# Formation Control in a Low-Cost Robot Colony

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## Abstract

Formation control, as it applies to the field of mobile robotics, is having robots maintain a certain distance and orientation between each other as they move as a group throughout an environment. This can be a simple and effective method of coordinating the movements of multi-robot systems and has several applications. Through this proposed research, the Colony Project will investigate how the principles of formation control apply to a colony of low-cost robots. In an attempt to develop a flexible research platform for formation behaviors, we will explore how formation control can enhance the movement and sensory capabilities of our robot colony. This work is a continuation of previous Colony Project research and will serve as a foundation for future research within the Robotics Club.

## Research Question and Significance

Thus far, the Colony Project has had many successes in accomplishing tasks with a single robot. Additionally, the Colony Project has been able to successfully utilize multi-robot behaviors in the form of cooperative mapping and manipulation. However, in some cases multi-robot behaviors can lose effectiveness as the number of active robots increases. This happens when robots spend more time trying to avoid collisions with other robots and the environment instead of carrying out their assigned task. In formation, the robots can better determine their position in space and limit their interactions with the other robots which maximizes both robot and Colony efficiency.

By utilizing formation control, a robot colony can more effectively interact with its environment and use less expensive equipment. There are numerous examples where formation control can be implemented for the betterment of society, most notably mapping and cooperative object manipulation. Formation control lends itself to mapping because it provides a better way of distributing a given workload to multiple robots and allows the robots to work simultaneously. Maintaining control of a geometric formation allows the robots to spread themselves in such a way as to make the most effective use of their multitude of sensors. One of cooperative manipulation's shortfalls is that robots have a limited ability to differentiate between other robots and the target objects. With formation control, the locations of neighboring robots are known and thus the robots are much easier to distinguish from environment obstacles.

## Project Design and Feasibility

### Robots:

The Colony robots are small and oval-shaped, measuring approximately 15 cm in diameter and standing 8 cm tall. Robots move on two wheels with a caster for support and use a differential-drive configuration. Each robot is equipped with two buttons, a potentiometer, two RGB LEDs, and a piezo buzzer, and is powered by a rechargeable 6V NiMH battery. Robots use a custom microcontroller board referred to as the "Dragonfly," which was designed in partnership with Botrics LLC and is based on an Atmel ATMega128 microprocessor. The Dragonfly drives the two DC motors and controls the various devices on the robot. Analog and digital pins may support additional devices, including an LCD module for displaying text directly on the robot. Each robot is able to precisely and accurately measure distance and speed using wheel revolution data provided by magnetic encoders. Robots can also 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. Each robot may communicate using an integrated XBee wireless module, or via USB, I2C, and SPI ports. The total cost per robot is approximately $350.

**Bearing and Orientation Module (BOM):**
The Bearing and Orientation Module (BOM) is a unique low-cost sensor developed to allow one robot to determine in what direction other robots are located. The BOM consists of a coplanar ring of sixteen pairs of infrared emitters and detectors. For the original BOM 1.0 sensor all of the emitters on one robot were flashed at once. Other robots would then use the detectors of their own BOM 1.0 systems to determine in what direction the flash was coming from. The receiving robots determined the direction to the emitting robot by checking each of the circularly placed infrared detectors separately, and choosing the detector that received the strongest signal.

It became clear that only being able to turn all of the BOM emitters on or off together was a limitation to more complex behavior. Thus we developed the electronics for controlling emitter LEDs individually, and termed it the BOM 1.5 system. Individual LED control allows robots to stay within certain sectors of other robots without relying too heavily on wireless transmission. Up to this point, we have successfully implemented and tested the BOM 1.5 system on a pilot group of robots and successfully implemented behaviors such as orbiting and simple grid formation. Now we can continue to equip the rest of the robot colony with the BOM 1.5 system and move forward with more advanced robot formations and behaviors, including formation control.

**Wireless:**
Colony robots use an ad-hoc wireless network established by the XBee transceiver modules to communicate with each other and with any computers connected to the network. Used in conjunction with the BOM in a token-ring coordination scheme, robots are able to continuously share their positions and orientations over the network. In our proposed research, the robots will determine their desired positions based on the data that they receive about the other robots' positions. This communication will be critical to achieving formation control.

**End Goal and Demonstration:**
We seek to implement moderately complex formation control so that robots can maintain a formation while moving as a group through their environment. This would be a direct application of our added capability for the robots to control their distance and direction moved relative to each other. By writing behaviors that alter the desired formation over time and give robots freedom to move within a formation, we can carry out synchronous dynamic behaviors. Such operations involve the robots cooperatively working to not only maintain but also adjust their spacing and distance as the overall goal of the colony changes over time. Because the robots are equipped with sensors that allow them to detect changes in their environment, we are also able to implement reactive behaviors. These behaviors force the robots to use not only data from other robots and their goal as a colony but also information about their surroundings to decide how to act. One robot may receive a stimulus from the environment that requires the colony to adapt or change its goal outright. In this way, the colony can utilize multiple behaviors and decide autonomously which one is best.

An example of this dynamic formation control would be to set up a behavior in which the robots patrol an area in a way that maximizes their spacing, increasing both the efficiency of their patrol algorithm and total area a given number of robots is able to cover. Behaviors that force the robots to react to changes in their numbers exhibit the reliability of a low cost homogeneous robot colony. The loss of one or even several of the robots would not preclude completion of the colony’s overall goal. For example, robots that are forming a protective barrier could detect the sudden absence of a certain robot from the formation and call for another robot to take its place over the wireless network. Our goal for this research will be to demonstrate such a dynamic formation control behavior that can respond to the loss of a robot and regroup with other colony robots in the area.

## Project Background and Organization

The Colony team is a group of students within the Robotics Club. It consists of committed, hard-working students with a wide range of experience and backgrounds in computer science and various engineering fields. Veteran members use their knowledge and expertise to make significant developments on the project, as well as train inexperienced members so that the research can continue. Project members are divided into subgroups, which meet throughout the week to work on different components of the project. Project leaders Austin Buchan and Christopher Mar have been very successful in making progress on the Colony project over the past year, and will use their experience to guide the team towards further advancements.

## Feedback and Evaluation

Colony project members convene once a week to report the progress that was made on the different components of the project's research. These meetings provide a forum for peer feedback on different subprojects, discussing developments on current goals, and brainstorming future goals. Our advisor, Professor George Kantor, meets regularly with the project leaders to give professional feedback on the project, attends review meetings, and offers suggestions for improvements.

## 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), 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 continue to present our findings and developments at the Meeting of the Minds Undergraduate Research Symposium in May 2010.

## Budget

| Item | Cost |
|---|---|
| Components for BOM 1.5 x 10 (Digikey + Mouser) | $234.82 |
| BOM1.5 collimators | $150 |
| Modular environment for formation behaviors | $75 |
| 13' Tripod | $80 |
| Camera Adapter for Tripod | $30 |
| 2 4x8 whiteboards (US Markerboard) | $166.24 |
| 20 whiteboard markers | $20 |
| Marker mounts for 15 robots | $30 |
| parts for general maintenance | $150 ($10 x 15 robots) |
| ZigBee firmware upgrade board | $75 |
| ***Total*** | ***$1011.06*** |

**Notes:**

- The BOM collimators are pieces of plastic that keep the emitters and detectors of the BOM at the correct angle, and prevent them from getting bumped out of place. This critical since individual LED angle now matters with the BOM1.5.
- The tripod is necessary in order to take long exposure pictures of movies of the robot formations. the 13 foot height is appropriate because it will allow a field of view that can see 15 robots moving in a formation at once.
- The whiteboards and markers are useful as a way to demonstrate and test the formations. With up to 15 robots driving at once, it would be near impossible to see which robot made a mistake, and even trying to see the specific mistake in a video could be a challenge. Having the whiteboards would allow us to visualize the path each robot took and see any anomalies.
- As our colony is aging it becomes neccesary to replace parts. Also, since many parts are prototypes, they do not have the level of durability one might expect from a commercial product. Thus, in order to use the colony platform to carry out this research, we need to maintain the robots.