Control of a Robot Colony

Carnegie Mellon University Robotics Club, Colony Project
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Abstract

A group of robots requires a more complex system of control than a single robot. While a single robot performs tasks on its own, a group requires many robots to cooperate, share information, and be aware of their locations and roles within the group. The Colony project seeks to create a group of simple, low-cost robots that interact together to perform complex tasks. We will study robust control mechanisms in a group of robots by allowing humans to assign tasks while permitting the individual robots to determine how best to perform the task. In addition, we will use our control algorithms to enable cooperation among robots in order to accomplish a common objective. This work is a continuation of previous Colony work, in which the behaviors of colony robots were studied. It will serve as a foundation for future research within the Robotics Club.

Research Question and Significance

By using a team of robots, many insurmountable tasks become manageable. As we seek to understand dangerous environments on Earth and explore space, it becomes too dangerous to send humans as explorers. We can minimize this risk by sending robots. The current trend has been to send one specialized robot that is able to perform specific tasks very well. However, a single robot can be complex and expensive while still prone to failure. Additionally, some tasks, such as construction, are notoriously difficult for a single agent.

Colonies yield additional advantages in that they can be robust to individual robot malfunctions, and a single robot is often much cheaper to replace if it does fail. However, as the number of robots in a colony increases, how to control them effectively becomes an important question. More advanced coordination will be required for activities that involve multiple agents acting simultaneously. For instance, the manipulation of larger objects, such as pushing or carrying, requires several robots to position themselves precisely around an object and then act in a tightly coordinated fashion. If the colony is mapping out a new environment, the robots must cooperatively distribute themselves through the desired area. Similarly, if we want to create a sensor network in a given environment, the robots must have rules to maximize the sensor coverage of each robot in the area. Alternatively, robots may need to control their formation to arrange themselves in a pattern or shape. We will investigate more advanced control methods that will enable us to perform these tasks.

Project Design and Feasibility

The fourth year of the Colony project will be focused on developing new systems of control, specifically to execute complex behaviors using a group of relatively simple robots. Because each robot is designed with what could be considered the "bare minimum" for sensing and localization, the primary focus will be to control an entire colony of robots in a decentralized fashion using control laws that rely on local information only. We will address this problem by increasing the size of our existing colony, building upon previously-developed behaviors, and developing new algorithms to control the colony. We will introduce each of these aspects below.

Robots

We already have several functioning robots from past years of the Colony project. Each robot is about the size of a compact disc and five inches in height. Robots move using two wheels with differential drives and are able to interact with their environments through a variety of sensors. The robots communicate with each other via a wireless network. Using some of the funds from this grant, we will be updating the design of the Firefly+ microcontroller boards we've used in the past to the Firefly++, which has new features including USB connectivity and charging capability. The code library, written in C, has already been adapted to the new design. Since this is the fourth year of the project, we already have a great deal of knowledge (and code) to expand on and improve. This year, we will be purchasing additional robots to expand the resources of the colony.

A fundamental element of any robotic platform is the set of sensors that transform environmental conditions into data that can be used by the robot to make decisions. There are three major categories of variable conditions that our colony robots will be aware of:

- Their surroundings, such as obstacles or ambient light levels
- The existence and location of other robots and their status
- The robot’s own status, such as its location, speed and battery level.

Existing sensors for these purposes include infrared rangefinders, bump sensors, photoresistors, and the Bearing and Orientation Module, or BOM. The BOM consists of 16 emitter/detector pairs arranged in a horizontal circle that sits on top of the robot. This bearing information can be used in combination with rangefinder data, the wireless network, and triangulation techniques to determine relative position between robots. This information is vital for performing any coordinated effort such as formation control, following, and relaying the position of a target element in the environment such as a light source or recharging station.

The new robots will include internally-mounted magnetic shaft encoders to determine wheel positions, which can be integrated to determine position and orientation with respect to a global frame. Combining encoder readings with BOM bearing information and other sensor data will enable us to create a map of the environment. Additionally, an internal battery charge monitor can alert humans when the battery is low or initiate a routine to seek a charging station, recharge, and then resume normal operation. This would remove a major obstacle to colony autonomy, thus allowing tasks to run for days at a time.

Behaviors and Control

Robotic control is a heavily-studied area in robotics. Centralized and decentralized control of groups of robots is often done with small groups of specialized or expensive robots. We seek to find control algorithms that perform well with our inexpensive colony of robots. To begin this process, we build simple behaviors that form the building blocks of more complex actions. We have already developed behaviors for maze-solving, lightseeking, robot-following, and robot orbit, amongst others. Our goal for this proposal is to implement more complex behaviors in the following categories:

- Formation control
- Object manipulation
- Environment mapping
- Sensor networks

Formation control requires that robots know the locations of other robots around them. Forming a circle of robots, for instance, would be useful in a case where surrounding an object is desired. Using sensors such as the BOM and rangefinders, we hope to develop algorithms that help our robots move into such formations.

In the case of construction or object manipulation, robots will need to constantly interact with objects in their environment and with each other. This requires precise coordination and relative localization along with behaviors such as wall-following.

Multiple robots that are used as part of a sensor network must be able to determine the most effective position to collect information as efficiently as possible. These positions are often determined in a manner that optimizes the amount of coverage provided by each node in the area. Using this information, one can direct the robots to their specified optimal locations.

To aid us in controlling robots, we are developing a control interface known as ColoNet. The purpose of ColoNet is to enable communication between the colony and a central computer. It will use the existing robot-to-robot wireless network to send data and commands to the colony, as well as receive status information and data the robots have collected. Human users will be able to access control capabilities and collected data in a single interface at the computer terminal. The user will distribute instructions, which the robots will interpret and perform using their local systems. In addition, the ColoNet will enable us to monitor the behaviors of the colony more effectively, which will assist us in testing and debugging. Using a webcam positioned above the colony, we will not only provide visual feedback to the user but also be able to track robots and evaluate the performance of our control algorithms. While a single computer will directly interface with the colony, that computer can also act as a server, enabling other computers to connect to the ColoNet through the internet. This will allow users to control and view the status of the colony from anywhere in the world through a web interface.

Project Organization

The Colony team is a hardworking, dedicated and capable group. The team has grown significantly from the previous year and consists of members of the Robotics Club. Team members have a variety of experience levels and come from many academic areas such as Electrical and Computer Engineering, Computer Science, Mechanical Engineering, and Industrial Design.

Felix Duvallet and Aaron Johnson will lead the project again this year. They will use their experience and leadership skills to guide the project and keep it running efficiently. The large number of new members presents a wonderful opportunity for the continued development and expansion of the Colony project. The division of the project into specific task groups allows for efficient development and dissemination of knowledge to new members. These groups meet once or twice per week to work on their project objectives. Later, each group makes a presentation and gets feedback at weekly project meetings. Attached is the full list of members of the Colony project.

Feedback and Evaluation

The Colony group will continue to hold weekly meetings to assess the status of the project. Sub-groups will present progress made over the previous week and plans for future development. These meetings will help steer the general direction of the project as a whole.

Professor George Kantor is our advisor and a primary source of feedback. He attends review meetings and offers helpful insights and a professional perspective on the project.

Dissemination of Knowledge

All source code and documentation will be published and made freely available online at our site, www.robotcolony.org. This will allow other groups and individuals to benefit from the years of research and development behind the Colony project. We hope that by providing the base technology and knowledge, other groups will be able to undertake their own investigations and expand upon our research in emergent behaviors in a robot colony. As in the past, we will present all of our findings and interesting developments at the Meeting of the Minds in May 2007, where we plan to provide a live demonstration of the robots. We also plan to attend the 2007 National Conference on Undergraduate Research, and we hope to publish a paper in a major robotics conference. In addition, the Colony project will continue to research robot cooperation for years into the future.

Budget

Device	Per-robot cost	Total cost (4 robots)
Robot kit	$150	$600
IR Rangefinder x 5	$10 x 5 = $50	$200
OLED Display Module	$20	$80
Wireless Module	$15	$60
Magnetic Encoders	$20	$80
Webcam		$50
TOTAL		**$1070**

The basic parts of the robot are contained in the robot kit, including the base, motors, and microprocessor board. The five rangefinders attached to this base provide obstacle detection in all directions. Each robot has a color OLED display that assists in debugging and provides feedback to the user directly on the robot. The wireless module enables communication between robots and to a computer. The webcam will be used with ColoNet to provide remote users with visual feedback and to evaluate the performance of our control laws.

Members

<u>Project Leaders</u>
Felix Duvallet
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<u>Senior Members</u>
James Kong
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Eugene Marinelli
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