A Multidisciplinary Team Project for Electrical Engineering, Computer Engineering, and Computer Science Majors

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Abstract

This paper describes an interdisciplinary project for a freshman course designed for electrical engineering, computer engineering, and computer science majors. The project uses LEGO building sets and a microcontroller in the design, implementation, and documentation of a sequence of increasingly complex tasks. Students learn interdisciplinary team skills, and are introduced to computer hardware concepts and the C programming language. Project tasks, costs, and suggested equipment are discussed in detail.

I. Introduction

The Electrical Engineering and Computer Science (EECS) Department at the University of Evansville offers three bachelor's programs: electrical engineering (EE), computer engineering (CoE) and computer science (CS). Due to historical concerns and logistical difficulties, at the present time the EECS freshman students take separate sections of an introductory freshman course divided by major, and the classes and sections are only loosely tied together. With the advent of a newly renovated building and a new evaluation criteria for ABET Engineering Criteria 2000 that students will be able to work in multidisciplinary teams, it was felt that the freshman course would be an ideal place to introduce multidisciplinary practice.

During Summer 1999, the authors developed a hands-on project compatible with computer science, electrical engineering, and computer engineering objectives, and suitable for all freshman students in these majors, allowing us to mix them. The project was designed to meet the following objectives:

- The project must be suitable for EE, CoE, and CS majors. There must be some circuit design and construction for the EE majors, some "real time" control operations for the CoE majors, and some significant programming for the CS majors.
- The project must be able to accommodate groups as small as 3 and as large as 6.
- The project must be challenging and creative, and it must be attractive to typical, traditional-aged freshmen.
- At least 75% of the project equipment must be reusable. (In fact, nearly 100% of the project equipment will be reusable.)

From this list of requirements, we determined that a hands-on robotics project involving a LEGO building set, a controller board, and controller software would meet all our requirements.

Robotics is an inherently interdisciplinary endeavor involving wiring and connecting sensors for the EE majors, using an embedded microprocessor to control these sensors for the CoE majors, and programming for the CS majors. In addition, using LEGO as a building platform allows some mechanical design as well. Robotics also is inherently interesting to students. Many students often ask about the field, and a few of our students have gone on to do independent research projects in robotics.

II. Background

The use of LEGO robotics for educational purposes has become widespread. The first LEGO robotics course was developed at MIT as a computer engineering design competition course modeled after a mechanical engineering design competition course[1]. Since then, courses using LEGO robotics have been developed that range from high school courses exploring engineering career options to graduate courses devoted to actual robotics design. A sampling of such courses include:

Toying with Technology at Iowa State University[2] - A summer course for high school women to encourage them to pursue science and engineering careers, and an education course to teach K-12 science teachers about engineering careers.

Robotic Design Studio at Wellesley College[3] - A course that introduces the application of engineering and design concepts to everyday life.

Artificial Intelligence Robot Building Lab at Bryn Mawr and Swarthmore Colleges[4, 5] - Explores artificial intelligence by building an autonomous vehicle.

Autonomous LEGO Robotics at Case-Western Reserve University[6, 7] - A junior-level engineering and science design course that "teaches critical thinking and interdisciplinary teamwork by building your own animal," culminating in a contest.

Introduction to Robotics at University of Southern California[8] - A senior-level technical elective that teaches concepts in modern robotics by building one, culminating in a contest.

III. Project tasks

In Fall 1999, the authors conducted a six-week pilot run of this project with twelve students chosen from the current introductory freshman course sections. The students were chosen based on the recommendation of their instructors identifying them as students that would benefit from this activity. For the pilot project run, the authors wanted to limit the team size to four students so that we could require each student to be in charge of one aspect of the project. The students were divided into three teams of four students, each having a least one EE, CoE, and CS major. We will first describe the activities conducted during the pilot run, followed by our assessment and future plans.

Each team was initially given an assembled vehicle with the following characteristics:

A LEGO vehicle with two motor-driven rear wheels and a front pivot.
Two forward-looking light sensors.
Two bump sensors attached the front right and left bumpers.
A microcontroller with its own power source, analog-to-digital (A/D) converters (for the light sensors), motor driver amplifiers, digital I/O ports (for the bump sensors), and beeper.

The microcontroller is programmed using the C language. A set of library functions was provided to ease the interfacing to the motors and sensors. Most of the students had not had a formal course in the C language, but each group had one or more members who had some programming experience. Hence, we were able to illustrate the operation of the vehicle using skeletal programs and examples. After four hours of instruction all of the groups were mildly proficient at creating new programs to control the vehicle. Students were asked to program their vehicles to locate static light sources, track moving light sources, find their way around random obstacles, and stop and start in response to external signals. By the end of the third week of class (nine hours of instruction), students were ready and eager to take on a more challenging project.

For the pilot program, a design project was assigned that was to be completed in just three weeks. Teams were given a complete LEGO building set and a computer module, including the pre-assembled vehicle (see the resources section below for details). Students were given a one-hour overview of LEGO construction and design techniques, including bracing and gear reduction techniques. Students were also given the paper *Art of LEGO Design*[9] to use as a reference.

Each team member had a specific area of the project for which they were primarily responsible. The team itself decided which members were assigned to each area. The four areas and their responsibilities are listed below:

Coordination - Responsible for arranging all meeting times and places. The coordinator will also be the “keeper” of the parts and will be responsible for seeing to it that parts are available when they are needed and for working with the instructors on problems related to parts and equipment.

Software - Responsible for organization of the software and for its proper operation. This includes documenting and adding comments to all of the source code.

Construction - Responsible for the physical construction of the project. The constructor will ultimately be responsible for what the project looks like.

Documentation - Responsible for keeping the project notebook and presenting the final project. The documentarian will be the team spokesperson and will be responsible for producing the written documentation for the project, which is to be handed in.

The project notebook is a log of all of the team activities related to the project. Each entry in the notebook lists the time and date of the activity, the team members present, and summarizes the important results. This might include rough sketches of various designs in software or hardware, and it may include printouts of software. The notebook serves as a complete log of the time spent by each project member working on the project (alone or as part of the team).

The project itself consisted of constructing a vehicle to navigate its way through an obstacle course, with both lit and unlit obstacles, and deposit a load of marbles in a lit garage. Vehicles were set in place at the start of the course and were not allowed to begin until the room lights blinked three times. The vehicle had to be able to locate and maneuver around randomly placed obstacles, follow a lighted path, sense the path end, and drop its load of marbles.

Faculty members not initially involved in the project were enlisted to serve as objective evaluators for the projects. Evaluators examined the project notebooks and observed the vehicle as it made its way along the course. Each evaluator assigned points for the documentation, complexity and creativity of the design, and success in completion of the course and delivery of the marbles.

This pilot project has allowed us to commit to a larger-scale project for Fall 2000, which will include all EE, CoE, and CS freshman majors, about 50 students total. The first four weeks of the term will be devoted to items peculiar to the specific major. EE majors, for example, will work with common meters and the oscilloscope. During this time there will be several small projects in which the majors interact with each other. This is directed at developing a working familiarity with each other so that the team atmosphere of the 10-week LEGO-based project is comfortable and familiar. For the 10-week LEGO-based project we will retain some critical features of the pilot project that we believe worked well. These include:

Four-person, mixed-discipline teams with specific team assignments.
An introduction in which each team is given a complete vehicle and is assigned a variety of tasks to make it function.
The C programming language and development environment.
A project involving a moving vehicle and opportunities to use a variety of sensors
A project notebook for documentation.

These features allowed for a smooth development from small projects to larger projects with reasonable documentation. The project notebooks showed that students made significant effort to meet outside of class to work on the final project.

The purpose of the pilot project was to find out what things are likely to work best in a larger environment involving the whole freshman class. The pilot project has led us to suggest a number of improvements that will be incorporated in the course for Fall 2000. These include:

An upgrade of the computer system from the 8051-based Dallas 5000T to the Philips 89C51RD+ (also 8051-based). (See the resources section below for details.)
A wider selection of sensors and more of them. The pilot project included only two bump sensors and two light sensors. For Fall 2000, we will introduce a microphone for a sound sensor, a focused and a color light sensor, and an electromagnetic sensor. Infrared transmitters and receivers are being considered for intercommunications.

The beeper will be replaced with a speaker so that the vehicles can produce a variety of sounds.
The C library of drivers will be updated and better documentation will be added. A facility will be added to allow teams to introduce their own library functions.
Interrupt-driven and real-time programming concepts will be added to the project.
Formal instruction in LEGO design with specific introductory task assignments will be added to the project.

IV. Project resources

The LEGO building set, motors, and touch sensors are available from PITSCO/LEGO Dacta. (URL: www.pitsco-legodacta.com, but it is easier to call 1-800-362-4308 and ask for a catalog.) For each project kit, we purchased:

One Technology Resource Set (about 1700 LEGO pieces including one 9V non-gear-reduced motor)
Two 9V Motors with Gear Reduction
Two 9V Touch Sensors

The total cost of these LEGO parts was around $320. We also purchased some extra wire leads, since the ends must be cut off to interface the LEGO motors and sensors to the microcontroller board.

Light sensors are also available from PITSCO/LEGO Dacta, but they are expensive. We chose to construct our own sensors from readily available parts. Infrared photo-transistors are inexpensive, very small, and have a good sensitivity to visible light as well as infrared. We embedded such a transistor in a LEGO brick along with a single small resistor, and a miniature three-prong connector to form a light sensor. Such sensors are then easily connected to the LEGO body and neatly attached to the microcontroller's A/D converter.

The front pivots used in the initial vehicle design are nylon drawer knobs available at any home center. The center holes of the knobs were enlarged slightly to allow a LEGO axle to be inserted, but still provide enough friction so it would not fall off. We chose this design because steerable or castering front wheels proved to be very difficult to design. The nylon drawer knobs are smooth enough to slide easily over most surfaces.

Several microcontroller boards are commercially available and readily adaptable to a LEGO vehicle. The most popular board is the MIT Handy Board available from Gleason Research Products (URL: www.gleasonresearch.com). The board makes use of the Motorola 68HC11 processor and costs about $300. In addition, a combined LEGO and MIT Handy Board kit with pre-wired motors and sensors is available from the KISS Institute for Practical Robotics (URL: www.kipr.org) for about $900.

As a less expensive alternative, we chose to construct our own microcontroller board from resources readily available in the EE program. The microcontroller board used for the pilot project has the following characteristics:

Intel based 8051 microcontroller made by Dallas Semiconductor (DS 5000T).
An 8-bit A/D converter with 8 multiplexed channels and a 40 µsecond conversion time.
Two Texas Instruments SN754410 H-drivers each capable of driving two dc motors at 1 amp each.
On-board voltage regulator that accepts power from either four conventional AA batteries (6 volts), six 1.5 volt rechargeable alkaline AA batteries, or eight 1.2 volt rechargeable NiCad AA batteries.
Piezzo beeper and driver.
A single 1 line by 16 character LCD display board.
One 8 bit digital output port with 8ma per bit.
One bit-programmable 8 bit I/O port.
11.0592 MHz clock frequency, reset button, and on LED.

The total cost of the parts for the microcontroller board is around $135, mostly in the processor and display. (Details of the circuit design and a complete parts list may be found on the project home page at URL: csserver.evansville.edu/~lego101.) The microcontroller board with its battery pack and LCD display is 3" x 5" x 2" and has LEGO slides glued to the bottom for easy connection to the vehicle.

The printed circuit board for the microcontroller was laid out using software from Express PCB (URL: www.expresspcb.com). Express PCB provides the layout software by free download from their web site. After laying out the 2-sided board, the software calculates the board fabrication cost, accepts a credit card number, and transmits the order. Boards are typically received within four days. The LEGO computer board used in the pilot project cost about $12 per board, plus a one-time $75 set-up fee.

The software we used to program the microcontroller board is the Keil C compiler. A free, evaluation version of the Keil C compiler is available at the Keil website (URL: www.keil.com). This version has the same features as the full, professional version, except that it is limited to programs of 2K or less. (The professional version is available to universities at a substantial educational discount.) The Dallas 5000T microcontroller is a variation on the classic Intel 8051 family of processors. In essence, the Dallas 5000T is an 8051 processor, 32K of program RAM, and an on board lithium battery in a single 40-pin DIP package. The chip costs about $60. Dallas also provides a small development programmer for the chip that allows programs to be downloaded via a telephone cable from the serial port of a computer station. The programmer costs about $90 (URL: www.dalsemi.com). Since these were readily available in the department, we used them for the pilot project.

A less expensive alternative has been developed for the larger class project for Fall 2000. The Philips 89C51RD+ is a 16MHz 8051 processor with 64K of user programmable flash memory, 1K of RAM, and 1K of boot ROM. The chip's flash memory can be serially programmed without removing it from the application. The chip cost is about $10 (a lower cost 32K version is available for $7.50) and provides all of the facility to download and execute developing code (URL: www-us.semiconductors.philips.com). Use of the Philips CPU should reduce the cost of the controller board to about $80.

V. Summary

This paper described an interdisciplinary project for a freshman course designed for electrical engineering, computer engineering, and computer science majors. The project features programming, interfacing with sensors, and LEGO construction design set in a team environment where each team member has a specific area of responsibility. Detailed descriptions of project tasks and project resources were given.

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