Survey on Urban Search and Rescue Robots

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1. Introduction

Earthquake disaster mitigation requires rapid and efficient search and rescue of survivors. Urban Search and Rescue (USAR) workers have 48 hours to find trapped survivors in a collapsed structure, otherwise the likelihood of finding victims alive in nearly zero. As recently seen in Turkey (1999), Taiwan (1999), New York (2001), and Iran (2003) the magnitude of the devastation of urban environments exceeds the available resources needed to rescue victims within the critical first 48 hours. Moreover, the manner in which large structures collapse often prevents heroic rescue workers from searching buildings due to the unacceptable personal risk from further collapse. Finally, collapsed structures create confined spaces which are frequently too small for both people and dogs to enter limiting the search to no more than a few feet from exterior.

Robots on the other hand can bypass the danger and expedite the search for victims immediately after a collapse. This technology can assist rescue workers in four ways: (1) reduce personal risk to workers by entering unstable structures, (2) increase speed of response by accessing ordinarily inaccessible voids, (3) increase efficiency and reliability by methodically searching areas with multiple sensors using algorithms guaranteed to provide a complete search in three dimensions, and (4) extend the reach of USAR specials to go places that were otherwise inaccessible.

For the robots to handle these tasks, appropriate mobile bases need to be developed which can crawl through unstructured terrain, heavy rubble and confined spaces. Some hardware platforms such as small robots, shapeshifting robots, and flexible snake robots already exist, but they have not been specially designed for urban search and rescue. Moreover, and perhaps more importantly, current and future devices will not be usable by USAR personnel unless software is developed to reduce or eliminate the burden of tele-operating them for long periods of time under emotional and physical stress. So, both robot mechanisms and software development are the current focus of development for urban search and rescue robots.

2. How Can Robots Help?

USAR workers typically assume that they have 48 hours to locate and remove survivors. After 48 hours, mortality drastically increases due to exposure, and lack of water, food, and medical treatment. Unfortunately, rescue workers will not have enough assets (personnel, equipment) to rescue all victims; instead the situation requires triage. The first thing rescue workers do is attempt to assess the physical characteristics of the site and determine entry points which might lead to pockets of survivors. As the search progresses, workers constantly attempt to both locate survivors, as well as assess the effort/risk involved in rescue due to the physical characteristics of the structure surrounding the survivors.

The most important information to a rescue worker is the understanding the location of the survivors and the characteristics of the surrounding structure. When rescuers find a survivor, they often try to talk to them to establish what happened and determine if there may be other victims nearby (making that area a higher priority for excavation). Communication is often important to provide some emotional comfort to the victim and to help workers locate rest of the body (“do you feel that?”) during removal.

Despite of the extensive training and broad range of equipment of the Task Forces, they have several limita-
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Fig. 1 Structural collapse (a), iRobot’s Packbot (b) and the fleet of robots (c) that assisted in search at the World Trade Center (WTC) disaster in New York

ations. For example, upon arriving at the disaster site, the rescue workers cannot enter the location until an engineer assesses the physical structure. A major concern is whether the weight and movement of rescue workers will trigger a further collapse as they go into or on the building to manually deploy sensors. This is true for situations like in Taiwan where a 16 story apartment building was intact but tilting. The structure was easy for workers to work in, but there was an unacceptable risk of collapse. Large commercial buildings are even more difficult to work in because of the amount of pancaking; workers can only access these buildings via the roof which limits access to most of the lower levels and presents another danger because parts of the structure may not support the weight of rescue workers. Due to the danger of workers being crushed by structural collapse, the site needs to be shored up and made safe for rescuers to enter [3]. This procedure takes up three to four critical early hours of the disaster which are crucial to finding victims alive [4].

Another limitation of the human rescue workers is their inability to search through confined spaces and unstable structure. This was observed at the Humberto Vidal multistory building collapse in San Juan, Puerto Rico in 1996. The building was deemed too unstable to perform recovery operations and the rescue workers were unable to recover a trapped victim whose location was identified by search dogs. The victim was unable to be rescued until the building was razed by implosion [2]. There is also a significant health risk to the rescue workers. Not only can they get cuts, scrapes, burns and broken bones, but also suffer respiratory injuries due to hazardous materials, fumes, dust and carbon monoxide. They are also susceptible to diseases such as diphtheria, tetanus and pneumonia. As observed from the rescue efforts at the Oklahoma City Bombing event in 1995, the rescue workers are also affected with, psychological and emotional trauma caused by the gruesome scenes they encounter [3].

Robots are very well suited to address the limitations of the current USAR approach. Their ability to navigate through tightly confined spaces which people or dogs cannot access makes them extremely useful for quickly getting to a location within the disaster site [5]. Dispensable robots can be risked in searching for survivors in unstable structures and confined spaces. During the search they can deposit radio transmitters to be able to communicate with victims, use small probes to check victim’s heart rate and body temperature and supply heat source and small amounts of food and medication to sustain the surviving ones.

Robots can assess structural damage in remote locations where engineers cannot see. They can also carry temperature, carbon monoxide, LEL (explosive limit), oxygen, pH level, radiation and weapons of mass destruction sensors on board in order to conduct atmospheric reading and hazardous materials detection and analysis to warn the rescue personnel.

Several robots can be deployed at once in response to a large disaster to search multiple locations simultaneously to expedite the search process. They can map the area and identify the location of victims to direct the rescue workers. They can also guide the insertion of jaws-of-life tools to aid extrication and shoring, and identify the location of limbs to prevent workers from damaging a victim’s arm or leg with rescue equipment. With their potential ability, the robot can serve as a resource to the rescue workers and keep them out of harms way.

3. Robots at The World Trade Center in New York City

One of the first uses of robots in search and rescue operation was during the World Trade Center disaster
in New York. On Sept 11, 2001, the Center of Robot-Assisted Search and Rescue (CRASAR) responded with several robots within six hours of the disaster. Under the direction of LTC John Blitch, a team consisting of robots from Foster-Miller led by Arnis Mangolds, iRobot led by Tom Frost, SPAWAR (Space and Naval Warfare Systems) led by Bart Everett and University of South Florida (USF) led by Professor Robin Murphy. The robots assisted the Fire Department of New York (FDNY) and Federal Emergency Management Agency (FEMA) teams in finding the bodies of at least five victims in the first ten days [6]. These victims were found from places where dogs or humans could not physically or safely enter. This section describes the robots used at the Twin Tower site.

Foster-Miller had two robots, Talon and Solem. Talon is an all-terrain, all-weather platform with day/night capability. It is controlled through a two-way RF or fiber optic link from an attaché-sized Operator Control Unit (OCU). The OCU displays video from up to seven cameras with audio and data feedback for precise vehicle positioning and control at distances out to 1 mile (1.6 [km]). Vehicle speed is 4 mph (6.6 [km/h]). TALON can carry more than 200 pounds (≈90 [kg]). It uses a two-stage arm that can reach a maximum length of 64 inches (1.6 [m]) and a gripper attachment to manipulate hazardous materials or ordnance. Other attachments deploy special sensors such as FLIR, night vision, microphones and zoom cameras [7].

Solem vehicles carry color cameras and do reconnaissance in the field. The suitcase-portable, 15 [kg] robot is controlled through a two-way RF link from the OCU that provides video and data feedback for precise vehicle positioning at distances out to 1 mile (1.6 [km]). It is equipped with drive wheel encoders, a three-axis compass and an arm potentiometer so the operator knows the vehicle’s distance, heading and arm angle respectively. A wearable OCU is available and features virtual reality goggles, a handheld control unit, and vest-mounted electronics. In the standard configuration, Solem’s color camera can be elevated to 15 inches (38 [cm]) above the vehicle to see above brush and obstacles. With a resolution of 400 TV lines, 1.0-lux illumination and auto shutter, the camera has the clarity for most missions. Camera output can be seen on the OCU monitor or with VR goggles for a higher resolution picture [8].

The Packbot is a wireless, suitcase-sized, tracked vehicle. Communication is wireless. The sensor suite consists of an 84-degree field of view low light camera, 118-degree field of view color CCD camera, and an optional Indigo Alpha FLIR. The Packbot is waterproof up to 3 [m] depth and is self-rightable with fippers. The fippers also provide the ability to increase the height of the camera on top of the robot and give it some mobility advantage.

The SPAWAR Urbot is a wireless, large suitcase-sized, 33in. long tracked vehicle. The sensor suite consists of a Sony EVI-330/T camera system with 12x mechanical zoom, 24x digital zoom, auto-iris, and auto focus. Two low-silhouette drive cameras on the top and bottom cover panels provide views in either robot con-
figuration: right side up or up side down. Attitude sensor detects inversion and is used to determine what cameras to view. Video overlay displays menus, vehicle status, video output, mode, heading, pitch, roll and speed. The pushbutton array control unit is used for control. The Urbot is fully invertible. On board software inverts video and steer/drive commands.

The robots brought by Inuktun were MicroVGTV and MicroTracs. Micro VGTV, or Variable Geometry Tracked Vehicle, is a unique system because the vehicle's shape can be altered during operation. The tracks, in their lowered configuration, take the shape of conventional crawler tracks. When the geometry is varied to the point where the vehicle is in its raised configuration, the tracks take the shape of a triangle. The MicroVGTV remains fully operational throughout these shape alterations and as a result, can continue to travel and maneuver while its configuration is being changed. This unique feature allows the vehicle to negotiate obstacles and operate in confined spaces and over rough terrain. The Micro VGTV is a compact, remotely powered and controlled inspection system [9].

Choosing among available technology can be difficult. Some researchers are already developing metrics which compare robots and assist future rescue workers in deciding which robot is best for a particular task. The following chart gives a side-by-side comparison of the existing robots described in this section.

![Fig. 5 SPAWAR Urbot. Courtesy of Space and Naval Warfare Systems Center](image1)

![Fig. 6 The Micro VGTV System (top) and MicroTracs (bottom) by Inuktun with its control unit. Courtesy of Inuktun Services Ltd](image2)

<table>
<thead>
<tr>
<th>Properties</th>
<th>Solem and Talon - Foster Miller Robots</th>
<th>VGT and MicroTracs - Inuktun</th>
<th>Urbot - SPAWAR</th>
<th>Packbot - iRobot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>Suitcase sized, 20&quot; long, 14.72&quot; wide, 8&quot; high</td>
<td>Shoe box sized</td>
<td>Large Suitcase, 33&quot; long</td>
<td>Suitcase size, 27-34&quot; long, 6&quot; wide, 7.14&quot; high</td>
</tr>
<tr>
<td>Weight</td>
<td>33 lbs</td>
<td></td>
<td>60 lbs</td>
<td>40 lbs</td>
</tr>
<tr>
<td>Mobility</td>
<td>Tracked</td>
<td>Multi-tracked</td>
<td>Tracked</td>
<td>tracked</td>
</tr>
<tr>
<td>Tether</td>
<td>No tether, Wireless</td>
<td>YES. Tether used for power, video and communication</td>
<td>Wireless</td>
<td>Wireless</td>
</tr>
<tr>
<td>Vision</td>
<td>1/3&quot; color CCD camera, 70 deg FOV</td>
<td>Color CCD camera, 53 deg FOV</td>
<td>Sony EVI-330T camera. Cameras on top and bottom to provide view when robot is inverted</td>
<td>Low light camera with 84 deg FOV Color CCD camera with 118 deg FOV</td>
</tr>
<tr>
<td>Illumination</td>
<td>Two halogen headlights</td>
<td></td>
<td>Two halogen headlights</td>
<td></td>
</tr>
<tr>
<td>Camera and light mount</td>
<td>10&quot; long arm</td>
<td>Tilt unit</td>
<td>Attached to the invertible body</td>
<td>2.4 GHz 802.11</td>
</tr>
<tr>
<td>Communication</td>
<td>1 Watt RF for max 1 mile line of sight</td>
<td>Through tether</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed</td>
<td>1.5 ft/s max speed</td>
<td>0.15 m/s max speed</td>
<td>2.5 ft/s</td>
<td>2.2 – 3.7 m/s</td>
</tr>
<tr>
<td>Power supply</td>
<td>Four NiMH batteries (1-4 hrs duration)</td>
<td>Three 12 V batteries connected in series</td>
<td>Two on board battery power packs</td>
<td></td>
</tr>
<tr>
<td>Other Sensors</td>
<td>Encoder feedback, 3-axis compass, arm position feedback</td>
<td>Encoders</td>
<td>Attitude sensor detects inversion. Electric compass and sensors for heading, pitch, roll and ambient temp. info.</td>
<td></td>
</tr>
</tbody>
</table>
The robots at the world trade center were limited in their mobility. Extreme heat sources deep within the pile caused softening of robot tracks leading to immobilization [10]. The software on some robots would not accept new sensors and the poor user-interface design made the robots hard to control.

The teams also had a difficult time communicating with robot since at WTC, 25% of communication between wireless robot and control unit was extremely noisy and therefore useless. Bandwidth problems, loss of communication and on board embedded processing caused loss of one robot [6].

4. Conclusion

The task of search and rescue is very demanding emotionally and physically. Rescue workers have to work rapidly to be able to save any victims. But the workers are often limited by insufficient man-power, their inability to reach confined spaces and the lack of information about the location and condition of victims. The threat of secondary collapse of an unstable structure also makes the rescue task extremely dangerous. Robots can be a valuable asset to the search and rescue teams. They can navigate rough terrain, access confines spaces, withstand chemical, biological and physical hazards and carry gas and chemical sensors. The tragic disasters in Turkey, Taiwan, New York, and Iran serve as a reminder of the magnitude of devastations and have provided researchers and the government with greater motivation and urgency for developing robotic aids. Researchers are working on developing versatile mobile bases such as snake robots and shape shifters as well as intelligent software for sensor fusion and multi-robot coordination for use in USAR scenario. But research in urban search and rescue robotics is still emerging and a lot more work needs to be done. The next generation of researchers needs to be educated and inspired to take part in this field. By promoting national and international competitions in USAR as well as developing more classroom activities, students and the community can be made aware of the importance and challenges of this humanitarian application of robotics.

References


Binoy Shah

Binoy Shah was born in India in 1981. He received his bachelors from Carnegie Mellon University in 2004 where he studied Mechanical Engineering and Robotics. As a teaching assistant he has helped design and administer the Urban Search and Rescue competition for an undergraduate robotics class and as a research assistant he has interviewed members of the Pittsburgh Fire Department and Pittsburgh Strike Force to determine their USAR needs. He plans to pursue his graduate degree at Northwestern University starting September 2004.

Howie Choset

Howie Choset is an Associate Professor of Mechanical Engineering and Robotics at Carnegie Mellon University where he conducts research in motion planning and design of serpentine mechanisms, coverage path planning for de-mining and painting, mobile robot sensor based exploration of unknown spaces, and education with robotics. In 1997, the National Science Foundation awarded Choset its Career Award to develop motion planning strategies for arbitrarily shaped objects. In 1999, the Office of Naval Research started supporting Choset through its Young Investigator Program to develop strategies to search for land and sea mines. Recently, the MIT Technology Review elected Choset as one of its top 100 innovators in the world under 35. Choset directs the Undergraduate Robotics Minor at Carnegie Mellon and teaches an overview course on Robotics which uses series of custom developed Lego Labs to complement the course work. Professor Choset’s students have won best paper awards at the RIA in 1999 and ICRA in 2003. Finally, Choset is a member of an urban search and rescue response team using robots with the Center for Robot Assisted Search and Rescue.