# Communication and Positioning Module for Multi-Robot Collaboration

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## *Abstract*

Robotics research involving group behavior often requires robots to know positions of other robots in the group or region. This is a difficult problem, and there are several possible approaches with different trade-offs in terms of memory and processing requirements, type of information gained, and information accuracy and availability. A SURG-funded project addressed this problem last year and faced difficulties due to the computational complexity of the proposed solution. We are researching a new approach inspired by biological colonies that is equally accurate and far more efficient. To implement this new approach, a device is needed that can be mounted to the robots and report information about the range, bearing, and orientation of neighboring robots. The device will work using modulated infrared (IR) light, which is a well-suited and also low cost technology. After initial development costs, the device will be relatively inexpensive to reproduce. Further, it can be used with essentially any robotic platform. This facilitates the development of inexpensive colony robots that can localize and perform complex behavior.

## *Research Question and Significance*

There is considerable interest in the robotics community in developing systems in which many robots interact and work together toward a common goal. There are many advantages and applications for this kind of robotic system. If one robot in the system is lost or disabled, the overall behavior of the colony remains intact. Further, a colony of robots can approach a problem in a distributed fashion, enabling high efficiency in complex problems and environments. A few example applications of mobile multi-robot systems are searching for survivors after an earthquake, locating landmines in a large field, herding sheep, simultaneous localization and mapping (SLAM), and detecting the presence of toxic chemical agents.

A central problem in multi-robot systems is for each robot to know how it is positioned in the environment. Without this knowledge is it difficult for the robots coordinate and perform useful behaviors. There are a number of approaches to this problem. In one scenario, each robot has universal understanding of the world and knows where each of the other robots is located. This approach was taken in a previous undergraduate research project at CMU. This solution has high per-robot computational and memory costs, and involves unnecessary redundancy in environment knowledge.

Another approach is to look at how nature handles this problem. Ants, bees, and birds are a few animals that exhibit colony behavior. Often these behaviors are quite complex. Generally these animals do not have global knowledge about the environment or other animals in the colony. In nature, interesting large scale behaviors emerge when components in the system only have local knowledge. We propose to develop a sensor that facilitates emulation and study of this behavior paradigm in robotic systems.

The sensor will use rapidly pulsed infrared (IR) light to calculate range, orientation, and bearing information. A sensor with this functionality could be widely useful. Advantages of using IR include small size and low cost, compared to other technologies such as sonar or laser. We plan to utilize the sensor on the robots from the Colony II project at CMU, but potentially the device could be used on other colony robotics projects as well. This device makes emergent behavior robotics research more accessible to groups on limited budgets.

## ***Project Design and Feasibility***

This project seeks to develop a small device that can be attached to the top of a mobile robot and detect the range, bearing, and orientation of surrounding robots. This enables each robot in a colony of robots to know where it is and how it is angled with respect to other robots. This information is crucial for making the robots interact in a coordinated fashion.

A SURG-funded project from a last year also addressed the problem of relative localization in a robot colony, with an entirely different approach. Rather than have each robot know only about robots immediately neighboring, the project from last year sought for each robot to know about every robot in the colony. Although the previous project was fairly successful, this approach was inefficient and difficult to implement on low budget hardware. It was hypothesized that the same problem can be solved in a considerably more efficient and robust way by employing principles that enable, for example, ants to coordinate in a complex fashion to build an anthill while each ant likely does not sense beyond its immediate vicinity.

The central insight gained was that global understanding of the colony can be extrapolated from local position information. This can be achieved when each robot knows the locations of neighboring robots, and each robot can communicate with those neighboring robots. The module we propose achieves both local communication and localization. The primary mechanism at work is modulated IR light. Each robot will contain a ring of IR emitters and detectors, around 12 of each. The IR light will be sent in pulse that encodes a packet of data. The packet contains information such as the identification number of the robot initiating the packet, the identification number of the particular IR emitter that sends the packet, and the position of the robot sending the packet.

Range is the distance between two robots. Range can be determined by measuring how much the intensity of the IR light is diminished at the destination robot versus the source. This works because the IR beam produced is slightly conical and widens with distance. Orientation is the angle between two robots with respect to the environment. This quantity is measured by comparing the relative intensity readings of adjacent IR detectors. Bearing is the rotation of one robot relative to the rotation of another robot. Since the packet encoded by the IR signal encodes the number of the emitter sending the signal, and since the number of the detector that received the signal is known, the relative difference in rotation can be ascertained.

Our name for this device is the Range, Bearing, and Orientation Module (RBOM). Unlike the device built previously, the RBOM will contain a microprocessor and FPGA onboard to shift the computational burden off the main robot processor and make the device function as a standalone module. The FPGA will provide reconfigurable logic between the IR circuit components and the processor for filtering and low level processing of the infrared signal. A software interface will be developed for the RBOM that makes it straightforward to collect up-to-date range, bearing, and orientation information at each specified time interval.

Similar relative localization functionality using modulated IR was implemented in the "Swarm" project developed by iRobot Corp and initially funded by DARPA. However, the localization functions were implemented as an integrated part of their robot, and thus the functionality is not available for use on other robots. Because the project was government and commercially funded, the documentation detailing the specifics of the iRobot implementation is not in the public domain. Nonetheless, we feel that we have an adequate understanding of the device that we can feasibly implement it.

Research and development of the RBOM device is slated to proceed as follows: First, we will purchase infrared circuit components and perform experiments to characterize their behavior. Next we will develop simulation routines in MATLAB to develop more precise models for extracting range, bearing, and orientation data. Concurrently we will build prototype circuits to test our simulation results and update our simulation with additional data as it is acquired. Once we have developed a functioning prototype, we will design a circuit board layout and then have the device fabricated. We hope to complete this phase by the end of the Fall 2005 semester. The next phase will be to perform tests with the board mounted on the robots and development of software to control and interact with the board. This phase will take place during Spring 2006. By summer 2006 hopefully we will be able to use information collected from the RBOM to create interesting colony behaviors.

## Background

The student team developing the RBOM is experienced and capable. Aaron Johnson is a sophomore in Electrical & Computer Engineering. He has worked on several robotics projects through the Robotics Club including localization in the Colony II project last year. He is also researching snake robots in the Sensor Based Planning Lab in the Robotics Institute. Ryan Kellogg is a junior in Electrical & Computer Engineering and Biomedical Engineering. This is his third year to work on colony robotics with the Robotics Club. He concurrently researches in the NanoRobotics Lab in the Robotics Institute. Suresh Nidhiry is a sophomore studying Computer Science. He made many contributions to sensing mechanisms for the Colony II project last year and brings experiential knowledge to the RBOM project. Kevin Woo is a freshman in Electrical & Computer Engineering and is new to colony robotics. Through experience working with LEGO Mindstorm robots and knowledge of programming concepts, Kevin will help characterize IR circuit components and aid development of the RBOM software interface.

## Feedback and Evaluation

The project will receive advice from our advisor Howie Choset. Professor Choset will attend meetings, offer suggestions, and provide feedback on the how the group is progressing on the project. He will also provide advice on how the group should progress further and how to overcome obstacles encountered during the project.

## Dissemination of Knowledge

The completed Range, Bearings, and Orientation Module (RBOM) will be documented and shared online at the Robotics Club website (http://www.roboticsclub.org). This will allow everyone to view how the RBOM operates and the underlying technology behind the device. As a result the RBOM can be used in a variety of future applications. The finished device will also be presented at the Meeting of the Minds in May of 2006.

## *Budget*

Components for one RBOM module:

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| Atmel Microprocessors | $8 |
| FPGA | $20 |
| IR emitters/detectors | $15 |
| Board fabrication | $6 |
| Other electronics | $5 |
| RF transmitter | $13 |
| RF receiver | $18 |
| | |
| Total cost per module | $85 |
| **Total Expenditure (Cost per module * 12 robots)** | **$1020** |

The Atmel Microprocessor will execute algorithms for analyzing the IR signals and gleaning out useful information. The FPGA provides intermediate reprogrammable logic between the infrared emitters/detectors and the processor. The IR emitters send out an IR signal at a frequency created by the FPGA, probably around 40KHz. The IR detector only allows modulated IR signals to pass, effectively filtering out ambient light and other extraneous light sources. Board fabrication, the process of having the board physically constructed, is relatively inexpensive when several boards are being made. Radio Frequency (RF) transmitters and receivers will be utilized at least in the initial versions of board design to make parallel programming of the RBOM processors possible.