By Robin R. Murphy

Rescue Robotics for H

Applying hard-earned lessons to improve human-robot interaction and information gathering.

One aspect of homeland security is response: what to do when disaster occurs? Rescue robotics is gaining increasing attention as the first new advance in emergency response since the advent of boroscopes and cameras on poles 15 years ago. The attention is due in part to the use of rescue robots at the site of the collapse of the World Trade Center towers in New York. The WTC response was an example of an urban search and rescue (USAR) mission. USAR deals with man-made structures, has a different emphasis than traditional wilderness rescue or underwater recovery efforts, and can be even more demanding on robot hardware and software design than military applications.

Robots were used from Sept. 11–Oct. 2, 2001 to search for victims and help assess the structural integrity of the WTC foundation under the direction of the Center for Robot-Assisted Search and Rescue (CRASAR). Teams from DARPA, Foster-Miller, iRobot, U.S. Navy SPAWAR, the University of South Florida, and Picatinny Arsenal operated small robots, some small enough to fit into backpacks. The robots were used for tasks that rescuers or canines couldn't perform, for example, to either go into spaces that are too small for a human or to pass through an area on fire or without breathable air in an attempt to reach a survivable void. In the two years since the WTC incident, CRASAR has expanded the utility of rescue robots to include victim management (adding two-way audio, sensors for triage, mechanisms for fluid delivery, remote reachback to medical specialists) and is working to use robots for shoring up structures to speed up extrications of survivors.

The roots of the WTC response can be traced back to the Oklahoma City bombing in 1995, which motivated our interest in the domain of rescue robotics for urban search and rescue. In 1996, we established a small cache of rescue robots with funding from the National Science Foundation, and in 1999 we began extensive field studies and technical search specialist training with Florida Task Force 3, a state regional response team. Also in 1999, both the American Association for Artificial Intelligence and the RoboCup Federation started rescue robot competitions to foster

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research in this humanitarian application of mobile robots. But good theory does not necessarily lead to good practice. None of the algorithms demonstrated by CRASAR or other groups at various rescue robot competitions or at related DARPA programs were actually usable on robots that could withstand the rigors of real rubble. As a result, all the robots used at the WTC site had to be teleoperated.

A view of the Inuktun micro-VGTV robot being inserted into a sewer pipe at the World Trade Center site in an attempt to locate an entry to the basement. Note the small size of the robot, the use of a tether as a safety line for the vertical entry, and the use of a camcorder to display the video because of better resolution than the manufacturer's display. This is the only external view of the robots that was allowed to be photographed at the WTC site.

In the aftermath of Sept. 11, CRASAR has taken on the role of midwife to smooth the transition of key research from laboratories all over the world to the hands of responders. We became an independent center at the University of South Florida and created a formal response team with scientists and medical personnel trained for USAR. Recently we were awarded a NSF planning grant with the University of Minnesota for an Industry/University Cooperative Research Center on Safety, Security, and Rescue Robotics to further encourage investment by companies in this critical area.

As a result of our expertise as both researchers and users, we have identified many major research issues. The physical attributes of the robot itself require improvement. Currently, no robots are made specifically for USAR. Mobility experts often make the mistake of developing platforms that can climb over rubble, not crawl vertically into the interior. We find a more significant limitation is the lack of sensors that can be mounted on the robots. Many navigation and mapping algorithms exist that are likely to be useful for USAR but require multiple sensors approximately the size of an average countertop coffee maker. Given the most useful robot size is about the dimensions of a shoebox, these sensors can't be used. The complexity of the environment—highly confined, cluttered—viewed with video and FLIR (forward-looking infrared) cameras mounted only a few inches above the ground present a formidable challenge for autonomous control and especially perception. Indeed, several sets of victims' remains were missed at the WTC due to these issues in perception.

Communications remains a huge issue. Micro-sized robots require a tethered connection back to a power and control source. The tether tangles but also serves as a safety line as the robot descends down into the pile. Wireless robots are larger and more mobile, but still require a safety line and communications is easily lost in the dense rubble. Indeed, the only robot lost in the rubble at the WTC and not recovered was a wireless robot, which lost its control link and did not have any onboard intelligence to attempt to move and reacquire the signal. Trade-offs between tethers and wireless connectivity must be explored. All of these issues will be exacerbated by chemical, biological, or radiological events. Robots will have to be hardened, easy to operate from protective gear, and easy to decontaminate (or be inexpensive enough to be disposed of).

In the rush to contribute their particular areas of expertise, it is easy for researchers to forget that security, especially emergency response, is a human endeavor. Robots and agents will not act alone but rather in concert with a spectrum of trained professionals, cognitively and physically fatigued individuals, motivated volunteers, and frightened victims. One impact of the human side is that rescue workers today refuse to consider fully autonomous systems designed to act as "yes/no there's something down there" search devices. Scenarios where a swarm of hundreds of robot insects are set loose to autonomously search the rubble pile and report to a single operator not only appear impractical for search (and certainly for structural assessment, victim management, and extrication as well), but also ignore the organizational context of USAR, which has a hierarchy of operators who check and verify any findings from dogs, search cameras, or other sources. As a result, we believe good human-robot interaction (HRI) is critical to the acceptance and success of rescue robot systems.

In the USAR domain, the robot exists to provide information to rescue workers as well as interact with the victim. While these groups may not operate the robot, they must interact with it. On the other hand, HRI is not about all the other members of the team, it can also yield insights into traditional robot-operator relationships. We've encountered some surprises as well when we examined the interaction of the robot operator and robot in the field, both from our tapes of the Sept. 11 WTC response and our numerous field studies. Working with cognitive scientists and industrial psychologists, we've discovered strong evidence that it takes two people to operate one robot: one operator focused on the robot (how to navigate through this vertical drop without tangling the safety rope?) and what David Woods and his team at Ohio State refers to as a problem-holder (am I looking at signs of a survivor?).

CRASAR has many publications and reports on rescue robotics, most of which are available on our Web site, www.crasar.org. We also have limited opportunities for researchers to accompany us into the field and collect data with fieldable robots and rescue professionals as part of the NSF-funded R4: Rescue Robots for Research and Response project. C

FURTHER READING

1. Burke, J., Murphy, R.R., Coovert, M., and Riddle, D. Moonlight in Miami: An ethnographic study of human-robot interaction in USAR. *Human-Computer Interaction, special issue on Human-Robot Interaction 19,* 1–2 (2004).
2. Casper, J. and Murphy, R.R. Human-robot interaction during the robot-assisted urban search and rescue response at the World Trade Center. *IEEE Transactions on Systems, Man, and Cybernetics 33*, 3 (June 2003), 367–385.
3. Murphy, R.R. Rescue robots at the World Trade Center from Sept. 11–21, 2001. *IEEE Robotics and Automation Magazine* (June 2004).
4. Murphy, R.R., Blitch, J. and Casper, J. AAAI/RoboCup-2001 urban search and rescue events: Reality and competition. *AI Magazine 23*, 1 (Jan. 2002), 37–42.

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