Environment Mapping with a Low-Cost Robot Colony

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Abstract

Environment mapping is the process of constructing a map with features relevant to a task without any initial knowledge of the environment. The Colony Project would like to implement a mapping behavior with our low-cost colony of robots. Our goal for this research is enabling the robots to cooperatively construct a map of a simple two-dimensional environment and recognize pertinent landmarks with some coordination from a central computer. Key aspects of this research will involve making the best use of multiple distributed autonomous agents while still gaining an accurate representation of their environment. This work is a continuation of previous Colony Project research and will serve as a foundation for future endeavors.

Research Question and Significance

For many useful mobile robot applications, gathering information about a robot's surroundings is a critical component. While much research is being done on mobile robotic mapping, many of the approaches involve prohibitively expensive cameras that capture massive amounts of data which can take days to process. Instead we intend to tackle the problem from a different angle, using inexpensive sensors on a colony of mobile robots. Because of the low resolution of sensor data acquired by the low-cost Colony robots, we will merge the data from multiple robots on a centralized machine to create a map of the environment. We plan to use this map in conjunction with our previous work on relative localization to allow robots to better understand and navigate their surroundings.

Creating and using a map of the environment will allow the Colony robots to perform an array of more complex, real-world tasks. For example, a job involving transportation of a payload from one point to another would benefit from a map by allowing a robot to efficiently plan a route between the two points. One current technology which could benefit from a mapping method with limited sensor information is the new wave of domestic vacuum robots, which currently move based on heuristics. With our mapping method, these robots could create a map of the environment, which they could use to plan a more effective vacuuming strategy without adding any expensive new sensors.

Overall, the Colony Project seeks to bring down the price of simultaneous localization and mapping (SLAM) systems by developing a low-cost model based on our existing robots. Data sharing between robots and the server will be essential, so streamlining communication between robots and the server will be an important part of this research. Our goal is to first support mapping an environment, and then to support the localization of robots within that environment. Through this research, we aim to build the basis for mapping and localization, allowing for future use of SLAM on the Colony Project platform.

Project Design and Feasibility

The Colony Project uses twenty small, low-cost, homogeneous mobile robots. Each possesses the necessary sensory, computational, and communication capabilities to interact with other robots and networked computers. This phase of the Colony Project will focus on mapping the robots' physical environment and recognizing important landmarks in that environment.

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. The robots use a custom low-cost microcontroller boards based on an Atmel ATMega128 microprocessor designed in partnership with Botrics LLC. In addition to driving the two DC motors, the board interfaces with various devices located on the robots. Basic devices include two buttons, a potentiometer, two RGB LEDs, and a piezo buzzer. Additional analog and digital ports are available for 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.

In order to carry out the individual tasks required for this project, each robot is also equipped with several peripherals that aid them in their ability to function autonomously and gather data about their environment. To determine their location relative to other robots, colony robots use a Bearing and Orientation Module (BOM) consisting of sixteen pairs of infrared emitters and detectors that determine the direction of other robots by the strength of received signals. Five infrared rangefinders are arranged around the robot to gauge the distance between the robot and walls or obstacles. In order to map the path of the robot, magnetic encoders will provide data on the rate of wheel revolution as detailed below. An integrated charging board allows the robots to run for long periods of time without having to go offline for battery recharging. It carries this out by locating a charging bay and helping the robot home in and dock to the bay.

Odometry Sensors:

In order to get accurate information about how far the robots have traveled, we will use encoders on the wheel shafts of the robots. This will measure angular displacement with high precision. By keeping track of the relative displacement of the wheels over time, the robots can determine their path through environment. Small errors due to slipping and averaging will compound over time, limiting the effective distance encoder integration can measure. Even so, matching rangefinder and BOM information to encoder data provides one of the best ways to keep track of environment features.

Wireless Communication:

Wireless communication is essential to both mapping and localization in an environment that prevents line-of-sight communication between robots. The project has developed a fully-connected wireless ad-hoc network with which robots can communicate with other robots and any computers connected to the network. 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. Wireless communication enables Colony robots to share data and coordinate complex behaviors with relative ease.

Mapping Algorithm:

We have researched various methods of carrying out a mapping problem with similar setups, and decided to implement an adaptation of some of these algorithms. Our approach will have the robots initially explore their local environments in a random manner while recording and roughly mapping that area using the encoders and rangefinders. During this time a central server will be collecting and processing information from all of the robots. Once the server has compiled enough information about the overall layout of the environment, it can direct the robots' exploration on a high level to fill in any gaps in the map. When this is complete, the robots can request specific information about any part of the map from the server as needed without having to maintain a full map of the environment in their limited memory.

The server will accomplish its task by maintaining individual maps for each robot. These maps will be probabilistic models of the environment to account for inherent inaccuracies in the sensor information. As the accuracy of this data degrades to the point where it is no longer useful, robots will be assigned new maps and will be treated as distinct robots. Throughout the process BOM information will be used to orient the maps to one another through elementary image rotations. The orientation constraints will increase the overall map accuracy as more maps become associated with one another.

A correlation algorithm will be periodically run on the map segments to piece together overlapping sections. This processor-intensive step produces another image, which quantifies the similarity between two images through elementary translation. An issue we will need to resolve is that the algorithm will attempt to correlate all maps, even those that represent distinct portions of the environment, which have no physical relationship with each other. One possible solution is to have a threshold of minimal correlation, below which maps will be considered distinct. Ultimately, to complete the goal of fully mapping the environment the server will then request robots or teams of robots to move towards these ambiguous regions to resolve the global map.

Background

The Colony team is a group of dedicated and hardworking students. The team consists of members of the Robotics Club and has grown significantly over the years in both numbers and experience. Members of the team have a variety of experiences and come from different fields of engineering and computer science. Austin Buchan and Christopher Mar 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. A weekly general meeting allows members to discuss progress, receive feedback and set goals for the upcoming weeks.

Feedback and Evaluation

Colony project members attend a weekly status meeting to share the progress of sub-projects, discuss the overall status of Colony, and decide on future short-term and long-term goals. These meetings keep members and project leaders up-to-date and provide a forum for brainstorming project ideas and steering the general course of the Colony Project. 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 website, www.robotcolony.org. Through our site, we will allow other groups and individuals to take advantage of the years of research and development already invested in the Colony project. We hope that by providing both 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.

The Colony project has previously presented at the National Conferences on Undergraduate Research (NCUR), as well as the "Regarding the 'Intelligence' in Distributed Intelligent Systems" symposium hosted by the Association for the Advancement of Artificial Intelligence (AAAI). As in the past, we will present all of our findings and developments at the Meeting of the Minds Undergraduate Research Symposium in May 2009.

Budget

Item	Cost
IR/Visible Spectrum Webcam	$160
Dedicated Computer • Processor (Intel) • Motherboard (Intel) • Memory - 4Gb (Generic) • Hard Drive - 300Gb • Case and Power Supply (Generic)	$650
ZigBee-Computer Interface (2x)	$50
Environment Materials	$200
Total	**$1060**

The IR webcam is to be mounted above whatever environment the robots are interacting with so as to see the whole enviroment. Specific IR sensitivity will allow the BOM flashes of the robots to be recorded. The webcam will be crucial for diagnostic and benchmarking functions. The webcam would be attached to a dedicated server, which would constantly be tracking the robot positions, monitoring wireless network activity to collect information from the robots, running the mapping algorithm, and functioning as a dedicated server for ColoNet. Colony Project has not used a complex environment in the past. We would like to develop a modular environment so that it is easy to introduce complex wall and obstacle elements and reconfigure them as necessary to the progress of the project.