Heterogeneous Implementation of an Adaptive Robotic Sensing Team*

Bradley Kratochvil[†], Ian T. Burt[‡], Andrew Drenner[†], Derek Goerke[‡], Bennett Jackson[†], Colin McMillen[†], Christopher Olson[†], Nikolaos Papanikolopoulos[†§], Adam Pfeifer[†], Sascha A. Stoeter[†], Kristen Stubbs[†], David Waletzko[‡]

Center for Distributed Robotics, Department of Computer Science and Engineering
University of Minnesota, Minneapolis, U.S.A.

Abstract: *When designing a mobile robotic team, an engineer is faced with many design choices. This paper discusses the design of a team consisting of two different models of robots with significantly different sensing and control capabilities intended to accomplish a similar task. Two new robotic platforms, the COTS Scout and the MegaScout are described along with their respective design considerations.*

1 Introduction

In 2001, the University of Minnesota developed its second-generation Scout robots [4]. These small $40\,\mathrm{mm} \times 110\,\mathrm{mm}$ robots are intended to function as an information gathering team in situations potentially dangerous for humans. The Scouts contain sensing equipment such as cameras and small low-power microprocessors for control. These robots are designed to fit a very small form factor while containing as much sensing equipment and computational power as possible. This led to a complex and almost entirely custom design, which creates difficulties when trying to upgrade or mass-produce the devices. Due to the Scouts' small size and computing power, another agent is intended to accompany them into the field for deployment and supervision. Initially, this role was filled by a modified ATRV-JR known as the Ranger. Although the Ranger is a platform intended to transport the Scouts into position, it is not human transportable itself. In an effort to address these issues in a robotic team, two new robotic platforms have been developed.

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[†]Center for Distributed Robotics and Dept. of Computer Science and Engineering, University of Minnesota.

[‡]Dept. of Mechanical Engineering, University of Minnesota.

[§]Corresponding Author.

The Commercial-Off-The-Shelf (COTS) Scout, detailed in Section 2, has been developed to address the issues of small form factor and ease of deployment. The main focus of this platform is to reduce the cost and complexity of the device by limiting it to only a mobile camera platform with no processing power. This has led to a low-cost teleoperable mobile robotic platform. Since this platform is limited to teleoperation, another entity, human or robotic, must accompany it during deployment. For the case of a robotic command-and-control center, the MegaScout platform has been developed. The MegaScout, described in Section 3, is a larger, more powerful sensor platform that can either perform missions on its own or in teams consisting of COTS Scouts or other MegaScout robots. The platform is intended to combine the command and control nature of the Ranger with the portability and compact nature of the Scout. Although these platforms are still in their final fabrication stages, Section 5 describes future enhancements that expand the platforms' mobility, durability, and sensing.

2 Related Work

One of the problems when applying a distributed robotic team to a variety of tasks in hazardous environments is maintaining effective communication links which keep operators aware of the situation the robot is in. Projects such as [5] have worked to create a relay network in which each robot serves both as a node of the network and is capable of performing local sensing tasks. Such networks are crucial for tasks in Urban Search And Rescue (USAR) environments where relocating an operator to regain wireless communication is not permitted [1].

Designing robust robotic platforms for operation outside of the laboratory is a difficult task. In order to function in a variety of environments, researchers have looked into making easily reconfigurable or self-reconfiguring robots such as the PolyBot [9] and the

Figure 1: A prototype COTS Scout in an outdoor setting.

CONRO [2] for increased locomotion capability. Supporting the reconfiguration of sensors [6] also allows for more useful real world applications. Another example of creating hybrid heterogeneous robotic teams to accommodate problems associated with limited locomotion and sensing capabilities of a single platform are the Packbot and Throwbot discussed in [7].

3 COTS Scout

As its name implies, the COTS Scout, shown in Figure 1, is designed to incorporate as much standard hardware as possible. This approach is motivated by the high cost to reproduce the original Scout robots. While the original Scout prototypes cost on the order of thousands of dollars, the COTS Scout prototypes cost under $300. This has largely been made possible by using a significantly different approach to the robot design. The original Scout is based around a digital system. It has digital command communications and micro-controllers to handle its operation. Although this allows for a more sophisticated robot and more possible uses, it adds a great deal of complexity. The COTS Scout is designed to be as simple as possible while meeting its design objectives that are:

- Low construction cost,
- Large communication range,
- Ease of maintenance,
- Low operating cost.

To meet these objectives, the COTS Scout is designed around equipment available for radio controlled vehicles. The main shell of the COTS Scout is a 44 mm × 97 mm long cylinder. All supporting hardware is mounted to this shell for structural support. A jumping foot has been omitted from this design because of the increase in production costs, but multiple wheel sizes allow the COTS Scout to traverse a variety of terrains. The current wheels consist of 57 mm, 64 mm, and 76 mm discs. Table 1 shows experimental data taken from the COTS Scouts operating on a variety of terrains.

The main command receiver for the COTS Scout has the capability of using any of 50 different crystals enabling an equal number of command frequencies. The command radio is able to receive commands from approximately 45 m indoors and 90 m line-of-sight. The video transmission system is based around a FM modulator that is capable of three different channels. Since the COTS Scouts are capable of using many more control channels, hardware was added to allow each Scout to turn its video transmitter off or on. This allows multiple COTS Scouts to be used in the same area. The video transmitter can broadcast approximately 15 m indoor and 18 m line-of-sight using standard antennas. Due to the rugged construction of the COTS Scout, it can withstand the impact of being thrown more than 15 m horizontally onto a hard surface.

4 MegaScout

The MegaScout, Figure 2, is designed to support a Scout robotic team as well as perform missions independently. When supporting a Scout mission, the MegaScout can be equipped with command transmitters and video receivers to communicate with a host of Scouts. It can then relay this information back to a base station, effectively increasing the range of a Scout team. If communication back to the base station should fail, the MegaScout is also equipped with sufficient computing power to control the Scout team. When supporting a Scout mission, the MegaScout can be equipped with an array of sensors that would otherwise be too large to be deployed on the Scouts. In order to accomplish this, work has focused on developing a robust robotic platform that can easily be modified

Terrain	*Wheel diameter*		
	57 mm	64 mm	76 mm
5 cm tall grass	0 m/s	0.03 m/s	0.04 m/s
Small debris	0 m/s	0.17 m/s	0.40 m/s
Concrete	0.39 m/s	0.42 m/s	0.50 m/s
Max. incline	35 °	35 °	28 °

Table 1: COTS Scout performance characteristics.

and will operate in a variety of environments.

During the initial design phases of the MegaScout several capabilities were specified, and the robot was designed around them:

- Software Design: A robust, stable architecture would be needed to support the platform. The architecture should provide the developer with a sufficiently abstract interface, so that hardware can be changed or added with little or no change to the high level functions.

- Electronic Design: The electronics would need to be designed to support a variety of different sensors. The device needs a 32-bit central processor. The systems would be robust enough that software errors should not damage them.

- Mechanical Design: The robot would need to be able to withstand the impact of being thrown or dropped. It would need to operate in a wide variety of harsh terrains and be modular to support future upgrades.

The resulting robot is the MegaScout. Discussion of this platform will be divided into the above three areas: software, electronics, and mechanical hardware.

4.1 Software

Since the MegaScouts are intended to operate as part of a heterogeneous robot team, a very generic software API was defined. This allows command and control software to treat all individual robots as uniformly as possible. In the context of this API, a robot is modeled as a hierarchical collection of sensor and actuator objects, whose interfaces represent general types of robotic parts (motors, encoders, cameras, range finders, etc.) and whose implementations are left undefined. Concrete packages have been written to fill in all the implementation details necessary for the operation of the equipment on each MegaScout. A programmer writing an implementation for another type of robot can pick and choose from these packages or write new packages whose objects comply with the same interfaces.

The exact composition of each robot is defined by an XML file that enumerates its sensory equipment and its mechanical actuators along with any configuration data needed for each part. A robot object is then assembled dynamically at runtime by parsing the XML description into a hierarchy of objects drawn from the selected component packages. This structure makes it easy to support the robot's field-swappable sensory equipment without the need to recompile any code,

Figure 2: A prototype standard equipped MegaScout.

and allows each robot to maintain separate calibration information to account for variations between sensors.

The MegaScout runs White Dwarf embedded Linux on its main processor. Using Linux simplifies building the robot from relatively low cost commodity hardware while at the same time providing easy remote access to the system via SSH over a wireless network. It also makes it possible to customize the operating system very precisely to fit the limited disk and CPU resources available onboard. The control software is written in C++, which provides a rich object-oriented environment and fast, native executables. A large selection of compatible utility libraries is available.

4.2 Electronics

As mentioned earlier, much of the design for the MegaScout robot revolved around the electronics component selection. Early in the design process, a PC104+ stack was selected as the main processing module. The advantages of using a standard central processing board are the ease of upgradeability, little need for hardware customization, relatively small form factor, and industry standard parts.

By limiting the amount of electronics that our engineers create, the entire design of the platform can be accomplished more rapidly allowing more time to be spent on developing applications. The PC104+ stack chosen for the MegaScout has a 166 MHz Pentium processor, 128 MB of RAM, and a 128 MB Flash disk.

Although the Pentium chip offers a high amount of processing power, it is known not to be as power efficient as some of the other embedded processors (StrongARM, Crusoe, Geode, etc.). These new processors

Figure 3: The MegaScout equipped with balloon tires.

could offer potential savings in battery power, but were not chosen for this design due to their relatively recent introduction into the market and reduced selection of board features. Along with the main processing module, the PC104+ stack contains a 4-channel frame grabber and a PC Card adapter.

Due to the rapid increases in communications technology, it was deemed necessary for the robots communication hardware to be easily upgradeable. The PC Card module contains an IEEE 802.11b card, which serves as the main communication module for the robot. A PC Card was chosen as an interface to allow the robot to easily use different communication hardware such as CDPD cellular cards. With the current wireless hardware in the robot, it is able to communicate approximately to 100 m indoors and 600 m outdoors. The robot is equipped with a switched diversity gain antenna array for the wireless communication module, which improves the communications of the system by reducing fading regions [8]. For analog video, the initial prototypes of the MegaScouts are equipped with the same FM 900 MHz transmitters as the COTS Scout. This transmitter is included to provide a control station with high quality video to be used when the robot is moving at high speeds.

The included framegrabber allows the MegaScout to process analog video onboard as opposed to the original Scout system where all video was processed remotely. This greatly increases the robot's ability to perform local behaviors as well as reduces the amount of wireless communication traffic. By using digital video, the user has enhanced control of the quality and quantity of video being sent back to a central control area. The MegaScout is also equipped with a USB port, enabling USB cameras to be utilized. The main advantage of the USB camera is that it allows more processing to be done off the main CPU board.

The BrainStem by Acroname facilitates the communication between the main CPU stack and the rest of the electronics. Communication with the BrainStem is handled through a serial interface. Each BrainStem has 5 analog, 5 digital, and 5 servo I/O ports to communicate with the robot's sensors. The MegaScout has a BrainStem in each of the sensor bays as well as one specialized unit for motor control. This enables each robot to communicate with a variety of different types of sensors and manipulators. An interface layer between the main CPU and the other electronics is useful when the main CPU is upgraded or a large number of sensors change. This minimizes the effect such changes have on the rest of the systems.

Initially, there are only two different types of sensor payloads for the MegaScouts. One payload contains a camera with a tilting mechanism, an infrared range finder, and an analog video transmitter. The other contains a USB camera with an Eltec heat detection sensor. The Eltec sensor is used to detect motion in the infrared spectrum emitted by humans. A third sensor payload is under development, and will have a video receiver and command transmitter for the COTS Scout. The sensor bays are designed such that they can be replaced with a minimal impact on the rest of the system.

The electronics are powered by two 118 Wh Lithium Polymer batteries. With these packs in place, the robot has approximately 20 hours of standby time and 4 to 5 hours of average runtime. The Lithium Polymer packs were chosen due to their high energy density and ability to source large amounts of current. These particular battery packs are equipped with monitoring circuitry to watch battery health as well as provide battery statistic gathering capabilities.

4.3 Mechanical Hardware

The MegaScout was designed to operate in the difficult environments of urban warfare, urban search and rescue, and general field use. As a result, a great deal of engineering went into the mechanical design of the platform. Specifically, the design allows for use over a variety of different terrains including mud, dirt, and debris. This is accomplished through the minimization of entry points and the use of weather resistant features such as gaskets and shaft seals. Due to the sealed nature of the shell, all sensing to the outside world occurs through polycarbonate and other sensor transparent materials.

The MegaScout robotic platform is not only designed to tolerate environmental hazards, but also severe mechanical shock loading. A grade 5 tita-

Figure 4: The actuated-wheel MegaScout shown with its wheels retracted and expanded.

nium hull provides a tough and lightweight exoskeleton that resists local deformation under impact conditions. Lightweight Fortal aluminum gearboxes and bulkheads are used to provide a rigid support structure. The wheels are mounted on hardened chrome alloy output shafts which are designed to take severe impacts. This allows deployment under less than ideal conditions with a minimal risk of damage to the platform. A modular approach to the drive system allows for several types of wheels to be used and swapped easily in the field, while allowing provisions for future enhancements.

Since the form factor of the platform is of a two-wheeled robot, a tail capable of withstanding rugged use is included in addition to careful placement of the axle with respect to the center of gravity. This arrangement counters the high torques generated by accelerations. The MegaScout platform is designed to incorporate two 150 W output motors. These are run at 42 V to avoid resistive losses associated with high power low voltage systems. In addition, robust electronic control is facilitated through the use of low currents, allowing a total drive system efficiency near 90 %. These high torque motors are used to accommodate actuated wheels, and provide robust acceleration. The standard platform is designed for a top speed of around 6 m/s.

There are currently three types of wheels developed for the MegaScout. Each of them provides advantages under different circumstances. The standard wheel, shown in Figure 2, for the MegaScout consists of a billet Fortal aluminum hub with a 25 mm thick urethane tread. This not only encompasses the perimeter of the wheel but also extends onto the outer facing hub surface. Shore A durometer 60 urethane was chosen to balance traction, general wear, and shock travel. This allows for a lightweight wheel that can take moderate radial and axial impacts. A diameter of 230 mm provides environmental isolation for external parts by providing sufficient ground clearance.

Since the inertial energy stored in the mass of the robot is essentially constant for a given velocity, the larger the distance the system traverses under deceleration, the lower the resulting body forces required to transfer inertial loads. Thus, for severe duty, large foam filled rubber tires are used as shown in Figure 3. The 300 mm outer diameter with a hub diameter similar to the MegaScout hull allows for over 60 mm of radial travel. This design allows the platform to withstand deployment far above the point of interest, as well as providing general dampening of shock loading. The large diameter of the wheel also allows the platform to surmount rougher terrain than standard wheels.

With increased wheel diameter comes enhanced environmental mobility [3]. However, large wheels make the portability of the platform difficult. In order to keep a small robot with the benefits of higher ground clearance, variable-sized actuated wheels have been developed as shown in Figure 4. Through the use of eight radially symmetric, four-bar linkages, the diameter of the wheel may be altered to any point within mechanical limits. This is accomplished by using a solenoid to selectively fix the rotation of a threaded shaft with respect to the reference frame of the platform. The inner linkage pivots are fixed to a ring with threads that mate to the threaded shaft. By driving normally with the solenoid engaged, the ring is forced to slide axially and actuate the linkages. Friction with respect to the drive train keeps the wheel from actuating while not engaged with the solenoid. Careful pivot placement allowed for optimal transmission angles to be obtained throughout linkage travel. To minimize user encumbrance while transporting the platform and to facilitate a compact form, the wheels wrap around the outer hull of the robot in the closed position.

5 Future Work

The COTS Scout platform is currently in its third revision, and work is focusing on increasing the durability of the platform while reducing the cost. Initial results from this work imply that the prototyping cost for the COTS Scout can be reduced to below $150.

Although the MegaScout is still in its final prototyping stages, work has begun on expanding the platform's capabilities. Efforts are being focused on developing new deployment options, mobility modes, and sensor payloads. Future work will enhance the actuated wheels by replacing the rigid outer wheel segments with flexible segments, providing a suspension and a smoother riding profile. Another concept under development is to captivate a coiled spring to all eight ends of the wheel to provide a round surface at all stages of actuation. A flexible membrane is then stretched over the entire wheel to provide traction and prohibit foreign matter from interfering with the mechanism. Both concepts will be blended to provide passive suspension while maintaining a round wheel throughout actuation.

Currently, designs are in progress for a magnetic wheel system which, combined with improved weatherproofing, could operate in environments such as the sides of buildings or ships. During the early design phases, the idea of joining MegaScouts together was proposed and provisions for interconnectivity were included in the design. Combining the MegaScouts will allow the traversal of obstacles such as stairs and transportion of objects too large for a single robot. Due to the modularity of the sensor bays, new sensors will be some of the simplest additions to the MegaScout platform. Additions that are currently being investigated are such devices as GPS modules, Geiger counters, and infrared cameras.

6 Conclusions

The COTS Scout and the MegaScout are a team of new robotic platforms. The COTS Scout is a portable durable, and inexpensive platform with limited capabilities that can be deployed in many hard to reach locations. The expanded capabilities of the MegaScout enable it to be used in a wider array of situations by sacrificing a small portion of its portability. These systems are intentionally designed with a high degree of standardization to decrease the amount of time needed for prototyping and allow greater amounts of time to be spent researching applications of these new technologies.

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