A Micro-Controller Based Robotics Course for ME Students

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Introduction

For many years the emphasis of our robotics course has been on projects where students design, build, and test tooling to accompany an industrial robot in a workcell. At the end of a ten-week quarter, students were expected to demonstrate a working prototype that integrates sensors, actuators, and feeders together with software to accomplish a task. Recently, the emphasis in our course has shifted to the use of BASIC Stamp micro-controllers to control mobile robots for a variety of project applications including underwater data collection, buried mine detection, wildfire detection, and others. Some chassis are kit-built and some are student-built, but all have integrated sensors and actuators with control software. This paper discusses the transition to our new course curriculum, and how it is being received by mechanical engineering students.

Top Level Course Objectives and Structure

The top level objectives of the robotics course in the RIT Mechanical Engineering Program are to have students develop hands-on skills with robots, teaming skills where teams work in an independent mode on a rather complex project with little direct supervision, project management skills to complete a project on schedule, and oral and written communication skills. The course is interdisciplinary in nature involving mechanical design and fabrication, electronics and circuits, programming, and systems engineering. It is really an opportunity for students to apply many of the previous courses in our program.

This is a project-based course in which students spend the majority of their time solving an open-ended problem that results in the design, build, and test of a working prototype. Each student must keep a logbook of their day-to day activities on their project, which is graded weekly for progress. Deliverables include a demonstration to the faculty member and lab TA of a working prototype and a final written and oral report that includes a videotape of their working system. Lectures via PowerPoint™ slides on robotics fundamentals build up their robot literacy. Two exams are given throughout the quarter to test comprehension of the material. Weekly lab exercises develop their hands-on skills in preparation for the project. Solutions to the weekly lab exercises are demonstrated to the lab TA. Students sign up for lab time on the equipment and must come to the lab with a preliminary software program, flow chart, and wiring diagram.

Final grades are computed as follows: 20% for the two exams, 30% for the weekly lab exercises, 10% for the weekly project progress in logbooks, and 40% for the project. Project grades are highly dependent on the quality and robustness of the solution and whether the work meets, consistently exceeds, or fails to meet expectations.

Transition to Micro-Controllers

For many years the emphasis of our robotics course was on designing, building, and testing tooling and fixtures to accompany an industrial robot in a workcell. This approach was based on the premise that some of our graduates would become manufacturing engineers who would purchase and install a robot for a specific application at their company site. Since an industrial robot would be delivered with no tooling or fixtures to feed and handle parts, some experience in designing and building these, and developing a working prototype, would be invaluable. In order to support this experience, our robotics lab obtained, over the years, two PUMA 560 robots from General Motors that were later replaced by two rebuilt Puma 650 Mark II robots from Advance Research and Robotics (AR2), an IBM 7535 and an IBM 7565 scara type robot, a Zymark pharmaceutical robot, a pneumatic pick and place robot designed for sprue picking, and three Adept scara type robots. Each robot type required students to master a different language: the Pumas and Adepts used VALII, the IBMs used AML Language, the Zymark was menu driven primarily, and the pick and place was strictly playback in nature. Maintenance of these robots was a continuing endeavor that fell to the author, and a few of his more experienced students. There was no one on campus with the expertise to troubleshoot problems of major significance. Therefore, the Pumas would be packed on a pallet and shipped to AR2 for repair with about a four-week turnaround. Aside from the significant expense of the repair, being without a robot in the midst of a full quarter of lab instruction was painful for all concerned. Material handling equipment including a Bosch conveyor and student built conveyor, were also in need of occasional maintenance and trouble-shooting. Trouble with lab equipment and consequent student frustration was often a frequent item on the student course evaluations. In short, equipment downtime and trouble-shooting consumed a good portion of the lab TA and professor's time to keep the lab functioning, if sometimes only on a partial basis. With 16 to 18 students working in teams of two, it was imperative to have two robots set-up with complete sets of tooling and fixtures so that all teams could complete their weekly lab exercise before it was time to begin the next week's lab exercise. On the positive side, these robots provided students with the opportunity to confront a rather complex open-ended project problem, brainstorm alterative solution paths, select the best alternative for a detailed design, construct and debug a prototype, and make it work. As a result of working with industrial robots, students developed their hands-on skills and an appreciation of the difficulties involved in integrating everything into a working system. This was the most valuable kernel of the course, and the robotics principles learned along the way were almost an add-on benefit.

Many new products, recently developed, contain an embedded processor. These "smart products" typically use a microprocessor to control actuators of some type in response to sensor input. Because many of these new products are designed in a concurrent team format, and mechanical engineers are often members of these teams, we came to feel that our ME graduates should have a solid grounding in micro-controller-based project design and build. Because micro-controllers open up an exciting new area of mobile robot projects in an autonomous format, and are more fun, more easily maintained, and safer than industrial robots, it became clear to us last year that this could be our entrée into the micro-robotics arena. Transitioning the course to this new format would allow us to remove much of the expensive, difficult to maintain, industrial robots from our lab space while freeing up considerable space for workstations.

In order to get started with micro-controllers, in the summer of 2000 my lab TA purchased some BASIC Stamp micro-controllers from Parallaxinc.com, and began to formulate some elementary lab exercises that might be possible candidates for our course. By leveraging my lab TA's work, we included four lectures and one lab on the Stamp into the course during the fall of 2000, as well as the option for students to do a Stamp-based project. Because this was well received by students, this was repeated in the winter 2000 quarter. In the fall of 2000, approximately half of the students opted for Stamp-based projects and half for industrial workcell-based projects, while in the winter quarter 2000 all teams opted for Stamp-based projects. At the conclusion of the winter quarter 2000, it became very clear that micro-controller-based micro-robotics might be the direction of choice for the future of our course. The fall quarter of 2001 again confirmed that students find micro-controllers more fun, more reliable, more flexible, and more appropriate for their careers than large industrial robots. At the end of this quarter, we removed all industrial robots except the Adept robots, and another major restructuring of the course was undertaken. Two new Stamp labs were included, and all Stamp lectures were moved up to the beginning of the course in order to give students as much of a head start on their projects as possible. See Table I for the lab exercises in our new format.

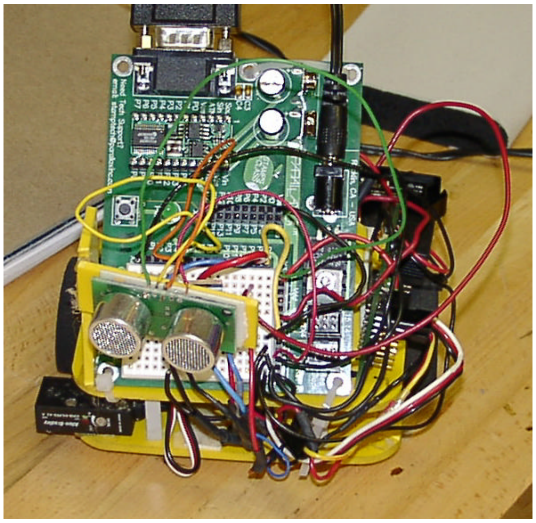
Table I: Lab Exercises in the New Format

WEEK	TOPIC

1	• Introduction to the BASIC Stamp
	  o Introductory Stamp circuits[1,2]
	  o Use of Serial Servo Controllers (SSCs) to control multiple servos[3]
	  o H-Bridge to control twin DC motors with gearboxes[4]
	  o Use of Wireless Transceiver Boards in Switch (on/off) Mode

2	• More Advanced Stamp II Topics
	  o RCTIME statement for variable resistor-based sensors[1,2]
	  o Thermistor use
	  o Serin and Serout serial commands[1]
	  o Use of Wireless Transceiver Boards in Serial Mode to transmit thermistor data to a second Stamp for plotting

3	• Mouse Maze
	  o BRANCH statement for control of a wall following mobile robot "mouse" chassis
	  o Programming the pre-wired chassis with ultrasonic sensor on the front, and two infrared proximity sensors on the side, to follow along a wall to complete a maze successfully. See Figure 1.

	 Figure 1: Mouse Maze Chassis
4	• Adept Robot with Palletizing ○ Introduction to VALII programming on the Adept ○ Programming an Adept Robot to pick parts from a feeder using a pneumatic two fingered mechanical gripper, and palletize them in a matrix
5	• Interim Project Presentations ○ Mid-term presentation of project goals, objectives, alternatives considered, and detailed design to date.
6	• Adept Robot with I/O and Conveyor ○ Use of the Adept input and output module ○ Programming the Adept robot to pick up parts with a vacuum gripper from a matrix of parts, and place them in a pallet matrix on a Bosch conveyor, continuously checking for part presence in the gripper using an infrared sensor mounted on the gripper. The Bosch conveyor has a pallet sensor to detect the pallet, and a stop actuator to release the pallet when it is filled. After release, the pallet crosses over to another conveyor line via a pallet lift station, and travels to a second pallet stop. All must be controlled from the Adept I/O module.
7	• Machine Vision ○ Use of the Cognex Insight System to sort good and bad parts supplied by a parts feeder, including edge and circle finders for gaging purposes.
8	• Review of Robotics Research Paper ○ Students present their critique of a current article from the

		literature published 9/1/01 or later. The intent here is to have students practice their oral presentation skills, and to get some exposure to the state-of-the-art in robotics research.

New Course Prerequisites

With the implementation of our new format, it is becoming increasingly important for students to have the prerequisite skills needed for success as well as for an enjoyable experience, with a minimum of frustration, before they come into the course. They should be fourth or fifth year status to insure a requisite level of maturity in order to work independently with little direct supervision on a rather complex project, and the potential to develop good project management skills including the ability to deliver a working prototype in ten weeks according to the project milestones (see Table II). See Table III for recent Stamp projects. Students should have some programming experience with a higher-level language like BASIC, C++, or FORTRAN, and be familiar with the use of flow charts for logic documentation. Experience with basic circuits, use of a multimeter for circuit debugging, and electronics basics including the ability to patch up circuits on a breadboard with resistors, capacitors, pots, voltage regulators, power supplies, and op amps, is highly recommended.

Table II: Project Milestones

• Topic selection due by week one
• Two page project proposal due by week 2
• Concept selection, after a literature search and identification of alternative concepts, due by week 4
• Drawings for a prototype due week 5
• Parts obtained by week 7
• Prototype demonstration to Professor and TA week 9
• Final oral and written report due week 10

Table III: Some Recent Stamp Projects

PROJECT	DESCRIPTION
Mine Sweeper	The intent here was to detect mines with metal cases and mark their location for later demolition. One previous project designed, built, and tested a Stamp-based mobile robot that used a metal detecting sensor on board. The robot encountered some problems, and tended to roll over any mines it detected. A new project is in progress.
Wildfires Detection and Tracking	The overall intent of this project was to develop sensors that could be dropped on the ground from a plane in order to detect and track the path of a fire, since smoke makes aerial tracking difficult or impossible, in some cases. As a first step, students built a chassis that detected a change in ambient temperature above a set point, as well as avoided obstacles while searching an area. The area searched was mapped for “hot spots,” and locations of these were displayed on a grid on a PC screen.

Aquato	This project built and tested an autonomous submersible robot that collected temperature and pressure data as a function of depth in the RIT Pool. It had an electric thruster to force it to the bottom of the pool, but horizontal propulsion was not included.
SUMO Robot	A robot was built consistent with the rules for the national competition in which two Sumo robots try to push each other out of a circular ring drawn on the floor. Our robot had an ultrasonic sensor on board to detect the opponent, and Cds cells to detect the ring boundary. A prior project won second place in last year's competition.
Cyclops	An RC car chassis was controlled with a Stamp on board to avoid obstacles detected with an ultrasonic sensor. A video camera on board transmitted video images in real time via a pair of wireless video transceiver boards to the screen on a laptop. The vehicle was capable of autonomous operation or remote control via the keyboard on the laptop by wireless communication.
Smart Toaster and Coffeemaker	The smart toaster had a photo sensor to detect the darkness of the bread and the Stamp compared this in real time with a user setting selected via a pot. When the toast was at precisely the correct darkness, an actuator popped the toast up. The Smart Coffeemaker used a Stamp microcontoller to sense the water level in the filter in order to control the power to the boiler. A rather inexpensive unit as originally purchased, it made poor coffee since the water typically overflowed into the carafe carrying the grounds with it. Stamp control prevented this, and made great coffee possible.

Student Reaction

During the lab period, we typically introduce the lab exercise to the students, and show them a demonstration of what their solution should accomplish. Teams then sign up for lab time to work on the lab, when it is convenient for them. We recommend that some time be spent during the TA's lab hours. Students, however, have card access to the lab from 7am until 11pm seven days a week. They are required to work in pairs for safety reasons, so that no one is working alone in the lab when the TA is not there. During the transition to this new format, student course evaluations have often mentioned that we need multiple equipment set-ups, so four or five teams can work on their lab exercise simultaneously. Although each team is assigned a basic kit consisting of a Stamp Board of Education (Stamp plus attached breadboard) and required resistors, LEDs, and capacitors, etc., we often have only two complete set-ups in the lab consisting of wireless transceiver boards due to the cost involved. Now that the Department Head has requested that we increase our enrollment from 16 to 24 students to keep pace with our department's increasing enrollment, we are negotiating for more Stamp equipment to meet this challenge. Our Adept labs will still be limited to two set-ups per lab, however, as only two sets of tooling and fixtures are currently available. This is a constant source of student concern. Overall, student feedback has been very favorable on the transition to micro-robotics. The Stamp equipment is very reliable, and this has eliminated much of the frustration that students have experienced in the past with the Puma robots. Students often do not fully appreciate the systems nature of the labs and project, and rather than get each subsystem working separately, then combining them one at a time to complete the system, they often hook up everything together and get frustrated when it does not work the way they expect. Students also still report that the course is a lot of work, but they seem to enjoy it!

Conclusions

We plan to continue the transition of our Robotics course and lab into a Studio Laboratory Education and Research Environment consisting of 12 workstations that will serve the course and provide opportunities for undergraduate and graduate research projects. Although the Stamp microcontroller is too basic a device to be used in industry, it is very user friendly and exposes ME students with little formal programming experience to most microcontroller principles. We plan to introduce more sophisticated microcontrollers including the PIC and Intel 8051 into the course this year to augment the Stamp experience. Both require C++ language, which our ME students do not previously get, so this may be a challenge. Our vision is to make our robotics course and lab the premier hands-on undergraduate robotics laboratory in the United States. We would like to establish relationships with the Robotics Institute at Carnegie Mellon University, MIT, Stanford, and other outstanding graduate schools, which will seek to recruit our graduates.

Students enjoy the new robotics course format with an emphasis on micro-controllers, and they see the application to new product development where embedded processors have become commonplace. It is essential for mechanical engineering students to have a working knowledge of these devices in order to be cutting-edge. In the past, our enrollment was severely limited by the availability of a few expensive industrial robots. In contrast, micro-controllers are more fun, safer, and more easily maintained and upgraded.

Bibliography

[1] Parallax Inc. *BASIC Stamp Programming Manual, Version 2.0c*. (2001).
[2] Edwards, Scott. *Programming and Customizing the Basic Stamp Computer.* New York, N.Y.: McGraw-Hill (1998).
[3] URL: http://www.robotstore.com
[4] URL: http://www.parallaxinc.com

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