A Robotic Platform for Exploring Emergent Behavior

Felix Duvallet, Elizabeth Liu, Eugene Marinelli,
Alexander May, Iain Proctor
Carnegie Mellon Robotics Club

Advisor: Howie Choset

Abstract

In nature, some of the most successful species are those that form colonies. For instance, while individually vulnerable, myopic, and simple minded, the ant is remarkably effective in groups. We wish to take this same philosophy in designing robots. We seek to explore how complex the behavior of a robot colony can be when the constituent robots are, like the ant, limited in their sensory and processing capabilities yet inexpensive and abundant.

Research Question and Significance

A colony of robots has many advantages over a single robot. Colonies can better adapt to damage, and their capabilities are easily extended by adding more robots. In hostile environments, it is clearly superior to lose a single cheap robot and have the colony's abilities degrade gracefully than to have an expensive robot disabled because of damage to a single critical component. Some problems are naturally suited to a colony. Exploration, mapping, and monitoring are best tackled by many coordinated robots. However, much research still remains to be done before we see these colonies realized. The fundamental issue of how best to coordinate a group of robots has yet to be solved.

Our research is two-fold. Our first goal is to develop a platform that is inexpensive enough to allow more widespread experimentation in multi-robot systems. Current research relies on robots costing thousands of dollars each. Our colony consists of robots costing only hundreds of dollars which despite their low cost are versatile and capable.

Our second goal is to use these robots to explore the possibilities of robot-colony behavior. One specific application is to have a "hunting" behavior, where robots would locate and converge on a mobile target. Another application for the colony would be environment mapping. As a collective group, the robots could share information about their environment, creating a complete map of the world.

With this project, we hope to extend and accelerate research in the field of multi-robot systems.

Project Design and Feasibility

The Colony project is in its third year, and hence has been titled ColonyIII. As such, the team continuing the project will contain members experienced with the colony hardware and software as well as a large knowledge base from which newer members can be taught. We will be expanding on the work accomplished in past years. Although many parts of the colony used will remain the same, most will be improved based on last year's observations.

Robots

The robots used will be a modified version of the previous colony. They will still be small circular robots with two wheels. Many of the same sensors will be re-used on a slightly redesigned base, while some parts of the robot will be completely re-worked. The base will be modified to accommodate for motors instead of servos, giving us greater mobility. The heat sensor, the bump sensors, and the IR rangefinder will all be reused in the new robots. The robot will also support new sensors we plan to implement, such as sonar. The base will remain flexible such that any future modifications will not require a complete re-design.

The microcontroller will undergo the biggest change, as last year's proved to be insufficient for our needs. The Cerebellum controller, while adequate for many other projects, did not have enough processing power, was hard to program, and did not have enough input/output capabilities. For our new board, we will expand upon a previous microcontroller design to allow for more sensor I/O, as well as give us a more flexible programming environment and more processing power. The design will be based off an existing microcontroller, the Firefly, used for the "Fun With Robots" course. The board will use an Atmel AVR chip, which will allow us to program the robot using standard C. The addition of more I/O pins will allow for more sensors to be connected at once, increasing the capabilities of each robot.

Localization

A key element of a robot colony is the robots' ability to localize relatively to each other. This enables all further colony-based behaviors, as relative robot location is a critical factor in most multi-robot applications. For this purpose, a custom sensor was designed last year that enables each robot to determine the relative bearing of each other robot. This sensor will be completely re-worked as part of a parallel project, entitled "Communication and Positioning Module for Multi-Robot Collaboration."

Relative bearing data from this sensor must be processed by the robot to create a map with each robot's position. The algorithm responsible for this processing is an iterative one, performing triangulation operations between any set of 3 robots. The algorithm was created last year, and implemented both as a MATLAB® simulation and a standalone C program. This algorithm will be the base of many colony-based behaviors.

We also plan to include data from other sensors to better the localization approximations. Using range data from an IR range finder, we would also be able to determine absolute distance between robots.

Behaviors and Simulation

We have already experimented in simulation with behaviors based on a few simple rules. This design philosophy is to create the desired, complex behavior from the interaction of many robots using only simple rules. This is the way one might design a simulation of ant behavior. It is suited to our hardware platform since processing power is limited. In the simulator, we developed rules based only on immediate sensory input and localization information to chase and encircle a target, and to organize into a grid.

With our new hardware, there is also the opportunity to experiment with other design philosophies. In the previous colony, only one rule could be in action at a time. With more processing power, it may be possible to write behaviors that build on one another. The simplest behaviors could be overridden or altered by higher level behaviors. This will naturally allow for more complex and robust behaviors.

We have a simple simulator already developed to aid in developing behaviors before the hardware is completely ready. Even when the robot is ready, the simulator will allow faster development since certain difficult computations, such as localization, can be abstracted. We will further develop the simulator, and include it as part of the platform.

Methods and Timetable

ColonyIII will be completed as project of the robotics club. Weekly project meetings are already in progress, with a room reserved in NSH. In addition to these general meetings, each separate team will have group meetings throughout the week. The teams thus far include software, hardware, behavior, and sensors. Each group will report their work at the general meetings, receive feedback on their progress and discuss plans for the following week. The following is a timetable of our expected progress:

- November 2005
    - Entirety of code ported to new microcontroller language
    - New mechanical model for the robots
    - Basic Board Design for the new microcontroller
- December 2005
    - New robots
    - Microcontroller board layout done, sent to fabrication
- Spring 2006
    - Working colony. Explore emergent behaviors.

Participants

This team consists of robotics club members from a wide variety of academic concentrations and experience levels. Each has taken courses in their respective disciplines that will prepare them for the work this project requires. **Felix Duvallet** is a Junior Electrical and Computer Engineering major with a Robotics minor. He participated in both previous colony projects, as well as numerous other robotics club projects. His work last year focused on robot communication and localization. **Elizabeth Liu** is a freshman physics major, and while new to the robotics club, is eager to contribute to the group. **Eugene Marinelli** is a freshman Computer Science major, and is also new to the robotics club. He has past programming experience, which will be very useful for programming the robots. **Alexander May** is a freshman Mechanical Engineering major, and is familiar with the CAD software necessary to create a model of the robots. He has already completed several upgrades to the robot bases, and is looking forward to more. **Iain Proctor**, another returning member for the colony project, is a sophomore double majoring in Cognitive Science and Computer Science. Last year he worked on a simulator to develop robot behaviors, and will continue his work this year.

Dissemination of Knowledge and Evaluation

The progress of each team will be evaluated at each weekly project meeting. Specific tasks will then be assigned to each group within the project for the following week. In addition, we will stay in contact with our advisor to keep him updated on our progress and to get feedback.

As in the past, we will present our work at the Meeting of the Minds. Our poster presentation at the 2005 Meeting of the Minds won the "Judges Choice" award for our previous work on robot localization. Last year's group also submitted a paper and presented at the National Conference for Undergraduate Research. We hope to submit a paper highlighting our work done to IEEE's International Conference on Robotics and Automation.

In addition to presenting our accomplishments, we are releasing our work under the GNU General Public License. Our website will make all of the code created available for anyone to use and modify. We will also document the parts used in each robot, such that anyone wishing to create their own colony using our work may do so. By creating such an "open-source" robot, we hope to allow others to take our work and expand upon it, furthering the development of colony-based emergent behaviors.

Proposed Budget for the ColonyIII Project

Component		**Cost**
New microcontroller board	8 x $100	$800
Sonar Sensors	5 x $20	$100
Encoders	16 x $10	$160
Mechanical Parts		$100
Total		$1160

The new microcontroller board will be designed and sent for fabrication. The cost includes both the cost of fabrication and the cost of parts. Sonar sensors are one additional sensor we plan to use to further improve localization. Encoders will be used for odometry data, which will help when the robots are moving in their environment. Each robot requires two encoders, one per wheel. Although we eventually want to have at least a dozen robots interacting as part of the colony, we will begin by prototyping a few, altering our design if needed, before mass-producing the robots.