Cooperative Manipulation in a Robot Colony

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Abstract

Cooperative manipulation is a critical issue in the field of mobile robotics. The Colony Project is interested in understanding how principles of robotic manipulation apply to a colony of low-cost robots. In situations where multiple robots cooperate, sensor data can be shared, improving the collective intelligence of the colony. We will investigate how cooperating robotic agents utilize shared sensor data and coordinate to efficiently manipulate objects in their environment. In doing so, we seek build a platform for cooperative manipulation applications. 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

Mobile robots are being used not only to collect information about their environments, but to interact with their environments simultaneously. Robotic manipulation is a field of study that seeks to understand the principles under which robots are capable of interacting with their environments. We aim to apply these principles of robotic manipulation to our colony of small, low-cost robots. The focus of our research will be to investigate how multiple robotic agents can effectively share information and coordinate actions to cooperatively manipulate objects within their environment.

From examples in nature, we know that teams of physically limited cooperative agents are capable of coordinating actions in order to effect much larger changes in their environment. For example, ants are capable of identifying pieces of leaves, gathering other ants towards a leaf, and cooperatively moving a leaf to a different location. Individual ants themselves are incapable of moving objects a fraction of that size. However, by cooperating with a group of ants, such tasks become feasible.

The Colony Project seeks to emulate nature by using limited, low-cost robotic agents to perform cooperative manipulation tasks. By using many homogeneous low-cost robots, our colony inherits redundancy and parallel processing advantages apparent in living colonies. However, robots differ from natural organisms by the methods in which they collect, process, and communicate information. In order to perform cooperative manipulation tasks, robots must be capable of interpreting sensor data from their environment, sharing data with cooperating robots, and coordinating actions among the cooperating robots. The Colony project seeks to understand the necessary actuation, sensory, and communication structures needed to support cooperative manipulation. In addition, through this research, we aim to develop a platform for which applications of cooperative manipulation can be explored.

Project Design and Feasibility

The Colony Project uses 20 small, low-cost, homogeneous mobile robots. Each possesses the necessary sensory, computational, and communication capabilities to interact with other robots and networked computers. The fifth year of the Colony Project will focus on extending robot interactions into their physical environments.

Robots

Colony robots are small, oval-shaped robots approximately 16 cm long and 14 cm wide. They stand about 8 cm tall on two wheels and a caster and are individually powered by a small 6V NiMH battery. The cost of each robot is approximately $350 per robot. The robots use low-cost microcontroller boards based on an Atmel ATMega128 microprocessor custom-designed in partnership with Botrics LLC. In addition to driving the two DC motors, the board interfaces with the various sensors and user I/O devices located on the robots. These include two buttons, a potentiometer, two RGB LEDs, a piezo buzzer, and five IR rangefinders. A further four analog and six digital ports are available for custom homebrew sensors, and an LCD module is supported for displaying text directly on the robot. The robot can communicate via USB, I2C, and SPI ports, as well as through an integrated XBee wireless module. Mounted on each robot is our custom localization sensor, the Bearing and Orientation Module (BOM), which has been developed in previous research.

Object Interaction

In order to investigate cooperative manipulation, our robots must be capable of interacting with their environment as well as receiving feedback. We will implement this by designing and fabricating an object manipulation device to be mounted onto each robot. This device will be augmented with the with pressure-based force sensors, allowing the robots to detect when they are pressing against objects and how hard they are actually pressing. Feedback from force sensors will allow the robots to work with objects of varying levels of fragility without the risk of damaging or destroying the objects.

Distinguishing objects from fixed obstacles in the environment - walls, for example - poses a unique challenge since our robots have no way to distinguish differing surfaces from one another. The ability to detect the difference between obstacles and environment features is necessary for deciding which objects to move and when objects have been moved enough relative to the environment. Most robotic research projects use embedded cameras for robotic vision guided control. However, embedded cameras are currently expensive. Since the Colony Project focuses on developing function on low-cost robotic platforms, we will research object recognition strategies that do not involve installing cameras on each robot. Established techniques that we will consider include adding symbols to objects to be manipulated such as barcodes or fiducials (with associated visual sensors), infrared beacons on the objects, and optical ground movement tracking combined with tactile sensors to determine if a robot is moving an object it is in contact with.

Feedback and Motor Control

Existing Colony robots do not have a sensor for measuring displacement or velocity in open space. Without accurately knowing how far or how fast they move, our robots cannot reliably move to an arbitrary position. This ability is crucial for robotic manipulation as it allows robots to act precisely within their environments. In order to allow the Colony robots to acquire displacement data, we will equip each robot with two encoders, one for each motor. Using displacement measurements from motor-mounted encoders, robots will perform calculations to determine their velocity and acceleration for encoder-based control laws. By using these control laws, our robots will be able to move accurately at variable speeds that will be consistent across robots.

Wireless Communication Infrastructure

Localization and wireless communication are essential to multi-robot manipulation. Previous Colony research focusing on scalability and power management platforms has enabled the project to begin exploring manipulation within a cooperative multi-robot environment. The project has developed a fully-connected wireless ad-hoc network with which robots can communicate with other robots. Used in conjunction with the BOM in a token-ring coordination scheme, robots are able to continuously update and propagate bearing data for topological localization. This inter-robot communication enables Colony robots to coordinate complex cooperative behaviors.

Navigation and Cooperative Manipulation

While previous Colony research has produced simple behaviors for obstacle avoidance, a more complete and robust version of this behavior will be developed in order to navigate environments effectively for cooperative manipulation. The Colony Project will focus on combining existing rangefinder-based obstacle detection with encoder-based motion control in order to map environments to aid navigation. By sharing mapping and localization data, robots will be able to quickly explore and create maps of their environment. Using data from mapping and obstacle detection, we will implement algorithms for coordinating movement and distributing work among cooperating robots for object manipulation. Each Colony robot will be able to assess the progress of the object manipulation and correct for manipulation errors using feedback from other robots.

ColoNet

Previous Colony Project work has produced an interface between Colony robots and the Internet, named ColoNet. We use ColoNet to communicate with and control the robots wirelessly using general computing platforms, such as desktops and laptops. In addition to strictly robot based manipulation, the Colony Project will investigate how remote user monitoring can assist with multi-agent robotic manipulation tasks. To support manipulation tasks, ColoNet will be modified to keep track of objects, obstacles, and robots in a way that will be useful to both the robots and the human supervisor. In order to monitor robots interacting in their environment, ColoNet will interface with an overhead video camera. By combining live image data about the environment and wireless communication with robots, we will develop a means for which a remote user can provide useful input for assisting robots in completing manipulation tasks.

Background

The Colony team is a hardworking, dedicated and capable group consisting of members of the Robotics Club. The team has gained significant experience from previous years of research and has attracted a large number of underclassmen eager to become involved in the project. Team members have a variety of experience levels and come mainly from the fields of engineering and computer science. Project leaders, James Kong and Kevin Woo, have experience from two years of previous work on the Colony project. Using their leadership skills, they will guide the project and ensure that its objectives are met. Other veteran members of the project have gained considerable knowledge and experience presenting an opportunity for the continued growth and development of the Colony project. Project objectives are worked on twice a week during work meetings. A weekly general meeting allows for team members to discuss progress and receive feedback. These meetings allow team members to set goals for upcoming weeks and inform members about the latest project developments.

Feedback and Evaluation

The Colony group holds weekly meetings to assess the status of the project. Sub-groups present both progress made over the previous week and plans for future development. These meetings help steer the general direction of the project as a whole. Professor George Kantor, our advisor and a primary source of feedback, meets regularly with the project leaders, 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. Through our website we hope to allow 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.

The Colony Project has previously presented at the National Conferences on Undergraduate Research (NCUR) and will present at the Association for the Advancement of Artificial Intelligence (AAAI) symposium this fall. We will continue to present our findings and developments at the Meeting of the Minds Undergraduate Research Symposium in May 2008.

Budget

Item	Unit Cost	Quantity	Total Cost
Encoder Chips	$6.00	40	$240
Encoder Boards	$3.25	40	$130
Encoder Magnets	$0.25	40	$10
Mechanical Parts (Mountings, Structural Components, Casings)	$100	1	$100
Servos, Actuators	$5	20	$100
Force Sensors	$5	40	$200
Environment, Objects for Manipulation	$100	1	$100
Video Camera for Remote Monitoring	$70	1	$70
Object Identification (BOMs, barcodes)	$8	10	$80
Total			**$1030**