A Robotics Lab for Engineering Undergraduates

Tim Annesley and **David P. Miller**
School of AME, University of Oklahoma
tim@ou.edu and dpmiller@ou.edu

Abstract

This paper describes an upper division robotics lab course taught at the University of Oklahoma in the School of Aerospace and Mechanical Engineering. While targeted to AE and ME majors, this course has some participation of CS, CEIE and EE majors. The paper describes the structure, content and learning objectives of the course. Assessment results based on tests and student surveys is also presented.

1 Overview of the OU AME Robotics Lab Course: AME 4802

The school of Aerospace and Mechanical Engineering at the University of Oklahoma offers a *Robotics Lab* course which fulfills the requirement for experimental elective in both the AE and ME degree programs. The course is typically taken by junior or senior undergrads, though the occasional graduate student may also enroll. Many colleges and universities now include one or more robotics courses in their curriculum. Many are being used in CS departments (e.g., [10, 6, 4] and numerous others) to promote the CS curriculum and increase the otherwise declining number of CS majors. Our class has almost the opposite motivation. The fields of ME and AE are both becoming more software dependent – yet many of the undergrad majors say that they selected one of these fields because they do not like working with computers. This robotics course forces them to face the programming demon. A rotating assignment of duties within each team is used to ensure that all students participate in the software development, in addition to the other engineering aspects of the projects.

Because these are upper class AE and ME majors, they have had CAD classes and shop experience. This allows the course to address problems that are beyond the scope of many Lego robots, though Lego remains a preferred building material for some students. The advanced mechanical design and construction capabilities (when compared to a typical CS based robotics course) enables there to be a larger and more diverse set of projects than is typically found in robotics classes; many of which may concentrate on building towards a single task, e.g., [1].

1.1 Class Structure

In order to best understand the function of the course its first necessary to outline the structure of the course. Enrollment for the course was capped at 30 due to lab size and Teaching Assistant limitations. Each week, the entire class met once for a 50-minute lecture then, again, in groups of 15 for a 110-minute laboratory session. Each group of 15 was then divided into teams of 3. The teams worked together for the duration of the semester. The idea behind teamwork is to promote synergy amongst the members in addition to a variety of individual skill sets be available for use by the team. The layout of the lab was designed to give each team a space where individual team work can be performed and discussed, as well as a place where inter-group collaboration could occur around a common central work area. Sharing of gained knowledge was encouraged as long as credit is given in the written portion of the assignments.

1.2 Instructional Strategy

The instructional strategy used for this course incorporated elements from traditional lecture as well as an, alternative, problem-based learning approach (PBL). This discussion will describe each strategy and outline the reasoning behind using them. The teaching strategy that most higher education students are familiar with is the lecture. Although it has benefits that include cost effectiveness and efficiency for material presentation, it is not always the most effective means for learning in the classroom. Traditional lecture involves an instructor that presents material to a generally passive group of students that may or may not be actively engaged with the material that is being presented. The instructor is responsible for the direction that the class takes and the material that is presented. This can be beneficial in some areas of study but due to the nature of this course it is used minimally and not the focus of the course design. The AME 4802 design uses the single weekly lecture to present material associated with the current problem to be assigned, as well as a time where tests can be administered.

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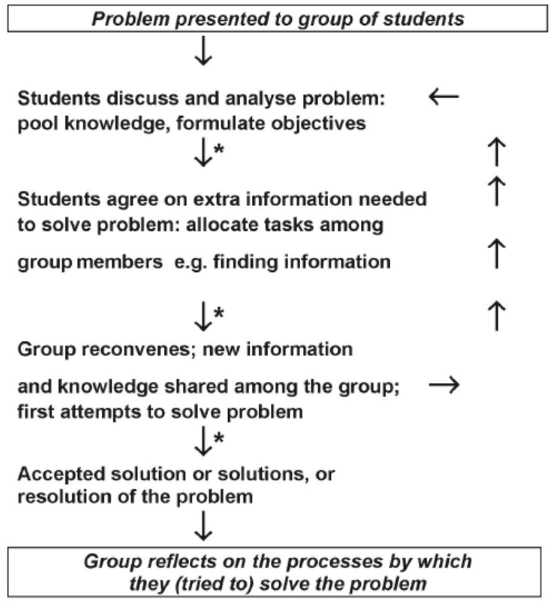

Figure 1: Model of problem-based learning process [11]

The bulk of the learning that takes place in AME 4802 is through PBL. As seen from Figure 1, PBL can be modeled as an iterative process that begins with the introduction of the problem to the students. For the purposes of this class, the problem would generally be a particular objective that must be accomplished by using a robotic device designed and built by each team. From early on in the process, the students are able to take many possible paths towards solving the problem. Current research shows that although problem-based learning does not significantly increase a students ability to problem solve, the strategy does impact the students future success at self-directed learning [3]. The students set learning objectives after the initial discussion of the problem. Many times, when research is performed and new knowledge is acquired, students find that a new set of sub-problems have arisen and must be solved in order to proceed. This cycle continues until the team obtains a successful solution to the problem [11].

The role of the instructor in PBL is more of a facilitator. The facilitator is present during meetings and closely follows the potential paths laid out by the teams. The facilitators role is not to teach the students knowledge but to help guide their learning and head off any potential disastrous paths taken. In AME 4802 there are 2 facilitators that monitor the 5 teams during the lab session. At times, some students will find the process a bit frustrating because all the information needed isnt presented directly to them. The frustration is far outweighed by the sense of ownership and achievement experienced when the problem successfully solved as a result of their own effort and self-direction. Throughout the semester, problems are assigned, increasing in complexity. As illustrated in Figure 2 , less guidance is needed as the students learn and become able to handle problems involving a more complex number of components [7]. PBL has shown to be a successful strategy for achieving the objectives of deep learning and improved ability for self-directed learning.

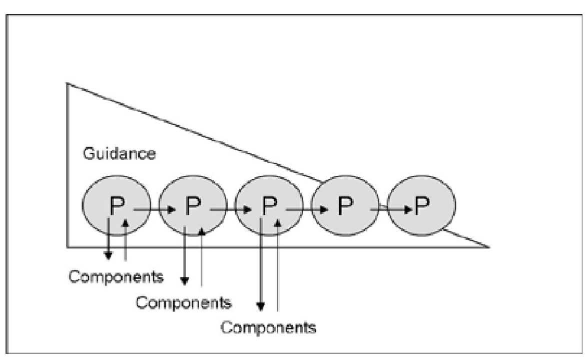

Figure 2: Relationship between progressive problem complexity and required guidance [7]

2 Projects

The problems assigned were designed to lead the teams into areas of knowledge commonly used in the field of robotics. The problems in this course were designed for students using an XBC (Xport Botball Controller) [5] and an iRobot Create. The XBC provided a platform for data acquisition and processing using various types of sensors. Programming is done using Interactive C (IC) and KISS C, C-based programming environments. The Create is a mobile platform that can be interfaced with the mobile XBC or computer controlled using KISS C [8]. The Create has several on-board sensors that allow it to safely navigate detecting bump and reflectance. The Create is also outfitted with a 25 pin I/O connection where additional sensors can be read from and 3 motors can be driven. Most fabrication of parts were done using lego although some chose sheet metal, aluminum, and wood.

Simulator: The first problem made use of the simulator included with IC. The students were faced with the problem of having a virtual Create perform some predetermined task in a virtual environment. Simulation provides a gentle introduction to the robot build program test cycle [2] and allowed the students to become familiar with the programming functions that control the Creates drive mechanisms and various on-board sensors. The problem involved finding the center of a virtual rectangular arena when placed at a random starting point. It was discovered soon into the assignment that the virtual robot shared some of the limitations of the actual robot in that error accumulation occurs during dead reckoning exercises. The popular solution to the problem was fairly straightforward. The virtual bot began with it's heading aligned perpendicular to a wall. The bot traveled to the wall, turned 180 degrees, then found the opposite wall, measuring the distance between them. The bot was then able to travel to the center of that axis of the room. The procedure was repeated to find the center of the axis perpendicular to the first. The distance traveled and the turns are calculated based on encoder data from the bot. The challenge to many students was that the approximated 180 degree turn must be precise or the measurement of the distance will be greater than the actual width of the room. One group found that by eliminating the turn by returning to the other wall by driving in reverse, they were able to minimize the error accumulation of the bot and more accurately find the center of the arena.

Mark the Middle: The second problem was more complex than the first and required more components for the solution. This problem involved the Create autonomously marking the center of a 4x8 rectangular board when placed at a random starting position on the board. Students whose bots could be positioned in a random orientation received a higher grade. This is similar to the first problem, but involves the need of a mechanical marking device mounted to the robot. A motor was actuated using a PWM signal supplied by the Create. This problem allows the teams to explore the physical limitations of the Create and the level of accuracy that can be achieved through various approaches to the solution of the problem.

Multiplexer DAQ Board: As a robot's design becomes more complex it is often times necessary to add additional sensing capabilities for successful function. In order to expand the sensing capabilities of the create the Create's single analog port is expanded to 8 channels using a DG406DJ multiplexer chip. The address lines of the MUX chip are controlled using 3 of the Create's digital I/O ports. The students populated and soldered a pre-cut PCB board where the chip is mounted and connected to the create. The board also provided a platform for interfacing the Create's 3 motor drivers, 4 additional digital ports, and serial communication lines. The structure of this project was more of a traditional lab where directions were supplied instructing the teams on assembly of the board.

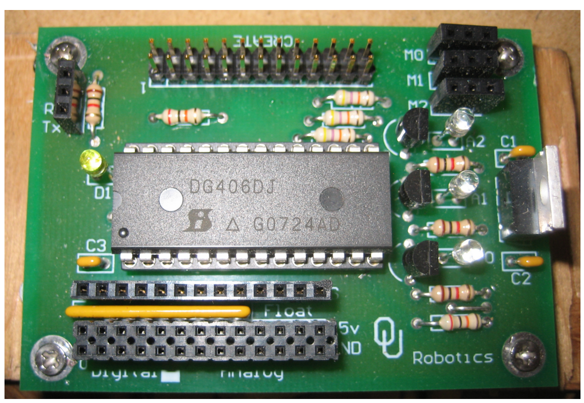

Figure 3: Multiplexer board used by AME 4802 students

Inverted Pendulum: The inverted pendulum problem involved the use of the Create as a mobile base capable of balancing an inverted pendulum. Its at this point that students begin taking the paths of their teams in different directions. Teams experimented with several designs looking for ways to optimize the performance of their robots. A rotary potentiometer mounted inline with the pivoting axis of the pendulum was used as an analog sensor giving the absolute position during trials. Figure 2 shows one team's approach – formal engineering documentation of a pendulum made from less formal ,but somewhat traditional materials, of water bottles and duct tape.

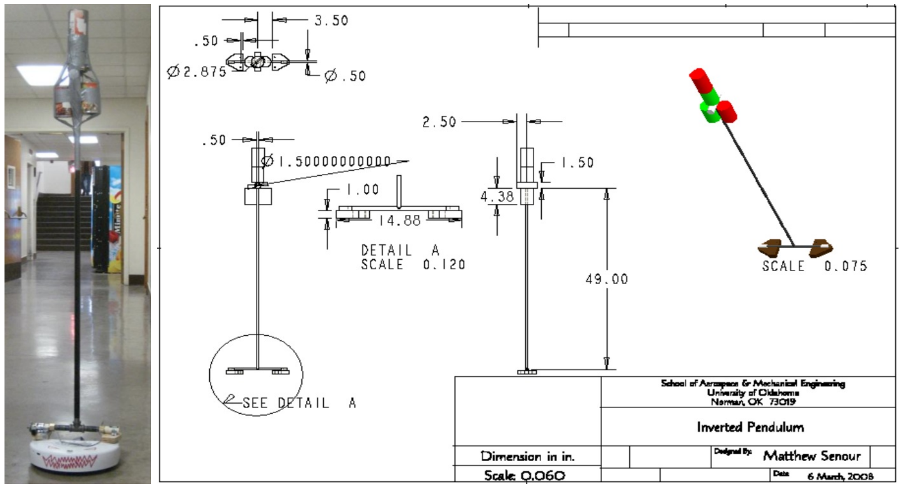

Figure 4: One team's inverted pendulum bot and an excerpt from their documentation

Seek and Deposit: The problem faced by the students in this case involves the need to deposit a ping pong ball in a bucket thats attached to another Create thats following a line around the lab. The drone Create also carries a light that can be tracked by each teams chase Create. Each teams creativity is really expressed in the different types of mechanical systems built by the teams.

Color Sorting: This is the first introduction to a problem that requires the use of vision for the robot. The students are given a vision capable XBC to replace the MUX board used for previous problems. This problem involves the need for a robot to identify and sort several small green and red plush balls according to their color. The problem only specifies that a single straight line separate the sorted piles. The teams are given the option of starting with all the balls in a pile or in an line alternating in color.

Beyond Botball[9]: This is the final problem of the semester. This is also the most complex problem, involving all of the various skills gained from previous work. The students are challenged to acquire the maximum number of points accomplishing various tasks while playing the Beyond Botball game. An assortment of mechanical manipulators and control algorithms are needed to successfully solve this problem. The students are free to develop any strategy that fits within the game rules. Figure 5 shows two different approaches: the left bot uses two specialized grippers made from Lego designed to pick up specific items; the right bot uses a large gripper to pick up numerous objects at a time, drop them into a hopper, and then use a feeder equipped with a camera to sort the objects into bins as they fall through.

3 Student Assessment

One of the challenges faced when using PBL is the ability for the instructor to assess each individuals learning throughout the course. Due to the nature of the strategy, various paths of learning can be taken based upon the direction taken by each team. The individuals grade is broken down according to the following percentages.

- Lab Results 33%
- Lab Reports 54%
- Exams 10%
- Discretionary 3%

The first section assessed how well the students were able to implement a successful solution to the assigned problem. The performance was graded according to a rubric made available to the class prior to the demonstration. All members of the team received the same grade for the performance.

The reporting section of the assessment was designed to measure the individual students ability to communicate what was done during work on each of the problems assigned. Each team's report was broken down into three sections: *Overview, Mechanical* and *Code.*

Each individual was responsible for completing one of the three sections for each problem, rotating section responsibilities for the following assignment. A grade was assigned for each individual for their section.

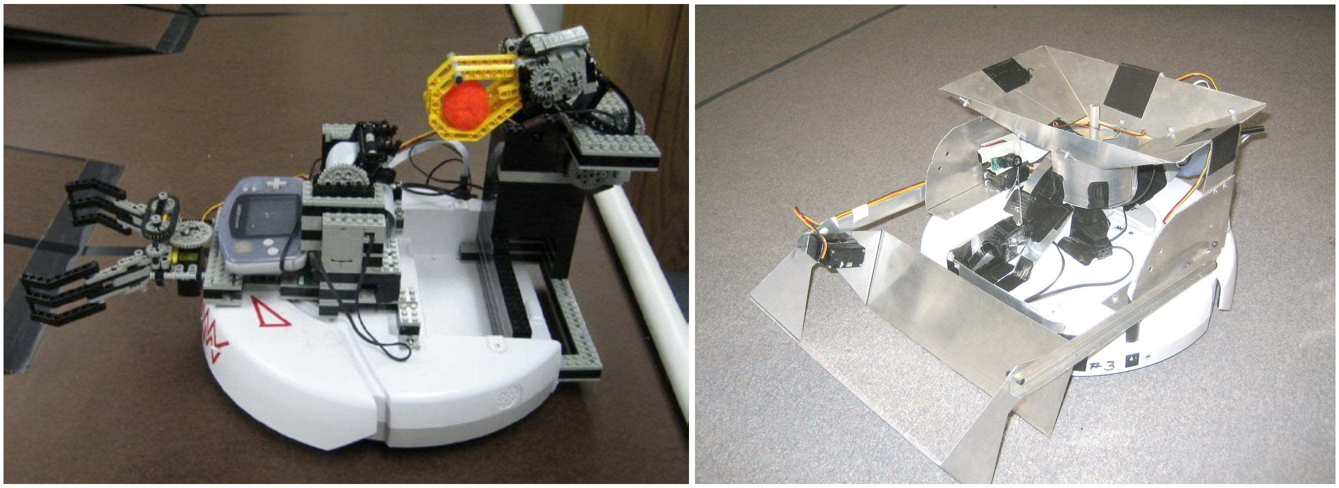

Figure 5: Two construction approaches for Beyond Botball entries

Overview: The content of this section contained any theory used to approach the problem. This section also contained quantitative and qualitative data that validates the success/failure to solve the problem. The individuals grade was based upon their ability to think critically and communicate effectively.

Mechanical: This sections content included a summary of the design and fabrication process. The students explained why they made the design decisions that they made. This section also includes a description of the mechanical operation of the device. The final component of this section is a CAD model of the device communicating key features and dimensions.

Code The code section included a summary of how to run the robot using the software as well as a detailed summary of the function of the algorithm as it operates and makes decisions. The student included a copy of the commented code.

Being a lab course, only a minor emphasis was placed on exams. Theoretically, the theory of all of this material has been learned by the students in other courses. The purpose of the exams was to jog their memories – and discourage them from, as often happens with engineering students – and engineers – from just building whatever comes to mind. We tried to encourage a thoughtful and analytical design phase before building started – but we were not always successful.

4 Course Assessment

This course has, in various altered forms, been offered six times over the last eight years. Originally, it used Handy Board - based Lego robots. Over the years the processor technology has improved along with the platform tools available to the students. Creates were added to the course in late 2007, and a notable improvement in the design of manipulators and in code has been the result – less student time is spent trying to get a stable platform. The occasional custom platform does appear from students who feel the Create is too limiting, or because they are creating a multi-robot system.

Test scores from the class, especially with respect to programming, have improved since the rotating task role system has been implemented. We plan to continue, and perhaps strengthen the rotating slotting of students in specific roles for each task.

The course itself (as with all courses at OU) distributes a student evaluation form during the last week of the semester. This course consistently rates above average for engineering courses. Usually, and in the 2008 course described above, the course also rates above average for the students' self-assessment on how much they learned, in comparison to other engineering courses they have taken at OU.

From our own observations, and from student comments, the major criticisms about the course material had to do with the inverted pendulum lab. Most students found this a frustrating lab. It was introduced in 2007, and most students were unable to create a successful system due to the mobility system they had designed (Creates had not yet been introduced). In 2008, again there were problems getting a working system – this time due to the time lag inherent in the Create sensor bus and the communications calls in order to get an analog sensor reading and have the Create move in response. The mechanical and control hardware are simply not up to the task as currently configured, and this task will probably not be used in future versions of the class – at least not until faster hardware is in place.

However, the pendulum lab was the exception – the other tasks were both enjoyed and (in large part) successfully implemented by the students. The variations in approach and design, and the success in having students get past their distaste of coding, make this course a valuable part of the AME curriculum.

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