Mobility and Sensing Demands in USAR

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Abstract

Since 1999, the members of the Perceptual Robotics Laboratory at the University of South Florida have worked with the Hillsborough County Fire Department on identifying opportunities for robotics in urban search and rescue. This paper provides an introduction to the USAR environment and the impact on sensors and platforms. It discusses the possible roles of mobile robots, and the need for adjustable autonomy.

1 Introduction

Urban search and rescue focuses on finding and removing people trapped in man-made structures. This may result from a building collapse, such as from the Oklahoma City bombing in the US or the Kobe earthquake, or more commonly from a cave-in in a trench at a construction site. Mobile robots have many opportunities to contribute to a speedy rescue (finding and extracting survivors) or a methodical recovery (finding and extracting bodies). This paper concentrates on the roles of robots in reconnaissance, victim identification, and victim localization. Reconnaissance, victim identification, and localization are needed to provide the incident commander with information to support rational decision making, allocation of finite resources, and triage. This paper does not consider the use of robots for manipulation and removal of material, which is also a very important potential contribution.

A USAR site in the US is likely to be divided into three zones. The *hot zone* is the rescue site itself. Generally only essential people and equipment actively involved in the rescue operation are permitted in the hot zone. The hot zone may extend well beyond the nominal search area. For example, in a collapsed trench, the hot zone may include a radius of 250 feet surrounding the trench because vibrations or additional weight in that area may trigger a secondary collapse. The *warm zone* is where the operation workers have their command, personal rehabilitation, and equipment staging stations. The family may be collected in an area of the warm zone, out of contact with the press. The *cold zone* is the remaining area, and is open to the public and media.

The hot zone is very rugged and difficult to explore. It is often structurally unsafe, forcing rescuers to operate slowly and carefully and to occasionally have to leave the site. Although there are distinct categories of building collapses, in most cases the hot zone will qualify as a *confined space*. A confined space is an area in which movement is restricted. It implies the risk of entrapment as well as poor ventilation. As such they are inherently unsafe, and rescue workers in the United States must follow safety standards published by the Occupational Safety and Health Administration (OSHA). This often creates a bottleneck in personnel, since regulations may limit entry to those few rescuers who have had specialized training and certification.

As shown in Fig. 1, the entry voids are on the order of 2 feet in diameter or less, presenting physical limitations on robot size. In many cases, the entry to a confined space is from a hole cut in the top of the structure (Fig. 2), making the search more vertical than horizontal. Tethers may or may not be acceptable depending on the type of void and the needed penetration depth. For example, a tethered robot may be desirable for a vertical exploration of a pancaked house since the tether can be used to lower the robot. A tether may present serious tangling difficulties for a winding horizontal descent.

The hot zone is exposed and may be very noisy and wet. Rain, snow, or other weather conditions may impact the search environment. Rescue and recovery efforts will undoubtedly continue for at least four hours for a straightforward trench rescue to 24 hours a day for several days for an earthquake or natural disaster

a.

b.

Figure 1: A pancaked house: a) view showing a significant change in height from the ground to the surface, and b) a view of entrance to underside of pancake with a large pile of rubble blocking part of the entrance.

scenario. The effort is likely to span day and night lighting conditions. The duration of the effort and the almost certain under supply of certified rescuers suggests that personnel operating under high levels of fatigue and stress.

The ambient noise level outside of the structure can be very high due to the presence of power generators, chain saws, people moving about, and even helicopters from news organizations. However, inside the structure the ambient noise level often drops significantly making it possible to hear cries for help. If there is a sign of a survivor, most noise sources can be temporarily shut down to permit the use of sensitive microphones.

The structure itself may be wet. Responders may have had to put out fires, soaking the building. The damage may have ruptured water and sewer lines, leaving significant puddles of standing water long after the utilities have been cut off. Foundation damage may lead to water intrusion, further increasing the risk of a secondary collapse. In some cases, large amounts of body fluids may be present, posing challenges for navigation and health hazards to responders.

Figure 2: A entry cut into the roof.

USAR sites are also characterized by high risk to the rescue workers. In the United States, the workers may be subject to acting in accordance with the Occupational Safety and Health Act. The structure itself may have lost structural integrity and the response team has to constantly monitor for the possibility of a further collapse. Workers must monitor for adequate ventilation of the search area as well as for the presence of hazardous materials and gases. Carbon dioxide, hydrogen sulfide, explosives such as methane, and oxygen content must be routinely screened and monitored before a responder can enter an area.

Most of the challenges appear at first to have mechanical solutions: rugged platforms, watertight seals, etc. However, the USAR environment poses many constraints on computing. Off-board or proxy computing may not be possible since USAR sites are unfavorable for communication. The amount of metal in a collapse of an office building or a situation at a manufacturing facility interferes with communication. Often all available radio channels are consumed by emergency personnel or the media. In the case of a suspected bombing, radio communication may be suspended to prevent accidently triggering a second bomb. This severely limits pure teleoperation.

2 Motivation for Mobile Robots

Mobile robots are well-suited in theory for urban search and rescue. The hot zone is dangerous to responders and rescue dogs. This risk forces the search for victims to proceed slowly. In many cases, the voids are not penetrable by even dogs. Robots are not subject to the safety requirements and can be used in more risky situations, assuming that they are relatively inexpensive and can be destroyed. A partial list of the roles that mobile robots might play is given below.

Reconnaissance. One of the most dangerous phases of a search and rescue is when the incident commander and other relevant personnel reconnoiter the site to determine if it is safe for workers. Because this is the first time near the site, the vibrations of the responder may set off a secondary collapse of the structure. The collapse could trap or injure the commander and structural specialists.

Search. This is the most obvious use of mobile robots: penetration of otherwise inaccessible voids and localization of victims. An important aspect of the search is that once a victim is found, the rescue team needs to establish communication to try to obtain more information on the situation, the location of other possible survivors, and to monitor the survivor's health.

Robots can also work along side of the responders in a variety of assistive roles, such as those listed below.

Minimization of Risk to Rescue Workers. Two important jobs are monitoring for site collapse (e.g., visually confirming that there has been no ground or structure movement as seen in Fig. 3a) and monitoring for responder protection (e.g., air quality metering as shown in Fig. 3b). These jobs are usually done manually at regular intervals. They do not require specialized training, so do not create a manpower bottleneck. However a robot might be able to monitor from hard to reach places as well as continuously and more reliably, especially using unique sensor modalities that are hard for humans to interpret (e.g., thermal and seismic signatures.) Image processing software could possibly significantly improve the early detection and classification rate.

General Assistance Mobile robots may be able to provide a variety of other services, including being adaptive, mobile communication relay stations trying to maintain radio communication with workers and victims inside the structure. Mobile robots might also provide self placing lighting or additional viewpoints for teleoperation. The same mobile robot technology may be extensible to tools, improving the maneuverability of heavy critical equipment (jaws of life) or biomedical sensors in confined spaces.

a.

b.

Figure 3: Minimizing risk to workers: a) periodically manually inspecting a site for signs of ground movement and incipient secondary collapse, and b) initial monitoring for hazardous gases or inadequate oxygen.

Interestingly enough, mobile robots may not be useful for transporting equipment between the warm and hot zones. As noted earlier, the bottleneck in a recovery is trained rescuers. There will often be more people available than can be permitted to participate. These workers can transport materials. The exception may be in extremely fragile situations, where a lightweight robot may be less likely to create vibrations and trigger a structural collapse than humans.

2.1 Requirements for Mobility

The impact of the USAR environment on mobility is significant. Platforms need to be small to fit through voids, yet highly mobile and flexible. The platforms must be stable and self-righting, as well as sealed from the environment (and from cleaning).

A diminutive platform size is perhaps the most important requirement for a vehicle to perform any sort of search. Particularly in the pancake structure, the average amount of headroom appeared to be less than two feet. A small navigational footprint is also important. In these situations, there is no shortage of obstacles to maneuver around. In addition, a technique frequently employed by the rescue workers was to cut holes in the skin of the structure, and investigate from these new entry points. A robot could be used for this task only so long as its size allowed rescue workers to place it through the opening.

USAR robots must be extremely mobile. While physical constraints dictate that the robot be small, it must also be able to overcome obstacles that are in its path. There was no shortage of rubble from loose pebble to cinder blocks that affords no other option but to roll over it. The vehicle must not become high-centered or lose its traction in such circumstances. Another challenge was the alarming frequency of vertical ledges. While it was possible to find segments of the structure with a relative flat surface on which to traverse, these segments were broken up by vertical rises/drops of 1 to 2 feet. If the robot were able to negotiate these types of challenges, it would almost certainly become an invaluable tool.

Platform stability and self-righting capabilities are critical. Given the nature of the terrain, it is no surprise that traditional vehicles would have a difficult time keeping their footing. Rubble could move as the robot traverses it, and it is almost a guarantee that miscalculations will eventually cause the robot to invert itself. When this happens, it should either be able to right itself, or carry on in this stance. It may well be that the correct vehicle for the job has a high degree of symmetry such that no side is "up."

A sealed enclosure is necessary for the robot when dealing with any sort of severe weather (displayed by having to keep the robots in the truck due to lack of weather-proofing) or nuclear, biological, or chemical hazard. Biological hazards are typically present in USAR operations; two obvious examples are sewer line breakage and victims laying in their own bodily fluids that are an immediate corrosion for the robot. While the cleanup may require only soap and water or bleach, the vehicle does need to withstand being hosed down. There are also situations where the robot must be sterile before people can work with it. In many situations, an intrinsically spark suppressant vehicle is needed to avoid disrupting a highly sensitive environment.

3 Requirements for Sensing

Sensors for USAR robots fall into two broad categories: control of the robot and victim identification. Video cameras can be used for both teleoperation and victim identification, since they support human visual perception. However, cameras are not as good for autonomous navigation and are less than ideal for victim identification. Newer technologies such as digital thermal cameras appear to be much better for victim identification but harder for rescuers to interpret. These cannot be used effectively for autonomous navigation.

Video cameras are essential since they permit the workers to navigate and see the site via teleoperation. Robots must carry lighting for the cameras. However, the USAR site may often simple perceptual cues that can be exploited even with the current state of computer vision. In a building collapse, everything ends up being coated with dust. This has the interesting property that everything turns an even gray. With a victim who move s about, this dust is likely to be displaced. Likewise, motion detection is straightforward. Therefore, color video is nearly indispensable. Omni-cams or fish-eye cameras might be used here with a great deal of success. Range cameras would be useful in creating a three dimensional map of the site. Sonars are unlikely to work well due to the high density of sharp edges and inconsistent material properties. Laser range finders may produce better results, but the cost and energy consumption may be prohibitive.

An item on the rescuers wish-list was a microphone and speaker, so that they could talk back with the victim. Not only will the victim know that help is on the way and be able to receive instructions, but he/she might also give information leading to the discovery of more victims. While sound can be a valuable tool, we must be careful not to depend on it too much. Rescue scenes can be very noisy places. Above the roar of generators and chain saws, it is unlikely to detect either the cries of a victim or the reflection of sonar.

Beyond traditional sensors for identifying victims or mapping the site, personal protection sensors would be helpful. Oxygen, hydrogen sulfide, methane, and carbon dioxide sensors may not be extremely beneficial for locating victims, but they can be very beneficial in preventing rescue workers from also becoming victims. If high levels of any of these gases are encountered, rescue workers can take necessary precautions to prevent explosion or asphyxiation. In the staged confined space situation, the robot would have been helpful to reach the victims first, assess the environment, send information back to the rescuers so they would know that a hazardous chemical is involved and could prepare. This would save time as well as lives.

Most other sensors would facilitate the identification of victims. Digital thermal cameras, ground penetrating radar, and microwave radar appear promising, though outside the budget of most fire departments. Another possibility is to use artificial intelligence to exploit inexpensive sensors. For examples, heuristics could be used to interpret carbon dioxide readings as being near a victim. Furthermore, if the victim is suffering from severe hypothermia, or not breathing, it might be better for rescue workers to divert their resources to another victim.

4 Adjustable Autonomy

From a robotics standpoint, the ideal would be an autonomous robot rescue team that would traverse an USAR situation, locate victims, and communicate with the home base. This involves a great deal of software, not to mention intelligence. The software has to be able to execute in real-time on a computationally bound micro-rover since off-board processing may be severely limited due to intermittent or restricted communications. Autonomous path planning algorithms, path following and more methodical algorithms might not be as helpful because of the diversity of the voids. Therefore, from a practical software perspective, autonomy must be adjustable (i.e., the degree of human interaction varies).

Autonomy must also be adjustable because of the nature of USAR. Interaction with an operator is crucial. The rescuers must know what is going on in order to best deploy resources. The robot might be more helpful in some situations to serve as a tool, acting as an extension of the rescuer. An operator could drive it around looking into interesting areas. Software requirements in this case require a good human-computer interface that reduces fatigue and confusion. Also, a teleoperation scheme is needed (which already exists). For a more intelligent robot team, the operator would still be needed to determine an area to go to, and the robot gets there on its own. Teleoperation is needed, but intelligent software for traversal is required. This is more of a cooperation between the operator and robot.

5 Work at USF

Our efforts are focusing on three areas. First, we are interested in teams of cooperative robots. One project is focusing on how robots can cooperatively provide viewpoints useful to a human operator trying to perform precise maneuvering of a robot. Initial studies show that presenting the teleoperator with an external view of a mobile robot in addition to the "through the eyes" view decrease task performance times on the order of 30%. Second, we are interested in polymorphic or shape-shifting robots which can autonomously adapt the best pose for the current situation. The third area of interest is sensor fusion, where the robots may have to use multiple inexpensive (and inaccurate) sensors rather than expensive specialized detectors. This problem of distributed sensor fusion, how data from sensors on multiple robots can be fused, is also of interest.

6 Summary

The impact of the USAR environment on mobility and sensing is significant. Platforms need to be small to fit through voids, yet highly mobile and flexible. The platforms must be stable and self-righting, as well as sealed from the environment (and from cleaning). Sensors must permit control, either teleoperation or autonomous, of the robot through confined, cluttered spaces. The robot must carry victim identification sensors. At the same time, the robot will have physical, computational, power, and communication constraints that make autonomy difficult.

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