Using Mobile Robots to Explore Intelligent Behaviors: The Obstacle Course Challenge

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Abstract:

A recently concluded NSF-ILI grant provided equipment to create hands-on laboratories for CIS students. The goal of this laboratory environment was to provide a setting to reinforce course concepts. One of the target courses was the Artificial Intelligence (AI) course. After the AI course, many students desired to pursue more tangible and applied experiences. Additional equipment was purchased to design and construct multiple mobile robotic platforms. With this equipment and a motivated group of students, a special topics course was created. The goal of this new course was to expand on the basic concepts of the AI course. Special topics involving motion, sensoring, planning, fault recovery and hardware/software interfacing were discussed and supported by supplemental readings from the literature. Each topic was linked to a laboratory exercise where students would design and implement both the hardware and software to accomplish an intelligent behavior. The ultimate challenge was to integrate the behaviors from the exercises into the ability to navigate an unknown obstacle course. The obstacle course was designed to include path following, landmark recognition, hitting a target, obstacle detection, obstacle avoidance, and path reacquisition. Students competed in teams of two and each team was evaluated on their robot's ability to independently accomplish each task. The most successful teams were awarded prizes and shown on the local news report. The instructor found that the AI course served as a solid foundation for this new course and provided the opportunity to explore more advanced topics of AI and robotics. The students, having prior experience in the AI course, could be expected to have a more mature understanding of the literature and use it to develop their robotic projects. This paper will outline the goals of the course, the approach taken, problems encountered and solutions used along with lessons learned.

Introduction:

This paper describes a new course developed to provide students with the opportunity to apply knowledge gained in earlier Artificial Intelligence (AI) courses to a more tangible domain. In this new special topics course, students, working in small groups, are required to design and build a mobile robot, interface the robot with a computer, and program semi-intelligent behavior into the resulting system using concepts learned in both prior AI courses and the lecture component of this course. The robots, using limited sensing capabilities, are required to navigate a previously unknown obstacle course. This obstacle course is designed to include path following, landmark recognition, hitting a target, obstacle detection, obstacle avoidance, and path reacquisition. Students work in teams of two or three and the teams are evaluated based on the ability of that team's robot to accomplish the assigned tasks of the obstacle course independent of human intervention. The students have greeted the course with enthusiasm as it affords them the opportunity to apply their previously acquired knowledge and to observe the machines they have constructed and programmed function in a semi-intelligent manner.

This work was done to partially complete the goals of a prior NSF-ILI grant[3]. That grant established a hands-on laboratory environment, which would apply the concepts of various courses throughout the Computer Science curriculum. In addition to the reinforced learning of those concepts found in the target courses, a repository of learning experiences was created for integration throughout the entire curriculum[2]. These experiences serve as a starting point for projects in those courses and can be built upon to extend the level of complexity. These projects can likewise serve as demonstrations in prerequisite courses. These demonstrations serve to show students what will be expected of them in the subsequent courses. We have enjoyed a high degree of success with student projects based on this model. Students have presented papers and posters at various conferences in the past three years. Several of these presentations have been awarded first, second or third place honors in competitions. In all cases, the work presented either established a research environment or built upon the prior work left in the repository created by the hands-on laboratory. Based upon this success and the desire to expand our undergraduate research experience, special topic seminar courses were created. A course in semi-intelligent robots was desired to build upon prior elements created for the repository. The course would be created to combine a theory-based component, building on AI and other courses, with a hands-on hardware component.

Methodology:

Course Concepts:

The course topics were selected to build on the prior knowledge of the students from the AI course and other related courses in the curriculum. An understanding of these topics would also be necessary to make a robot perform the desired tasks in the obstacle course. Some of the topics covered included: the history of robots, applications of robotics, definitions associated with robotics, use of sensors, data gathering/interpretation, use of actuators, navigation, landmarks, learning and adaptive behavior, and future of robotics. These topics were covered by use of a textbook[4] and various readings from the literature. A crucial reading was that of a paper by Robert Aiken[1]. This paper encouraged the students to focus on a reflective problem solving experience that would merge together all aspects of the computer science curriculum. It was this capstone experience that Aiken[1] mentions as necessary to complete the educational process. It is also this blending of prior experiences and undertaking of a major project that was the goal of our NSF-ILI grant.

The actual format of the course consisted of two meetings each week over the course of the eight-week summer session. Each meeting was two and a half-hours long. One meeting was devoted to the concepts mentioned above. The other meeting was treated as a laboratory period for actual construction and testing. The course concepts were covered by use of lecture, discussion and student presentation. Traditional lecture using the textbook was appropriate and natural for historical and factual information as is the case with most courses. Some selected readings were also the basis of lecture but often this led to a class discussion. All readings were pre-assigned with an outline and summary due before class. This led to a sharing of ideas and the impression that the instructor did not have all the answers (often we were learning as we went). This open discussion would lead to many creative and unique approaches to solve the problems. Also, students were assigned topics and made a presentation and submitted a more formal report.

Basic Robot Design:

Each student team is required to design and build its own robot from a selection of component parts rather than a fixed prepackaged kit. A list of available components is provided in Table 1. Students are advised of the types of tasks that the robot is expected to perform and the limited capabilities of the sensory equipment. This approach requires students to consider the effects of design decisions on the actual performance of their robot. For example, the dimensions of the main chassis directly affect the steering capabilities and turn radius of the robot. Students also have to consider the space requirements to mount a three-degree-of-freedom arm, a line-tracking module, the control circuitry, power supplies, and a limited tactile array while still providing for the necessary aesthetics of a "hip" looking machine.

HS-300 Hitec servo	Expanded PVC
Servo Controller	Female RJ-11 to DB9 converters
7.2v rechargeable battery	8' or longer modular phone cable
7.2v battery charger	Male RJ-11 to DB25 converter
Battery Quick connect	Micro-momentary switches
Line Tracker Module	5k Ohm Trimmer Resistors
3" Wheels	RJ11 phone Jack
Plastic Tubing	3 contact connection housing
High Performance Caster	

Table 1: Robot Components

One example of the student robots is displayed in Figure 1. All of the designs use a two-wheel drive system. Coupled with a third caster wheel to provide balance, the two controllable wheels also provide the steering capabilities. Each wheel consists of a 3-inch foam tire mounted to a servo, which has been modified to rotate a full 360 degrees. Each robot is also required to have an extendable arm that rotates at its base approximately 190 degrees and has two joints. Students are encouraged to devise creative solutions to providing a robust yet functional arm given the material constraints. Varying the rotational speed of both the modified wheel servos controls the speed of the robot and steering is accomplished by modifying each servo independently.

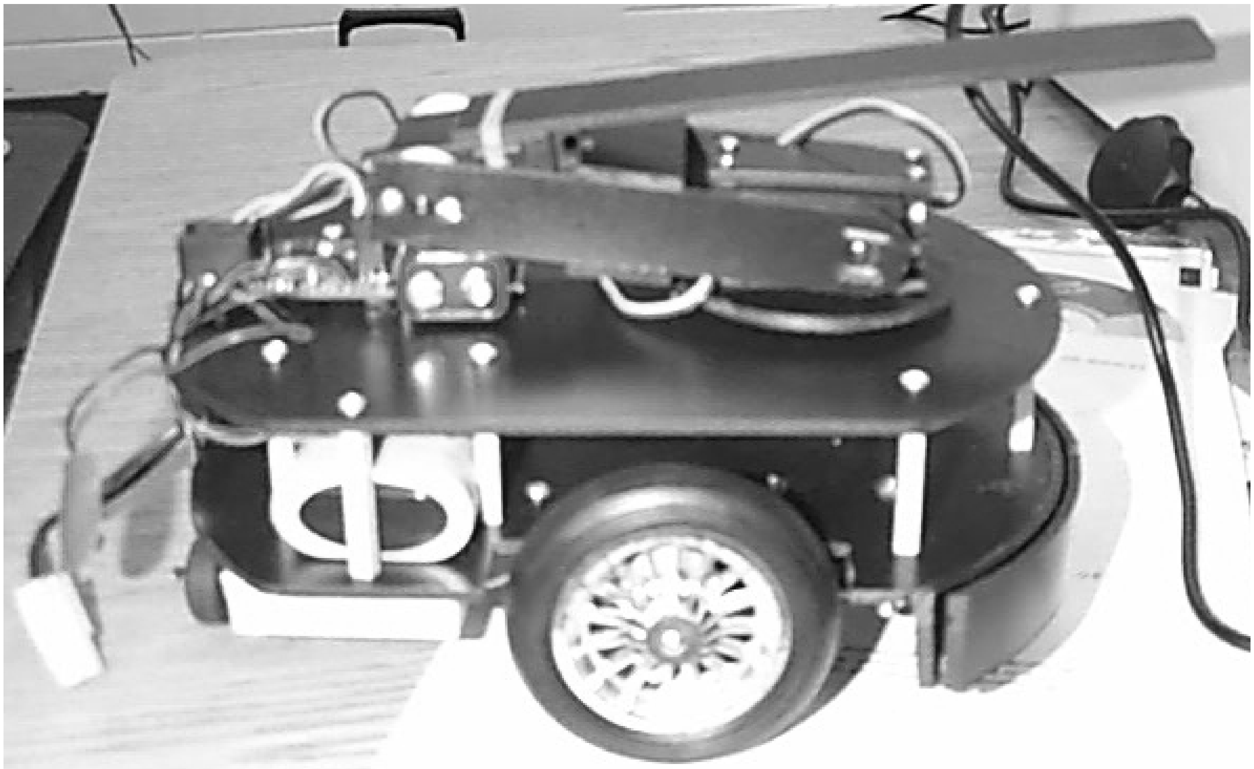

Figure 1: Example Student Robot

The sensory capabilities allowed for the robot include an infrared line tracker and a set of tactile/momentary switches. The line trackers are provided pre-assembled to limit the amount of soldering a student must do. Students are allowed to decide where and how to mount all sensory devices based on certain constraints. The line tracker must follow a line underneath the main chassis of the robot and the tactile switches must detect objects that are position in front of the vehicle. The majority of designs, however, follow the same basic sensor positions: line tracker in the middle of the chassis mounted between the drive wheels and the tactile switches coupled in two pairs to the front of the vehicle.

Robot control is performed off of the robot itself. This is accomplished through a data tether connected to the PC's serial port. Design considerations have to be taken into account to provide accessibility to the tether connections on the robot. Sensor state detection is also performed off robot via a second data tether connected to the PC's parallel port. Each sensor data line has to be connected in some manner to the parallel port tether. Students are encouraged to determine their own wiring schematics but most use a fairly standard design. In general each of the three data lines for the line tracker is attached to an individual tether data line and the contact switches are wired in two sets containing two switches in parallel.

All on-board systems are required to be self-powered. A 7.6-volt rechargeable battery provides power for each of the five servos on the robot. The line tracker and the servo controller are each powered by a 9-volt battery. Students have to consider the mounting and placement of the three batteries as well in their overall robot design. The chassis and arm can be made of the provided expanded PVC, which can be bought from any local sign shop. Students are encouraged to be creative in the overall look of their robot by being allowed to form a chassis under very loose constraints. The resulting vehicles tend to develop an individualized look and many provide a multi-level machine. The bottom level tends to hold the batteries and wheel servos and a top level to mount all necessary circuitry, though, single level machines appear frequently and three level machines occasionally.

By allowing students a great amount of creative freedom in the designs, this also requires them to give serious thought to the consequences of their design decisions and the effects those decisions have on later stages of development and overall robot performance. In addition, this from-the-ground-up approach introduces students to the vagaries and unpredictability of performance that can be encountered in such real-world devices. This results in software that must be able to control the behavior of their creations in less than ideal circumstances. Students are also introduced to the problems of interfacing external hardware to the PC's and some of the unexpected difficulties that can arise in a semi-controlled laboratory environment.

Behavioral Control:

Most software developed by the teams to control the robots was written in C++. However, because of the limited input/output options, any programming language that supports serial and parallel port communications can be used. In the classroom, facilities are provided for Visual Basic or Java languages to be used as well.

The finished software includes routines to control the drive wheels, arm, and query the sensors for current states. Students are advised of the functionality required of their robots. Drive control routines that are required include forward and reverse locomotion at varying speeds, zero-radius (or tangent turns) in either left or right direction, and center-point or spin turns in either left or right directions. To support the drive routines, calibration software needs to be implemented to account for the varying performance of the equipment and any PC discrepancies introduced by using a PC other than the original development PC. Sensor routines include, state determination and calibration. Algorithms to interpret the raw data provided by the sensors also have to be provided. A large part of the software development centers around the intelligent behaviors expected of each robot. These behaviors include obstacle avoidance, guide-path following, guide-path reacquisition, landmark recognition via hash marks in the guide-path, and arm control.

The Experiment:

The final objective of the course was the obstacle course competition. The obstacle course consisted of a large area containing a single meandering guide-path. The guide-path was unbroken except for the reacquire guide-path challenge. A single hash mark signified that the robot should halt its movement and attempt to knock over a target at a specified distance to the left using its arm. Two hash marks separated by less then 2 inches indicated that the robot should halt and attempt to hit a target to its right. A single hash mark followed by a total loss of the guide-path indicated that the guide-path is broken and should be reacquired. Obstacles were also placed directly on the guide-path requiring the robot to detect, via tactile switches, the obstacle's presence and perform obstacle avoidance and path reacquisition on the other side of the obstacle.

This final event was handled as a good-natured competition and viewed as such in the past. Robot performance in negotiating the course was evaluated and prizes were awarded for the top contestants. Students are also made aware that grades are not determined strictly by their robot's performance, but by their participation, design, documentation, and implementation decisions.

Problem Areas:

One of the major drawbacks faced with this course was the unreliability of the physical equipment and the sensor interface. In an attempt to keep the equipment simple and inexpensive, students pay a higher cost in frustration occasionally with the seemingly random nature of their projects. The most frustrating and serious problem faced in this course deals with the inconsistent data provided by the line-tracking module. The module tends to provide highly inconsistent readings, which makes development of any software using such data difficult. This particular problem has yet to be solved and is extremely elusive.

Another problem encountered was with the format of presentation and organization. Since this course was offered over the shortened eight-week summer, time became an issue. Two meetings per week were probably perfect for a laboratory period but too long for a seminar. Also, to undertake a complete project from start to finish, while gaining both the theory and practical skills, was probably too compressed. Many students commented that over the course of a 15-week semester this would be the perfect course. Due to this time compression many concepts could not be fully explored or realized in the environment.

A final problem is the cost of equipment. Each time this course has been offered, funds were available from the prior NSF-ILI grant. This limited enrollment to 16 students. In the future, students will have to supply their own equipment at a cost of approximately $250. It is hoped that students will be willing to do so and continue to explore and build on these concepts.

Conclusion:

This course has been taught in two successive summer sessions. The students have enthusiastically received it. Most students feel that the course is not only a valuable learning experience, but that it is also an extremely fun course. To date, approximately 35 undergraduate and graduate students have participated in this course building about 14 of these robots. Few teams have succeeded in accomplishing all of the obstacle objectives, but some very creditable performances have been forthcoming. Most of the problems encountered with the performance of the robots can be traced to hardware inconsistencies rather than lack of effort on the part of the students. The students universally agree that the experience obtained in this class has been very beneficial and the faculty associated with the development and teaching of this new course agree. The University has received valuable publicity as well since local TV stations have broadcast news stories showing demonstrations of the winning robots.

This course is a valuable tool in providing students with practical, tangible experience in implementing intelligent behavior and in dealing with real world problems and the associated arbitrary behavior of the equipment. This is an extremely valuable learning tool and efforts to refine and expand this course are continuing.

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Biography:

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