

Multi-Robot Communication with LEGO Mindstorms *

Rachel Gockley

rgockley@andrew.cmu.edu

Advisor: Illah Nourbakhsh

illah@cs.cmu.edu

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Abstract

The LEGO Mindstorms system has greatly lowered the entry barrier into the field of robotics. To stimulate further activity in robotics, this project aims to develop communication and cooperation methods between two LEGO robots, and to demonstrate these methods by utilizing them in a dual-robot system that cooperatively dances to music. All findings of this project will be published online to encourage further development.

1 Objective

LEGO Mindstorms are a line of the popular LEGO toys that allow for the creation of robots. At the heart of the system is the RCX unit, a programmable controller for up to three motors and three sensor inputs. Each RCX contains a built-in infra-red (IR) port, generally used to download programs from a PC. A single Mindstorms Robotics Invention System (RIS) typically costs around \$200, making it a very affordable system.¹

This project entails two main goals: robust communication between two LEGO RCX units, and the demonstration of inter-robot communication through cooperative actions.

- **Communication** Each LEGO RCX unit contains an IR communication port. Traditionally, this port is used strictly to download programs from a PC to the RCX. However, many people² have worked to decode the IR protocol used by the RCX. Several programming languages have been developed that use this protocol to implement

*LEGO, LEGO Mindstorms, Robotics Invention System, and RCX are registered trademarks of the LEGO Group, Inc.

¹For comparison, the cost of the RIS is approximately the same as that of the Handyboard (www.handyboard.com), a popular controller board. However, note that the RIS contains enough parts to construct a complete robot, whereas the Handyboard is just the cost of the controller.

²For example, both Russell Nelson (<http://www.crynwr.com/lego-robotics>) and Stef Mientki (http://baserv.uci.kun.nl/~smientki/Lego_Knex/Lego_electronica/IR_tower/IR_tower.htm) provide information on the RCX IR protocol.

methods of sending a single character at a time from one RCX to another.³ Unfortunately, little documentation on such methods exists. One goal of this project is to examine RCX IR communication, document it, and improve upon it. In doing so, the following will be studied:

- *Robustness*: IR typically requires line-of-sight for accurate transmission. That is, the transmitter and the receiver must be aligned, with no obstacles between them, to guarantee communication. This project aims to determine how robust the RCX IR communication can be, by determining the minimal conditions necessary for successful IR transmission. This includes how far apart the two robots can be, how much of an angle can be between them, and what level of ambient light can be tolerated.
- *Language*: Transmission of a single character, equivalent to any one number from 0 to 255, is not always sufficient for communication. This project hopes to develop a fuller language, which will allow for the transmission of strings of characters or even of direct commands. This will provide a more intuitive setting for RCX communication, which will be much easier for others to reuse and utilize.
- **Cooperation** The use of multiple robots introduces several challenges not encountered with single robot systems. Such challenges include:
 - *Synchronization*: who goes first? If two robots are to perform the same task, they may need to take turns. How does each robot determine whose turn it is? One possible solution to this is a master-slave relationship; the slave can act only when given permission by the master.
 - *Motion planning*: two robots cannot occupy the same space at the same time. How can one robot move to a goal without knowing where the other robot is?

In order to demonstrate not only these difficulties but also possible solutions, the second part of this project is to develop sound sensors for the LEGO robots, and create algorithms to allow two robots to cooperatively plan and perform a dance in time with music. Dancing creates several interesting challenges, due to the high level of communication necessary for one robot to lead another, as well as the difficulties inherent in driving two robots in close proximity. Most likely, the dance will take the form of a waltz or similar dance with well-defined, planned motions that are well-suited to a master-slave communication relationship.

2 Design

2.1 Electronics and Mechanics

LEGOs will be used as the mechanical base for both robots. This serves two main purposes. Firstly, LEGOs are widely available, and their popularity provides the impetus to develop robust communication. Secondly, since LEGO robots can be constructed rapidly and with

³Two such languages are Interactive C 4.0 (<http://www.kipr.org/ic/download>) and Not Quite C (<http://www.enteract.com/~dbaum/nqc/index.html>)

little mechanical knowledge, concentration can be placed on algorithm development and programming, which are the main interests of this project.

Since the RCX has only three input and three output ports, its electronic systems are highly limited. One challenge that this project aims to overcome is this limitation, to determine how intelligent a system can be developed with only three ways to gain input from its surroundings. Sensors that this project intends to utilize include an ultrasonic rangefinder for obstacle avoidance and positioning, touch sensors, again for obstacle avoidance, and rotational encoders to determine wheel position. Also, a sound sensor will need to be constructed, to determine the rhythm of music.

2.2 Programming

The focus of this project is the development and dissemination of algorithms to control multiple RCX units. Different methods of cooperation will be explored. Further, the largest programming challenge will be in developing an algorithm for synchronous dancing. Just as most people find coordinating a dance – and not stepping on their partners' feet – it is challenging to develop methods for robots to perform similar actions. Causing two robots to move in patterns that are both technically correct and aesthetically pleasing will be the second focus of the project.

3 Background

Rachel Gockley is currently a Junior in Computer Science, pursuing minors in Philosophy and Robotics. She has had two years of robotics experience, due to involvement in the Carnegie Mellon Robotics Club⁴ as well as courses such as General Robotics (24-354), Mobile Robot Programming Lab (16-362), and Robotic Manipulation (15-384). She is currently working for her advisor, Illah Nourbakhsh, to develop high-level behavior for a small mobile robot for NASA.

4 Presentation and Dissemination

The motivation behind this project is to stimulate further creativity in the LEGO Mindstorms target audience, which, according to The LEGO Group, is ages 12 and above. To do so, all results of this project will be published online. Project details, including construction and programming details, such as the code libraries necessary for communication, are to be made publicly available, to aid others in completing similar tasks. All such details will be archived on a website⁵, and various public forums about LEGOs will be alerted to its existence.

⁴<http://www.roboticsclub.org>

⁵URL is still to be determined.

5 Budget

<i>Item</i>	<i>Details</i>	<i>Unit</i>	<i>Total</i>
LEGO Mindstorms Robotics Invention System (RIS)	Includes one RCX, two motors, several sensors, and various LEGO pieces. Although two RCX units will be required, one is provided.	\$200	\$200
LEGO Rotation Sensors	Count the number of times a wheel has rotated; one for each wheel of each robot is required for accurate motion. (x4)	\$15	\$60
LEGO Compatible Ultrasonic Rangefinder	Measures the distance to obstacles with 1/2-inch accuracy; required to keep the robots from colliding.	\$85	\$85
Miscellaneous LEGO pieces	While the RIS contains a large number of LEGO parts, often additional pieces, such as extra motors and gears, are required for construction.		\$60
Miscellaneous Electronics	For sound sensor construction, as well as any additional necessary electronics.		\$20
<i>Estimated Total</i>			\$425