A Robot Team for Exploration: Design and Architecture*

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1 Introduction

We describe the design and the architecture of a robotic team that consists of two types of robots. The first type is a larger, heavy-duty robotic platform, called the "ranger." It is used to transport and deploy a number of small, mobile sensor platforms called "scouts", the second type of robot, into the environment. Together, the scouts and rangers form a hierarchical team capable of carrying out complex missions in a wide variety of environments.

Many reconnaissance and surveillance tasks 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, report their findings, and accept commands to operate in a coordinated manner. To support all of these requirements, we have designed the scouts.

Rangers add functionality to the team in two ways. First, using their greater size and power, rangers add range and mobility to the team. Rangers carry the scouts to the mission site and launch them into position using a spring-powered "gun." Second, using their greater computational resources, rangers add intelligence to the team. Rangers do complex perception (e.g., vision processing) on behalf of the scouts and coordinate all of the robots in the team.

2 Scouts

A scout has a cylindrical shape, 40mm in diameter and 110mm in length (see Figure 1). Its shape allows it to be deployed by launching it from an appropriate barreled device (see Figure 3) or by throwing it by hand. Once deployed, it moves using a unique combination of locomotion types. It can roll using wheels (one on each end of the cylinder body) and jump using a spring "foot" mechanism. The rolling allows for efficient traversal of relatively smooth surfaces, while the jumping allows it to operate in uneven terrain and pass over obstacles, as shown in Figure 2.

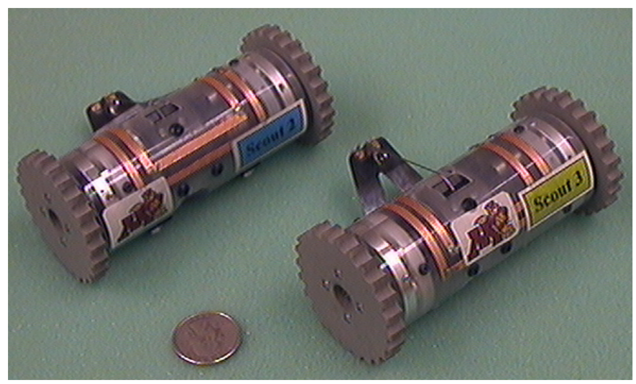

Figure 1: Two assembled scouts, ready for operation (shown next to a quarter for scale).

The scouts act as the mobile eyes and ears of the team. Their electronics includes sensors, transmitters/receivers, and microcontrollers. 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 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. More details on the hardware are in ref[1].

For communications other than audio or video transmission, a separate miniature transceiver is employed. This is paired with a microcontroller that processes the communication channel. A second mi-

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crocontroller is used for general purpose computing (such as computing the scout's orientation for jumping using readings from the tiltometers). However, the scout's computing power is limited and the ranger is used for proxy processing.

The scouts can be manually controlled by an operator, and used simply as "telemetry on wheels". We have designed a user interface to facilitate the task of the operator and demonstrated the scout capabilities in an obstacle course, that included moving through a narrow alley, jumping in and out of a box, and climbing a ramp. Figure 2 shows a scout jumping over a wall in the obstacle course.

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 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 platform, which we equipped 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.

3 Rangers

The rangers (see Figure 3) are significantly larger than the scouts. They are based on the ATRV-Jr.™ platform from the RWI Division of IS Robotics. They can carry a payload of roughly 25kg. With a battery life of 3 to 6 hours (depending on terrain and load), their maximum range is roughly 20km. We mounted a scout launcher on top and equipped them with radios and video cameras.

The rangers are equipped with Pentium-based onboard 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.

The scout launcher allows the ranger to "throw" scouts through windows or over obstacles that the ranger could not itself surmount (see Figure 4). 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.

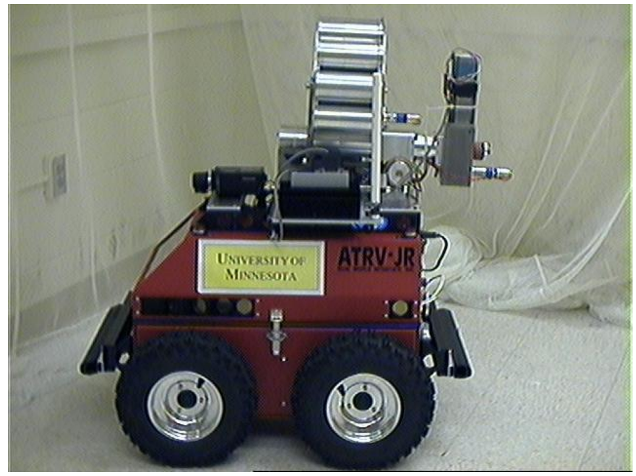


Figure 3: A ranger with scout launcher.

4 Scouts and Rangers as a Team

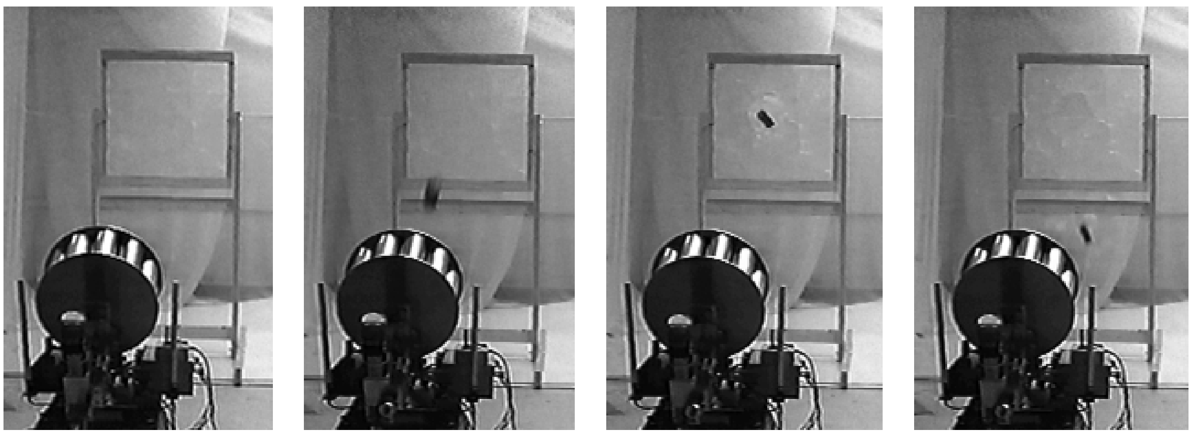
Multiple robots can do things that a single robot would not be able to do, such as pushing a large heavy object, or can do things faster and more reliably, such as picking up trash or exploring a large area. Scouts and rangers have been designed for the second type of tasks, where cooperation increases performance.

A team is created by pairing several scouts with one or more rangers, depending on the size of the area we want to cover. Because of range limitations of the radios on the scouts, a ranger has to remain close by to act as a proxy. Indoor the maximum range of communication for scout to ranger is approximatively 9.5m, and it decreases in the presence of large metal objects. This imposes some constraints on the operations of the team.

In order for the rangers and the scouts to coordinate their efforts and work together properly, a proxy processing system has been developed which allows the ranger to control the scouts. The scout's limited computational resources restrict it to handling only the most basic low-level motor control routines. High-level control is achieved through this proxy-processing scheme in which the individual control algorithms that direct the motion of the scout are run as separate threads on board the ranger's computer.

This proxy-control system is made possible through the use of a layered CORBA-based architecture as

Figure 2: A scout jumping over a barrier (sequence starts from left side).



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

Figure 4: A scout being deployed by launching. In frame (c) the scout breaks through the window.

described in Figure 5. This architecture provides distributed control of all of the the individual hardware resources, including (but not limited to) scouts, rangers and video capture boards. The objects in the physical level are controlled at the machine interface level by dedicated servers (such as the scout radio) or device drivers (for the video capture board). These servers interface to proxy processes in the logical object level which can run either on the same machine as the hardware or on other machines across the network. The logical object level provides an abstract interface for high-level programs running at the application level.

The logical software architecture is shown in Figure 6. The overall set of goals, a mission, is recursively decomposed into less and less complex behaviors. The user breaks the mission intuitively into reusable tasks that are generally executed in sequence. Metabehaviors correspond to team-oriented actions and manage multiple coordinated behaviors using transition triggers (similar to finite-state machines). Coordinated behaviors combine several robots in a physical, functional, temporal or spatial relationship. At the lowest level, primitive behaviors map directly to a robot's capability. The figure is augmented with descriptive text of an exemplary decomposition of a military mission.

A scenario we have demonstrated requires the team to quickly set up a sensor network within a building and use it for surveillance. In this scenario, a ranger moves into the building and searches out rooms into which to deploy scouts, using navigation software to move autonomously along a corridor and to find open doors . The ranger then launches a scout into each room. The scouts "look" around the room (by transmitting images to the rangers for proxy processing), find dark corners in which they can hide, move into hiding, turn to watch their area, and wait for people to move through the environment. Details on the experiment are reported in [2].

References

[1] D. Hougen, S. Benjaafar, J. Bonney, J. Bu-

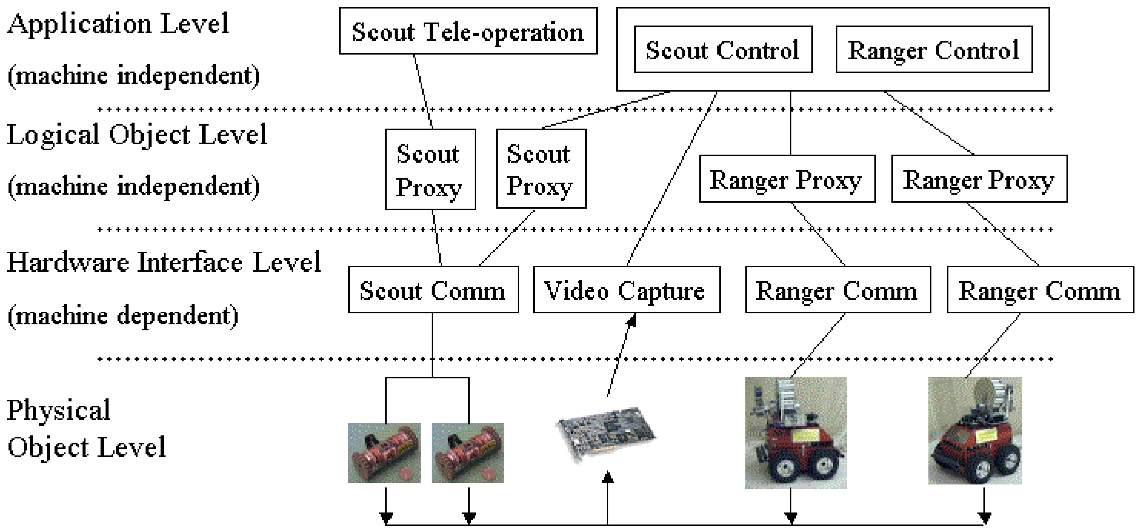


Figure 5: Distributed software architecture.

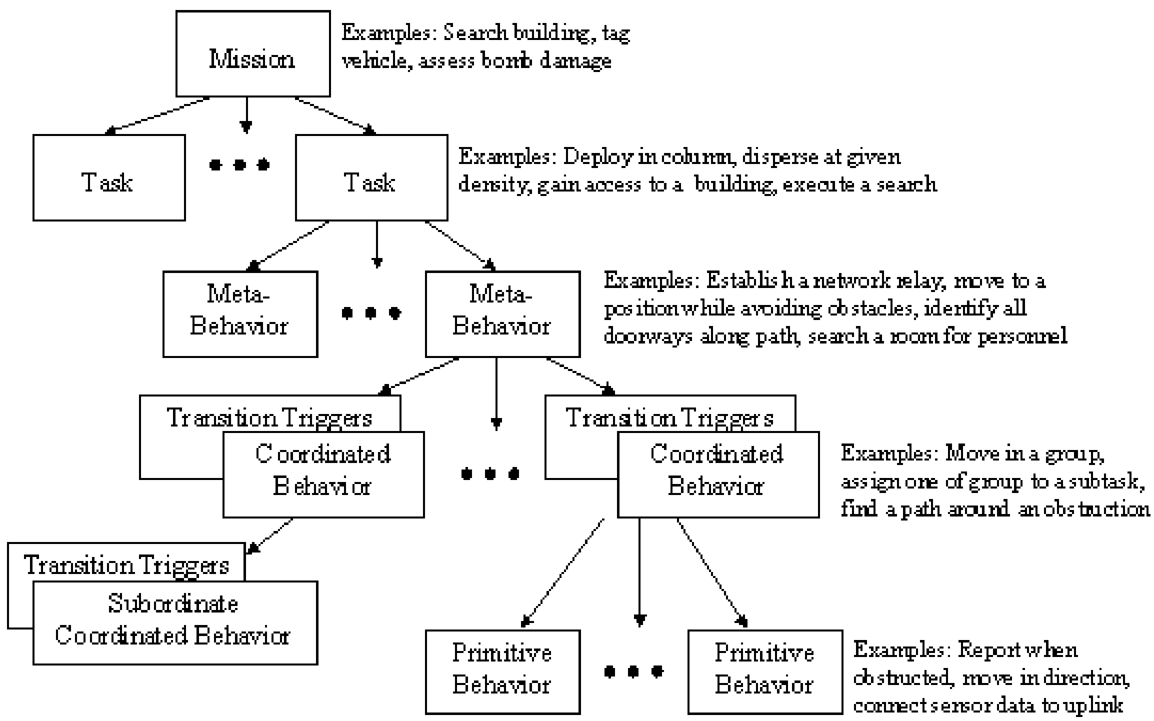


Figure 6: Distributed software architecture.

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[2] P. E. Rybski, S. A. Stoeter, M. D. Erickson, M. Gini, D. F. Hougen, and N. Papanikolopoulos. A team of robotic agents for surveillance. In *Proc. of the Int'l Conf. on Autonomous Agents*, June 2000. To appear.