Navigating Dynamic Traffic Environments 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. For our proposed research, the Colony Project is interested in emulating vehicular traffic in a city-like environment. The development of intelligent, networked cars is a growing field of interest in mobile robotics research, and we will use our robots to study related algorithms and behaviors. Our goal is to enable the robots to autonomously navigate a dynamic environment and to handle interesting traffic objects and events such as lane changes, intersections, tollbooths, and obstacles in the road. This work is a continuation of previous Colony Project research, and it will serve as a foundation for future endeavors. We also hope to contribute to this rapidly growing area of robotics research.

Research Question And Significance

Self-driving cars are the future of road transportation. These cars must not just be able to follow roads and laws, but also be able to navigate and interact safely with other vehicles and objects in their environment. Using a central hub to manage such traffic is not only inefficient, but dangerous because the hub presents a single point of failure. Thus, a system that distributes the management of traffic among the individual cars themselves proves to be more reliable and feasible.

The DARPA Urban Grand Challenge required full scale automobiles to autonomously drive around a simulated city environment while obeying all traffic laws. The winner of this competition, the Carnegie Mellon-designed Boss, was a platform to research how a robot could safely maneuver through a city environment. However, the Boss project did not involve communication with other vehicles to form a fleet of smart robotic vehicles that could work together to optimize traffic flow and communicate road information. By abstracting the complexities of navigation in a real world environment, our research will focus on the robots working together for better traffic flow on a simulated road map.

The Colony Project will emulate autonomous traffic within a model city using low-cost robots. These robots will demonstrate the kinds of behaviors necessary for safe and efficient travel in a city-like environment with other vehicular traffic and unknown road conditions. We plan to study how to have our robots work with each other for efficient traffic flow and trip optimization. Through this research, we plan to have a model of autonomous traffic that can be applied to a larger scale.

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. There are several key components of Colony that are needed to complete the task of modeling vehicular traffic, including the robots, their sensors, the wireless network, the environment, and our simulator.

Robots

The Colony robots are small, circular, and approximately 6 inches in diameter and 3 inches tall. They move on two wheels in a differential-drive configuration with a caster for support. Each robot utilizes a custom microcontroller board referred to as the "Dragonfly," which is based on an Atmel ATMega128 microprocessor.

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 and measure their proximities using five infrared rangefinders located at the front and sides of the robot. One robot may determine the direction in which another robot lies 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 rotation, allowing the robot to accurately measure distance and speed.

New Sensors

In order to follow the roads and make interactions with other robots and the environment easier, the following sensor technologies will be added to the current robot platform:

- Compasses: The robots will be able to use digital compasses to determine their absolute direction and efficiently coordinate with other robots.
- Line sensors: Reflective line sensors and color light sensors will allow the robots to follow the edge of a high contrast line, which will represent roads in the environment.
- Radio Frequency Identification (RFID): RFID tags will be embedded in the environment, which the robots will detect using RFID readers. Robots will use this system to obtain information about the environment, such as whether there is an intersection ahead.

Wireless Communication

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, resulting in occasional packet loss. Imperfect communication would inhibit safe traffic navigation. Accordingly, we have recently redesigned the robots' wireless communication software to improve reliability, enabling such features as error checking and resending of dropped packets. The new architecture also streamlines the use of these features to speed the development of applications requiring robust communication, such as cooperative navigation.

Environment

The environment will be constructed of modular blocks which can be reconfigured for different city models, including intersections, multiple-lane highways, and roadblocks. The base will be constructed from grid tiles, each of which will contain different road patterns that can be combined in different orientations and positions to create different city grids. The roads will be represented as lines which the robots will follow. The robots will then be able to navigate the lines using one or two sensors aimed at the ground. Points of interest in the environment will be marked with RFID tags. The robots will read these tags using RFID readers and gain information about their locations.

Physical barriers will also be added to the environment including buildings, which the robots will have to navigate around, and obstacles that might obstruct the robot's path. We will simulate a road closure by adding a physical barrier to an otherwise continuous road. The robots will sense the barrier and compute a new path, as well as communicate to the rest of the Colony that the path has been blocked.

A final, more complex feature will be a gate, similar to a "railway crossing" that closes at certain times and for variable lengths of time. This gate will physically block the path of the robot, but will also communicate to the robot whether or not the path is open, and when and for how long it will close.

Simulator

In order to facillitate rapid code development for numerous driving scenarios, the Colony Project will develop a simulator capable of running the same code as the robots, but on a fully fledged computer. This simulator will greatly improve productivity by allowing programmers to test their code both at a faster pace and through more varied scenarios than we can physically accomplish. The Colony Project has previously explored the development of a simulator as part of our Spring 2009 SURG "Investigating Reliability and Robustness in a Low-Cost Robot Colony". We plan to build on this by adding the ability to more accurately simulate noisy sensors and to create more complex and interesting environments such as multi-lane roads or busy intersections. A robust and accurate simulator provides both a means of rapid prototyping and a way to allow anyone to develop code for the Colony robots even without access to the hardware.

End Goal and Demonstration

We plan to have the robots moving on a system of roads, autonomously navigating while cooperatively avoiding collisions and sharing information about the road network. Planned sub-behaviors include:

- No-stop intersections: If multiple robots are approaching the same intersection, they will cooperatively decide which goes first and how fast to drive through the intersection so that none of the robots stop.
- Smart road-block avoidance: If any robot discovers an obstruction on a road, it will alert the other robots so they can avoid it in their route planning.
- Smart gates, tollbooths: Robots will communicate with parts of the environment to gain access to roads.
- Smart lane-changing: Robots will be able to drive in a multi-lane environment and change lanes without collisions or stopping.

Project Background

The Colony team is a group of hardworking and dedicated members of the Robotics Club. Over the last several years, the team has accumulated a wealth of experience and has grown substantially in membership. Each year, Colony focuses on attracting new underclassmen members to ensure the group has no shortage of new ideas for projects. Veteran members of Colony have backgrounds in a wide range of robotics related disciplines, including engineering and computer science, providing an opportunity for the project to grow and develop. The leader of Colony this year, John Sexton, keeps the group running efficiently by organizing work meetings and weekly planning meetings to discuss progress, set goals, and prioritize tasks.

Feedback and Evaluation

The Colony project holds weekly meetings to evaluate the status of the project, including discussing the status of sub-projects and setting short and long term goals for the group as a whole. These meetings keep members of Colony on the same page and allow them to collaborate, brainstorm and adjust the direction of the 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. Our site affords other groups and individuals an opportunity to learn from and build upon the years of research and development invested in the Colony project. We hope to provide an intellectual and technological base for other groups to further expand and build 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). In addition, we will present all of our most recent findings and developments at the Meeting of the Minds Undergraduate Research Symposium in May 2011.

Budget

Item	Unit Cost	Quantity	Total Cost
Compass module	$35	5	$175
Color sensor	$20	5	$100
Line sensor	$3	40	$120
RFID readers	$31	5	$310
RFID tags	$4	20	$80
Servos	$20	5	$100
Materials for environment (roads, buildings, obstacles)			$150
		Total	$1035