ROBOTS IN EDUCATION: MIDDLE SCHOOL TO GRAD SCHOOL AND BEYOND!

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Abstract

Robots are an effective tool for capturing and retaining student interest and teaching complex concepts to students over a wide range of cognitive levels. We have employed robots to engage students in science and engineering concepts from as early as sixth grade. From this early introduction, we use robots as a recruiting tool for a variety of middle school and high school pre-college enrichment programs. We also use robots to engage middle and high school educators to encourage their students to consider careers in Science, Technology, Engineering, and Mathematics (STEM) related fields. All students within the college are exposed to a robotics project via the Orientation to Engineering course required of incoming freshman. Within the Electrical and Computer Engineering curriculum, we use robots to instruct students in complex concepts related to embedded system design, hardware descriptive language system design, real time operating systems, and fuzzy logic controllers. In this paper we will review different programs where robots are used in the curriculum, robot technology employed, concepts taught, and the results of using robots as an educational tool. We will also discuss how undergraduate and graduate students are employed as designers and facilitators of this technology.

Overview

Robots are an effective tool for capturing and retaining student interest and teaching complex concepts to students over a wide range of cognitive levels. We have employed robots as a teaching tool starting with middle school enrichment programs, followed by high school pre-college recruiting programs, and also throughout our engineering curriculum. Employing robots as a motivating educational tool is not a new idea. This idea has been used with great success at many institutions [1, 2] including Trinity College in Hartford, CT [3, 4]; the Massachusetts Institute of Technology [5], and the United States Air Force Academy [6-8].

We begin this paper with a brief background review of each educational program that employs robots. This is followed by a description of the robots used and concepts taught in each program. We also discuss the concept of developing educational materials via a "For Students By Students (FSBS)" approach. In this approach, undergraduate and graduate students develop educational materials, in this case robots, as a design exercise. The result of their work is then used as an educational tool in a variety of educational programs. Many of the robot projects discussed in this paper were developed using this technique. We gratefully acknowledge the dedicated work by a number of undergraduate and graduate students over the past decade to make these robot-based educational programs possible. Much of this work has been previously reported in ASEE papers and CoED journals articles. We will cite appropriate references throughout the paper.

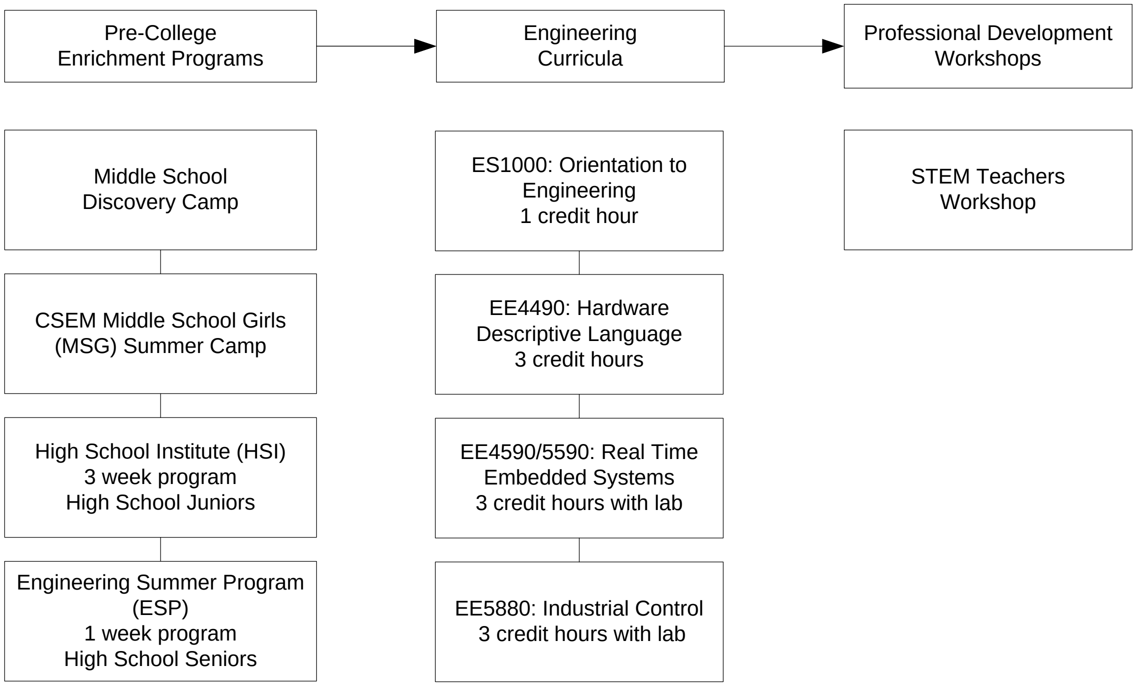

Figure 1. Robot as educational tools across a continuum of cognitive development.

Background

Robots are used in a wide variety of educational programs over a wide range of cognitive development as shown in Figure 1.

These include pre-college enrichment programs, engineering curricula at the freshmen, senior elective and graduate level, and also professional development workshops for STEM educators. In this section we briefly describe each of the programs depicted in Figure 1.

Pre-College Enrichment Programs

There are four different Pre-College Enrichment Programs employing robot technology. Each of the programs is briefly described below. These pre-college programs are described in detail in [9]. A brief synopsis of each program is provided here for completeness.

"Middle School Discovery Camp. In April 2006 the Wyoming Department of Education awarded Laramie County School District #1 (LCSD#1) of Cheyenne, Wyoming a grant $230K to integrate mathematics, science, and language arts into the district's seventh grade curriculum. The overall goal of the grant was to enhance the technical and cultural literacy of the students. To achieve this goal an objective was set that all seventh grade students would improve their authentic critical thinking skills by developing inquiry skills through the use of Discovery Boxes that would integrate mathematics, science, and language arts skills. A Discovery Team was formed to implement the grant. The team consisted of professional educators. Approximately 20 team members were teachers from constituent middle schools within LCSD#1. The remaining six team members were subject matter experts including educators from the nearby university and community college and the private sector [10]." Following this initial grant, the team developed a Middle School Discover Camp for LCSD#1 sixth through eighth graders. The camp was run as a summer enrichment program during summer 2009.

"Computer Science, Engineering and Math (CSEM) Middle School Girls Camp. The CSEM Middle School Girls Camp offers a variety of learning experiences for girls who have completed 6th, 7th or 8th grade and have an interest in broadening their knowledge about computer science, engineering and mathematics. The camp, directed by Professor Jerry Hamann of the Department of Electrical and Computer Engineering, is part of the Engineering Schools of the West Grants Initiative provided by the William and Flora Hewlett Foundation. The camp focuses on educational, hands-on study to increase and maintain interest in science and mathematics. This one-week camp offers experimentation and exploration in the area of robotics, graphical programming, 3-D design prototyping, and applied mathematics. In addition, there are several social activities such as picnics, swimming, climbing and field trips to nearby engineering and natural resource sites. All activities are provided by faculty from the College of Engineering and College of Arts and Sciences with assistance from graduate and undergraduate students in the disciplines [Adapted from 11, reported in 9]."

"Summer High School Institute (HSI). The mission of HSI is to provide a place where some of Wyoming's most intellectually talented high school sophomores can gather before their junior and senior years, living and studying in an environment with no pressure for grades, and sharing ideas and friendship with other gifted students. The primary purpose of the program is to annually draw 100 talented high school sophomore students to the university for an intensive examination of unanswered questions and unresolved challenges. Among the areas that are probed include: world hunger, plants and people, knights and cowboys, drama, ethics and society, communicating with computers, understanding cultural development, pharmacy, fundamentals of computer design and programming, and the links between life and the arts. The goal is not to require students to learn another body of knowledge and pass yet another test. It is, rather to challenge imaginations, focus diverse disciplines on specific issues or problems, and integrate various individual talents into a larger perspective. In the process it is hoped that the selected high school students achieve their academic and personal potential by cultivating their leadership capabilities; to expanding their horizons, developing their adaptability, creativity, and critical thinking abilities, and to heighten their sensitivity to future possibilities for themselves, Wyoming society; and to stimulate and reward excellence in Wyoming schools [Adapted from 12, reported in 10]."

"Engineering Summer Program (ESP). The College of Engineering and the Wyoming Engineering Society, in conjunction with the J. Kenneth & Pat Kennedy Endowment and the University of Wyoming College of Engineering Hewlett Foundation Engineering Schools of the West Initiative offer high school juniors an opportunity to participate in a summer program of hands-on experiences in various engineering fields. For example, students may design and build a digital circuit, study solutions to an environmental issue, test the aerodynamics of a tennis racket or model rocket, fabricate advanced composite materials, or design timber trusses. Laboratory sessions provide basic instruction and give students the opportunity to put new found knowledge to the test. ESP participants work one-on-one with faculty members and advanced students. This one week program is designed to expand student horizons, develop creative thinking and problem solving skills, and challenge imagination [Adapted from 13, reported in 10]."

Engineering Curricula

Within the engineering curricula robots are employed in the freshman level Orientation to Engineering courses. Also, several senior and graduate level electives in the electrical and computer engineering programs employ robots to teach complex concepts in embedded systems design, Hardware Descriptive Language (HDL) based systems, real time operating systems (RTOS), fuzzy logic systems, and motor speed control concepts in an industrial control setting. A brief description of each course follows.

ES 1000. Orientation to Engineering Study. 1. Skills and professional development related to engineering. Involves problem solving, critical thinking and ethics, as well as activities to help transition to university environment. Required of all freshmen entering engineering curricula [14].

EE 4490. Hardware Descriptive Language (HDL) Digital Design. 3. Hardware Description Language design of digital systems. Industrial CAD tools are used to produce a functional description of hardware that is both simulated and then synthesized into hardware. Methods to describe both combinational logic and synchronous devices are given. Devices such as CPLDs and FPGAs are targeted in this design process. Emphasizes design techniques [14].

EE 4590/5590. Real Time Embedded Systems. 3. Emphasizes a systems approach to real time embedded systems. Students are expected to apply methodical system design practices to designing and implementing a microprocessor-based real time embedded system. Students employ a robot-based educational platform to learn the intricacies of real time embedded systems, distributed processing, and fuzzy logic. Students learn processor input/output interfacing techniques. Students use state-of-the-art design and troubleshooting tools. Prerequisites: EE 4390: Microprocessors [14].

EE 5880 Industrial Control. 3. This course emphasizes the control of industrial devices and processes using state-of-the-art programmable logic controllers (PLCs) and microcontrollers. We will investigate control algorithm design in detail and also discuss sensors, transducers, and interfacing. Students will also use state-of-the-art design and troubleshooting tools. Students will apply control theory to a series of hands on laboratory exercises.

Professional Development Workshops

"Science, Technology, Engineering and Mathematics (STEM) workshop. The Department of Electrical and Computer Engineering, working together with faculty colleagues from the College of Education's Science and Math Teaching Center, and with other engineering colleagues conducted a summer Science, Technology, Engineering and Mathematics (STEM) workshop. The 10 day workshop offered hands on training and instruction from engineering and education faculty utilizing engineering based teaching and activity modules adapted by the Wyoming Electric Motor Training and Testing Center. The workshop was an attractive format for introducing high-school teachers and students to the wonderfully diverse career prospects associated with technology. The workshop showed via a combination of lectures, field trips, and lab experiments how science and math knowledge is put to direct use [adapted from 15]."

Methods

In this section we will detail the robot technology and concepts covered in each of the different instructional programs previously discussed.

Middle School Discovery Camp. The educational objectives of the robotics portion of the Discovery Camp was to demonstrate to the middle school student attendees that:

- Programming is a lot of fun!
- A computer will only do what you tell it to. It does not have the capability to make its own decisions. We tell a computer what to do via a program.
- A program consists of a number of logical steps to complete a specific task.
- Often scientists and engineers will use a flow chart to visually determine what the steps will be before writing a program.

To achieve these objectives we first taught students how to write a program that computes the volume of a cylinder using a Texas Instruments TI-84 calculator. The TI-84 calculator provides an easy-to-follow tutorial on this topic. Once students were comfortable with the basic idea of programming, we then discussed the concept of a flow chart and explained how it is a visual tool to map out a complex computer algorithm.

We then provided the students with the Norland Research robot kit (US $100). The robot is illustrated in Figure 2. The robot consists of a platform with two large wheels. The platform contains the motors and interface electronics to drive the motor wheels. The platform also contains the robot battery compartment. At the leading edge of the robot is a spring loaded bumper connected to a switch to detect robot contact.

The Norland Research robot has been designed for easy interface to the Texas Instrument line of programmable calculators. The robot interfaces directly to the calculator via a short interface cable. By employing the calculator's "send" and "get" functions the robots may be programmed to do a variety of movement tasks under timed conditions or until a bumper contact is sensed.

Students were then taught how to program the robot to complete basic movements such as turn left or right, forward, reverse, etc. Due to the simple syntax developed by Norland, students were able to understand robot programming concepts quite rapidly. Students were then required to have the robot navigate about a square on the laboratory floor. Students were then introduced to a small (4' x 4') maze laid out on the laboratory floor with masking tape. As a group students developed a flow chart to have the robot navigate through the maze. Students were then split up into teams of two to program their robots to complete the maze challenge. Once students completed the maze challenge, they were challenged to develop their own large (8' x 8') maze and then program their robot to navigate through the maze.

Students were very motivated and excited about all aspects of the workshop. They demonstrated a keen ability to readily understating programming and flow charting concepts.

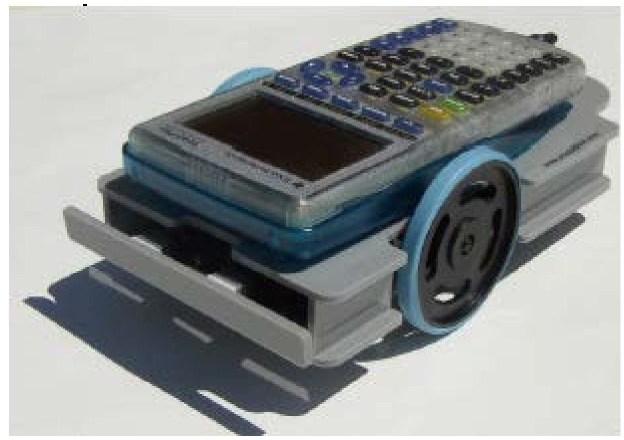

Figure 2. Norland Research robot (figure used with permission of Rick Rowland, Norland Research [16]).

MSG, HSI, ESP, STEM Teacher's Workshop – Lego Mindstorm. The University of Wyoming offers various summer courses that focus on math, science and engineering. These include the Middle School Girls (MSG) program for 6th, 7th, and 8th grade girls, the Summer High School Institute (HSI) for high school sophomores, the Engineering Summer Program (ESP) for high school juniors, and STEM Teacher's Workshops. A robotics course is offered to students in each of these summer programs providing an opportunity to learn more about computer controlled systems.

The Lego Mindstorm Inventors kit is a great resource used for teaching about microcontrollers and solving simple microprocessor control problems. A microcontroller acts as the brains of the kits from which the user can specifies instructions to control various input and output devices such as sensors, and motors. From the kit, a simple car is built. The microcontroller in this kit is used to control the motion of the car. A light sensor on the car is used to read black and white patterns on the ground. The student uses the information from the light sensor to control the left and right motors that ultimately controls the motion of the car. A short program is written by the student that controls each motion of the car based on the black and white sensor.

Some the car driving challenges include having the car drive around within a closed box. The box is composed of heavy black lines drawn on white paper. The idea is for the car to move forward until the sensor detects a black line, then immediately reverse for a short distance, then turn, and then proceed forward until the black line is detected again. A similar challenge is for the car to follow a black line that is drawn on white paper. The student must design another set of instructions for this project. The Lego Mindstorm cars can also communicate with other cars through the infrared port. This allows students the ability to transmit motion code to other cars. The other cars can detect the motion code and respond by performing the same motion.

After completing a series of structured projects, the students are encouraged to develop their own projects. The students in the picture below decided to write a program that would have the car draw a shape with the attached marker.

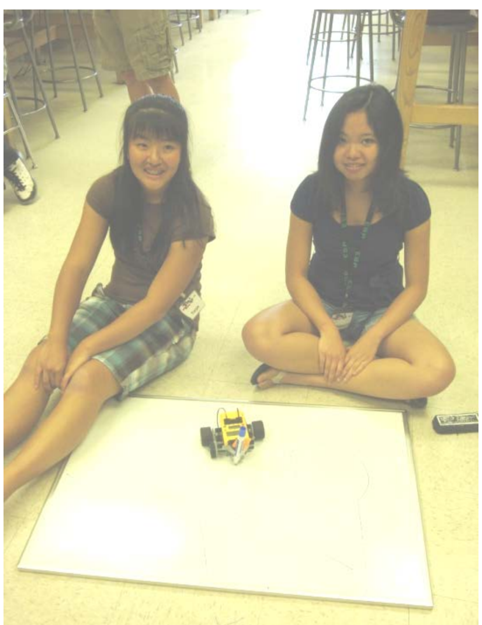

Figure 3. High school students working with Lego Mindstorm robot.

ES1000 Orientation to Engineering. In this course 13 sections of 24 students are divided into eight 3 student teams. Each section competes as a company against the other section. Within a section each 3 student team must design, fabricate, and test a robot to meet established requirements. On the day of the Design Challenge, each section competes against the other sections for achieving maximum points [17].

The Design Challenge in Fall 2008 was to design a robot vehicle to meet the following requirements:

- Design a vehicle from scratch using a provided motor, battery box, and gear set. No premade plastic bodies may be used.
- The robot must employ 2-AAA 1.5 VDC batteries as a power source.
- No more than $15 may be expended on parts.
- The complete vehicle must fit inside a 6-inch cube.
- The weight of the vehicle must not exceed 1 kg

The completed prototypes were scored on their ability to navigate a test track with the following parameters:

- Pass through the start gate,
- ascend a 15 degree hill ,
- propel a “hackysack” bean bag through the hole in a vertical wall at the top of the hill and past a line marked on the floor,
- knock down a flag or flags located at the top of the hill, and
- descend the hill and round the exit run-out to the finish line.

The robot test track is provided in Figure 4.

Figure 4. (left) the robot test track, (right), robot navigating the test track.

EE4590/5590 Real Time Embedded Systems

The Real Time Embedded Systems course exposes students to advanced and often complex topics in an embedded systems. Some of the advanced concepts covered in the course include Real Time Operating Systems (RTOS), multiple interrupts, fuzzy logic and complex system design. To allow students to visualize some of the more involved concepts, a low cost robot platform was developed.

The robot was co-developed by a team consisting of faculty members, graduate students, undergraduate students, and laboratory technicians for a senior/graduate level electrical and computer engineering course. In this course each two-student laboratory team is issued a mobile robot for use throughout the course. The students must program basic tasks such as robot movement and maze wall-detection. The complexity of required programming tasks escalates as the semester progresses. Students are required to program the operating system for the robot that must simultaneously handle wall-detection, simulated land mine detection, and information exchange with other robots. These complex scenarios force the students to learn and employ complex real time embedded systems concepts in a motivational atmosphere.

The robot developed for the course was dubbed the PROFBOT (Professor Robot). The prototype was developed with the goal of designing a low cost robot, using off-the-shelf components, that would be easy to fabricate initially and easy to maintain for a long time. We expect to use this robot for microcontroller based projects for at least the next five years. Early attempts at developing a prototype included a completely in house design [18]. However, the fabrication costs rendered this design cost prohibitive. We elected to use an off-the-shelf approach when a student-developed prototype proved to be a sound, low cost alternative to early in house attempts [19]. The prototype PROFBOT robot is illustrated in Figure 5.

As with other project components, a reconfigurable maze was designed and fabricated by two engineering students. The two students completed this project as a portion of a research experience program for freshman engineering students during the summer. The maze is equipped with walls that are easily moved to allow creation of a new maze on every test run [19].

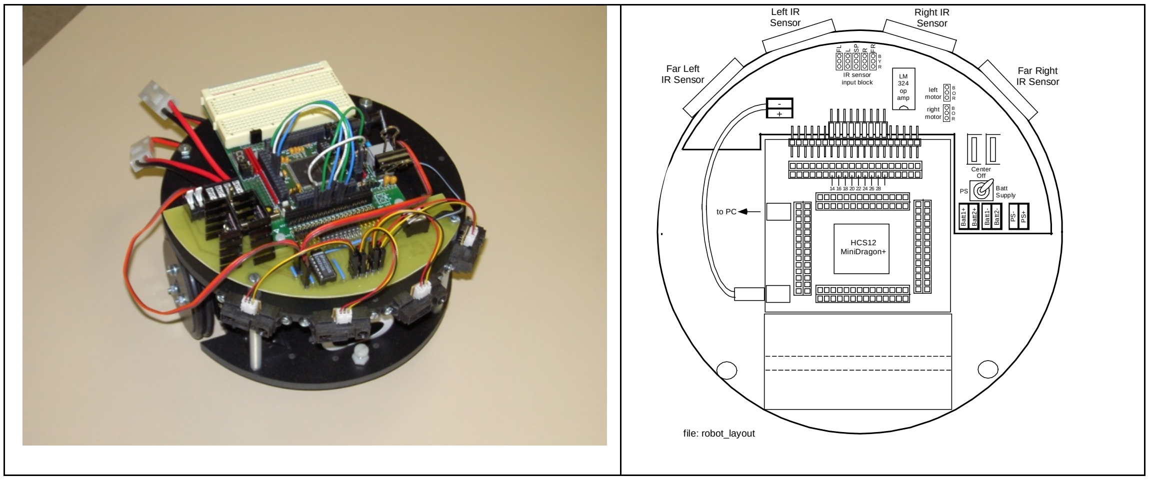

Figure 5. PROFBOT Educational Robot. (left) finished [19].

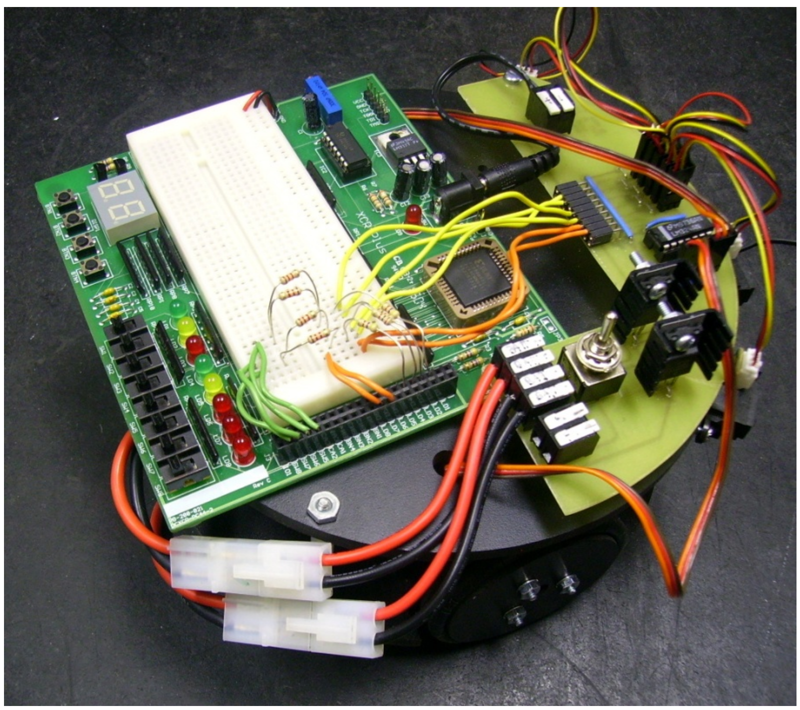

Figure 6. PROFBOT Educational Robot equipped with a Digilent XCR Plus board. The board hosts a Xilinx CoolRunner XC3064CPLD [20].

EE4490 Hardware Descriptive Language

The EE4490 Verilog Hardware Descriptive Language (HDL) course is a required course for computer engineers and elective course for electrical engineers and computer scientists. In an effort to provide a motivating (fun) atmosphere to teach HDL, we have developed an autonomous maze navigating robot based on the PROFBOT platform previously discussed. We equipped the robot with an off-the-shelf CPLD development board. The PROFBOT robot configured with the CPLD board is shown in Figure 6 [20].

Through the sequence of laboratory exercises students incrementally design and implement an autonomous control system for the robot. The first laboratory exercise acquaints students with the features and programming of the CPLD evaluation board. They then develop modules to provide basic robot movement via pulse width modulation techniques. The third laboratory provides for fine robot control and includes providing the robot the capability to turn in multiple directions. In the fourth laboratory exercise the robot is equipped with vision via the complement of four IR sensors. The vision system is then linked to the motor control system to provide for autonomous robot navigation about the maze in the next laboratory exercise. As students test their robots in the actual maze they will encounter real world problems such as the robot getting stuck in a particular wall configuration. The final laboratory exercise allows them to optimize their design to counter these real world challenges. Figure 7 provides a top level design diagram for their control system [20].

EE5880 Industrial Control

In Spring 2008 a new course was launched to expose students to industrial control concepts. The first half of the course is devoted to advanced embedded system techniques including motor speed control, feedback, complex systems design, interfacing, system power consumption. The second portion of the course is devoted to programmable logic controllers (PLCs) using Allen-Bradley SLC 500 PLC racks. The course was made possible by a gracious grant of a department alumnus interested in enhancing the instruction of industrial control concepts vital to the state's economy [21].

To explore advanced concepts in a motivational environment, student teams are issued a Blinky 602A robot kit from Graymark, Incorporated [22]. The Blinky 602A was originally designed as a line following robot with an analog control circuit. Starting with the basic platform, motors, and drive mechanics; students are required to convert the robot into an autonomous maze navigating robot controlled by an Atmel ATmega164 microcontroller. This is accomplished by equipping the robot with three Sharp GP2D12 infrared range sensors to detect maze walls. The microcontroller along with interface electronics is mounted to the robot platform via two small prototype boards as shown in Figure 8 (left).

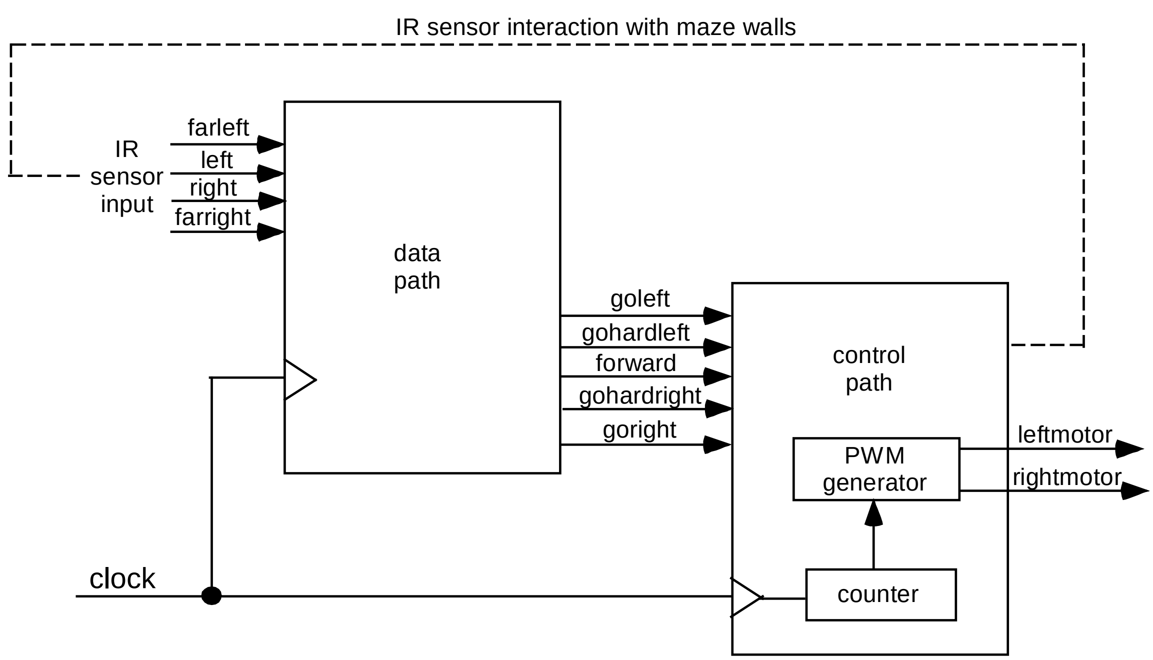

Figure 7. Top level robot control design diagram [20].

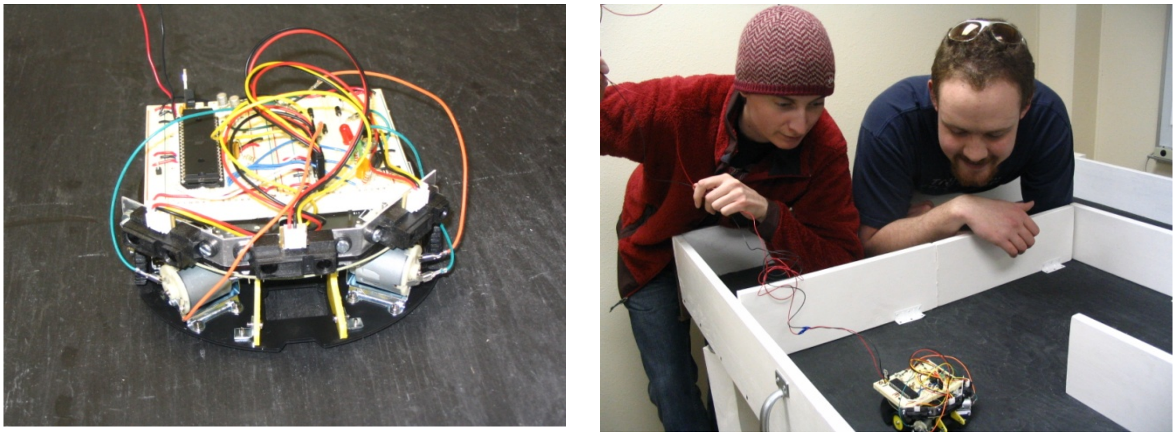

Figure 8. (left) Modified Blinky 602A robot, (right) robot navigating the maze.

During the laboratory portion of the course students learn concepts of motor speed control, algorithm development, complex system design, power budget, and the tradeoff between hardware and software. Also, bonus "first to market" points are provided to the student group that has the first operational robot that can successfully navigate the maze without wall collisions. In the final lab exercise student teams compete against one another to determine the fast maze navigating robot.

Results and Discussion

Time and again we have found robots to provide the motivational spark for students to learn about complex engineering concepts. We have found this to be true from middle school and high school students, to undergraduate and graduate students, to middle school and high school teachers.

In the middle and high school recruiting and enrichment programs, students find their first exposure to engineering to be fascinating and fun. They also develop basic algorithmic thinking skills, teamwork competencies, and an awareness of the engineering field.

In the undergraduate curriculum students are exposed to engineering design skills, working in a constrained time and financial environment, scheduling, and teamwork skills in their freshman design project. We then employ robots in senior and graduate elective courses to teach complex computer engineering concepts in a motivational environment. Robots have been used successfully to teach fuzzy logic control, real time embedded system concepts, HDL system design, and industrial control concepts. The robots have transformed these complex concepts, that are often difficult to teach, into a motivational and challenging experiential activity.

For over ten years we have used student designed and developed laboratory equipment with great success. We have dubbed this approach as "For Students By Students" (FSBS) development. Typically a student team will design and fabricate a prototype of a next – generation piece of laboratory equipment. Other students are then hired to fabricate multiple production run pieces of the equipment. Student developed laboratory equipment solves two challenging problems confronting most engineering programs: 1) the need to update laboratory exercises and equipment without adequate funds and 2) satisfying Accreditation Board for Engineering and Technology (ABET) requirements for a major design experience within the curriculum [23].

This highly successful program provided state-of-the-art computer engineering laboratory equipment using student designed, fabricated, and tested laboratory equipment. Furthermore, the students were completely responsible for developing all of the supporting courseware such as laboratory assignments for the new equipment. From the department's point of view, state-of-art, custom laboratory equipment was obtained at a lower cost than commercially available trainers. Furthermore, students were exposed to a real world design problem and all of the inherent related issues such as: working on a design team, interacting with highly skilled technicians, budget constraints, timelines, manufacturability issues, reliability issues, and customer satisfaction [23].

Conclusion

We heartily recommend the employment of robots in all aspects of engineering education. Our experience has been that when robots are used everybody wins. Students are motivated to explore new areas and often at higher cognitive levels. We have also found students will go above and beyond the requirements of a specific educational activity because they are having fun. Educators can cover concepts in an innovative fashion that are difficult to present using other methods.

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Paul M. Crips received his B.S. degree from the University of Wyoming in 1978 in Industrial Technology. He received a M.S. degree from the University of Wyoming in 2001 in Natural Science. Crips has spent the last 32 years as a teacher of junior high school aged students teaching both industrial technology and science. His most recent assignment is teaching seventh graders physical science, which includes classical physics and biological adaptation. Crips is an Amateur Radio operator holding an Extra Class FCC license (KI7TS). He is the advisor of two after school clubs, the Carey Junior High School Amateur Radio Club (KC7OEK) and the Society of Student Astronomers. He is also the co-founder of the statewide "Women in Science Forum" that promotes gender equality in science, mathematics and technology. Crips is a Milken Family Foundation teacher of the year for Wyoming, 1999, Walt Disney Corporation American Teacher Awards Honoree for middle grades science, 1999, Arch Coal Teacher of the Year, 2004, U.S. West Teacher of the Year for Wyoming, 1996, STARDUST Mission Fellow, NASA, 1999-2006, Christa McAuliffe Fellow for Wyoming 1994. He is also a Maury Project Trainer for the U.S. Naval Academy and the American Meteorological Society on oceanography. Crips is also a military veteran serving honorably three years in the United States Naval Reserve and 17 years, Wyoming Army National Guard. Crips recently completed the graduate requirements from the University of Wyoming to teach mathematics and is on a governing board for the development and implementation of a charter school in Cheyenne, Wyoming called "Bridges to Success". This school will work with middle school and high school aged students in a project based learning (PBL) environment.