Hands-On Robot Design in an Introductory Engineering Course

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Abstract

Our course 'Introduction to Engineering Design' is aimed at freshmen students entering Mechanical and Aerospace engineering. The course is structured as a 2-credit lecture coupled with a 1-credit design laboratory. While the lecture presents an overview of the profession, engineering design and methods, small student teams conduct a structured hands-on design project in the lab. Each team develops an autonomous robotic vehicle to perform assignments such as terrain navigation or collection of objects. Students find the robot project highly motivating and voluntarily spend several afternoons weekly working in the lab. The design course ends with a competition among participating teams at the end of the course. Through the design project the students gain valuable experience in professional design, engineering practice, and teamwork. Additional course objectives are student recruitment and retention, i.e. we seek to attract a broader range of students, including those from underrepresented minorities, to the Mechanical and Aerospace Engineering program.

Background and History

Prior to the fall 2002 semester, the design project segment of the freshman course 'Introduction to Engineering Design' comprised a conceptual design by a team of three to four students. Students would design a solution for an engineering problem, creating several alternatives, selecting evaluation criteria and performing some analysis. These design projects followed a customary format as described in introductory textbooks such as Eide et al [1], Voland [2]. Because the projects remained purely conceptual, the students would not typically devote much energy or motivation to their assignments. Rather, they tended to treat the design project as another obligation required for passing. Motivation levels among students were somewhat low, resulting in a dropout rate averaging about 20% from the enrollment levels at the beginning of the semester.

As is well known from numerous studies, e.g. Parsons et al. [3], motivating learning environments for engineering students are characterized by features such as:

- Hands-on creative design
- Direct feedback to the student (usually by experiment), either as confirmation of success, or as guidance towards improvement.
- Encouragement of creativity and rewarding excellence.

Many engineering colleges have restructured their freshmen curricula to reflect these insights and make their programs more attractive and rewarding. Following a series of presentations on the use of robots as instructional tools (see [4] through [9]) at the ASEE 2002 conference in Montreal, the author decided to include hands-on robot design into our freshman engineering design course. The main objectives were to increase student motivation and recruitment as well as to enhance students' abilities in the crucial areas of problem solving, teamwork, project planning and execution.

A comprehensive discussion of typical first year learning objectives is presented in Davis et al. [10]. By designing and programming a mobile robot, the freshmen engineering students learn techniques for problem solving in a challenging and rewarding setting that addresses a majority of the learning objectives listed by Davis et al. [10]:

- Computer control of processes (timing sequences, response to sensor signals)
- Design concepts for autonomous robotic vehicles (controller, motors, sensors, system integration)
- Team work
- Programming skills

Design project objectives - In the design project the students learn to structure a project systematically, to search for pertinent literature, to create and evaluate multiple designs, and to work in teams. Each team designs an autonomous vehicle using CAD software and other design analysis, and develops and tests the robot controller software so that the vehicle can perform the required operations on its own. Training in solid modeling CAD software is not an objective of the design course. Solid modeling is taught separately. At the end of the semester, each team documents its efforts in a written report and an oral presentation before the class. The design course ends with a robot competition and prizes for the winning team.

Implementation

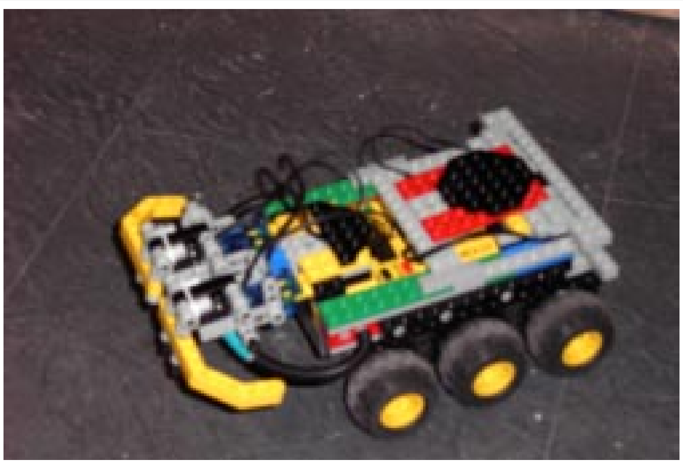

Figure 1 Autonomous Mars Rover created during the summer program, July 2002

Students build their robots with the LEGO Mindstorms Building Kit, which is well suited for rapid mechanical component assembly as well as for easy programming, for which they use the Robolab [11] software. The Lego kits are also comparatively affordable (from $200 per kit). Each team meets a least once weekly in the undergraduate robotics lab. There is no limitation on project work time, however, and the lab is open daily to all participants. Each team of three to four students is given a Lego kit to experiment with. The lab contains a number of PC's for robot program development. Students can conveniently transfer their code to the robot and test it immediately. The typical student team spends several afternoons each week on design and programming.

Table 1: Course Objectives

Category	Objectives
Design Process	Basic Knowledge, Application of Knowledge, Critical Analysis 1. Information collection: Library and patent search 2. Idea generation: Multiple conceptual designs are required 3. Decision making: based on evaluations and testing 4. Programming: Flow carts, branching, sensor-based decisions 5. Implementation: Merging all components and software into a functioning and competitive product
Teamwork	Weekly team meetings are mandatory and must be documented in a log book which will be graded. Assignments: 1. Team allocates tasks among team members. 2. Team manages and organizes design activities. 3. Team ensures fair distribution of assignments among members.
Design Communication	1. Weekly reports 2. Final Design Presentation (Powerpoint) 3. Written final report 4. Competition of all robots at end of semester.

Figure 2 Freshman student working on a ball collecting autonomous robot at UNLV, October 2002

For each semester project, student teams are asked to design mobile robots that perform specified tasks. These design tasks vary each semester. Fig. 1 shows a student-built 'Mars Rover' autonomous vehicle (climbing, navigating, avoiding obstacles). In the fall semester of 2002, the assignment was the design of a robot to collect ping-pong balls from a playing field, see Fig. 2. The project topic can readily be varied from semester to semester, e.g. a robotic 'dog' fetching a stick, space station assembly using cooperative robots, or a robot for pick-and place operations.

The design project objectives are listed in Table 1. The instructor seeks to accomplish the objectives through weekly assignments, starting with a formal problem definition and ending with a competition of all robots as outlined below:

Weekly Design Project Assignments

Week	Assignment	Comments
2	Identify need: Describe problem and possible approach. Define the product to be designed and the scope of possible features (within the bounds of the Lego kit).	Reading: Textbook chapter on problem definition. **Each** student submits one-page outline and concept sketches for robot gripper and for propulsion system (motors and steering concepts)
3	Literature Search	**Each** student submits report on mobile robots Literature including patent search.
4	Prepare technical drawings part 1	Robot gripper design. Use of Solid modeling software is required (Autocad or ProEngineer or similar) **Develop three alternative gripper designs.**
5	Prepare technical drawings part 2	Robot chassis design. Use of Solid modeling software is required (Autocad or ProEngineer or similar) **Develop three alternative chassis designs.**
5	Submit: Solid model drawing of complete robot design.	Definition of the best overall robot design according to formal criteria (e.g. compactness, light weight, robustness in collisions).
7	Present completed vehicle. Demonstrate all functions: sensors and motors.	Presentation in the laboratory to the teaching assistant.
9 through 13	Develop and test robot control software	Development of program flow chart and Robolab code. Documentation of robot's response to code segments.
14	Update literature search, present design and results orally before the class and submit written final report.	Powerpoint presentation, 10 minutes per team. Each team submits detailed complete report and log book, documenting semester activities for each team member.
15	**Robot Competition:** Each robot must complete the assigned task autononomously.	Competition rules are agreed on by the entire class and posted in writing.

The Fall 2002 Experience

The assignment was to collect five ping-pong balls from a table within 2 minutes or less. Figures 3 and 4 illustrate the solid modeling part of the design process. Fig. 3 shows one of the approaches used for ball collection, a motorized vertical gate activated by a light sensor detecting the presence of a ball. Fig. 4 shows the complete CAD model. Fig. 5 illustrates another team's design employing a paddle-wheel type sweeper to collect the balls.

As expected, the students spent the most time programming their robot. They used the Mindstorms software that came with the kit in 2002. The more versatile Robolab software [11] is being used from the spring of 2003 onwards. Fig. 6 and 7 show examples of successful programs demonstrating effective ball collection.

Figure 3 Motor driven Gate activated by light sensor. Autocad drawing.

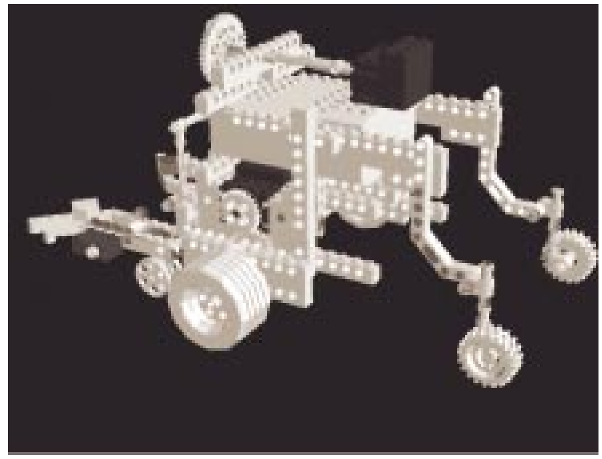

Figure 4 Ball collecting robot. Autocad drawing.

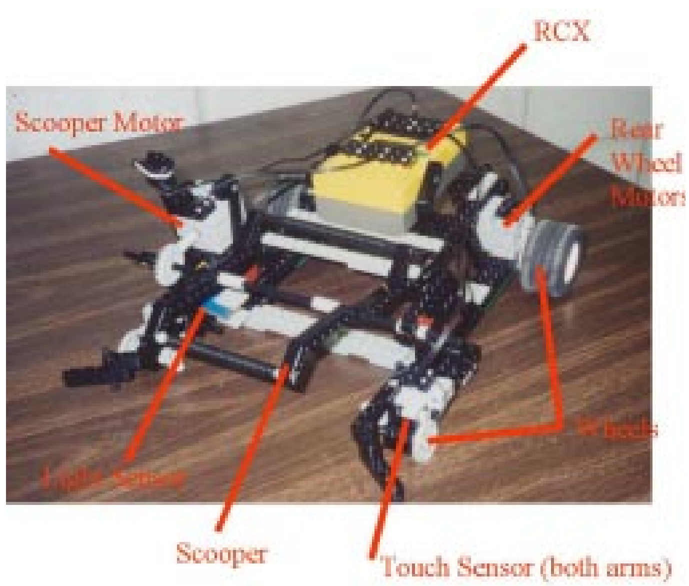

Figure 5 Ball collecting robot. Balls are swept into the storage area underneath the RCX unit by two rotating bars.

Within the bounds of the formal requirements listed in the project schedule above, the students worked independently and were encouraged to explore design and programming options on their own. Teaching assistants were available to answer questions and provide assistance in the lab every day of the week. The students responded with high levels of motivation to the challenge placed before them. The motivation to succeed in the competition and the focused attention by the lab teaching assistants encouraged the students to spend many afternoons in the lab voluntarily. All six participating teams produced functional robots and programs that enabled the robots to recognize the presence of balls and collect them. Similarly, all robots had the ability to recover consistently when confined in a corner. Fig. 8 shows some of the students and their ball-collecting robots during the final competition.

Figure 6 Control software example for one team's ball collecting robot

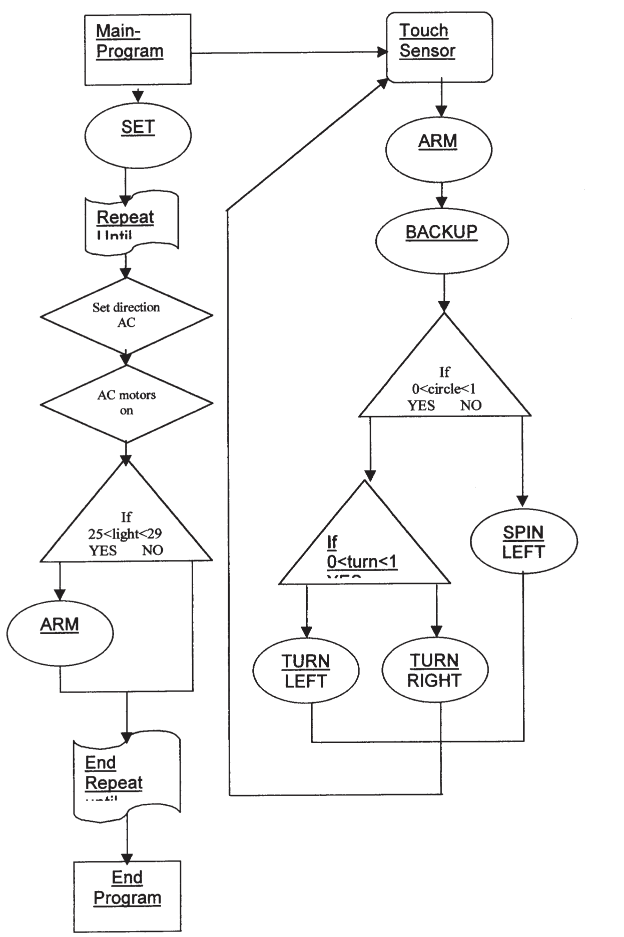

Figure 7 Another control software example

Results and Outcomes

The most notable improvement (compared to our previous introductory design course format) lies in the high motivation of the students. All six end-of-semester presentations earned an “A” grade, while those of previous years averaged a “B”. A second indicator of motivation was time spent on the project: On average the student teams spent three afternoons weekly in the laboratory and learned a wide range of skills: solid modeling, structural design, installation and integration of electrical motors and sensors, machine-computer interfacing, and programming. They experienced the benefits of systematic planning over ad hoc solutions, and were generally more receptive and motivated when basic engineering concepts were presented in class. Quantitative data are still preliminary after one completed course. One notable distinction was observed in the fall semester of 2002: whereas on average one fourth of the students dropped the introductory design course in previous years, all students enrolled during the first week of the fall 2002 completed the course. The table below presents statistical data pertaining to student enrollment and retention.

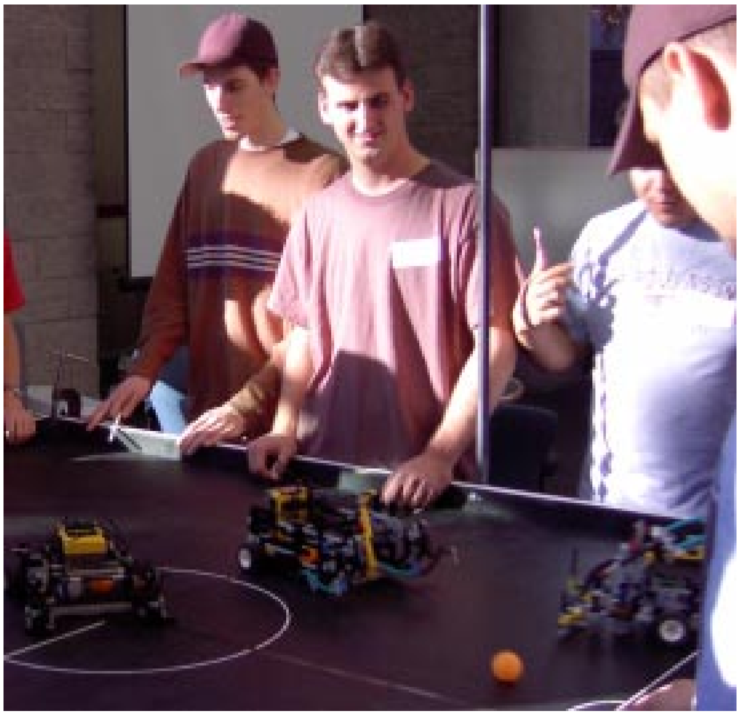

Figure 8 Three ball collecting robots during the competition

Table 2 Enrollment and drop-out data

Course Date	2nd week enrollment	15th week enrollment
Fall 2002 (hands-on design)	30	30
Fall 2001 (conceptual design)	20	17
Spring 1998 (conceptual design)	13	10

Student views and attitudes – Anonymous student comments regarding the design project in the course evaluations prior to 2002 most often emphasized a perceived vagueness regarding the project assignment. The textbox below contains typical quotes made by students in the class evaluation at the end of the semester.

Fall 2002 verbatim comments

- Good class. The project was enjoyable and fun.
- Class was enjoyable.
- Real life examples helped in relating the material… The lab was interesting. Building the robot gave us hands-on experience in a fun way.
- (The instructor) did a great job organizing the final robot competition. He generated a lot of good advertising for the engineering program.
- I've enjoyed this class! Especially the robot project! Funnest project I've ever done!
- This class integration with the lab was excellent. The competition was a good motivator to go to class and the lab.

Conclusion

An introductory engineering design course with a hands-on project component to build mobile robots was presented. In the project, students learn and apply a wide range of engineering skills, such as solid modeling, mechanisms design, sensor-based control, and programming. They also gain experience in teamwork and communication. Observations and student feedback during the first semester of the hands-on design course indicate high levels of student motivation and satisfaction.

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