Building Intelligent Robots in a Cooperative Learning Environment

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Abstract

The mobile robotics course introduced at the University of Missouri-Columbia is similar to other robot-building courses, with one important distinction-- instead of competition among student teams, cooperation and information sharing are encouraged across all students in the class. The course covers the design and development of intelligent machines, particularly emphasizing topics related to sensor-based control of mobile robots. Students are grouped into teams of 2-3 people, representing multiple disciplines. Each team is assigned a robot kit, which includes a small micro-controller board, motors, sensors, and technic lego parts. Programming projects using the kits are designed to stimulate creativity and exploration. The first three projects are structured to promote incremental progress, culminating in the completion of a small, autonomous mobile robot. At the completion of each project, each group gives an oral presentation and demonstration and also submits a written report that becomes part of the lab manual. For the final project, the class collectively designs an experiment on cooperative robots, redesigns the team robots as necessary, and conducts the experiment. Throughout the course, the class operates in a cooperative spirit. Students are encouraged to discuss ideas and problems with each other, even members outside of their group. Using a technique developed by another student or group is also acceptable as along as the developer is credited in reports and discussions. The cooperative class spirit has proven to be a good environment for individual learning and at the same time promotes teamwork. Student productivity, as well as student satisfaction, has been high.

Introduction

Cooperative learning has been defined as "instruction that involves students working in teams to accomplish a common goal, under conditions that involve both positive interdependence (all members must cooperate to complete the task) and individual and group accountability (each member is accountable for the complete final outcome)" (Karl Smith, University of Minnesota[1]).

Robot-building courses have become popular for incorporating cooperative learning by grouping students into teams. Typically, the teams compete against each other, to see which group has developed the best robot. In this paper, we describe a course in which students also build mobile robots within a team setting. However, rather than promoting competition among teams, the course encourages information sharing and cooperation of all students, so that the entire class functions as one cooperative unit.

The course described here has been taught by the author as an introductory robotics course at both Texas A&M University and the University of Missouri-Columbia. The course is targeted for senior undergraduates and beginning graduate students. At each university, the pilot class included 12 students (10 undergraduates and 2 graduate students), who were grouped into 5 teams. In the remainder of the paper, we describe the course overview (including goals, structure, grading, and course philosophy) and the team projects. Finally, the cooperative learning environment is discussed and conclusions are given. For more detailed information about the course, the reader is referred to the course webpage[2].

Course Overview

The course is designed to provide students with an introduction to sensor-based robotics for unstructured environments. The course begins with an historical perspective on robotics and then covers components for robot building, such as sensor use, mechanics and motors, real-time programming, and simple reactive behaviors. The second part of the course focuses on how to achieve more intelligent machines by combining multiple sensory inputs and multiple behaviors. In this context, several control architectures are discussed, including methods of controlling multiple robots.

The course includes a lab component in addition to the lectures. For the lab projects, students are grouped into teams of 2-3 people, representing multiple disciplines. Each team is assigned a robot kit, which includes a small micro-controller board[3], motors, sensors, and technic lego parts. Programming projects using the kits include enough flexibility to encourage design creativity and are designed to stimulate exploration. At the completion of each project, each group gives an oral presentation and demonstration and also submits a written report.

Student grades are based on a combination of exams, group project work, and individual weekly reports. Two midterm exams make up 30% of the grade. The four project grades comprise 65% of the total grade, with everyone in a team receiving the same grade. In addition, each student must write a weekly status report, which is emailed to the instructor. The reports can be used to describe successes and problems with the project work and to document any difficulties arising between team members. From the instructor's viewpoint, the individual reports also provide a means of determining whether the workload is evenly distributed among all of the team members.

The general course philosophy is that students benefit by cooperating and sharing project information. The following statement appears in the course syllabus. "The class will operate in a cooperative spirit. Students are encouraged to discuss ideas and problems with each other, even members outside your group. You may also want to use a technique developed by another student or group; this is acceptable as along as you give them credit in your reports and discussions."

Team Projects

The course projects provide an excellent vehicle in which to address the criteria established by ABET. Through the project work, students receive hands-on experience in the integration of sensing and control. The project assignments are flexible enough to stimulate creativity and exploration, and provide experience in open-ended problem solving. Communication skills are developed through the oral and written reports. Finally, students learn how to work in a multi-disciplinary group setting.

At the beginning of the semester, students fill out a survey in which they provide information on educational backgrounds, skills, and work experience. The surveys are used to make team assignments, with a special effort on creating balanced teams. That is, an effort is made to assign team members together with different engineering backgrounds and complimentary skills. Students are allowed to request team members, but the final team assignments are made by the instructor.

The first three projects provide incremental progress towards the ultimate goal of building a multi-sensor robot. The project assignments include general guidelines only and encourage creativity in both functionality and design. Students are also encouraged to reach for their limits, taking risks in their robot design. Figure 1 shows the grading criteria for receiving an A for the project. (See the course webpage for the complete grading guidelines.[2])

1. The project shows creativity and substantial effort. Either good results have been achieved or there is an explanation and analysis of what went wrong and suggestions for improvements.
2. The project report is well-written and easy to understand. The technical descriptions are accurate and complete. (Definitions may be given to clarify ambiguities.) Data is presented in an easy-to-understand format (tables and/or graphs). Diagrams are labeled and clear. Grammar, typing, and spelling errors have been corrected.
3. The oral presentation is done in a professional and organized manner, describing the main highlights and contributions of the project

Figure 1. Project Grading Guidelines for an 'A'

The four projects are described below. For each project, teams present an oral report and live demo and also produce a written report. All team reports are added to the class lab manual so that any student in the class may reference the material.

Project 1: Sensor Characterization

The sensor components provided in the robot kits include a variety of inexpensive parts purchased from surplus catalogs. In the first project, each group is assigned different sensor types, and the class collectively produces characterization data on the sensors. After the investigation, each group reports back to the class with a written report and a short presentation. The written report is added to the lab manual so that each team has access to the complete characterization data. The following items are included in each report:

1. Sensor interface to the Handy Board (with diagram).
2. Type of sensory information returned. Where appropriate, include a table showing the range of signals for different environment conditions.
3. An explanation of how the data was collected.
4. Recommendations for using the sensor on a mobile robot (either alone or in a combination)

Project 2: A One-Sensor Behavior

In the second project, each team builds a robot base and implements a behavior using one type of sensor. The choice of sensor and the design of the robot is decided by each individual team. The team reports must include the following items:

1. Robot description, including vehicle control and sensors
2. Environment description (e.g., white/black obstacles, a black line, etc.)
3. Behavior description-- what sensor state triggers the behavior and how the robot should act with respect to its environment

Project 3: Multi-Sensor Mobile Robot

The third project is to build a more complex robot which uses at least 3 different types of sensors to perform some intelligent-like function or functions. The design of the robot, the choice of sensors, and the architecture used to combine sensory information and behaviors are decided by each individual team. Creativity is encouraged. Demonstrations are presented for each robot, and reports are produced with the following information:

1. The design of the robot base, including control of the actuators
2. The sensors used and the desired information gained from the sensors
3. The environment in which the robot operates, including any limitations.
4. The desired function/s of the robot, especially how it should act with respect to its environment
5. The architecture used to combine sensory information or behaviors
6. Lessons learned by doing the project (e.g., which strategies worked, which didn't work very well, and what you would do differently next time)

This project produced some very creative efforts, with robot names such as Killer, Camel, Roach, NSF3D, and BeanDip. Each team's robot was unique in design and functionality. The robots ranged from a simple but elegant light-seeking, moth-like robot with a differential drive to an Ackermann steering system with wheel encoders and an environment map to a sophisticated sensing system with an elaborate behavior arbitration scheme. Some robots were more reliable than others, which was immediately obvious during the class demos. In the end, the students learned certainly from their own projects but also learned from observing the results of other groups. Figure 2 shows some representative Project 3 robots.

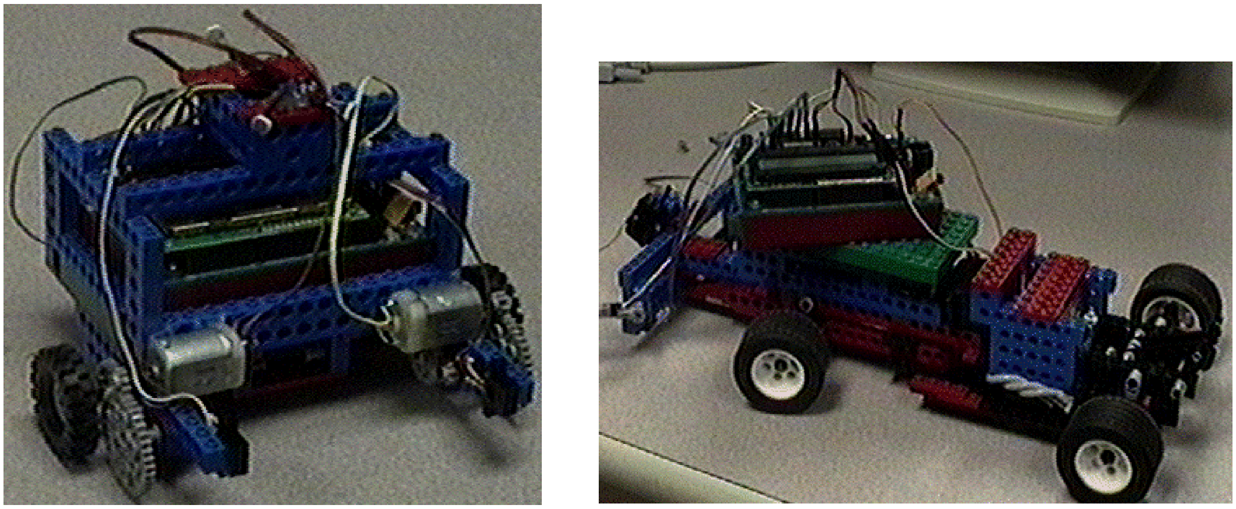

Figure 2. Representative student robots for the multi-sensor robot project.

Project 4: Cooperative Robot Experiments

By the fourth project, the students have accumulated experience in building a robot and working with the robot components. Building on that experience, Project 4 is run as a class experiment. Collectively, the class decides on a strategy for controlling a group of robots.

In the pilot class, the existing robot bases were used, but the robots' sensors and behaviors were modified so that each robot had similar behavior capabilities. Although the robots were similar, they were by no means identical, as they traveled at different speeds, had different turning rates, and even varied in the sensors used for obstacle avoidance. Experiments were then run using the heterogeneous group of robots. Each team produced a report documenting the changes made to the robot as well as the results of the experiments, with the following information:

1. an estimate of the nominal speed (in cm/sec)
2. the distance at which obstacles are detected
3. integration and implementation details on the sensors
4. driving control method, including turning
5. behavior arbitration
6. any assumptions (e.g., about the environment or other robots)
7. any distinguishing characteristics
8. a description of how well your robot performs the behaviors individually and in a group
9. lessons learned from the project

As a research experiment in robotics, the project was of limited value; however, as an educational endeavor, it was a great success. Again, the students learned a great deal from the project work and obviously enjoyed seeing the robots moving together and "interacting".

Cooperative Learning Environment

A cooperative learning environment was established at the beginning of the semester with the first project. It was not feasible for each team to characterize every sensor; the only practical way to test them all was to assign different sensors to each team. By including all of the project reports (i.e., the sensor results) into a class lab manual, each team was able to benefit from the collective work. At the same time, the students were not graded by success in sensor use but rather on the integrity of the experiments, completeness of the results, and the effectiveness of the oral and written reports.

Having set the tone for cooperation at the beginning of the semester, the students were perhaps more willing to cooperate in the remaining projects. In general, the students seemed to share their successes and their failures and openly discussed ideas for design improvement. Evidence of the class mood was observed in the use of email. Initially, students were asked only to email weekly status reports to the instructor. However, after a short time, students began requesting email access to the entire class and eventually began sending out additional status reports to the class. In addition, students included references to earlier project reports (even from other teams) in both oral and written reports. In one case, the developer of a particularly successful technique was asked to give a mini-lecture to the class, describing in detail the technique used.

The last project was particularly effective at bringing the class together into one cohesive group, as its success really depended on the class working together. For this project, the instructor took a role of facilitator and observer. The students played a very active role in determining the behavior design and the interaction methods of the various robots. As might be expected, student leaders emerged in this process. However, there were no passive observers among the students, as all of them were actively engaged in the process.

At the end of the semester, the students appeared to have truly bonded and seemed almost reluctant for the class to end, in spite of the fact that they all reported working much harder for this class compared to other classes. One of the final email reports sent to the class by a student is shown in Figure 3. It illustrates the class mood at the end of the semester.

Conclusions

In this paper, we described a course in which students are grouped into teams and build small mobile robots from kits. Instead of the teams competing against each other, all students are encouraged to share information and cooperate so that the entire class functions as one cooperative unit. We included a description of the projects assigned and explained how such a class-wide cooperative learning environment was encouraged.

In general, the attempts at establishing a cooperative environment were quite successful. The students worked hard, produced creative projects, and reportedly experienced a high level of learning. The results are perhaps partially due to the small class size and the high level of maturity in the students (seniors and graduate students only). It is difficult to predict whether the same cohesiveness in the class would have emerged with a much larger class size or a different mix of students.

One challenge in such an environment is achieving a fair assessment of each individual student's work for assigning a grade. For this purpose, the individual weekly status reports have been quite useful, as it is relatively easy to determine from the reports how much each student has contributed. The reports have also proven to be a good source of feedback on what is working, what needs to be changed, and whether the students are learning anything, which in the end is the ultimate measure of success.

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Well, it's been some semester, eh?  Lots of interesting people and lots
of interesting robots...

Well, in closing,

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...Camel, BeanDip, Roach, NSF3D, Killer...

   are all gone....

   ...this is Ripley, last survivor of the _Nostromo_, signing off...


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END OF TRANSMISSION
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Figure 3. Email sent by a student at the end of the semester.

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References

[1] Vincent Ercolano, "Learning through Cooperation", *ASEE Prism*, Nov., 1994, pp. 26-29.

[2] Course web page: http://www.cecs.missouri.edu/~skubic/301/

[3] Fred Martin, "The Handy Board Technical Reference", Oct., 1997.

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