Session: 1420

Revisiting the Autonomous Robot: Finding the Engineer within the Student

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Motivation and Goals

In 1999, the ECE department at Auburn University implemented a major curriculum reorganization that created four self-contained laboratories, two at the sophomore level and two in the junior, to introduce students to laboratory procedures and design projects[13]. The final laboratory, an autonomous robot, is intended to be an open-ended project that prepares students for a senior-level capstone design course. In the lab, students use the PIC12F675 microcontroller from Microchip Technology, Inc. to create an embedded systems solution[14]. We found that although the robot laboratory was being completed successfully, our average students were not prepared for the independent thinking required in their capstone designs. To address this issue, we identified six new goals and methods for the robot laboratory.

1. Fully custom design – As much as possible, we wanted students to have complete control over the details of their designs, both mechanical and electrical subsystems.
2. Design of experiments – Although a design concept might meet the robot specifications, without step-by-step procedures to validate the design, it is difficult if not impossible to implement efficiently. Having students include verification procedures early in the design process became a major goal.
3. Generating diagnostic procedures – Limited equipment resources impact the verification process and, thus, design options. Sometimes, the clever students can successfully modify their verification scheme, other times the design itself is affected. However, being aware of this reality is part of an efficient implementation.
4. Project management – In the past, the laboratory instructor set the weekly schedule of tasks to be completed. This insulated students from a critical skill in project management - setting realistic milestones that lead to project completion on time. We wanted the students to set their own project schedules within reason.
5. Professionalism and ethics – Recently, the technical and business worlds have been ripe with unethical professional conduct. While the headlines focus on executive officers and pols, we preferred ethics for entry-level engineers. In addition to Lockheed Martin's "Ethics Challenge" role-play system, we included classroom discussion of case studies taken from industry.
6. Independent Learning – To facilitate the transition from student toward engineer, we decided to provide students with the means to conduct experiments outside the laboratory proper. Each team now purchases a PICkit™ 1 Flash Start Kit

programmer/evaluation board from Microchip Technology, Inc., shown in Figure 1[14]. At only $36.00, it is an economical solution that can be used to program microcontrollers via a USB port and conduct experiments at home. The key features of the PICkit™ are listed in Table 1. The PICkit™ has ramifications beyond the robot lab in that students now *OWN* a complete low-level embedded systems kit for extracurricular projects.

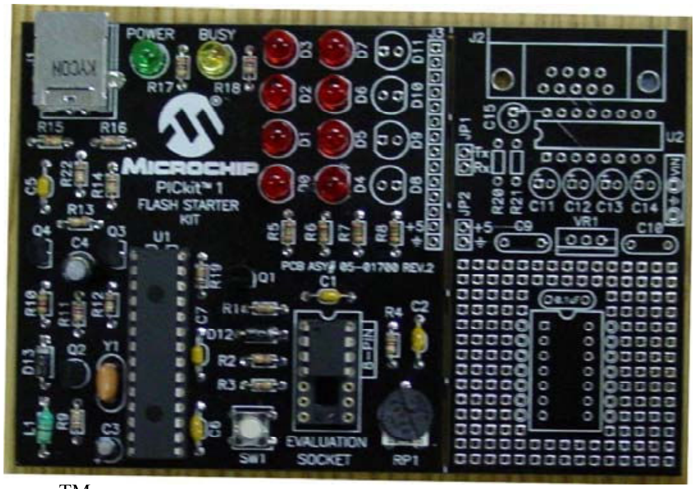

Figure 1. The PICkit™ 1 Flash Start Kit programmer/evaluation board from Microchip Technology, Inc.. The right side of the board is the unpopulated serial communication circuit.

Table 1. Features of the PICkit™ programmer.

Programs 4 different PIC MCU's
Compatible with MPLAB
Self powered from USB
Unpopulated serial comm. circuit
Mutiplexed LED's
Pushbutton
Potentiometer
External access to all MCU pins
User's guide with 7 coding tutorials

Course Format

In the curriculum, the robot laboratory is a one-hour credit course that meets formally twice each week. On Monday afternoons, all students meet in a lecture format, conducted by the laboratory coordinator, for discussion of major issues and policies. In this way, all students get the same information early in week for consideration. During the week, sessions of 10 – 14 students meet in the laboratory room under the direction of teaching assistants to work directly on their implementations.

Due to the complexity of the project, students work in teams of two. Grading consists of two major progress reports that are graded by the coordinator, a formal presentation of their work before their peers, lab journals graded periodically by the assistants and progress towards completion, which is also graded by the assistants.

Robot Specification

At it inception, the robot was a mechanical platform kit with custom analog control based on discrete components and common integrated circuit chips. It has evolved to an embedded systems approach based on the PIC12F675 microcontroller. The salient features of the PIC12F675 are listed in Table 1.

Table 1. Key Features of the PIC12F675

Core Architecture	*Peripherals*
8-bit data bus	Two timers
8-pin package	10-bit SA-ADC
Harvard bus structure	One analog comparator
Orthogonal RAM	8-bit EEPROM for data storage
Direct, indirect and relative addressing	Internal 4 MHz oscillator

To exercise the PIC12F675 to its fullest extent, the robot specification calls for an autonomous robot for office navigation. A path grid, shown in Figure 2, mimics the office environment. At the Destination Download Station, the robot receives commands serially. These commands are intersection codes that define a path from point A to point B. After power to the robot is recycled, (this forces use of the PIC12F675 EEPROM to store intersection codes) the robot must travel the prescribed path. Sensor outputs are analog and must be processed either by the comparator or the ADC. The timers are used for timing critical issues such as PWM generation for motor drive and, in some implementations, turning at intersections. Having only 6 I/O pins, two motor drive circuits and serial communication requirements, the internal oscillator is recommended and the number of sensors is limited.

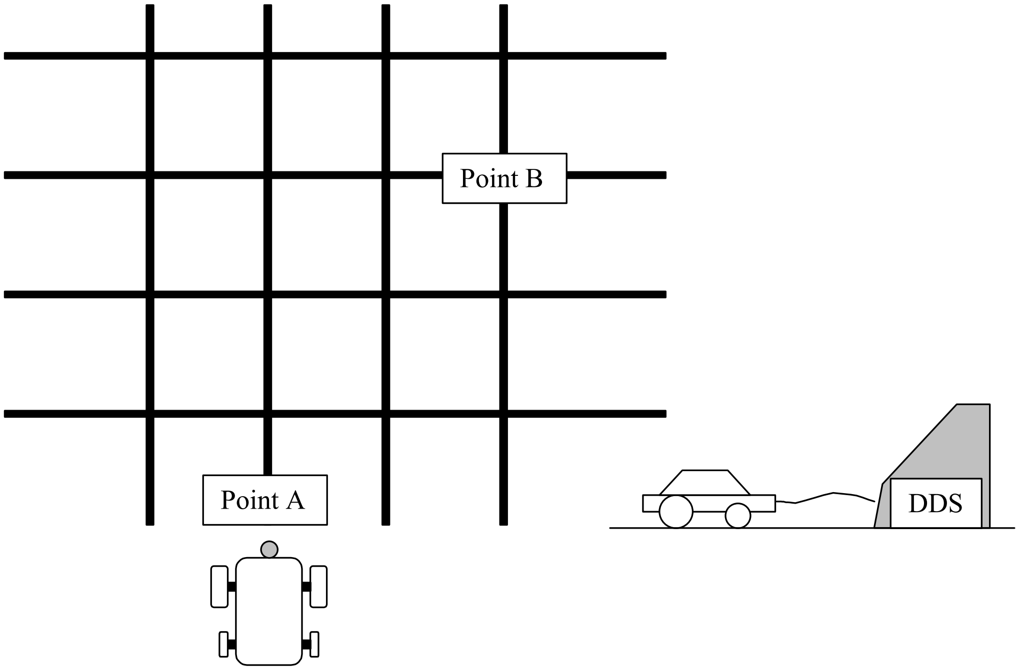

Figure 2. The robot must first receive a set of intersection commands at the destination download station (DDS), then successful navigate from point A to point B.

A Contractual Perspective

To support the pedagogical changes in the laboratory, a change in student perspective was needed. In particular, we wanted them to view themselves more as engineering apprentices than as students. The course is presented as a contractual agreement between two companies, the instructor and the student team where the contract calls for a deliverable prototype robot. In the past, students submitted assignments in their names. Now each team acts as a two-person company, complete with company logos, letterheads and email signatures. All contact is conducted as inter-company communications. As the semester progressed, these "techniques" became habits and professionalism, especially reports, presentations and emails improved significantly.

A Milestone-Driven Pedagogy

Introducing students to project management while maintaining progress toward robot completion required tradeoffs in the grading policy. As in any realistic engineering proposal, we used a series of milestones. These were set by the lab administrator to ensure progress and to provide a standard for grading. The milestones used in fall semester 2003 are listed in Table 2. Students did, however, set the schedule for completing each milestone. As shown in Table 3, each milestone was assigned 2-week window. Using the grading policy described in Table 4, students submitted a timetable for completing each milestone. The grading policy stresses meeting the deadlines rather than setting an aggressively early schedule.

Table 2. The Robot Laboratory Milestones

Milestone	*Task*
Reading Inputs	As the pushbutton is pressed, cycle through the LED's
Interrupts	Use the interrupt input pin on the 12F765 to toggle a single LED
Optics	Demonstrate an IR optic system that distinguishes electrical tape from the floor
ADC	Use the ADC to read an analog voltage between 0 and 5. Display to LED's is initiated by the interrupt pin.
Motor drive	Demonstrate your motor drive, showing all features used in your design (stop, forward, brake, reverse, etc.)
PWM	Demonstrate a PWM output using the ADC to read an input signal.
EEPROM	Demonstrate that you can write to and read from the EEPROM.
Serial Comm.	Download the intersection codes from the DDS and store in EEPROM. After download, turn off the PIC MCU, restart and extract codes from EEPROM when the pushbutton is pressed. Display codes on LED1 and 2.
Track tape	Show that your robot can track accurately on straight lines.
Stop	On STOP command stop at an intersection.
Pass through	On PASS command pass through an intersection.
Turn	On RIGHT/LEFT commands turn correctly at an intersection.
Full demo	Complete entire path without error.

Table 3. Milestone Scheduling Matrix

Milestone Number	*Milestone Window*	
	Week A	*Week C*
1	9/9	9/24
2	9/9	9/24
3	9/16	10/1
4	9/23	10/8
5	9/30	10/15
6	10/7	10/22
7	10/14	10/29
8	10/14	10/29
9	10/21	11/5
10	10/28	11/12
11	10/28	11/12
12	11/4	11/19
13	11/11	12/3
14	11/18	12/10

Table 4. Milestone Point Accumulation

Set date	*Demo date*	*Points*
Week A	Week A or earlier	3
Week A	Week B	2
Week A	Week C	1
Week A	Later	0.5
Week B	Week B or earlier	2.5
Week B	Week C	1
Week B	Later	0.5
Week C	Week C	1.5
Week C	Later	0.5

Alternative Implementations

Each team was issued a pair of LEGO 9-V motors and bought a PICkit^{TM} programmer. Otherwise, each design is fully custom from mechanical to electrical. Photographs in Figure 3 show just a few of the incarnations. Beyond appearances, the critical mechanical issues are sensor location, motor location and motor speed. All three have dramatic impact on turning left and right at intersections, particularly sensor location with respect to the pivot point for turning.

Electrical issues are sensor output range and the motor driver. With a wide sensor range, the PWM signals generated for motor control are less sensitive to position with respect to the path, producing smoother travel. Regarding motor drives, we feel that commercial H-bridge IC’s conceal the driver operation and prefer to have students build their own motor drives. Some designs have more current drive than others affecting speed. Thus, each team must tune their system to find a reasonable compromise between straight-line speed and intersection turning.

Results and Assessments

Two assessment surveys were administered to 23 students during the semester to gauge student performance and attitudes under the new course structure. The first survey targeted the student’s perception of the their preparedness for an embedded systems laboratory and their careers. The data for seven very revealing questions are listed in Table 5. We found students to be much more confident about their hardware skills than software, particularly

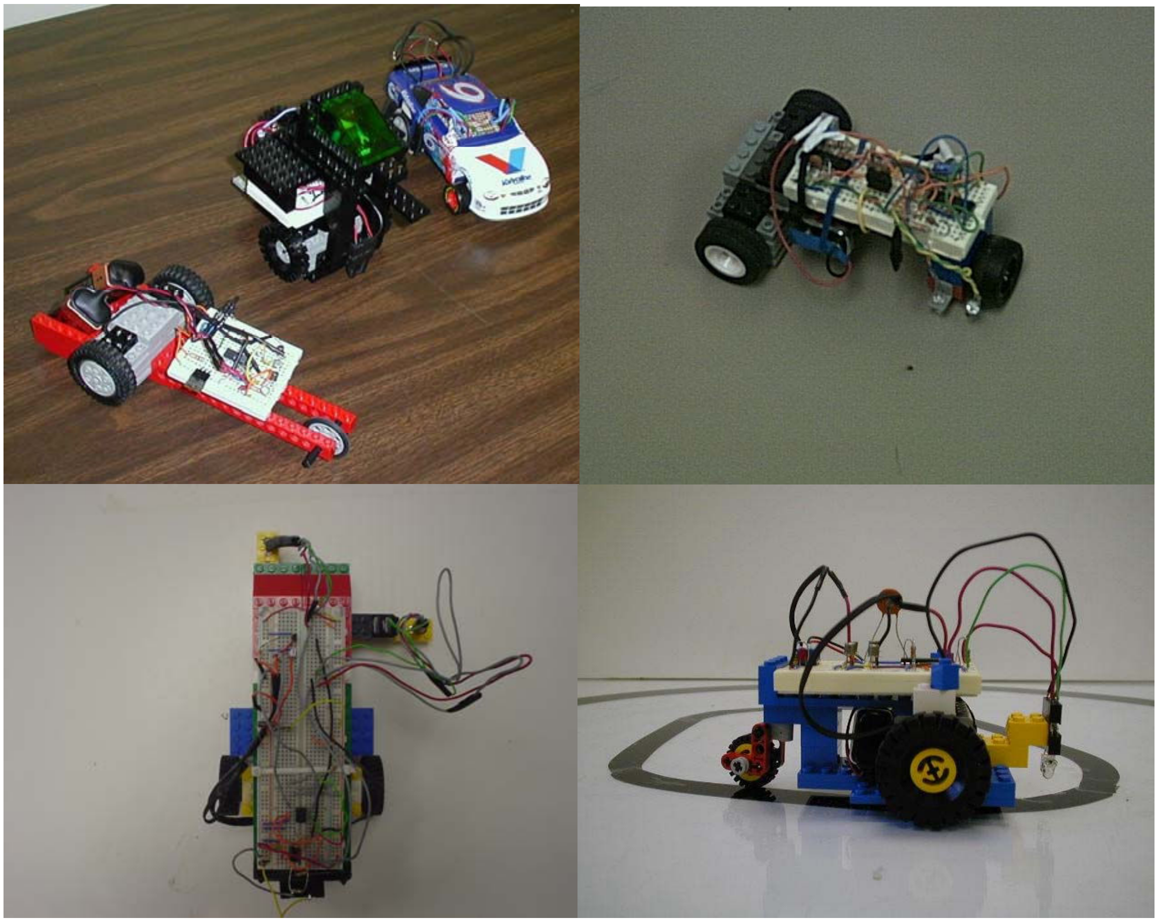

Figure 3. A collection of robot implementations showing a variety of form versus function priorities.

assembly language programming. Given that these students had complete three previous hardware intensive labs but only one assembly programming course, these results were not surprising. Essay questions revealed that students appreciate the relevance of embedded systems and coding in modern technology. We used that perception as motivational fuel throughout the semester.

Table 5. Critical Data from Survey 1 on Perceptions of Preparedness

Question	*Score (out of 5)*
Confidence with assembly language	2.70
Confidence constructing circuits	4.45
Confidence designing circuits	3.25
I know the branch of EE I want to work in	4.29
I know which skills are required	3.29
I know which courses will provide them	3.71
I often think about preparing for my career	3.71

The second survey, administer at the end of the semester, measured the impact of the lab structure on the student's transition towards being an engineer. Responses to questions 1 and 2 demonstrate the impact of ownership. Although less that 15% of the students had even done any independent designs with the hardware they had collected over their first three labs in the ECE department, fully 70% are now thinking of the possibilities. Particularly encouraging were the responses to last three questions, indicating that the course structure is having the desired effect on perceptions and career thinking.

Question	*Score (out of 5)*
I've built my own projects in the past.	1.14
Owning a PICkit^{TM}, I've thought of independent projects to build.	3.57
Will use PICkit^{TM} in senior design or extracurricular projects.	3.29
PICkit^{TM} was a valuable intro to embedded systems.	4.14
Course structure enhanced "career-thinking"	3.89

Informal interviews with both students and instructors were conducted throughout the semester. These indicated that, given the required milestones and the time allotted to the laboratory in the curriculum, the PICkit^{TM} tutorials were inadequate to introduce students to the necessary coding skills. Although student motivation was high, there simply was not sufficient time to master the hardware and software aspects of the MCU, sensors and motor drives and the mechanical issues of the robot. Since the most offending task was coding, it was recommended that more lecture time be allotted to coding techniques and that the PICkit^{TM} tutorials be augmented with tutorials specifically targeting the robot project.

Based on these interviews, one outcome goal is well met – changing student self-perception away from "student" and toward "engineer". As we had hope, the contractual course model, the milestone grading policy, the emphasis on professionalism and, in particular, owning an embedded systems kit were cited directly as key instruments of this change.

In spring semester 2004, we found two senior design groups that were using their PICkit^{TM} programmers to develop subsystems for their capstone projects. One project, in the area of landmine detection, utilized a PIC MCU to pulse a coil at a fixed frequency and duty cycle and to monitor the time constant of the resulting magnetic field. The time constant is a function of subsurface materials. The second project is a low-cost electronic "measuring tape" suitable for distances between 30 and 300 meters. In that work the MCU pulses a focused light source, microsteps a stepper motor, monitors the reflected light energy, then calculates and displays the distance to the reflector. These senior design projects are one of the desired outcomes of our work – students viewing simple embedded systems as just another implementation option at their disposal and *OWNING* the tools to implement them.

Conclusions

A new autonomous robot laboratory structure based ownership and a contractual grading policy has been implemented. The structure directly targets the students' self-perceptions, challenging them to view themselves as engineering apprentices focusing on career preparation. Teacher-student roles are replaced with a solicitor-bidder relationship where a deliverable prototype with specific milestones was required.

Successful teams stayed on schedule and continually adapted their designs to meet the specifications. Unsuccessful teams were not flexible, and failed to create verification schedules that matched their abilities and the lab resources. This too is education.

Assessments in the form of surveys and interviews with both students and instructors indicate that the format was successful. However, improvements are needed that will accelerate the coding learning curve, saving valuable lab time for system level debugging. These include more lectures on embedded system techniques and custom tutorials for the PICkit^{TM} programmer/evaluation system.

Acknowledgements

I must mention Mr. Nathan Loden, and Mr. Anish Anapour, graduate students at Auburn University, who served as my teaching assistants for the robot laboratory. Also, my sincere thanks to each of my students enrolled in ELEC 304 during the fall semester of 2003.

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