Investigating Reliability and Robustness in a Low-Cost Robot Colony

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Abstract

The overarching goal of the Colony project is to maintain a flexible yet inexpensive group of robots for researching emergent behavior and cooperative problem solving. Based on this we have implemented several features and behaviors over the years, but we have never been able to operate the entire colony of robots in concert for days at a time. The two main obstacles to this goal are an inconsistency in robot input/output capabilities and the inability of the robots to recognize and recover from failure. Through research into reliability and robustness we seek to better understand the capabilities of the robots by quantifying their performance and that of Colony as a whole. Developing this benchmarking system will provide an incredibly useful tool for debugging and assessing the feasibility of future projects.

Research Question and Significance

Reliability and robustness are important concerns in any robotics design because they are necessary to guarantee the completion of a task in less than ideal situations. For example, if a group of robots were assigned to clean up a chemical spill, it would be absolutely critical to know how much of the spill had been cleaned, and if there were a robot failure why it happened and how the other robots could work around it. We define reliability as a measure of the frequency of individual robot failure due to hardware or software malfunctions. Robustness is a measure of how well the multi-robot system as a whole responds to failure. While there is ongoing research in these areas using more expensive hardware, we intend to analyze both properties within the context of our low-cost robot colony.

Our research thus far has focused on developing hardware and behaviors for our robots, such as autonomous recharging and object manipulation. We have yet to closely analyze the performance of these behaviors. The inconsistent performance of our robots has been a major obstacle to the development of new behaviors. Having more reliable and robust robots will significantly facilitate our future research. For example, our current research involves cooperatively exploring a region and creating a map of the robots' environment. Having multiple reliable Colony robots allows this distributed task to be performed with minimal hardware failures. Moreover, if robots do fail, other Colony robots will continue to work together to map the regions previously allocated to the failed robots.

Overall, the Colony project seeks to improve the reliability of its individual robots and the robustness of its multi-robot system. This proposed research will give us the opportunity to qualitatively and quantitatively measure the performance of our robots. This analysis will in turn direct us in improving the Colony robots, enabling us to develop more interesting and useful behaviors in the future.

Project Design and Feasibility

The Colony project uses fifteen small, low-cost, homogeneous robots. In addition to observing the performance of the robots, investigating the reliability and robustness of the colony will include benchmarking some of our previous work such as autonomous recharging and wireless networking.

Robots:

The Colony robots are small, oval-shaped, and approximately 15 cm in diameter and 8 cm tall. They move on two wheels in a differential-drive configuration with a caster for support. Each robot uses a custom microcontroller board referred to as the "Dragonfly," which is based on an Atmel ATMega128 microprocessor and was designed in partnership with Botrics LLC. This board drives the two DC motors and interfaces with various devices on the robot, including two buttons, a potentiometer, two RGB LEDs, and a piezo buzzer. Robots may communicate via USB, I2C, and SPI ports, as well as an integrated XBee wireless module. Analog and digital pins support additional devices, including an LCD module for displaying text directly on the robot. Each robot is powered by a rechargeable 6V NiMH battery. The cost per robot is approximately $350.

Robots can detect objects using five infrared rangefinders located around the sides of the robot. Robots may also determine the location of any other robots using the Bearing and Orientation Module (BOM), which consists of a coplanar ring of sixteen pairs of infrared emitters and detectors. Magnetic encoders provide data on the rate of wheel revolution, allowing the robot to precisely and accurately measure distance and speed.

Autonomous Recharging:

Autonomous recharging lets Colony run tasks that take longer than the battery life of a single robot. Each robot continuously monitors its battery levels and requests a charge bay if its power drops below a certain threshold. The robot then finds its way to a charging station and docks using a combination of the BOM and homing beacons to locate it. An integrated charging board mounted on each robot monitors temperature and voltage and regulates current while the robot is charging. Though we have demonstrated autonomous recharging with a few robots we do not know the average recharge time or how long that charge will last across Colony with robots performing various tasks. We will benchmark these times in order to develop more reliable battery thresholds, recharge scheduling, and charging algorithms.

Wireless:

Colony robots use an ad-hoc wireless network to communicate while executing group behaviors. The XBee wireless modules on each robot have limited hardware reliability, which results in occasional packet loss. This issue particularly affects the token ring network when the robots are continuously sharing bearing data for topological localization because a dropped packet can lead to inconsistent data. Analysis of wireless network performance will be a major component of the current proposed research. A thorough understanding of wireless performance and reliability issues will help us improve the reliability and robustness of our wireless network.

ColoNet:

ColoNet is an interface we have developed that enables interaction between Colony robots and users connected over the Internet. A computer that is in proximity to the Colony serves as a internet to robot wireless network bridge so that a user can send commands to individual robots from any remote computer. Robots can also relay real-time data on battery life, sensor readings, motor settings, and program state back to the user. ColoNet will play a critical role in monitoring robots while investigating reliability and robustness.

Diagnostic Station:

A central focus of this project will be to build a diagnostic station that will help ensure individual robot reliability by testing all robot components. Initially, robots will be placed in the diagnostic station to determine if all hardware is present, then tested to see if its sensors return their expected values. Results of the testing and calibration will be returned to the user to indicate if any components require calibration or replacement. When complete, this diagnostic station will run a semi-automated stress test. This will include testing the beam alignment, angle, and intensity response of the BOM; verifying the accuracy of the rangefinders with fixed distance walls; and testing the speed and encoder response of the motors with a compact dynamometer. A Dragonfly board with the appropriate peripherals will be integrated with the enclosure to stimulate all of the sensors and record results. This enclosure will be portable and self-contained to allow diagnoses of problems during demonstrations or when computers are unavailable.

End Goal and Demonstration:

Our goal is to achieve a period of continuous operation of 10 Colony robots for 24 hours with no human interaction. Throughout this time the robots will be performing a task such as mapping that uses a majority of their input and output capabilities while data about the robots' performance will be logged by ColoNet. For example, we will track wireless communications within the colony, including packet loss percentages, network throughput, and mean time to failure. These metrics will be used to analyze wireless network performance. We also plan to use this experimental run to benchmark autonomous recharging times, encoders, BOM, and rangefinders.

Alongside this new research on reliability, we will continue developing the overall robustness of the colony, increasing its ability to recover from and handle individual robot failures. One current example of robustness is the token ring. Due to critical hardware failures, wireless communication between individual robots is occasionally broken. However, the token ring is able to recover from such failures and operate without the participation of all robots. We intend to incorporate similar robustness features into our other existing behaviors, such as cooperative maze solving and autonomous recharging.

Project Background and Organization

The Colony team is a group of hardworking and dedicated students. The team consists of Robotics Club members and continues to grow in size and experience. The Colony project makes a special effort to bring in and educate new members every year so we can take the greatest advantage of fresh ideas and veteran knowledge. Project members have a broad spectrum of previous knowledge and come from different fields of engineering, computer science, and design. Austin Buchan and Christopher Mar will lead the group this year by prioritizing tasks, organizing project teams, and running group meetings.

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 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 on our website, www.robotcolony.org. Through our site we give other groups and individuals the opportunity 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, we will assist other groups in 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). We will present all of our findings and developments at the Meeting of the Minds Undergraduate Research Symposium in May 2009.

Budget

Item	Cost
Diagnostic Station:	
- Frame (IR reflective panels, aluminum)	$230
- Sensors and stimulus devices	$275
- Microcontroller Board	$185
Large Environment Materials (wood, hinges)	$150
Battery Analyzer	$115
JTAG Debugger	$80
Total	**$1035**

Battery Analyzer:
The charge capacity of the robots' NiMH batteries decreases over time from general use and improper charging. A professional battery analyzer can measure the capacity of each battery and determine if and when they need to be replaced.

JTAG Debugger:
One of the most difficult problems we have encountered is when the microprocessor on the robot boards partially fails such that it can still be programmed, but some of it's I/O peripherals are nonresponsive. A JTAG debugger is instrumental in pinpointing this problem.