Investigating Scalability in a Robot Colony

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Abstract

A group of robots can accomplish many tasks that a single robot cannot. Increasing the size of the group and equipping robots with application-specific sensors or manipulators greatly expands the complexity of applications that can be performed. However, as the group size increases, many issues associated with scalability must also be taken into account. Wireless communication networks that work with a small number of robots may not be optimal for a large and perhaps changing number of robots. We seek to explore many of the issues associated with a large colony of autonomous robots, such as wireless communication, sensor fusion, localization and mapping. This work is a continuation of previous Robot Colony projects and will serve as a foundation for future research within the Robotics Club.

Research Question and Significance

The colony project seeks to develop behaviors that control a large number of robots working together as a team. Past development has focused on improving the individual robot design, and implementing simple behaviors with very small groups of robots. Now, with a relatively inexpensive platform in place, the goal is to create a much larger robot colony. This project aims to create advanced behaviors for this large group, which will enable the colony to accomplish things that individual robots would not be able to perform. Behaviors that have already been developed will be extended. What was once performed by a few robots will be performed by many more. This includes robots moving together in geometric formations as well as robots working together to surround a moving target.

There are many real-world applications for colony-based robotics. Landmines are a very serious problem in many parts of the world. A colony of robots searching for hidden mines can have greater coverage with a larger number of units. It also decreases the chances of missing mines. Robots can also be used to locate chemical spills. A robot colony can search for and surround the spill, determining the location and shape of the spill.

Project Design and Feasibility

As the Colony project is entering its fourth year, a wealth of knowledge has already been accumulated. Much of the work in the past revolved around designing a robotic platform that would serve as the base for the robotic colony. Each year saw a new revision of the individual robots. The robots have evolved to an acceptable level, and we are now ready to create a full-scale colony.

Robots

Each robot consists of three main components: the mechanical base, the microcontroller, and the sensors.

Mechanical Base

The mechanical base will remain mostly unchanged from previous designs. It will still be small and circular, about the size of a CD. Two motors will drive the robot and a 6V NiMH battery pack will provide the power for all components of the robot. Keeping the robot size small allows us to fit many robots in a small area without the need for a dedicated environment.

Microcontroller

We have partnered with Botrics LLC, a CMU spin-off company, to create the new microcontroller board. We worked directly with them to design the new Firefly+ board, which is based on an existing microcontroller used for Fun With Robots, a StuCo course offered at CMU. We have already written the libraries that give the Firefly+ its flexibility and power. These allow the Firefly+ to control the motors, communicate over a serial link, interface with sensors, read the battery charge level, and make use of other features of the board. The board also allows us to use a small LCD panel, which serves as a visual output for the robot.

The microcontroller board is powerful enough to meet our computational requirements, and since we can program it using standard C code, developing and testing programs will be streamlined. The large number of input and output pins will allow us to interface with multiple sensors at once. Additionally, an integrated wireless module will allow each robot to communicate with others around it.

Sensors

The sensors connect the robot to the real world. Our primary sensor is the Bearing and Orientation Module (BOM), a custom sensor that was started two years ago. It consists of a ring of IR emitters and receivers, which we can use to gather relative bearing data of other robots. This sensor, paired with a localization algorithm and the wireless network, allows each robot to localize relative to other robots. Additionally, the BOM is currently being redesigned to provide a communication link between neighboring robots, as well as supply orientation data for surrounding robots.

Some of our behaviors rely on bump sensors, which can tell the robot if it has hit an obstacle. We will continue to use these sensors for obstacle avoidance. We plan to use Sharp IR rangefinders to determine distances to obstacles or other robots without physical contact. For example, we can use multiple robots to create a mapping of the obstacles in an environment by continually detecting and measuring the location and distance of the obstacles from various robots.

One of the many possible application-driven sensors could detect liquids on the ground. This would allow our colony to detect spills of chemicals, for example. A robot would need this sensor to detect where the spill has occurred and signal its location to the other robots.

We feel that each individual robot is now sufficiently equipped to be a useful part of a large-scale robot colony. Each robot has a mechanical base that gives it mobility, a powerful microcontroller that will control the robot, and many sensors to interface with the world. In addition, each robot has room for additional parts and sensors, which will allow us to easily change the colony as needed.

Colony Behaviors

A larger scale colony will allow us to explore more complex and appealing behaviors. For example, with a large number of robots, we will be able to implement a herding behavior, or simulate how insects interact with the world. A behavior that maps out an area is another possibility afforded by a large number of robots.

Furthermore, with the plethora of new sensors and manipulators that can be added to the colony, the robots will be able to interact with and learn more about the world around them. For example, with an arm, a group of robots will be able to move objects around cooperatively as opposed to having a single robot perform the task alone.

Scalability

The primary goal of this year's Colony Project is to investigate the scalability of our colony. While existing behaviors and communication protocols use a relatively small number of robots (1 to 5), we would like to see how the colony performs with a much larger number of robots. Behaviors will have to be modified to deal with the large number of robots, but the larger number of robots drastically increases the Colony's possibilities. Many of the planned behaviors, such as herding and mapping, cannot be accomplished with a small number of robots. The existing wireless communication network works well for a small number of robots, but it may prove too slow once more robots are introduced into the system. The new wireless module should allow us to implement a more complex networking structure that won't rely on a specific ordering of robots.

Current Members and Project Organization

The Colony team is experienced, capable, and eager to continue working on the project. Its members are part of the Robotics Club, and come from diverse range of academic backgrounds. These backgrounds range from ECE and Mechanical Engineering to Computer Science, as well as Cognitive Science. Many participants are enrolled in the Robotics minor, and several of us are also contributing to research projects in the Robotics Institute.

The Colony Project is a part of the CMU Robotics Club. As in the past, we will hold weekly project meetings for all members of the project. Smaller groups responsible for specific parts of the robot colony will also meet outside of this general meeting.

The project leadership has evolved, utilizing the strengths of existing members. Both Felix and Aaron will continue to lead the project next year, and most of the members will remain on the project. New members of the Robotics Club are always welcome to join the project, and as such, the project will continue from generation to generation.

Thanks to continued funding, the Colony group constantly builds upon existing work from past years. This past year, the colony project has improved upon the existing base for the robot, which will allow us to build a colony with a larger number of robots. The work to be done next year will serve as a foundation for future work done by the next generation of the Robotics Club and the Colony Project.

Feedback and Evaluation

As in the past, the status of the project will be evaluated regularly at our weekly project meetings. Weekly goals will be assigned to each sub-group, and we can re-evaluate our direction in more general terms.

Professor Howie Choset is our advisor and attends various project meetings. Professor Choset is able to offer feedback from a professional perspective, which helps guide the development of the Colony, and helps us to solve some our technical issues.

Dissemination of Knowledge

We plan to pass on the knowledge and technology created by the Colony Project in a number of ways. We will continue to publish the source code and documentation along with the workings of the colony on the project's website. By allowing others to see and manipulate the source code, they will be able to create their own low-cost colony without the hassle of developing the base technology from scratch. This, in turn, will allow them to spend more time researching colony topics such as emergent behaviors. The team will also publish the results of the emergent behaviors discovered with a larger colony on the project website. All findings will also be presented at the Meeting of The Minds, and other academic conferences should they arise.

Budget

As we received a Ford grant last semester, we plan to apply for another one this semester, so that we can extend our previous work. However, we have many things planned regardless of the grant size we receive. A smaller grant will only mean we may have funds for a smaller number of robots. As such, we have come up with a per-robot cost, which will allow us to scale our colony depending on the amount of funding we receive. In either case, all funds will be put to use developing the colony.

Component	**Per-Robot Cost**
Microcontroller board	$100
LCD Module	$20
Wireless Module	$15
IR Rangefinder Ring	$30
Total	$165

Descriptions

The new microcontroller boards are required for the operation of each robot. We are getting this board at-cost, as we have designed it ourselves. LCD modules allow for convenient debugging and for monitoring the status of each robot. Wireless modules enable the robots to communicate with one another, and the modules carry a 25% educational discount. Infrared range-finding rings provide the robots with distance measurements required for complex behaviors. This ring of Sharp IR rangefinders would retail around $120, but we are able to get a large discount through the Robotics Club. The functionality afforded by the above components improves upon the existing capabilities of previous colony robots.

Colony Size

The amount of funds the Colony Project receives determines the number of robots that can be purchased. Since we are partly outfitting the robots with existing equipment, if a large enough number of robots are purchased, additional funds will be needed to outfit the additional robots with the required components that we do not already have. In addition, we may require specialized parts and testing equipment for more complex behaviors. These may include small-scale robotic limbs, application-specific sensors, and testing obstacles.

Total Number of Robots	**Per-Robot Cost**	**Estimated Additional Cost**	**Total Cost**
6	$165	$0	$990
10	$165	$50	$1700
14	$165	$100	$2410
18	$165	$150	**$3120**
			Requested Amount