

AC 2007-2026: AN INTRODUCTION TO MECHATRONICS EXPERIMENT: LEGO MINDSTORMS NEXT URBAN CHALLENGE

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An Introduction to Mechatronics Experiment: LEGO Mindstorms NXT Urban Challenge

Abstract

This work describes a laboratory experiment designed for an introductory mechatronics course to employ discovery-based learning. Two robotic vehicles are constructed using new LEGO Mindstorms NXT sets. One of the two moving robots is equipped with sensors and programmed to follow the prescribed path on an enlarged city map. The other robot has no sensors and is programmed to follow the first robot. Programming of the robots is accomplished using the National Instruments LabVIEW Toolkit for LEGO Mindstorms NXT and the Mindstorms NXT software. The inter-robot communication necessary for robot following uses Bluetooth wireless technology. This experiment mimics some segments of the Defense Advanced Research Project Agency's (DARPA) Urban Challenge – a 2007, \$2,000,000 prize autonomous vehicle challenge to complete 60 miles in traffic in less than six hours.

Introduction

LEGO Mindstorms NXT Urban Challenge is a six-hour engineering design experiment implemented as a part of an introductory mechatronics course. Its major function is to promote discovery-based active learning and knowledge systematization. Robot building is a powerful student motivational tool¹. Mimicking an actual multimillion-dollar robotic prize competition² further enhances student motivation. A set of new tools like LEGO Mindstorms Education Base Set with NXT technology (became available in August 2006) and the National Instruments LabVIEW Toolkit for LEGO Mindstorms NXT (became available for downloads in mid-December 2006) are implemented in this novel engineering design experiment. Bluetooth technology is used for robot-to-robot communication and control.

Previous Work and Justification

The LEGO Mindstorms NXT Urban Challenge experiment is a part of the pedagogical system implemented in the Introduction to Mechatronics course and the Mechatronics curriculum. This pedagogical system is based on McCarthy's³ version of the Kolb⁴ learning cycle and was motivated in part by work presented by Harb *et al*⁵. According to Kolb and McCarthy one can learn new concepts by following a pattern (the learning cycle) exemplified by the questions why, what, how, and what if. A set of activities is associated with each part of the learning cycle. Active discovery-based learning is considered an important part of this learning cycle, especially in engineering⁶. Bruner⁷ defines discovery learning as a cognitive instructional model whereby students are empowered and encouraged to learn concepts and principles through active hypothesis testing and discovery. "The student will have to explore examples and from them 'discover' the principles or concepts which are to be learned⁷."

Engineering laboratory courses use active learning. Depending on the course objectives, the laboratory experiments are either of a cookbook type where students follow a set of instructions and all produce similar results, an organized project type where the instructions are not precise

and allow for some creativity, an open-ended project type where the course instructor has a reasonable knowledge of the final outcome, or research where neither the students nor the instructor know the final outcome of the experiments. Often, open-ended projects are used as powerful pedagogical tools for discovery-based learning. To minimize the time to build prototypes and to minimize the cost of such projects by using low-cost plastic parts and enforcing reusability of parts, many instructors adopted LEGO bricks and LEGO computerized systems as educational tools. There are hundreds of papers describing the use of LEGO bricks in engineering research⁸. Many papers use LEGO Mindstorms RCX with the Robolab programming environment (RIS 2.0) based on National Instruments LabVIEW software for various projects and courses like robot competitions^{9, 10}, programming^{11, 12}, and project-based learning¹³⁻¹⁹. The literature reviewed shows positive results like increased student enthusiasm towards engineering, perceptual and actual increase in students' knowledge, and development of design and team skills. However, some evaluators of LEGO Mindstorms RCX found it to be restrictive for more advanced projects in both hardware and software. A number of third-party solutions were proposed to increase its flexibility^{12, 20}.

LEGO's response to a need for an improved microcontroller system is addressed in their new LEGO Mindstorms NXT product. LEGO Mindstorms RCX is already over eight years old (introduced in 1998) and LEGO stopped its production and any further developments in favor of its new product, LEGO Mindstorms NXT. Furthermore, there is no hardware or software compatibility between the two systems. The only exception is with the old sensors, which can be connected to the new system with conversion cables and programmed using downloadable software modules. Even though the support for the old system will continue and the warehouses have a number of the old systems left, LEGO urges new users to buy NXT sets. While the ideas from literature using old LEGO Mindstorms RCX sets will still be valid, the implementations are quickly becoming dated. Since a recent literature search did not reveal any education research articles implementing the new LEGO Mindstorms NXT with its improved hardware and software capabilities, this report will note some of the new, interesting, and possibly useful features.

Curriculum Context of LEGO Mindstorms NXT Urban Challenge Experiment

Introduction to Mechatronics is a two-hour lecture two-hour laboratory one-semester junior-standing course available within the recently offered Bachelor of Science in Engineering with specialization in Mechatronics (BSE-Mechatronics) program at Colorado State University - Pueblo. The LEGO Mindstorms NXT Urban Challenge experiment is implemented within this course. The lecture portion of the course deals with the basic elements of a mechatronic system like actuators, sensors, data acquisition subsystems and various controllers with their underlying principles as well as mechatronic systems case studies.

During laboratory sessions, students use the National Instruments (NI) LabVIEW programming environment and NI ELVIS prototyping boards to verify characteristics of a few chosen actuators and sensors and interface these devices to a PC-controlled data acquisition and control subsystem. In addition, through a set of three lab sessions, students become proficient with programming Microchip's PIC16 microcontrollers for embedded applications.

To add an encompassing system's view to the course, facilitate discovery-based learning and promote further development of graphical programming skills, a three session project, LEGO Mindstorms NXT Urban Challenge, is designed and implemented. Some of the specific discovery-based learning objectives for this project are to increase the practical knowledge of basic robot controls and inter-robotic communications.

Since this is the last experiment in the course, students are already familiar with graphical programming concepts through LabVIEW and microcontrollers. Additionally, in their first year Introduction to Engineering course, they were exposed to an older LEGO Mindstorms RCX environment allowing them to transfer some of the experience to the new system. Experiment grading is based on fulfilling two basic criteria (line following and robot following) and on fulfilling some additional criteria from the actual DARPA Urban Challenge announcement².

Laboratory Assignment and Hardware Specifications

This laboratory experiment is designed to further develop student engineering design and graphical programming skills, and to specifically provide a practical experience with basic robotic controls and inter-robotic communications. The inspiration for the experiment comes from DARPA's Urban Challenge and from the Bluetooth wireless communication capability of the new LEGO programmable bricks. The experiment requires two LEGO Mindstorms NXT sets.

Laboratory Task

Two mobile robots are to be constructed, one with sensory inputs (master) and the other without (slave). The master should include at least two sensors: one light sensor for line following and one ultrasonic sensor for sensing any obstacles (park toy cars) on the road. A large map of the area with START and FINISH positions as well as the desired path will be provided. The two robots are to operate as follows:

1. After placing the robots at the START position one behind the other, both robots should be turned on, Bluetooth communication should be turned on and initialized, and appropriate programs executed.
2. Then, the master robot should follow the prescribed path (line following). The choice of a type and a number of sensors is open.
3. The slave robot should follow the master robot by receiving commands from the master robot.
4. When they reach the FINISH position, both robots will execute a parking maneuver resulting in the robots being parked one behind the other.

Hardware and software designs are not further specified. Students are allowed to use existing designs and modify them to satisfy the project requirements.

LEGO Mindstorms NXT Specifications

At \$250, LEGO Mindstorms NXT includes one NXT Intelligent Brick with four input ports and three output ports, four sensors (a light sensor, a touch sensor, a sound sensor, and an ultrasonic

sensor), three servo motors, and various connecting elements. Each servo motor has a built-in rotation sensor that measures speed and distance thus allowing precise motor control within one degree of accuracy. NXT Intelligent Brick includes two microcontrollers: one 32-bit ARM7 microcontroller with 4 KB FLASH and 64 KB RAM, and one 8-bit AVR microcontroller with 4 KB FLASH and 512 B RAM. Apart from a major change in microcontroller hardware, when compared to the previous LEGO Mindstorms RIS 2.0 version, NXT has more memory, is Bluetooth enabled, has an additional input port, has an 8-bit 12-16 KHz sample rate sound channel with external speaker, and is MAC compatible. USB 2.0 port allows fast program transfer. A quick-start program can get students started three times faster than with RIS 2.0. LEGO Mindstorms NXT is not compatible with any older versions of LEGO Mindstorms.

Robot programming can be accomplished using LEGO Mindstorms NXT software. For more complicated tasks and added functionality National Instruments LabVIEW Toolkit for LEGO Mindstorms NXT²¹ can be used to create and import modules into NXT programs.

Results

Hardware implementation is relatively simple. Both robots are built following the quick-start guide supplied with the LEGO Mindstorms NXT set. The master robot is then equipped with two sensors, an ultrasound sensor pointing straight forward and a light sensor pointing down. Photographs of the master and slave robot configurations as used in the project are shown in figures 1 and 2. There is a set of articles²²⁻²⁴ describing other simple configurations. However, they are not used since the LEGO's in-the-box solution is sufficient and available.

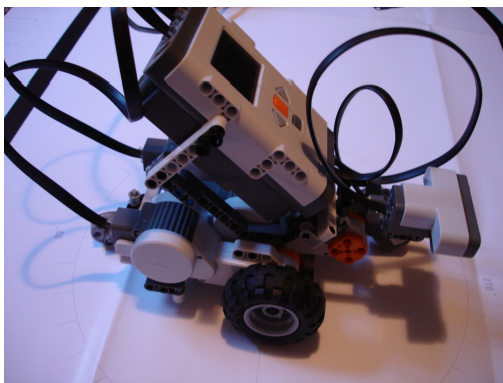


Figure 1. Master robot configuration

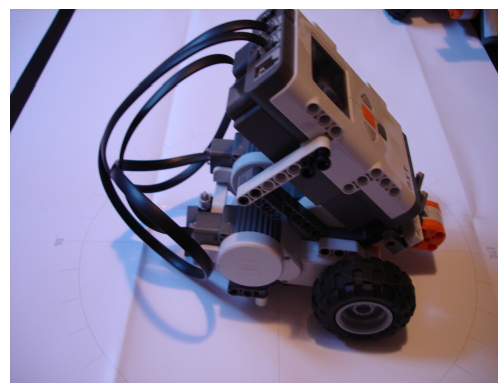


Figure 2. Slave robot configuration

A map of the area around campus with a desired path is downloaded from the Web²⁵, enlarged, printed on 12 sheets (8 ½ x 11 inch), and taped together. Figure 3 depicts the robots on the path on the map.

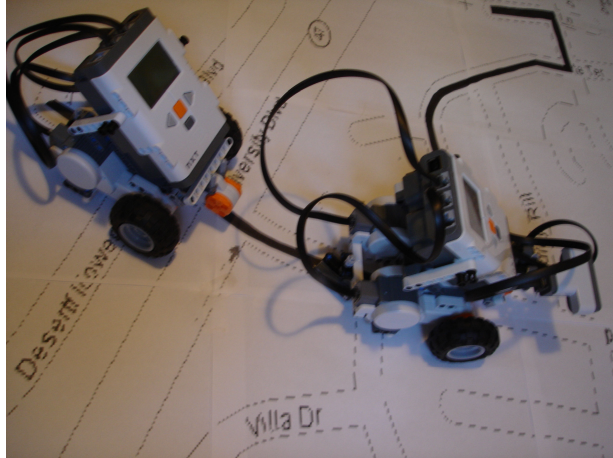


Figure 3. Robots following the path on the map

The line-following software was modified from a Web source²⁵. The robot-following set of programs (one for each robot) utilized an array block (customized LabVIEW NXT block) adopted from Hassenplug²⁶.

When started, the master robot sweeps left and right in widening arcs until the line is located by a single light sensor. Then it moves forward until the line is lost. At this time the search begins again. After traveling a great enough distance (approximately two wheel revolutions) directions are transmitted via Bluetooth to the slave robot to bring it to the close proximity of the master. If a line is not found within a ninety-degree arc during the line-search period, the end of the line (FINISH) is assumed. Then, the master robot moves forward another two wheel revolutions to allow the slave robot to move right behind it. The motion of the master robot is interrupted if the ultrasound sensor encounters an obstacle. The master robot program consists of the main program, nine My Blocks, and the array object and it is not shown due to its complexity. The simple slave robot program is shown in Figure 4.

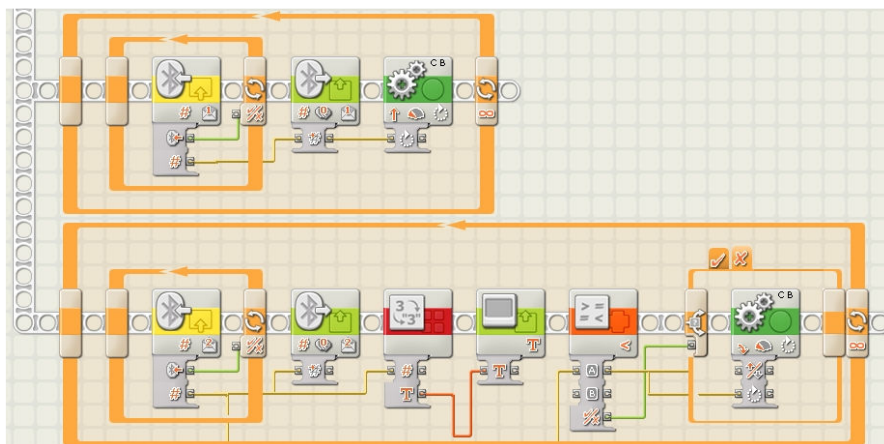


Figure 4. Slave robot program

Lessons Learned

Robotics projects are an effective educational tool for discovery-based learning. Student satisfaction is high at the end. However, the six laboratory hours dedicated for the LEGO Mindstorms NXT Urban Challenge project are not adequate. Considerable amount of unscheduled laboratory time is needed to complete the project. It was found that while easy to use for simple tasks, the LEGO Mindstorms NXT software is somewhat cumbersome for more complicated programs.

Conclusions

In this paper, a mechatronics laboratory design project implementing a new hardware/software environment (the LEGO Mindstorms NXT) is presented. The project combines a traditional robotic line-following task, an obstacle detection task and a robot-following task. The robot-following task includes two mobile robots following each other. The communication between robots is established using the Bluetooth wireless technology. Discovery-based learning objectives dealing with robot controls and inter-robot communications are satisfied. Student comments are positive, and the project setup is cost-effective (about \$500 per setup).

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