DESIGN OF THE UMN MULTI-ROBOT SYSTEM *

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Abstract Robotic reconnaissance and search and rescue are daunting tasks, especially in unknown and dynamic environments. The Scout is a robotic platform that is robust and flexible to operate in adverse and changing situations without revealing itself or disturbing the environment. The Scout can complete these missions by utilizing its small form factor for effective deployment, placement, and concealment while being equipped with a variety of sensors to accommodate different objectives. Unfortunately, the Scout has a limited volume to share among power, locomotion, sensors, and communications. Several novel approaches addressing deficiencies in specific tasks have been implemented in specialized Scouts and will be discussed in this paper. By building a diverse team of specialized Scouts, the team's strengths outweigh an individual weakness.

1. Introduction

A robot platform that is designed for covert surveillance and reconnaissance will encounter a variety of obstacles in which a single robot or single type of robot may not be able to accomplish the objective of the mission within the parameters of the mission. These obstacles can take the form of limited passageways, non-traversable surfaces, limitations in time to complete a task, or operating in adverse or dynamic environments. Larger robots, which may be able to adapt to other situations

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and carry large payloads, are unable to easily conceal themselves in many environments nor is it possible for them to traverse small passageways. One method of dealing with these is to develop a team of specialized small scale robots that can distribute a task rather than relying on a single larger robot.

Unfortunately, as the robots are made smaller, there is less room on-board to accommodate different environments or additional sensors. The Scout robot, developed at the University of Minnesota's Center for Distributed Robotics has been designed so that a team of specialized Scouts can work together to accomplish the tasks of semi-autonomous surveillance, reconnaissance, or search and rescue. This paper presents a reconnaissance scenario that utilizes the strengths of the members of the team to accomplish what no single member of the team would be able to. The specializations of the team involve changing both the locomotion methods of the Scout as well as the addition or replacement of hardware to improve the sensor capabilities of the Scout. This is followed by a look at some related work and finishes with a look at what can be done to further improve the Scout.

2. A Sample Reconnaissance Mission

The Scout robot was initially designed to be launched into a building to perform reconnaissance so that approaching individuals will know whether the building was occupied or could be considered safe. This objective expanded into a reconnaissance task which consisted of searching a collapsed or damaged building to find survivors rather than risk the lives of human rescuers or rescue dogs.

The traditional Scout robot, currently in its second generation is a small two-wheeled cylindrical robot, 40 mm in diameter and 110 mm in length. Shown in Figure 1, the Scout is capable of moving on relatively even surfaces on its wheels at approximately 0.31 m/s or hopping over obstacles through the use of its spring foot. The general Scout platform contains a variety of sensors including a black and white video camera, accelerometers, tiltometers, and wheel encoders. For more information on the general Scout platform, one may see Hougen et al., 2000.

The general Scout fares well in search and rescue scenarios in which there are few obstacles and relatively even terrain such as an office building that may not have much structural damage. However, the low ground clearance of the Scout, approximately 3.2 mm, results in difficulty when crossing common office objects which may be on the floor such as cords or even pens and pencils. In situations in which the Scout is inhibited

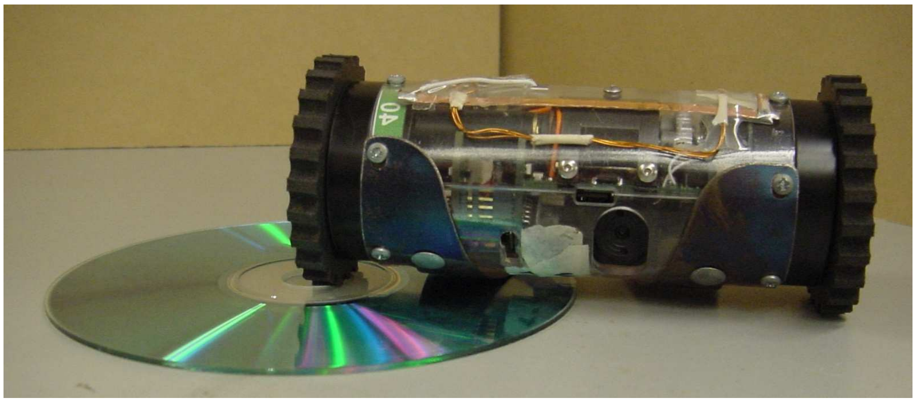

Figure 1. The Scout robot shown next to a CD for scale.

from forward rolling movement, the use of the spring foot enables it to hop in an arc over obstacles approximately 22 cm in height.

2.1 Debris Covered Surfaces

The typical Scout traverses flat surfaces and can overcome some small amounts of debris through its hopping mechanisms. However, a surface that is covered with debris can stop a traditional Scout in its tracks. The Actuating Wheel Scout has the capability of re-sizing the diameter of its wheels dynamically in the field which allow it to increase the ground clearance from the approximate 3.2 mm of the normal Scout to approximately 41.3 mm. This additional ground clearance allows the Scout to easily traverse much larger obstacles as seen in Figure 2. The improved ground clearance reduces the average speed when the wheels are at their largest diameter on smooth terrain to .2 m/s from the general Scout's .31 m/s to keep the torque of the smaller wheels.

There were several design criteria to be met by the actuated wheel system. The cylindrical form factor had to be maintained and the small size of the Scout required that no additional motors be added to directly power the actuation. The wheels needed to expand to at least twice the retracted size allowing for improved ground clearance. The wheels had to dynamically adjust to their environment, which is not possible with simple spring force. Finally, the wheel system needed to be as lightweight as possible yet still retain the strength needed to operate in adverse environments.

Of the possible designs, the current design has proven to closely match the specifications. The design involves the novel application of a latching solenoid to selectively couple the center wheel shaft to the body of the Scout. The inner side of the wheel is directly attached to the drive gear as well as having a bearing over the center shaft. The other side of the wheel is on a thread that runs along the center shaft. Thus, the drive motor is used to power the linear actuator in the wheel whenever the solenoid is engaged.

Figure 2. The Actuating Wheel Scout crawling over debris.

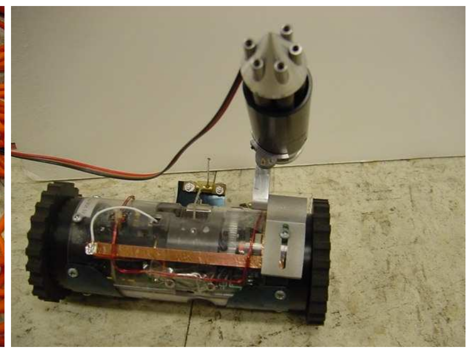

Figure 3. The Grappling Hook Scout carries a spring-loaded grappling hook that it can use to climb large obstacles.

2.2 Large Obstacle Navigation

When searching for survivors, rolling and hopping provide excellent forms of locomotion, but there are times when being so low to the ground limits what the Scout can see, especially when dealing with large obstacles such as desks, toppled file cabinets, or large debris. Rather than taking the time to drive around these large obstacles, the possible use of them as a vantage point for further investigation makes them extremely attractive. Unfortunately, the task of surmounting large obstacles is not something that a general Scout or one with actuating wheels is capable of, thus the need for the grappling hook Scout.

The grappling hook Scout, shown in Figure 3 is designed to provide an alternative method for crossing difficult terrain. With the grappling hook, a Scout can elevate itself onto a table, chair, bookshelf, or by using any other large object as an anchoring point. From its new vantage point, the Scout gains an improved range of vision and the possibility for a more concealed vantage point. Improved height also helps to reduce the effects of ground signal propagation and results in longer transmission distances. For further background on the grappling hook, one can see Drenner et al., 2002.

2.3 Aerial Reconnaissance

Through the use of the actuating wheels and grappling hook, the Scout has a wide range of terrain that it can successfully conduct reconnaissance in. However, there are still areas which can not be overcome through rolling or climbing. In these situations, the application of a Scout controlled blimp offers the advantages of being able to control flight through an area with many large obstacles, an improved "bird's eye view" vantage point, and possible platform payloads such as additional lighting for darkened areas.

The blimp, shown in Figure 4 is controlled through an interface to the Scout. The Scout is capable of turning on and off as well as reversing the direction of a total of three fans. Two forward facing fans are used for going forward, reversing, and changing direction while a third fan is used to control lift. The blimp can be controlled to navigate corridors or stairwells, or hover in a stationary position for observation.

There are tradeoffs for using the blimp. The volume of the blimp is dependent upon the weight of the Scout and any other additional payloads that it may carry. The weight of a Scout and basic fans for control calls for a blimp with a volume of .4 m^3 of helium. This in turn requires that there is a minimum amount of clearance for the blimp Scout to pass through an area which determines whether it can make it through doors and around corners.

Figure 4. A Scout-controlled blimp. The fans that control the blimp's motion are actuated instead of the Scout's own wheels.

Figure 5. The IR Scout is equpped with infra-red emitting LEDs which allow the Scout's camera to be used in complete darkness.

2.4 Low Light Operation

In terms of reconnaissance for survivors, a key aspect for completing such a mission is to be able to function in situations where lighting may be less than ideal. In damaged buildings there may be rooms where there are no lights, or there may be situations where the site is too remote for immediate repair of electrical lines.

While originally intended as a method of supplying light while concealing the presence of the Scout in surveillance or other types of reconnaissance roles, an attempt to address low light operation requirements has been to add a pair of infrared (IR) emitters, each consisting of 36 IR diodes and a supplemental external battery pack to a Scout as shown in Figure 5. The extra battery pack requires that stronger, larger wheels replace the standard foam ones in addition to the gearing down of the drive motors. The standard black and white camera on the Scout is capable of using this additional illumination to navigate in low light areas.

A series of tests conducted using the autonomous behaviors in the software control architecture (Rybski et al., 2001) have shown that the camera currently in the Scout can be used to identify features with a 2 m radius. An additional benefit is that these IR emitters make it possible for other robots to observe the area of interest as well, thus only a small segment of the team will require this enhancement to facilitate low or no light operation.

2.5 Human Identification

Once a robot is in an area where there may be survivors, there are numerous ways to detect whether someone is there or not. Audio cues from survivors shouting from help or visual signs of motion can indicate that a survivor is near. However, when a survivor is knocked unconscious, these signs are not as readily available.

To improve the chances of finding survivors in these situations, certain Scouts have had been equipped with a color camera which replaces their standard black and white camera. The color cameras allow for video to be sent back and analyzed for skin tones which may identify potential survivors.

While the color camera is not that sensitive to the additional illumination offered from the IR emitters of the IR Scout, the newer cameras can operate with a lower amount of illumination than the unaided black and white ones. The new color cameras also offer improved resolution. The new cameras do have one drawback though, in that they consume more power than their predecessors.

3. Related Work

Small scale robots face an imposing world which require them to traverse hostile environments, adapt to dynamic situations, and interact with their environments to complete a variety of tasks. Combining the capabilities to complete these tasks within the constraints of the small form factor results in some rather remarkable robotic platforms.

Small robots often face a more difficult task when traversing hostile environments. Numerous forms of locomotion have been developed for small platforms, among them using a single gyroscopically stabilized wheel (Brown and Xu, 1997) for rolling, hopping systems for mobility in rough terrain (Hale et al., 2000), and self-reconfiguring robots such as Polybot (Yim et al., 2000) which is capable of reconfiguring itself to move like a snake, walk as a hexapod, or roll like a wheel.

Small scale autonomous flight is an interesting form of locomotion that has a very useful future. There are numerous larger fixed-wing unmanned aerial vehicles, but few have the ability to navigate indoors and none seem to be as adaptable as the Entomopter (Michelson and Reece, 1998). The Entomopter's insect like flight is suitable for flight not only in military reconnaissance roles, but also allows operation in thinner atmospheres making it ideal for Martian exploration.

Sensing the environment is very important for robots of any scale. In terms of urban search and rescue (Murphy et al., 2000), some of the most important sensors are those related to identifying victims such as thermal cameras and sensitive microphones. Sensors can also monitor for gas leaks or aftershock vibrations which can aid in the safety of rescuers.

Several projects have been focused on packing as many sensors into the smallest package possible to complete a mission. The Millibots (Bererton et al., 2000) are an example where small scale robots are combined with reconfigurable sensor packages. The mapping and surveillance capabilities of the Millibots are enhanced through the use of redundant sensors which address the shortcomings of a single sensor.

4. Conclusions and Future Work

The Scout provides a unique and adaptable robotic platform capable of utilizing the diversity of the members of its team to accomplish difficult tasks in non-ideal conditions. Each Scout is suited for different operating conditions and teams of Scouts can be selected to handle specific situations depending upon the parameters of the current mission. In the example of searching a building for survivors, the Scout is able to traverse a variety of terrain, yet be small enough to drive through small holes in the walls without further damaging the surroundings.

Future generations of the Scout will have additional improvements to the mobility, communications, and sensing capabilities of the Scouts depicted here. Improvements in mobility will geared toward reducing the size further while still allowing for the freedom of movement found in devices such as the actuating wheels and grappling hook. Other sensors will be developed and integrated allowing for a wider variety of information retrieval. Increased communication range will allow wider team dispersal and the ability to operate in less wireless friendly environments.

The improvements come always in the form of a tradeoff, whether increasing mobility means a change in size or increasing sensing reduces overall operating lifetime by consuming more power. However, the incorporation of several specialized robots offsets the effects of the tradeoff because diversity in the team provides the strength to be both flexible and adaptable allowing for a wider range of missions and objectives than a single robot could accomplish.

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