Investigating Power Management in a Robot Colony

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Abstract

Power management is a critical issue in the field of mobile robotics. Managing the supply of power for a team of robots becomes an increasingly difficult problem as the number of active robots increases. As the capabilities and complexity of robots increase, so do power requirements. The Colony project seeks to build a scalable power management platform upon which an increasingly large colony of robots can operate without exhausting its power supply or compromising its assigned task. We plan to study algorithms for managing tasks and allocating power resources among groups of robots. This work is a continuation of previous Colony research in which autonomous recharging and basic behaviors such as navigating mazes were developed. This research will serve as a foundation for future robotics research in the Robotics Club.

Research Question and Significance

As robots are increasingly applied in field environments, power management becomes a critical issue. This problem applies to hostile environments such as deserts or other planets. In such cases, power may not be readily accessible for long spans of time. In order to continue operating, robots must use their power efficiently on critical tasks while conserving enough power to be able to relocate and access power resources when they become available. For example, a robot powered by solar panels on Mars would need to manage its power during the night when it cannot receive sunlight to power itself. The robot must monitor the amount of remaining energy in its batteries and change its behavior accordingly until it can recharge again.

A crucial aspect of power management is allocation of power in a multi-robot environment. Oftentimes, power resources are limited and access may be restricted due to the number of robots sharing those resources. How power distribution is handled ultimately affects the performance of the colony. If power is not allocated efficiently, overall colony performance will suffer as a growing number of robots become inactive and critical tasks are left incomplete. Take for instance, a colony of robots working to sustain themselves. Suppose the robots need to mine ore from a large distance away and carry it to a processing station in order to generate power. If the stations are not laid out efficiently, the robots will overcrowd particular stations, overall mining will decrease, and the amount of power available to the colony may not be enough to sustain their operation.

Effective power management will ensure that robots remain powered without compromising task completion. As seen in the above examples, not sufficiently dealing with the issue of power allocation leads to decreased efficiency and can ultimately cause the failure of a robot colony. As teams of mobile robots are increasingly used in the field, maintaining their power infrastructure becomes a serious issue. We will investigate strategies for managing power within a colony of mobile robots.

Project Design and Feasibility

The fifth year of the Colony Project will focus on developing an effective communication protocol between multiple robots and charging stations as well as algorithms for load balancing across charging stations. Development of a power management platform builds on previous research done on colony scalability and control. There are several key components needed to complete this task. These components include the robots, charging stations, wireless network, behaviors, and algorithms.

Robots

The Colony Project has over a dozen robots based on the Dragonfly board. The footprint of each robot is about the size of a standard compact disc and each one stands about four inches tall. The robots have two wheels and use a spherical caster for balance. Each robot is controlled by an Atmel microcontroller and programmed through a USB connector. Programs are written in C using the free open source WinAVR compiler and library. The robots are able to communicate with each other using a wireless network. Each robot is also equipped with an extensive set of sensors, including five Sharp infrared rangefinders and the Bearing and Orientation Module (BOM). The BOM is a custom built sensor composed of an array of 16 pairs of infrared emitters and detectors arranged in a circle on top of each robot. This sensor allows each robot to determine its orientation relative to other robots in the colony.

Each robot will be outfitted with a charging circuit board. The charging circuit is an essential extension which will provide power management resources to the robot without consuming computational resources that would otherwise be devoted for task management, communication, algorithm processing and navigation. The charging circuit will allow each robot to retrieve status information on its battery and will enable it to recharge its own battery when docked at a charging station.

Charging Stations

The Colony Project has prototyped several charging station designs during the past year. The various physical prototypes will be tested in order to ensure that the charging station base is suitable for the Colony robots. Each charging station will utilize a Firefly+ board which is powered by an Atmel microcontroller. The Firefly+ boards are equipped with the same wireless module as the Dragonfly robots allowing each charging station to communicate with robots and other charging stations. The charging stations will each have infrared light emitting diodes for use as homing beacons for docking robots. They will use a standard computer power supply to provide DC power to the robots.

Wireless Network

In order to manage power use, we will need a wireless network which allows our robots to communicate among each other and among the different charging stations efficiently. Our current wireless network is implemented as a token ring in which only one robot is allowed to speak at a time. Robots must wait until all other robots in the ring communicate before it is permitted to speak again. This protocol works well when robots are communicating amongst one another, but it is insufficient for handling the complexity of managing communication across multiple charging stations and robots simultaneously. Implementing an improved wireless network will require the investigation of various network topologies and their application to robot and charging station communication, power management algorithms and task allocation. An improved wireless network will facilitate power management by allowing expedient messaging and more reliable communication.

Behaviors and Algorithms

Past Colony Project research has produced several important behaviors for robot control. We have successfully implemented a behavior with which a robot can seek out a charging station once it detects that its battery level is low. Using the wireless network, the BOM, and an infrared homing sensor, a robot can communicate with, locate, and move towards a charging station. This behavior forms the mechanism by which robots are able to recharge their batteries and restore power used in the execution of a task.

Beyond simple locating and movement, colony power management will implement cooperative pathfinding to improve robot navigation towards charging stations. Cooperative pathfinding makes use of the greater collective visibility of a colony of robots as opposed to that of only a single robot. If a robot seeking a particular charging station does not see one within its field of visibility, it can use data retrieved from other robots across the wireless network to locate and move towards robots that can see that particular charging station. Using this algorithm, robots can effectively navigate spaces with obstructed visibility towards any number of charging stations.

Charging stations must also communicate intelligently to efficiently distribute power among the colony. Robots requesting access to charging stations over the wireless network generate a load on the charging stations that the power management algorithm must balance. The power management algorithm will actively assign and reassign robots to particular charging stations based on their availability, their distance from the robot, the robot's battery level, and other important factors. The effect of the algorithm should be an optimal allocation of the charging stations' resources.

Algorithm implementation will be tested with and adjusted for the physical placement of charging stations which can alter how effectively robots can be recharged while performing a colony related task. Testing will include quantitative analysis of robot activity. By monitoring with an overhead camera, we can collect data on the amount of work completed by each robot, how often robots recharge, which charging stations were most frequently accessed, and other relevant information. Such statistical data will allow us evaluate our power management algorithms and improve charging station placement towards greater efficiency.

Project Organization

The Colony team is a hardworking, dedicated and capable group. The team consists of members of the Robotics Club and has grown significantly both in numbers and experience over the years. Team members have a variety of experience levels and come mainly from the fields of engineering and computer science.

James Kong and Kevin Woo will lead the project this year. They will use their experience and leadership skills to guide the project and keep it running efficiently. The experience gained by veteran members of the project presents an opportunity for the continued 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 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. Professor George Kantor is our advisor and a primary source of feedback. He attends review meetings, 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 website, 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 knowledge and a technological base, 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 Research Symposium in May 2008, where we plan to provide a live demonstration of the robots. We also plan to attend the 2008 National Conference on Undergraduate Research as well as 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

Item	Unit Cost	Quantity	Total cost
Charging Circuit Board	$20	20	$400
Firefly+ Board	$100	4	$400
Power Supply	$70	3	$210
Miscellaneous Charging Station Components	$300	1	$300
TOTAL			**$1310**

The requested equipment will be an addition to current Colony robots and equipment. Each colony robot will be equipped with a charging circuit board. Charging circuit boards enable battery recharging and battery status monitoring. We are requesting 20 charging circuit boards to both equip all robots and have replacement charging boards should some break. However, even though this makes our total over the $1000 limit, we would use a smaller number of charging boards with the $1000 total.

Each charging station will use a Firefly+ board which provides processing and wireless communication functions. Power supplies are required to provide DC power to the charging stations for battery recharging. Miscellaneous charging station components include materials for building charging station bases, homing beacon components, charging contacts, and charging circuitry.