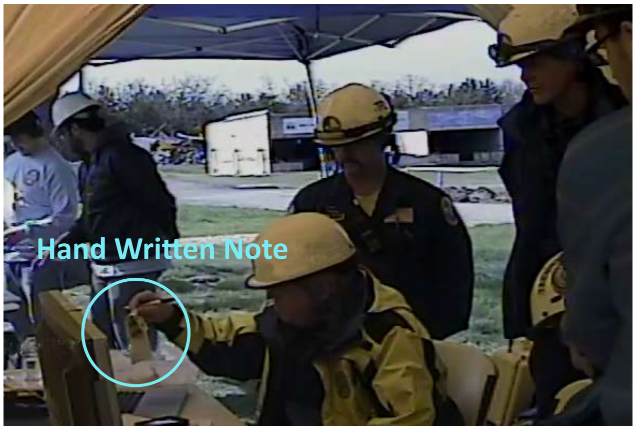

Fig. 7. Medical specialist using Post it notes to communicate with the victim.

any victims who do respond for more information about the situation or others who may be trapped. It also enables medical specialists to quickly conduct triage and help prioritize the rescue effort by attending to the victims who are most critical first. The event can be documented more effectively as the rescuers can record video and voice, as well as take still photos of the search. However, there are both technical and social disadvantages to this interaction scheme. First, video and audio use a significant amount of bandwidth, which may be limited depending on the platform used. Second, the initial use of video and audio followed by the failure of either system may leave the victim frustrated or may cause further anxiety. Finally, in situations where extrication is not possible for many hours, the responder will need to exhibit confidence and inspire hope for many hours.

B. One-way Video (from Robot to Responders) with Two-way Audio

One-way Video (from Robot to Responders) with Two-way Audio is an interaction scheme in which victims and responders can communicate using speech, and responders can see the victim using the robot's camera.

The robot's minimum needed capability for a one-way video with two-way audio interaction is a microphone, speakers, and a webcam. The robot may optionally have some illumination device to indicate its location to the victim and to provide lighting for the webcam to capture images of the victim and transmit them back to responders. The nature of disaster environments encourages the use of directional microphones and speakers, as well as webcams with night vision capabilities.

The victim needs to be cognitively responsive, have functional hearing, functional speech abilities, and speak a language that is understood by the responders. Responders can contribute to the victim's understanding of the situation by using the robot to explain the interaction scheme.

Responders in this interaction scheme should exert effort to explain the robot's actions before triggering them. Since the robot possess a camera to view the victim, responders will likely need to manipulate its vantage point, resulting in

	List of Questions
1	Do you speak english? Nod Yes or No.
2	Are you hurt? Touch the area where you are hurt.
3	How bad is your hip on a scale of 1-10? 10 is bad. Use fingers, we can't hear.
4	Are you alone? We are trying to get to you.
5	Are you bleeding? Do you have trouble breathing?
6	Any other problems?
7	Are you trapped?
8	Legs?
9	Both?
10	Are you allergic to any meds?
11	Is your area safe?
12	Do you feel any movement around you?
13	Do you hear any scary noise?
14	We are sending a team in to help you.

Fig. 8. List of questions used by a medical responder.

movements of the robot. The recommended steps for this type of interaction scheme are:

1) Use the audio feed to confirm that the victim can hear responders.
2) Inform the victim that they can be seen and heard.
3) Use the video and audio feed to conduct triage, collect information about the victim, and provide assistance.

The major advantage of this interaction scheme is that it is possible on the majority of rescue robot platforms. These robot's typically are equipped with a camera for navigation purposes and a two-way audio link for communications. This approach also requires less bandwidth than transmitting both audio and video. From a social perspective this scenario allows responders to act more naturally, without the victim constantly looking to them for visual confidence. A major disadvantage of this interaction scheme is that victims cannot see the responders and this limits their feelings of connectedness to the outside world. Additionally, it is not possible for responders to visually convey information to victims who may be deaf at the time of interaction.

C. Two-way Video with No Audio

Two-way video with no audio occurs when responders and victims can see each other, but there is no audio communication channel available.

The robot's minimum needed capability for two-way video with no audio interaction is a screen and a webcam. The screen must be located in at a point that it is visible to the victim, while the speakers and microphone must be powerful enough to facilitate auditory communication. Since disaster environments can be harsh and irregular, additional lighting may also be required to allow the webcam to capture the victim.

The minimum requirement of the victim that is he/she is cognitively responsive and able to see the display of the robot. If the victim is hearing impaired or speaks another language, visual diagrams or gestures can be used to communicate with the victim.

Responders in this interaction scheme must be careful to slowly and purposefully display gestures or text to the victim. Figure 8 lists several questions which were used in the field exercise examined by this paper. These questions were written on paper and placed in front of the responders' webcam. The victim responded by using gestures, such as a yes or no head gesture. Responders using this interaction scheme should have supplies available to write text or symbols. Responders should also be sensitive to the need to give ample time for recognition and responses from victims. The recommended steps for this type of interaction scheme are:

1) Display the video feed on the robot's screen, position the screen so that the victim can view it.
2) Use on-screen typing or a piece of paper with a handwritten note to visually communicate with the victim; use gestures to communicate with victim; if both responder and victim know sign language it may be used. The responder should be slow and deliberate with visual communication.
3) If the victim can hear, and the lack of audio is due to system failures, first inform the victim of this. Request victims to reply with vertical head nod gesture to indicate 'yes' and horizontal head nod gesture to indicate 'no' and frame the triage as short questions.
4) Use the video feed to conduct triage, collect information about the victim, and provide assistance.

The advantage of this type of interaction scheme is that it is applicable to populations that speak a different language or have their hearing impaired. It is also usable in situations where harsh conditions or system failures do not permit the use of two-way audio. The disadvantage is that it the handwritten notes take time to write and do not convey information as quickly as speech. Responders and victims will likely become cognitively tired from a purely visual interaction.

D. One-way Video (from Robot to Responders) with No Audio

One-way Video (from Robot to Responders) with No Audio is a interaction scheme, where the responders can see the video feed from the robot, but victims and responders cannot talk to each other. The robot is essentially a remote camera.

The robot's minimum needed capability for one-way video from robot to responders is a camera and a webcam. The victim can be be unresponsive or responsive. In either situation responders can visually inspect the victim using the remote camera. In some cases the responders may be able to use the robot's actuation to communicate a social presence to the victim. This type of interaction scheme requires little preparation or resources for responders. The recommended steps for this type of interaction scheme are:

1) Use the video feed to conduct triage, collect information about the victim, and provide assistance.

The advantage is that most existing search robots are able to provide video from the robot, and no modifications are required. This type of interaction can occur because of limitations of capability of the the robot or because of failures in the communication system of the robot. This interaction scheme limits the functioning of the medical specialists as it becomes difficult to conduct triage and assess the situation because of a lack of appropriate feedback from the "victim". While the medical specialists can control the movements of the robot head (head nodding) and base (movement of the flippers) to indicate that they are still around, victims may find this frustrating or confusing.

V. Recommendations

This section describes recommendations for the design of the responder's interface, and the design of the victim's interface. Together, these two interfaces shape the overall interaction between responders and victims.

A. Interface Considerations for Responders

It is critically important that control interfaces for the robot are both simplistic and representative of the robot's state and functionality. As responders are typically not trained for the specific system they will be using, it is important that a minimalistic and representative interface is provided.

Interfaces for controlling the robot should only show active controls for subsystems of the robot which are currently installed and functioning. Any feature or function which is unavailable have its controls disabled, and should be displayed as being unavailable. It is important to display unavailable functionality with an indicator, as it prevents newly trained responders from assuming there is system error when expected functionality does not appear. This includes providing responsive messages when boundary conditions are met. For example, if the robot has a pan and tilt head, once the maximum pan or tilt is reached, the button for activating the pan or tilt further should indicate the maximum range has been reached. It is also helpful to provide failover messages to responders if the system they are currently using becomes unavailable. For example, if while using two-way audio and video communications, the video link is lost, a message indicating this should be displayed. The message should also recommend or explain which contingency modality should be used to communicate with the victim.

The interface for controlling the robot should also provide a clear indication of the robot's current state. This is partially accomplished by clearly labeling the status of subsystems, but also requires that simple models of the robot be provided to responders. These simple models should indicate the physical state of the robot, as well as any sensor readings which can be obtained from the robot. Interface designers should restrict the information displayed to that which is helpful at a high level to responders. For example, a laser range finder may provide a large array of distance readings, but this should be distilled into a single distance reading which the responder can understand. If the robot has affective capabilities, like a moving head, a small model of the robot's current position should be provided, so that responders can visualize the appearance of the robot. These models also assist in recognizing the limits of the robot.

B. Interaction Considerations for Victims

Robots must be designed in a way that their state is transparent to the victims interacting with them. This includes both information about the robot's capabilities and predictive indicators of the robot's future actions. The robot should be designed in a way that it can easily indicate the interaction modality it is capable of. This can be accomplished by using simple cues, like LEDs where the robot's ears and eyes would be; or more complex cues like a speaker with a slash over it displayed on the screen to indicate a lack of audio. In addition, more complex robots should provide context information to the victim. For example, a robot with a display screen should indicate who the victim is communicating with. Furthermore, the robot should provide predictive cues when possible to inform the victim of its next actions. For example, the robot could play a beeping noise before it backs up or a small chirping noise as it drives forward. It is best that these types of cues be autonomous in nature, as relying on responders to communicate the robot's future actions can be unreliable and inconsistent.

VI. Summary

The paper reports on a discovery field experiment that examined how robots can be used by responders to interact with trapped victims during a building collapse and identifies four interaction schemes *Two-way Video, Two-way Audio*, *One-way Video (from Robot to Responders), Two-way Audio*, *Two-way Video, No Audio*, and *One-way Video (from Robot to Responders)*. The interaction schemes were operationalized by specifying a) situations during which the interaction scheme would use, b) minimum requirements of the robot and victim required for a interaction scheme, c) identifying tools and aids that would help the responder's to effectively interact with the victim, and d) formalizing protocols and steps for using a particular interaction scheme. The paper also provides recommendation for improving the interface for both the responders and victims based on feedback and experiences from the exercise. *Simplicity* and *functionality* are identified as key areas for interface design for responders, while *transparency of robot state* is seen to be extremely important for victims.

VII. Acknowledgment

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