AC 2011-553: EXPERIENCE TEACHING A MULTIDISCIPLINARY PROJECT-BASED ROBOTICS COURSE BUILDING AUTONOMOUS MOBILE ROBOTS

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Experience Teaching a Multidisciplinary Project-Based Robotics Course Building Autonomous Mobile Robots

Abstract

The robotics course taught as a professional elective in the RIT Mechanical Engineering program is a non-traditional project-based hands-on course in which students work in teams to build autonomous mobile robots to accomplish a task. A micro-controller on-board is used to control drive motors in response to sensors for object or boundary detection. Students complete five lab exercises to get their robot literacy up to the point where they can effectively apply the technology to their project. Day-to-day homework is not required, and teams focus entirely on developing a working robot. Teams must design, build, and test their robot all within a ten week quarter time period. Multiple disciplines of engineering are taught and implemented in the final project. Students are required to build the chassis, construct supporting electronics for sensors and program the microprocessor on-board. The evolution and development of the course, and experiences with various types of projects attempted will be discussed in this paper, along with recommendations for individuals wishing to try such a course format.

Introduction

The current micro-controller-based robotics course has evolved from a predecessor course whose focus was on industrial robotics. At that time, we had a number of industrial robots in our lab including PUMA, ADEPT, and IBM robots, many of which were donated by local industries including Xerox and GM. Some of our graduates were finding employment as manufacturing engineers, and needed a familiarity with implementing a successful robot work cell. The focus of projects at that time was on designing, building and testing tooling and grippers, and fixtures for a robot in a work cell, as well as integrating sensors and developing the accompanying software. Some projects were done for local industries, including Kodak. Maintenance of these robots were problematic, however, and this fell to one of the authors and his more experienced students. Major problems required a robot to be crated and shipped to a vendor for repair, with a resulting four to six week turn-around time. Being without the robot in the middle of the term was difficult to work around. For reasons of inconvenience and expense, an alternative venue needed to be found. The robotics lab TA at the time suggested we look into micro-controllers. Smart microcontroller-based products were becoming more common, and mechanical engineers are part of multidisciplinary teams to develop these new products. A microcontroller-based micro-robotics focus seemed, therefore, like a good fit. The transition away from an industrial robotics focus to our current microcontroller focus occurred about the year 2000.

The Stamp microcontroller was selected for its ease of programming in BASIC language. Our students at one time took FORTRAN, but no longer got a higher level language as part of their RIT Mechanical Engineering program. The Stamp, therefore, was an easy item for them to learn to program after a few hours instruction. While a number of alternative microcontrollers have been investigated, the Stamp continues to be our microcontroller of choice for mechanical engineering students with little prior programming experience.

Learning Objectives and Course Deliverables

The learning objectives of the course in our current format are to:

- Develop hands-on skills with microcontrollers and robots.
- Have a multidisciplinary focus, and provide an opportunity for students to apply many of the previous courses in their program.
- Develop teaming skills.
- Have teams work in an independent mode on a rather complex project with little direct supervision.
- Have teams need develop project management skills to complete a project on schedule.
- Focus the projects on the design, build, and test of mobile robots.
- Enhance oral & written communications skills.

Many of the above objectives are ambitious to achieve in a ten week quarter format while some students are also very busy taking the Multidisciplinary Senior Design (MSD) course at the same time. Some MSD projects, however, involve robotics, microcontrollers, sensors, and actuators, so their experience in robotics is helpful. For those who are not simultaneously taking MSD, their experience in robotics developing a prototype helps prepare them for what lies ahead in MSD. In robotics, students work rather independently in teams to complete their projects. Although lectures on robotics fundamentals are given with reading assigned from texts and class PowerPoint slides posted on myCourses.rit.edu, the major emphasis of the course is placed on a term project. Five weekly lab exercises to build robot literacy and hands-on skills for the term project are required from each team with a team report due the following week. Weekly project progress is documented in a bound logbook by each team member and a weekly progress report from each team, indicating what each team member has done for the week, is expected. Quizzes on lecture material and on the lab fundamentals are given weekly, but these are a small percentage of the final grade. Each team demonstrates their working robot to the class, writes a final written report on it, and makes an oral presentation to the class on the design, fabrication, and performance of their robot. A video of their working system is submitted with their final report and shown at their final presentation.

Multidisciplinary Engineering Focus

Prerequisite skills needed for the Robotics course are rather minimal. Students are required to have fourth or fifth year status in order to register for the course. They should have experience with DC circuits and circuit troubleshooting using a multimeter. Mechanical engineering students will have taken an electrical engineering (EE) course on circuits in their third year, so this is not usually an issue. Some programming experience in BASIC, C, FORTRAN, or other higher-level language is helpful, but not required. Lectures cover the requisite programming for the labs and project. Machine design and drawing skills are helpful during the design phase, and CAD assembly drawings and part drawings are required except for components–off-the–shelf (COTS) to be purchased. Robot fabrication is done in the machine shop, so basic shop skills using a band saw, lathe, milling machine, and hand tools are necessary. These skills are covered in their Materials Processing course and lab, although all students are required to be re-qualified on any machine by shop staff before being allowed to work on the machine in an independent

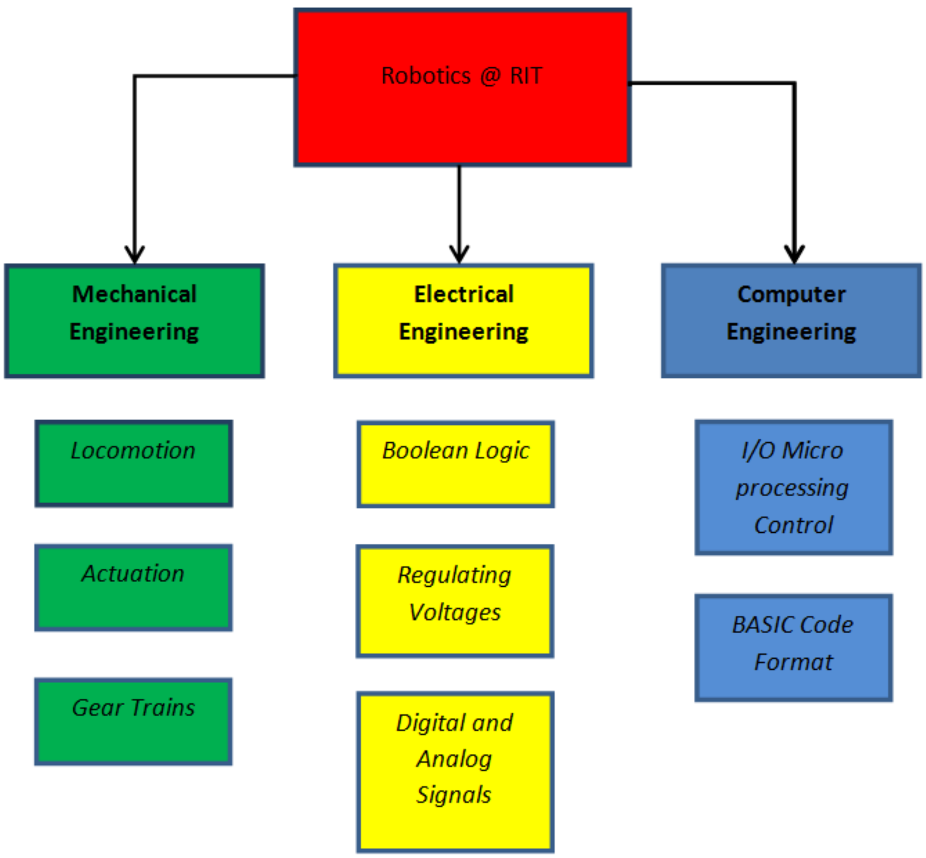

Figure 1: *Problems seen by students in Robotics class, split into three different disciplines*

mode. Teams need to develop some systems engineering skills to successfully integrate the various sub-systems together into a functioning robot prototype that is robust. Students quickly learn that although sub-systems may work well alone when bench-tested, they may not work so well when integrated with others. Teams commonly fail to leave themselves enough time for

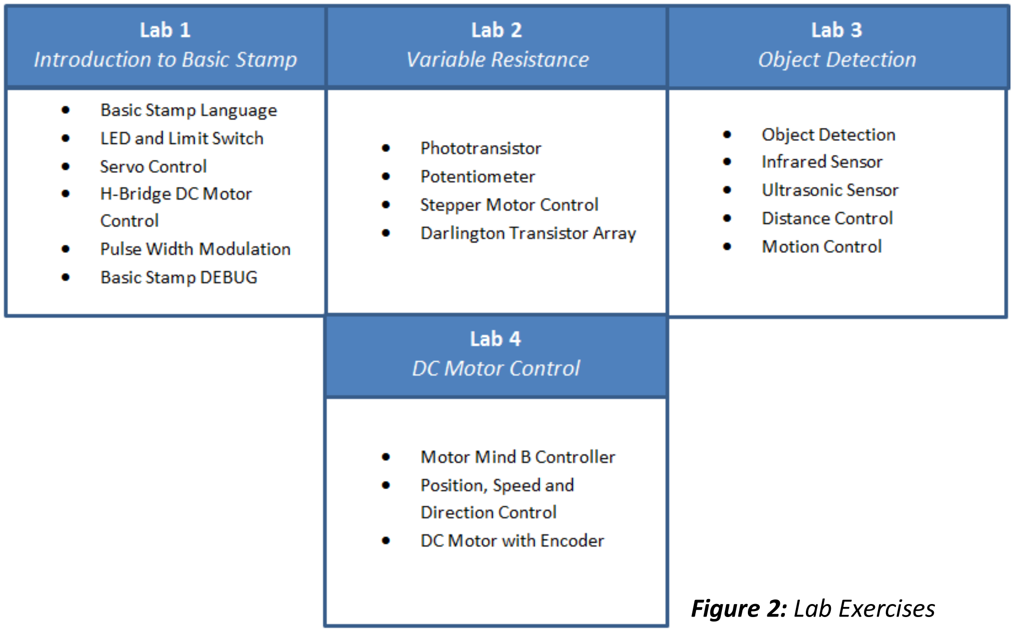

Figure 2: *Lab Exercises*

testing and debugging. As a result, robot performance may suffer, and this is hard lesson to learn at their class demonstration in front of their peers. Teams also must develop their people and team skills to deal effectively with team members that may not be doing their fair share of the work. Peer evaluations are given at mid-term to address this issue. The instructor and TA can get involved to help remedy the situation, but teams are encouraged to work through this among selves. On occasion, students from electrical engineering or engineering technology ask to enroll. They are considered on a case-by-case basis depending on their background and skill level. Topics covered in the course are shown in Figure 1.

Logistics We Have Evolved To

Four hands-on lab exercises are provided to build up student's robot literacy in preparation for full-time focus on their projects about mid-quarter. Project milestones, however, begin the first week, and will be discussed in a later section. The teaching assistant (TA) administers the lab exercises based on fundamentals and instructions covered by the instructor in a previous lecture. Teams of three students are assigned on a random basis, rather than allowing them to choose their own team members. When team issues arise when someone is not "pulling their weight," students find this more difficult to resolve with friends rather than assigned team members. They will also not likely get the opportunity to choose who they will work with on teams in industry.

Teams are required to buy a $100 Basic Stamp Board of Education [1] with USB PC connection, and asked to buy a $20 text. Costs can be shared among team members equally, or in a manner the team decides. Prior to each lab session, the TA will assemble a kit of parts for the lab exercise for each team, and prepare a live working demonstration at the start of the lab period. Lab assignments and all course files are available for download on the myCourses website.

Students are asked to prepare pre-labs with flow charts and wiring diagrams due at the beginning of each lab period.   If teams do not complete a working demonstration by the end of the class period, it may be demonstrated later in the week during TA office hours. One lab report per group will be due at the beginning of the weekly lab period the following week. A storage locker with a combination lock is assigned to each team to keep their lab and project materials secure. The robotics lab supplies components for the labs exercises and some for the projects with the understanding that if "You break it, you buy it!"

The composition of the four lab exercises are shown in Figure 2. In Lab 5, teams begin to assemble components specific to their term project.

Term Project Environment

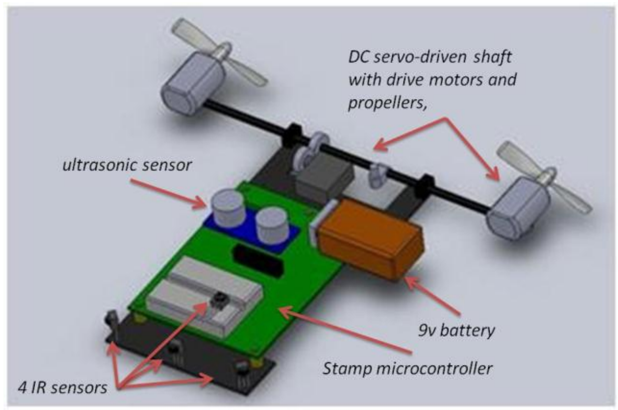

Figure 3 *- Propulsion concept sketch*

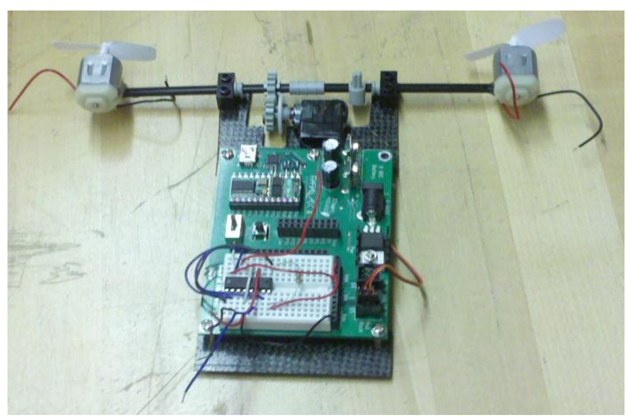

Figure 4 *- Propulsion Unit and chassis*

Teams can propose a topic and scope within the guidelines that it must have at least one input and one output. It should have the equivalent of functions for object finding, object discrimination and testing, object carrying and releasing, boundary-following, and home position finding. For example, in the recent past, teams built fire-fighting robots for a class competition. Two candles were placed in an 8' x 8' playing field marked out by electrical tape on a tiled floor. The playing field was divided in sixty four 1'x 1' squares. The field contained two candles. One candle was lit and one was an unlit decoy. The robot had to locate and extinguish the lit candle and return to the start position in one corner of the playing field in the shortest time. Water could not be used. Candles could not be tipped over or moved out of their square. Teams were allowed three attempts. The placement of candles on the field was the same for each team but varied for each attempt. Another variation of the competition was used for mine detection and retrieval where two plastic cylinders were used for the simulated mines. One had a metal top (mine) and the decoy cylinder did not. The robot had to find, pick up, and retrieve the mine to starting home position without going outside the boundary in the shortest possible time. Although the competition format worked well, it seemed to take a lot fun out of the project. As a result, we have gone back to a previous format of allowing teams to propose a project they would like to work on within the above guidelines. An example in this format is shown in Figures 3, 4 and 5.

RIT students built a balloon prototype to access feasibility of IR beacon navigation, a propulsion concept sketch of which is shown in Figure 3 [3].

Two DC motors are mounted on a rotatable shaft driven by a servomotor to control the direction of thrust. Control is provided by a Stamp microcontroller. Ultrasonic sensors determine whether the balloon should be driven up or down in order to adjust altitude. Differential motor control (turning one motor forward and one in reverse) provides steering. Steering direction is provided by four IR sensors mounted on the chassis to detect an IR beacon mounted on the ground at the desired location. Three of the infrared detectors were attached to front of the chassis, with one facing forward, and the other two facing approximately 45 degrees off axis to the left and right. The fourth infrared detector was mounted directly onto the Stamp breadboard, pointing directly down (to detect when the balloon was directly over the target). Steering direction was determined by which of the four on-board IR sensors were active. The propulsion unit and chassis in Figure 4 is attached to the underside of the balloon prototype shown in Figure 5. Although the altitude control worked well, the navigation capability needed improvement.

Figure 5 *- Balloon with auxiliary lift mini-balloons.*

Robotics Course Outline			
	Final Project Milestones:	Lab Performed	Lab Report Due:
Week 1:			
Week 2:	Project Topic Selection	Lab 1 – Intro to Stamp Programming	
Week 3:	Project Scope and Team Roles	Lab 2 – Stepper Motors	Lab 1
Week 4:	Literature Search	Lab 3 – Object Detection Using Sensors	Lab 3
Week 5:	Concept Selection	Lab 4 – DC Motors & Encoders	Lab 4
Week 6:	Preliminary Design	Lab 5 – Object Locating With Project Chassis	Lab 4
Week 7:	Detailed Design		
Week 8	Build complete		
Week 9:	Prototype Demo to Professor and TA		
Week 10:	Class Demonstration, and Final Oral and Written Report		
Week 11:	Project Presentation		

Table 1: *Robotics Course Outline with due dates*

An Overview of the project milestones and lab exercises is shown in Table 1. Table 2 shows recent team-developed class projects for the past two years.

Recent Class Projects		
20092		
Team #	**Robot Name**	**Description**
1	NerfBot	Locates a colored target & uses air to blow it over
2	UAV Blimp	Controls altitude & navigates to a location
3	Jerry	Programed algorithms to wave a toy in front of a cat
4	SpoonBot	locates colored object & drops it in an appropriate location
5	ArsonBot	Locates a candle & lights it
6	Constructocon	Locates blocks & piles them up
7	Coomba	Locates soda cans & loads them onboard
20102		
1	SAM Bot	Locates enemies & destroys them while rescuing friendly's
2	Spill Bot	Locates a liquid spill & removes spill
3	Depth Bot	Underwater depth detection & environmental pH and temperature observation
4	RoBoBin	Autonomous removal of recyclable garbage
5	Swift Bot	Underwater object detection & retrieval
6	Tron Tank	Locates enemy & destroys with disc projectile
7	MD^2	Mine detection, disposal & remote detonation

Table 2: *Recent Class Projects*

New Lab layout

Recently, lectures were moved out of the lab to a classroom, and the space was better arranged to facilitate course project work. See Figure 6. The new arrangement also allowed creation of research areas for graduate students. Due to the growing opportunities for robotics research, RIT has started to conduct research in such areas as hybrid locomotion, smart material actuation and biomimetics [2]. Creating a center where students can see ongoing robotics research projects encourages innovation and is the first step to creating new projects.

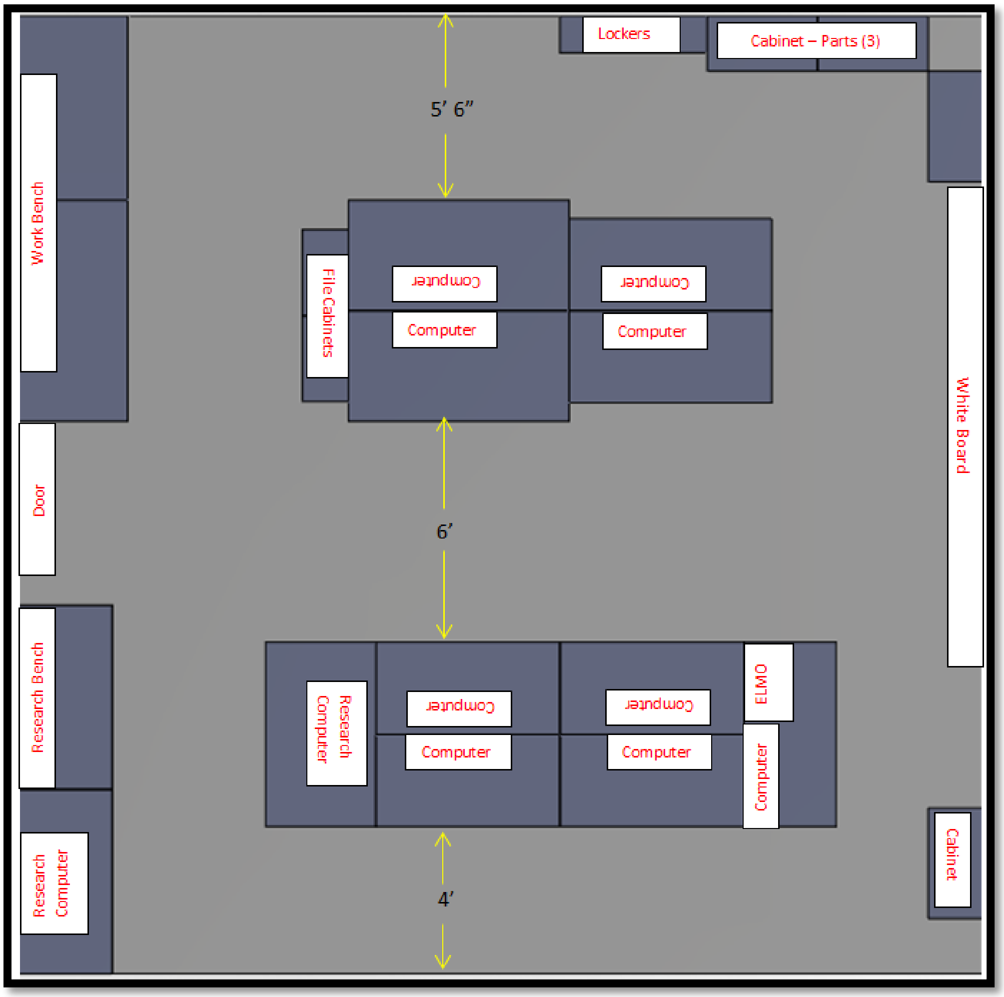

Figure 6: *Studio Laboratory layout for Robotics Lab section*

What Works Well and What Needs Improvement

The lab exercises have been well received by students, and have generally been completed in the two hour lab period provided. Student teams are working well together and have been resolving team workload issues without instructor or TA intervention. Teams seem to appreciate choosing their own project, and very much enjoy the hands-on nature of the projects and the lab exercises. Design, build, and test of projects of the type we have been doing, are quite feasible in a 10 week quarter period.

The Stamp processor is rather limited in speed, memory, and input/output capability. Alternative microprocessors, like the Arduino and PIC are being investigated, and could be more appropriate for the evolving level and complexity of recent projects. Students do not enjoy the PowerPoint slides posted on myCourses and used in the lectures. An alternative approach is needed here. Projects need to be funded entirely by the team, although some components are available on loan from the lab. A larger inventory of components (servos, sensors, steppers, etc.) is needed in the lab for check out by students.

Future Work

A future goal is to have two person teams rather than three person teams with the added infrastructure necessary to support this. More research projects are anticipated in the areas of autonomous mobile robots including Remote Operated Vehicles (ROV) and Unmanned Aerial Vehicles (UAV), as well as biomimetics. Course term projects will likely move into these areas. Our overall mission is to have our robotics lab become recognized as one of the premier robotic laboratories in the nation.

References

1. www.parallax.com
2. W. Spath and W. Walter, "Feasibility of Integrating Multiple Types of Electroactive Polymers to Develop an Artificial Human Muscle," in International Mechanical Engineering Congress & Exposition, Vancouver, British Columbia, Canada, 2010.
3. E. Brent, B. Clayton and A. Frenkel, "Autonomous Blimp Bomber", Final Report for RIT Robotics Course 20092, February 2010.