Evaluation of the Scout Robot for Urban Search and Rescue

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Abstract

A group of miniature mobile robots called Scouts were tested in the Urban Search and Rescue (USAR) course used in the RoboCup Rescue competition at IJCAI 2001. This testing was to evaluate the utility of using small robots with limited mobility and sensing constraints in the unstructured and chaotic environments present in disaster areas where USAR operations are required. The Scouts and their performance in the course are described. Finally, potential areas of future work that were revealed by these tests are discussed.

Introduction

The unstructured environments found in an urban search and rescue (USAR) setting present significant challenges for robotic systems. Collapsed structures, partially blocked passageways and large amounts of debris can make mobility quite challenging. Additionally, if a robot attempts to force its way through a partially blocked structure, the stability of that structure as well as the stability of surrounding structures might be compromised. Any robot traversing this kind of environment must have as minimal an impact as possible on the structures on and around which it is moving. A robot's sensors must be able to operate in environments that are completely dark and/or filled with airborne debris if it is to successfully navigate and search for survivors. Finally, the control system for such a robot should be small, portable and intuitive to operate.

This paper describes the testing of miniature robots called Scouts in a simulated USAR environment set up for the robot contest/exhibition at IJCAI 2001. The purpose of this testing was to evaluate the utility of these robots in such scenarios. Some advantages of using small robots are that they are lightweight, are easily deployable and will have a minimal impact on the structural integrity of the area that they traverse. A major disadvantage of small robots is that they may not be able to navigate over all but the most debris-free passages due to their limited ground clearance. Other disadvantages of their small size include limited space for sensors and computers, as well as reduced battery life.

IJCAI Urban Search and Rescue Contest

An urban search and rescue contest was held as part of the mobile robotics exhibition at IJCAI 2001 in Seattle, Washington. This contest was intended to challenge the research community to push the state-of-the-art in robotic capabilities for USAR scenarios. The course used for this contest (some of which is shown in Figure 1) was designed and built by the National Institute of Standards and Technology (NIST).

Figure 1: Part of the IJCAI Urban Search and Rescue Course. This course was constructed by NIST and was designed to simulate an urban disaster area. Teams earned points for locating and correctly identifying "victims" as well as notifying human operators of the victims' locations.

The course was designed to replicate a collapsed or partially-collapsed urban structure. Placed within the course were a number of simulated "victims" that were constructed out of plastic mannequin parts. The victims were designed so that a robot could tell whether one was "alive" or not by employing various kinds of sensor modalities. "Living" victims could have moving parts, audio playback systems which broadcast a voice crying for help, and/or small heaters to simulate body heat. The robots had to enter the course, locate as many of the living victims as possible, and broadcast the position of each of those living victims back to a console outside the course. Teams were awarded points when their robots reported the location of victims back to a base station. While it was assumed that most of the robotic entries would probably be teleoperated, teams with autonomous robots were eligible for additional bonus points because of the challenging nature of the course.

Related Work

Robots that are required to navigate through USAR environments will need the ability to handle complex terrain and obstacles. Additionally, robots may need to manipulate their environment to remove debris from their path or to open a passage. One solution to these problems is to provide the robot with a set of manipulators, such as arms or legs (Morse *et al.* 1994; Voyles 2000). Another solution is to make the robot extremely modular so that it can change its shape for different locomotion and manipulation requirements (Castaño, Shen, & Will 2000; Yim, Duff, & Roufas 2000).

In addition to sensors that will allow the robot to navigate, robots must be equipped with sensors that can detect victims, such as digital cameras (visible light and thermal) and microphones (Murphy *et al.* 2000). Other kinds of sensors that can be used to analyze the structural integrity of the building are also important as they will help rescue workers determine the safest course of action.

Some USAR applications may require fully teleoperated control of a robot while others may benefit from more autonomous operation. Adjustable autonomy is a useful characteristic for a robotic controller, giving the robot operators more flexibility in deciding how their robot will be used (Kortenkamp & Dorais 2000).

Scout Robots

Scout robots are miniature mobile robots 11 cm long and 4 cm in diameter. They are capable of driving over smooth surfaces with their two differentially-driven wheels and they have the ability to hop over obstacles 20 cm in height using their spring-loaded tails. At 200 g, Scouts are fairly lightweight and groups of them can be carried by rescue workers without difficulty. Scouts are designed to be hand-deployed, thrown, or even launched into the operating area. Figure 2 shows a group of the Scout robots.

Scouts are equipped with analog cameras coupled to video transmitters allowing them to broadcast video data to rescue workers. Commands are transmitted to the robot via a digital RF channel that is independent from the video channel. The Scouts' small size limits the power of their on-board computational resources. For teleoperated control, a Scout's video signal is broadcast to a human operator, who transmits motion commands back to the robot. For autonomous control, this video data can be received and digitized on a workstation for processing. Once the video is processed, a decision process (such as a motion planner) analyzes the data, decides on the correct course of action and transmits the appropriate commands to the Scout.

Figure 2: A collection of the Scout robots, including modified versions which have variable-sized wheels and low-light illumination abilities.

Variable-Sized Wheel Scout

The Variable-Sized Wheel Scout is an augmentation to the original Scout chassis design which allows it to control its ground clearance. The wheels on this Scout use a mechanism similar to an umbrella to expand and collapse. By increasing the diameter of the wheels, shown in the center left of Figure 2, the robot is able to drive over obstacles and holes that might stop or trap a regular Scout. When the wheels are collapsed, the Scout is the same height as a regular Scout and can climb inclined surfaces as shown in Figure 3.

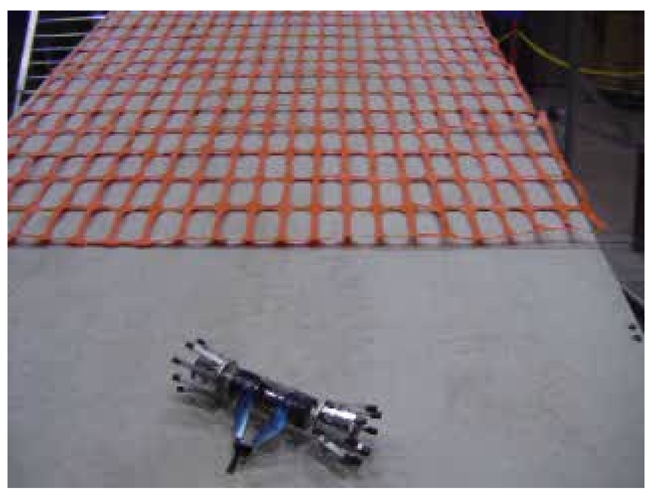

Figure 3: By collapsing the wheels, the Variable-Sized Wheel Scout is able to climb inclined surfaces.

Scout Control

To provide teleoperated control of the Scout robots, a portable controller has been developed. This controller contains a command radio and a video receiver and lets an operator send the Scout actuator commands from a Palm Pilot. The Scout's video data is received by the controller and is displayed to the operator through a head-mounted display. Figure 4 shows an operator controlling the a Scout robot with the controller. The operator does not need to be stationary when using the controller, and its internal batteries allow uninterrupted Scout operation over several hours. Commands can be broadcast to individual scouts by specifying their unique identifiers. This particular wearable interface does not allow the Scouts to function autonomously as there is currently no way to digitize and process the video. Future versions of the controller will contain an on-board PC and framegrabber that will allow such operations.

Figure 4: An operator controlling a Scout using a PDA.

Scout Testing in the USAR Course

The Scout's small size and remote operation capabilities give it the potential to be very useful in USAR operations. However, this small size is also a liability in environments with places in which the robots could easily become trapped. RF communications range is also likely to be diminished due to the amount of rubble and debris between the robot and the operator. The Scouts were run through the NIST course to evaluate how well they might perform in a simulated USAR environment. The NIST course actually consisted of three different courses of increasing difficulty. The easiest (yellow) course consisted of a relatively flat and uncluttered floor which allowed more traditional research robots to operate without too much difficulty. The second (orange) course had debris on the floor, passages that were partially blocked and difficult to traverse, and a second level that could be reached by a ramp or a staircase. The third (red) course was strewn with rubble and had several "pancaked" structures. The orange course was chosen for the tests because it provided a significant challenge to the diminutive Scouts while still being accessible. The Scouts were able to easily navigate through the yellow course because their small size allowed them to drive under obstacles that were designed to impede larger robots. The red course was avoided because it is unlikely that the Scouts would be of much use for locating or identifying survivors in such an environment. However, if the Scouts were deployed into the environment as stationary cameras, they might still be useful as monitors to detect structural instabilities such as shifting debris.

The capabilities of the basic (fixed-wheel size) Scout model were tested first. The Scout was teleoperated by a user wearing the portable PDA controller. The entry to the course consisted of "cracked" floorboards (wooden plates which had separations that could trap the Scout if it fell into them) which were covered with paper debris. To enter the course, the Scout had to jump over a door threshold and then do several more jumps to move past the separations in the floorboards, as shown in Figure 5. At one point, the Scout accidentally fell into one of the cracks and was unable to use its wheels to free itself due to the limited mechanical advantage it had in this position. The Scout was able to use its spring foot to propel itself out of the hole and back onto flat ground, as shown in Figure 6. The remainder of the first floor was relatively accessible as the Scout could jump over the additional debris. The second floor of this level was not accessible to the Scout as it was unable to get enough traction to scale the ramp and it was unable to reach the stairs (so it could jump up them) due to additional debris in front of it.

The capabilities of the Variable-Sized Wheel Scout were tested next. With the wheels fully expanded, the Scout had no difficulties traversing the entry way and was able to roll right over the crack between the floorboards that trapped the first Scout. The rest of the obstacles in the environment were easily driven over, as shown in Figure 7. By contracting its wheels to their minimum diameter, the Scout was able to scale the beginning part of the ramp to reach the second story, but was unable to reach the top due to obstacles over which its motors didn't have enough torque to climb. However, if placed at the top and commanded to descend the ramp, the Scout was able to climb over these obstacles in a controlled fashion (shown in Figure 8).

In both sets of experiments, the operator was able to view the video returned from the Scout and find several of the simulated victims. The small viewing angle of the Scout's camera and the close proximity of the robot to the floor made this task somewhat more challenging than originally anticipated. In the initial runs, the operator had a tendency to become disoriented because of the Scout's low field of view. However, with additional runs, the operator became more proficient at the teleoperation task.

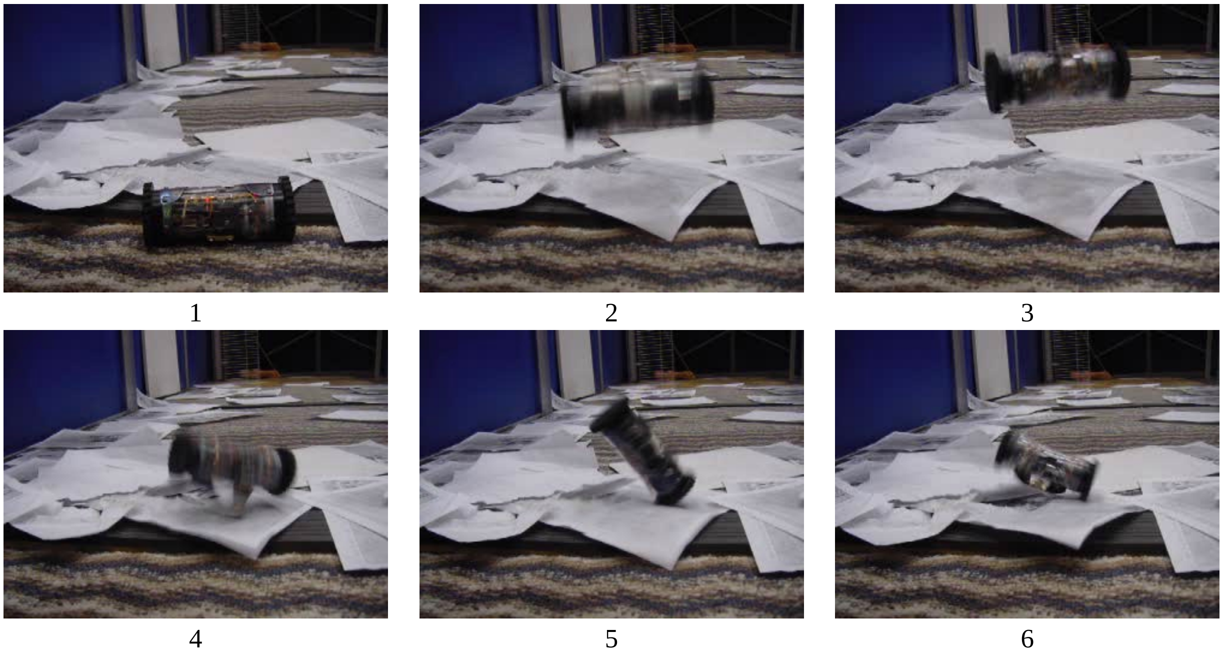

Figure 5: A Scout using its spring to avoid a hole in the floor.

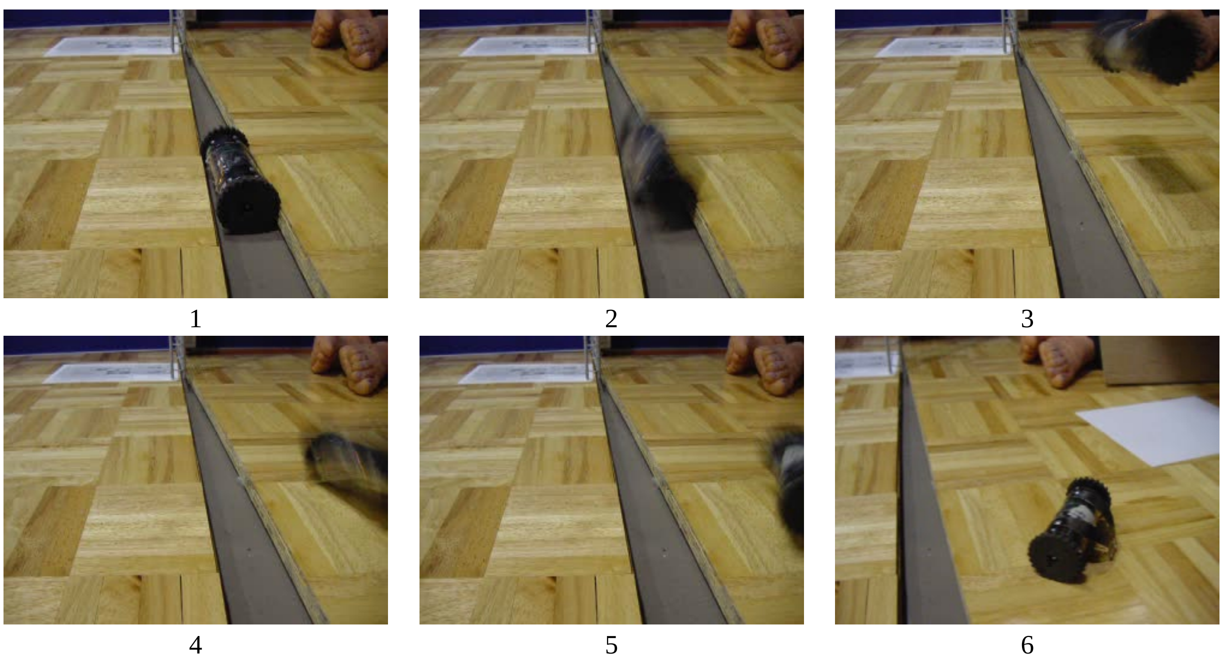

Figure 6: A Scout using its spring to free itself from a hole in the floor.

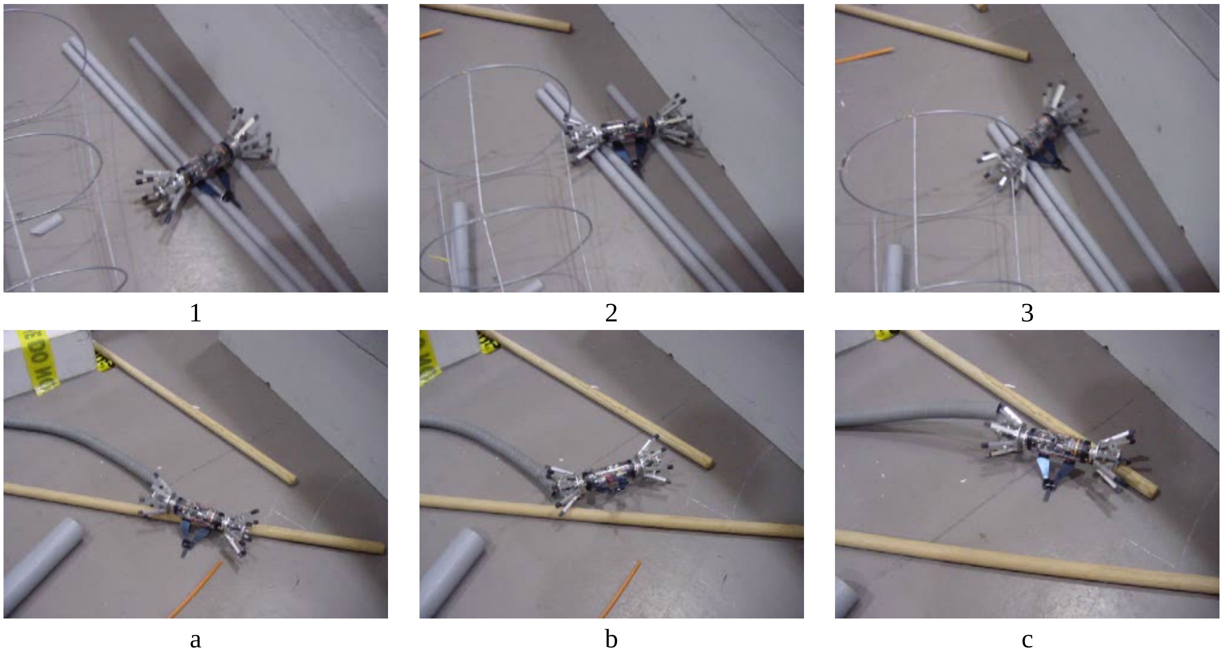

Figure 7: The Variable Sized Wheel Scout traversing two different obstacle sets on the floor.

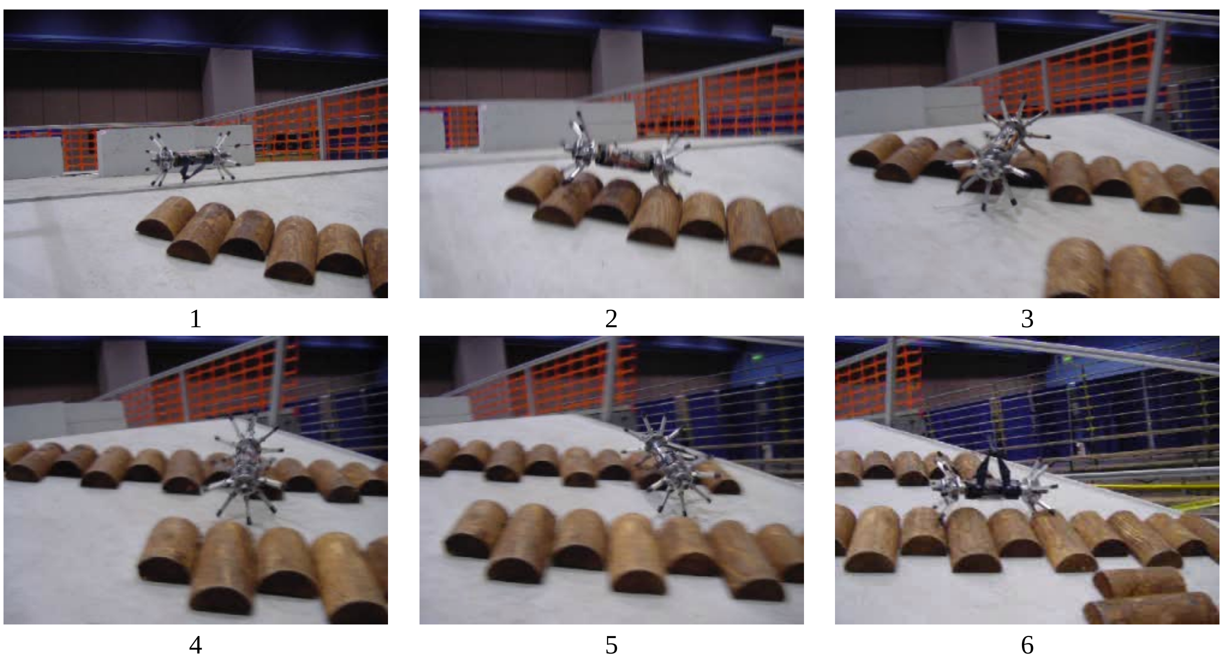

Figure 8: The Variable Sized Wheel Scout traversing obstacles on a ramp.

Summary & Future Work

Because the Scouts were untested in this kind of environment before they were used at IJCAI 2001, they were not entered into the competition. Instead, they took part in the exhibition and were allowed to operate within the arena when other robots were not competing.

These tests suggest that the Scouts could be useful in certain kinds of disaster situations. Because of their small size, the Scouts could operate within the yellow and orange courses because these courses simulated buildings that were mostly intact. The main challenge to their mobility was the debris and holes on the floor which they were usually able to jump or climb over. Given a favorable environment of this type, where most of the structures are still intact, additional reliability could be achieved by deploying multiple Scouts. If one robot becomes stuck or disabled, another robot could continue the operation where the first left off.

Another of the challenges faced during the tests was the noisy RF environment in which the Scouts had to work. Because there many other teams participating in the robotic competitions and exhibitions (as well as the RoboCup soccer competition taking place in the adjacent hall), some RF frequencies that the Scouts used were either partially corrupted with interference or rendered completely unusable. In particular, some of the video transmission frequencies that the Scouts used were also being used by the other teams for wireless networking.

Operating in a noisy RF domain is a challenge that must be addressed for any USAR robot because rescue two-way radios and other RF equipment are likely to be used quite heavily by rescue personnel at a disaster site. An area of future research for the Scouts is to provide more frequency agility in the RF communications system either by providing more channels for the robots or making use of a frequency-hopping RF system. The dependence on clean data communications channels is one of the tradeoffs that must be made when using robots of this small size.

Additional means of Scout locomotion are also being examined. The close proximity of the Scout to the ground greatly restricts its field of view, as well as making it more susceptible to being caught in debris. One area of future work is a grappling hook modification for the Scout. A Scout equipped with a spring-loaded grappling hook might be able to increase its field of view by firing the hook into the ceiling of a structure and then lifting itself up. Another method of mobility currently being researched is a blimp attachment which would be able to lift the Scout up and over damaged structures and provide an aerial view of an area.

Because the only exteroceptive sensor on the Scout is a video camera, the Scout's video can be rendered useless by bad lighting conditions. In a USAR scenario no assumptions about the existence of good lighting can be made. To address this problem, a Scout equipped with an external battery pack and infrared LEDs is being developed. This Scout is designed to illuminate an area with infrared light (to which the Scout camera is sensitive) allowing it and other Scouts to see in the dark.

Finally, the use of autonomous or semi-autonomous behaviors for this kind of operation is being researched. No autonomous behaviors were evaluated at IJCAI because the wearable controller used for these tests did not have an onboard computer capable of capturing and processing the video. Some of these behaviors, detailed in (Rybski *et al.* 2001), include autonomously moving the Scout into an area that is conducive for surveillance, and reporting if any motion is detected from within that area. The next phase of development would be to try to tune these behaviors such that they can be used in an USAR environment. This will provide more flexibility to human operators since they would be able to teleoperate one or two robots directly while allowing the other robots to autonomously perform simple tasks like navigating between waypoints or homing in on motion or noise.

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