AC 2007-1791: COOPERATIVE UNIVERSITY/INDUSTRY DEVELOPMENT OF A FRESHMAN ‘INTRODUCTION TO ECE DESIGN’ COURSE

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Abstract

Faculty members from Georgia Tech's School of Electrical and Computer Engineering (ECE) have worked jointly with engineers from National Instruments (NI) to develop a new freshman engineering course. This course is entitled 'Introduction to ECE Design' and is constructed around the use of the LEGO MINDSTORMS NXT robotics system. NI partnered with LEGO to jointly develop the programming software for the MINDSTORMS NXT, and their engineers are uniquely positioned to provide insight into the use and functionality of these kits. NI engineers have not only provided technical support but have also conceived and designed most of the laboratories for the course.

This course addresses the diverse objectives of providing students with a systems-level design experience at the beginning of their academic programs and introducing them to a broad range of ECE disciplines. A primary goal is to enable students to make better-informed decisions when choosing whether or not to major in electrical engineering or computer engineering.

Introduction

Georgia Tech's School of Electrical and Computer Engineering (ECE) has not offered an introductory freshman-level course for a couple of decades. In recent years there has been concern expressed by both internal and external constituencies that freshmen were choosing whether or not to major in ECE without ever taking a course in the field. Additionally, Georgia Tech's early ECE courses, such as circuits, digital logic design, electromagnetics, etc., while providing thorough, in-depth coverage of their subject areas, do little to provide students a broader 'big picture' perspective on our discipline. Thus, our goal was to design an entry-level course that would be informative, engaging, and challenging.

After examining a variety of freshman courses taught across the country, we chose to build ours around LEGO robotics. Because of their versatility, over the past 10 to 15 years LEGO robots have appeared in courses from elementary school through college. The engineering education literature describes many freshman-level engineering courses that have chosen to use LEGO robots.[1,4-6] Additionally, they have also been used in programming courses,[6] advanced robotics classes,[3] and for multi-disciplinary senior design projects.[2,5] In our background investigation we identified 23 universities and colleges using LEGO robotics, from both the US and the rest of the world, with 11 of them offering freshmen-level courses.

Thus, in choosing to base our course on LEGO robotics, we had several examples from which to draw. However, at least two facets of our course are unique. First, we chose to use the new LEGO MINDSTORMS NXT system, the newest generation of LEGO robotics. Second, Georgia Tech faculty members received significant help in developing this course from engineers who helped to design the NXT kit and its LabVIEW-based graphical programming environment.

LEGO MINDSTORMS NXT was designed from the ground up using input from LEGO robotics enthusiasts. All aspects of the NXT kit are significantly upgraded from earlier LEGO kits and have increased functionality at roughly the same cost. The NXT controller incorporates three processors, including a microcontroller for motor control, another for Bluetooth wireless networking, and the 32-bit ARM7 microprocessor. This improved processing power also enables a more sophisticated programming environment. A screen capture from the LEGO MINDSTORMS programming environment is shown in Figure 1. The motors and sensors all have six-wire cables connecting them to the controller, allowing both analog and digital connections. The motors feature built-in rotational encoders and are more powerful than earlier LEGO motors. Similar improvements have occurred in each of the sensors. In designing our course we exploited these changes to give students a more in depth exposure to ECE concepts. Our students are not just taught how to use these components, but also learn a bit about how they work and what their limitations are. Schematics for each component are readily available, and we have also had some access to their designers.

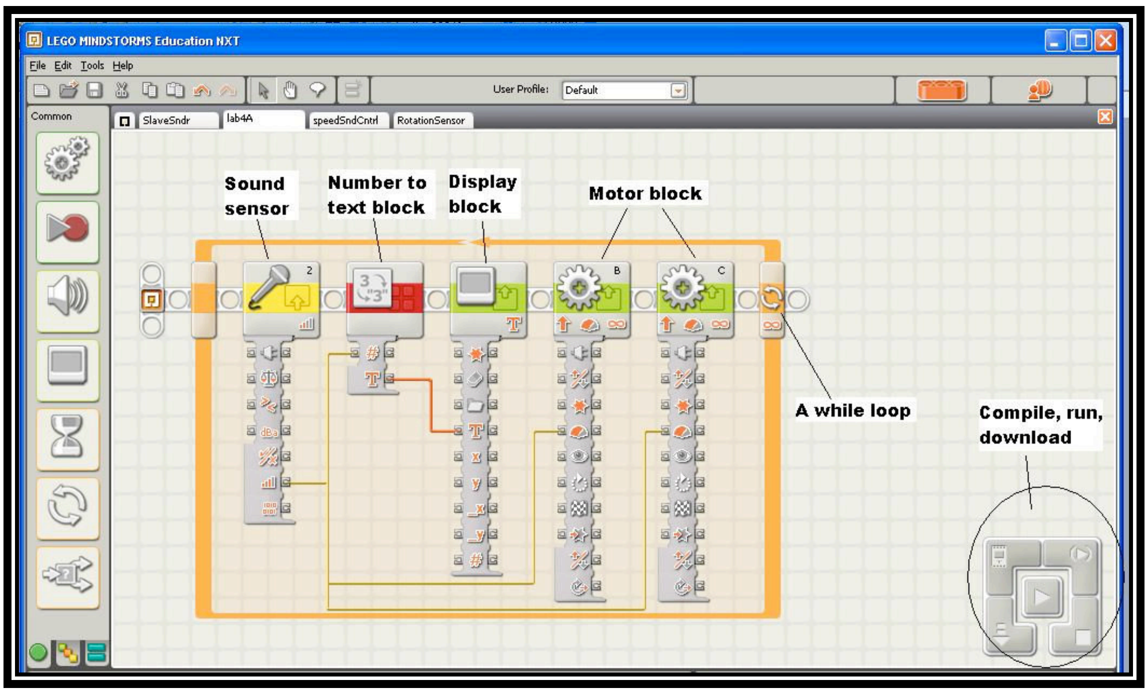

Figure 1: The LEGO MINDSTORMS NXT programming environment

LEGO MINDSTORMS NXT became available in the summer of 2006 with the first educational kits shipping in August 2006. Since Georgia Tech's fall semester started on August 21st, this course could not have been taught without significant assistance from both LEGO Education and NI. LEGO Education provided Georgia Tech's School of ECE with a trial kit, so that their faculty could determine the NXT's suitability for this course and, later, start to design the course around the kit's capabilities. They also helped to ensure that the kits would arrive before the start of the semester. Engineering teams at NI were involved in the design of both the hardware and software components of the NXT kits. Consequently, they have worked with these systems for quite some time and are familiar with their capabilities and limitations. Several of their engineers have developed hands-on labs for this course and have worked with the course instructors to integrate those labs into the class. They have also served as a resource for the class when instructors and students have had questions about NXT kits. When this course was designed and implemented, no NXT-specific textbooks were available, so all course materials were developed by Georgia Tech and NI personnel. Without this academic/industry partnership, 'Introduction to ECE Design' could not have been conceived and taught in Fall 2006 using these new robotic kits.

Course Structure

When designing the structure of 'Introduction to ECE Design,' we started with our basic objectives of reaching students early in their studies, engaging them in meaningful ECE-related design projects, and educating them about the scope of the field of ECE. Once we chose the NXT kit as the foundation of our design efforts, we developed a set of course outcomes where, by the completion of this course, students should be able to:

- Understand fundamentals of measurement: sampling interval, quantization/precision, forms of numerical representation
- Explain, easily recognize and differentiate fundamental concepts of charge, voltage, and current flow
- Understand basic mechanisms of physical sensing (light, sound, touch) and encoding of those measurements
- Apply basic concepts of computer program flow and organization
- Understand basic technical hardware/software specifications
- Demonstrate a basic understanding of DC motor control and how to work with them (power, speed, torque, and tradeoffs using gearing)
- Describe the many subdisciplines of ECE
- Design autonomous robots that respond to sensor inputs and use motors/actuators to accomplish simple tasks
- Assess the factors affecting the reliability and repeatability of the programmed tasks (How consistently does it work? How well does it work? Why?)
- Work in teams, including:
    - Fair delegation of tasks
    - Communicate with peers (i.e., other team members)
    - Assess the performance of team members
    - Create a realistic time-line for a design project and stick to it or assess why it didn't work
    - Write a report outlining a design strategy and assessing its strengths, weaknesses, and feasibility
    - Write a report describing functional/technical specifications of the proposed design strategy
- Write an end-of-project report presenting the final design, strategy, technical description, and performance assessment

These outcomes were then used as a template to guide development of the course.

In order to achieve both the education and design goals of this course, class periods are organized to be approximately half lecture and half laboratory. Lectures and labs are held in the same room to allow complete flexibility in choosing when to lecture or conduct hands-on classes. Proportionally more lectures are given early in the semester to give the student teams enough background to proceed. The early lectures focus on background material, such as programming basics and the MINDSTORMS programming environment, the basic concepts behind charge and current flow, and introductions to data acquisition and motor control. In order to achieve the course goal that students become familiar with the many subdisciplines of ECE, in conjunction with each lab, lectures are given on technical areas within ECE that are related to the lab topics. Later in the semester, most of the course time is spent on laboratories, especially building and programming robots for the semester ending competition.

Students' grades were determined by the results of their labs, the quality of their reports, and performance on quizzes and homeworks. Additionally, after each lab session, students were asked to submit a peer evaluation for the purpose of assessing the contributions of other team members. According to their classmates' responses in these evaluations, students collected points. At the end of the semester, students received an overall rating based on these peer evaluations of *average*, *above-average*, or *below-average.* These rankings were then used as a guideline for instructors to assess students whose overall course grades fell near the boundaries between letter grades. Overall, this notion of peer-evaluation assisted students to learn and improve their skills in evaluating other team members' performances in highly collaborative working environments – something, that they will need in their future engineering careers – while giving course instructors some indication of a student's actual performance from the perspective of his/her classmates.

Laboratory Modules

Most of the laboratory assignments were developed at National Instruments and modified slightly by the course instructors. Modifications were primarily necessary to facilitate grading, both of student groups and individuals, and to provide a better fit to the lecture material in terms of notation and assumed background knowledge. In order to allow first semester students to enroll, the course has no prerequisites and, in particular, does not assume that students have prior programming experience. The first lab begins with introductory programming techniques. As the students become more adept, later labs, in addition to covering the different properties and limitations of the NXT's sensors, motors, and controller, also introduce more advanced programming concepts. Here are descriptions of the lab assignments and associated technical area overviews.

Programming Basics: The goal of this lab is to provide an introduction to the MINDSTORMS graphical programming environment. Students start with some straightforward exercises using the sound sensor and motors, and they finish with an assignment to display graphically both current and maximum observed sound levels on the screen of the NXT controller.
Associated technical subdiscipline overview: computer engineering

Motion – Motors and Rotational Sensors: Students learn the ins and outs of programming the NXT motors, including the control of two motors working in tandem and use of the

built-in rotational sensors. The final challenge is to program the robot to move in a figure eight and to analyze how capable the robot is of returning to its starting position.
Associated technical subdiscipline overview: electric power and energy

Ultrasound, Touch Sensors, and Loops: The ultrasonic sensor offers a quick, accurate means of measuring distance. In this lab students measure the accuracy of this sensor and determine some properties that can affect its reliability. Students are also introduced to the different loop constructs available in the MINDSTORMS environment. In the final lab challenge students use the ultrasonic and touch sensors to have the robot move to positions at specified distances from the wall as quickly as possible.
Associated technical subdiscipline overview: digital signal processing

The Sound Sensor: The NXT's sound sensor can be used primarily to measure sound levels. In this lab students write a program to control their robots with handclaps (e.g., one clap indicates a left turn, two claps a right turn, and three claps means to stop). Students develop flowcharts to plan the control and timing structure of their program and then program their robots to respond reliably to their clap commands.
Associated technical subdiscipline overviews: electronic design and microsystems

The Light Sensor: The NXT light sensor is able to distinguish gray-scale light levels from ambient light or reflected from its self-generated light. A common use of the light sensor is to allow a robot to follow lines drawn on a surface. In this lab students learn how to use the light sensor to follow a black figure drawn on a white surface. The initial algorithm models the sensor as making binary black/white decisions, but in the final challenge students use simple prediction and feedback from the sensor's gray-scale output to improve the robot's tracking behavior.
Associated technical subdiscipline overview: systems and control

Bluetooth Communication: The NXT controller has built-in Bluetooth capability, allowing it to communicate with other NXTs or Bluetooth devices, such as PDAs, laptops, or cell phones. For this lab, student teams are paired with one team's robot designated as 'big brother' and the other's as 'little brother.' The big brother robot goes through a pattern of random turns that are communicated to its little brother, which is able to go through the same turns at the same time. Finally, the student teams modify the big brother to make it a remote control for its little brother.
Associated technical subdiscipline overview: telecommunications and networking

The Competition: During the final four weeks of the semester, students design, build, and program a robot to compete in a head-to-head competition. Two of the robots designed by the student teams are shown in Figure 2. The goal was to give students reasonable constraints in terms of what could be used in the competition and to get them to use much of what had been learned during the semester. During these weeks, each team submits two reports. Their Strategy Report describes how their robot will approach the competition and how they will work to defeat strategies that other teams might develop. Their Design Report gives detailed information on how their robot will be built and the structure of their program.

Three more technical overviews are given during this period. These overviews are not necessarily related to the competition but do cover ECE topics not presented earlier. Technical subdiscipline overviews: bioengineering, electromagnetics, and optics

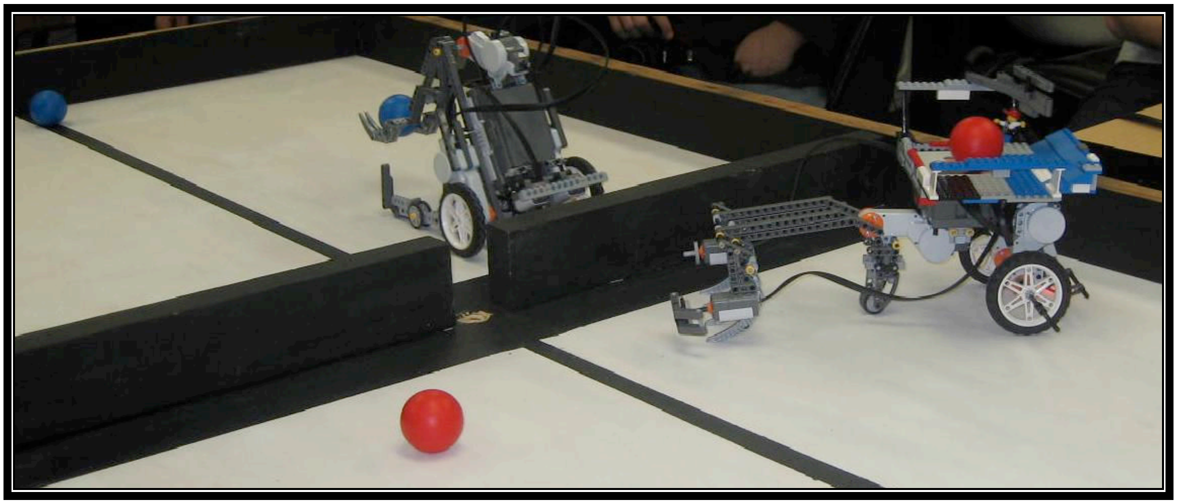

Figure 2: Two robots competing during the competition at the end of the semester

Impact on Students

This course was taught for the first time during the Fall 2006 semester and was open to freshmen with the majors of electrical engineering, computer engineering, and undeclared engineering. These students were surveyed at the beginning and end of the semester about their knowledge of ECE, their likelihood of changing majors into or out of ECE, and their career goals.

The course this past fall was successful in exposing students to different ECE topics. When asked about their areas of interest within ECE, 29% of the students said that the course reinforced their interest in a particular area of ECE. Additionally, 21% said that the course created interest for them in a different area of ECE, and 29% had developed interest in a new area of which they were previously unaware. Only 18% said that the course had had no impact on their interest in ECE. Note that students were permitted to check more than one response for this particular question.

The course also had an effect on the students' intended majors. Just 5% of the students stated that the course had had no impact on their current choice of major. Meanwhile, 71% said that the course reinforced their desire to major in ECE. There were indications that increased knowledge about the field of ECE also allowed the students to feel more comfortable in their early career decisions. Almost 24% stated that there is no chance that they will change their majors, and more than 44% said that a major change is not likely. Of course, just because students know more about ECE does not mean that they will all choose a major in our School. About 8% of the students said that they had definitely decided to choose a different major. However, helping these students to make better decisions earlier is also in line with our goal of enabling students to make more informed decisions.

Course Development and Logistical Issues

The course is offered as a 2 credit hour course. The course meets in a dedicated room that serves as a classroom and laboratory, with each lab group seated at a work area with a single dedicated computer. The course meets 2 days/week for 1.5 hours/class on Tuesdays and Thursdays. This structure allows a flexible lecture/demonstration/laboratory format. Laboratory exercises were scheduled for a consecutive Tuesday and Thursday, which allowed for continuity in working on the assignments from the first to second day of the lab.

Each section enrolled 21-24 students in lab groups of 3 students each, and two sections were offered. Drs. Williams and Butera, who were also responsible for developing/grading quizzes and lecture material, taught one section each. The course also utilized a dedicated Teaching Assistant (13 hours/week) who helped debug future labs and graded homework assignments, as well as staffing assistance hours during the design project.

Initial course development occurred during the preceding summer by Drs. Butera and Williams with active consultations with staff at National Instruments. The School of Electrical and Computer Engineering provided a dedicated Teaching Assistant (TA) for this effort, although Drs. Butera and Williams received no formal workload compensation for these development efforts. A dedicated TA was critical for setting up the laboratory/classroom and proofing the laboratories after they were initially written. While Georgia Tech does consider course development and innovation in the promotion and tenure process, both faculty are already tenured.

Conclusions

Many students find early ECE courses to be abstract, narrowly focused, and mathematically demanding. By using NXT robots as an instructional vehicle, our academic/industrial team has developed a course where students' first exposures to ECE are broad scoped, educational, and fun, yet also challenging. As successive lectures introduce the relatively sophisticated NXT controller, motors, and sensors, students learn not just how to use them but also how they work. Each new component allows an introduction to those areas of ECE related to the design and operation of that component. This deeper understanding also allows students to appreciate the abilities and limitations of each component. Additionally, students are able to develop a deeper and broader understanding of the field of electrical and computer engineering at an earlier stage. Consequently, they are able to make better-informed decisions when choosing majors and are potentially less likely to change majors at a later date.

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