Reconfigurable Robots for Distributed Robotics*

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Abstract

Small (roughly $116cm^3$) "scout" robots with multiple movement capabilities are presented. Scouts contain a complement of sensors (cameras, vibration monitors, etc.) along with transmitters/receivers and microcontrollers for clandestine reconnaissance and other covert tasks. Scouts are teamed with larger "ranger" robots that have greater range, battery life, and computational resources. Together they form a distributed, reconfigurable robotic team.

1 Introduction

Certain clandestine reconnaissance and surveillance tasks, along with other military functions in urban warfare, require the use of multiple small yet highly capable robots. The individual robots must be easily deployable and able to move efficiently yet traverse obstacles or uneven terrain. They must be able to sense their environment, act on their sensing, and report their findings. They must be able to be controlled in a coordinated manner.

To support all of these requirements, we have designed a "scout" robot with a cylindrical body and a volume of roughly 116cm^3 (see Figure 1). A scout can move about its environment by rolling using wheels and jumping using a spring "foot" mechanism. Each scout is provided with a sensor suite, which may vary with the scout's mission, and electronics for communication and computation.

The small size of the scouts provides many advantages. They are inexpensive and easily transportable, which makes them ideal for use in large teams. This allows them to be present throughout a wide area, forming a mobile sensor network. It also allows individual scouts to be expendable without jeopardizing an entire mission. Scouts are also well suited to clandestine operations since they can be concealed easily. The scout's small size and cylindrical shape also allows it to be deployed by launching or throwing by hand.

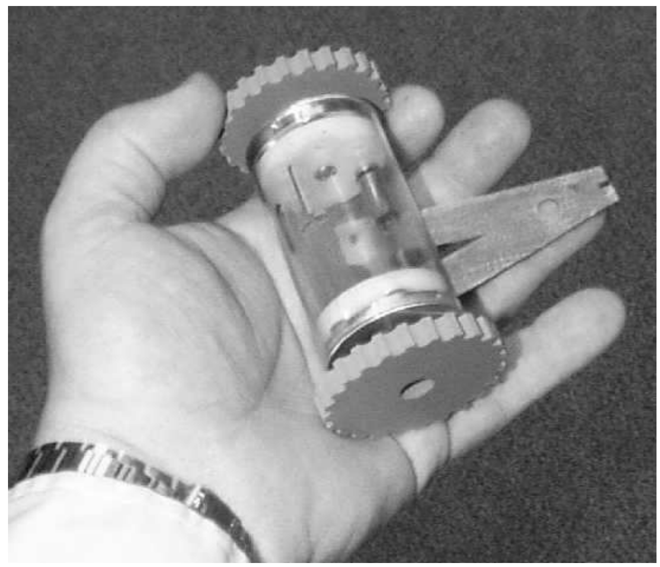

Figure 1: The scout robot showing its cylindrical body, motors and wheels, and spring steel foot.

The disadvantage of the scout's small size is that it limits the scout's movement range, battery life, and computing power. For this reason we team scouts with larger "ranger" robots. Rangers are based on a commercial off-the-shelf (COTS) platform with a volume of roughly 130,000cm^3 (approximately the size of a wheelbarrow). This platform is specialized for our purposes by equipping it with a scout launcher, radios, and additional sensors. Rangers serve as the command and control units in the team, as well as providing transportation for and deployment of the scouts.

2 Related Work

In recent years, there has been interest in using mobile robots for military exploration (reconnaissance) tasks. In general, however, such robots have been roughly the size of

*This material is based upon work supported by the Defense Advanced Research Projects Agency, Electronics Technology Office (Distributed Robotics), ARPA Order No. G155, Program Code No. 8H20, Issued by DARPA/CMD under Contract #MDA972-98-C-0008.

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a trash barrel up to the size of a golf cart [14]. Further these robots have been designed to work relatively independently of one another, rather than as a closely-coupled team.

Non-military exploration of difficult environments has benefited from mobile robotics. A prime example of such a system is Sojourner, roughly the size of a child's toy wagon, which was sent to Mars. Sojourner had limited autonomy — it was directed towards nearby waypoints and moved close to them on its own.

Somewhat smaller robots are being developed for other civilian exploration purposes. These include spherical robots roughly the size of a soccer ball and extended robots similar to a large snake [7]. These are envisioned as being restricted to certain special environments, such as water or gas pipes in need of inspection.

Miniature mobile robots (on the order of cubic centimeters in size) have been investigated but are limited to laboratory investigation of robotic algorithms [11]. Our scouts promise to be among the first miniature robots to be ready for field exploration.

Even smaller robots (microrobots and nanorobots) are the subject of speculation but realized systems are still to appear [3].

To provide small mobile robots with sufficient processing power, particularly for vision-based activities, proxy-processing methods have been investigated [9]. However, rather than relying on stationary computers, as these authors do, we have the proxy-processing done on the ranger robots to keep it mobile and in range of the scouts.

Multiple robots often can do tasks that a single robot would not be able to do or do them faster, as described in the extensive survey by Cao et al. [2]. The types of tasks and ways in which they can be approached by multi-robot groups has been taxonomized by Dudek et al. [4]. Some tasks that have been studied with multiple robots are search and retrieval [10, 15]; formation marching [1], which involves moving while maintaining a fixed pattern; map making [6]; and (simulated) hazardous waste cleanup [12].

The use of multiple mobile robots has also been investigated for security [5] and submunitions clearance [13]. In the former case, the large robots were meant to augment human security guards and fixed sensor systems in a known and semi-tailored environment. In the latter case, the lawnmower-sized robots were paired with a Pentium-based laptop computer used for oversight purposes.

3 Scouts

The scouts are the remote, mobile eyes and ears of the team. Their electronics includes sensors, transmitters/receivers, and microcontrollers (see Figure 2). All scouts contain magnetometers and tiltometers. Scouts may also contain a video surveillance module that consists of a miniature video camera and a wireless video transmitter. The camera may be kept in a fixed position within the scout body or may be mounted on a miniature pan-tilt unit

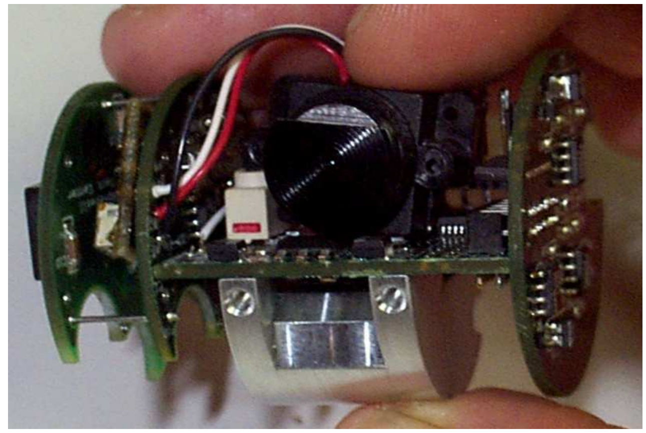


Figure 2: The scout electronics including sensor suite and computational and communication resources. Camera is shown at top center.

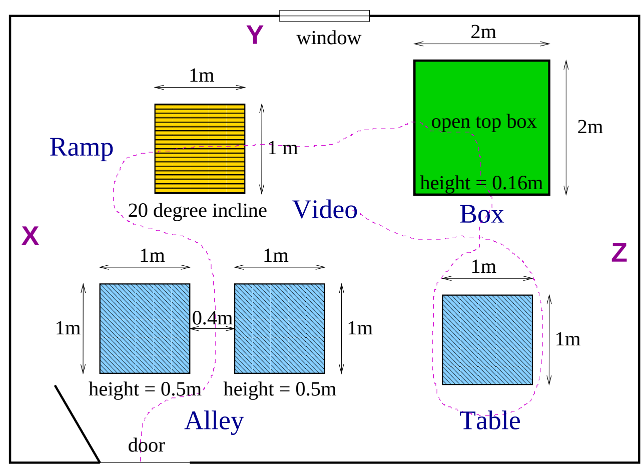


Figure 4: An obstacle course for the scout.

that uses micromoters for actuation. The wireless video transmitter may also be used in conjunction with a microphone to send audio signals. Other possible sensors include a passive infrared sensor, a vibration sensor, or a gas sensor.

For communications other than audio or video transmission, a separate miniature transceiver is employed. This is paired with a COTS microcontroller that processes the communication channel. A second COTS microcontroller is used for general purpose computing (such a computing the scout's orientation for jumping using readings from the tiltometers). However, the scout's computing power is limited and the ranger (see Section 4) is used for proxy processing.

Scouts move using both rolling and jumping. (For jumping, see Figure 3). To demonstrate the maneuverability of the scouts, as well as their video surveillance module, an obstacle course was designed (see Figure 4). To complete this course, the scout needed drive down an "alley" between two large obstacles without hitting either, roll up a ramp at a 20° incline and fall from the top (but not the sides), jump into and out of a box with walls 16cm high (four times

Figure 3: A scout jumping over a barrier (sequence starts from left side).

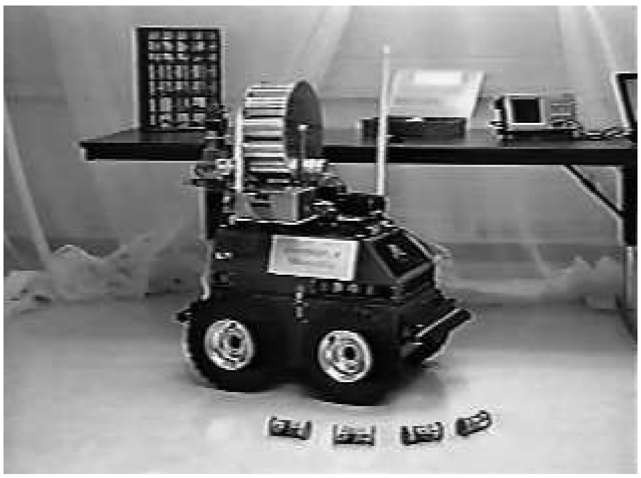


Figure 5: The distributed, reconfigurable robotic team. A four-wheeled ranger with scout launcher, radios, camera, and sonars is shown in the center of the figure. Four scouts are shown in the foreground.

the scout's height), drive around a table without hitting it, then transmit images of interest (large letters affixed to the walls of the room at a height of 1.5m). A total of 15 teleoperated runs through this course were performed at the U.S. Marine base in Quantico, VA under the supervision of personnel there. All runs were completed successfully with a minimum time of 4:28 and a maximum time of 10:05. The mean time was 7:08. Complete details are presented elsewhere [8].

4 Rangers

The rangers are both the brains and the brawn of the team. Significantly larger than scouts, they have a scout launcher mounted on top and are further equipped with radios and sensors such as sonars and video cameras (see Figure 5).

For brains, the rangers are equipped with Pentium-based on-board computers used for mission planning and task coordination. The on-board computers also have frame-grabber cards allowing the rangers to capture and process images from their own cameras and from cameras mounted on the scouts. This proxy-processing allows the scouts to engage in visual-servoing — an activity they would never be able to accomplish with their own limited computational resources.

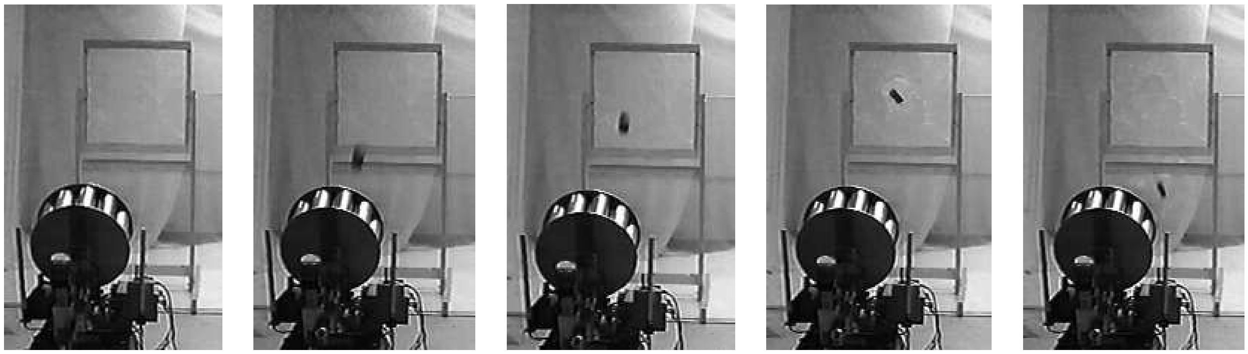
For brawn, the rangers have an electric-powered, four-wheel drive, skid-steering chassis that can cover distances of up to 20km. By carrying the scouts into position, the ranger effectively increases the scout range many times over. Ranger brawn also includes the scout launcher that allows the ranger to "throw" scouts through windows or over obstacles that the ranger could not itself surmount (see Figure 6). The ranger can launch up to ten scouts from its launcher before needing to be reloaded. It can select the order in which the scouts will be launched and, by choosing the launch angle and propulsive force, can launch the scout any distance up to 30m.

5 Scouts and Rangers as a Team

The strength of the team comes from pairing several of the highly original scouts with one or more rangers. Such a team can, for example, be used to quickly set up a sensor network within a building then use it for surveillance. In this scenario, rangers may either move into the building and search out rooms into which they deploy scouts or remain outside and launch the scouts into the building through windows. The scouts then "look" around the rooms (by transmitting images to the rangers for proxy processing), find dark corners in which they can hide, move into hiding, turn to watch their areas, and wait for people to move through the environment. When people are seen, the rangers can provide their locations, through knowledge of the scouts' positions within the building. This is, of course, only one possible scenario for a team of scouts and rangers, but is one which we have demonstrated in detail [16].

6 Conclusions

We have presented a distributed, reconfigurable robotic team. By choosing an appropriate set of scouts and rangers, missions of military significance including clandestine reconnaissance and surveillance can be accomplished. Future work will include making the scouts themselves more modular, so that a single scout can be reconfigured for a new task



(a) (b) (c) (d) (e)

Figure 6: A scout being deployed by launching. In frame (d) the scout breaks through the window.

by replacing its sensor payload. This will add an additional level of flexibility and reconfigurability to the team.

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