Mobile Robotics Based Capstone Design Course for Engineering Technology

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Abstract

This work describes the educational experience gained in the Senior Design Course, a fourth year course in the undergraduate Electrical Engineering Technology (EET) program at Georgia Southern University (GSU). The main topic of this course is concentrated on a team-based, two-semester-long project in which students design and build mobile robots for different applications. The authors present their experiences in using the topic of mobile robotics as the main subject for the senior design course, with focus in interdisciplinary interactions and teamwork for the design and implementation of autonomous mobile robots that have been able to participate in different robotic competitions. The paper provides motivations and background information, describes the senior design organization and the description of the projects involving the autonomous vehicles developed and their main characteristics. The paper concludes with a summary and recommendations for future work.

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1. Introduction

The number of electronic systems used in robotics, industrial automation, and other control systems continues to increase dramatically. These systems typically include sub-systems with separate processors or controllers. The processors must communicate to coordinate their activities. For example, a typical autonomous navigation system (mobile robot) may have several motors and a collection of sensors connected to a real-time controller. As these systems become even more complex, the need for team work becomes even more critical. A mobile robot is a system that contains mechanical and electronic parts that can be programmed to perform some specific functions, responding to sensory inputs under the control of an internal or external computer. The reasons to use mobile robots as the main topic for the Senior Design course is that in addition to involving the electrical and mechanical engineering disciplines, robotics deals with other sciences and humanities subjects, such as animal and human behavior imitation, learning techniques, and environment interactions. Robotic systems can relate to most processes in nature and human behavior. Because of this, their potential as educational tools for teaching and learning various subjects in technology and sciences is unlimited[1].
The design and implementation of an autonomous navigation vehicle requires a broad knowledge in areas traditionally not covered in a single discipline. These areas include electrical and computer engineering, computing sciences, mechanical engineering, and other engineering disciplines. As a result, it is very difficult to train students and engineers within a single discipline to effectively design and implement complex mobile robots. Thus, we felt that it was important to offer a senior design capstone course to establish an interdisciplinary framework to teach the basics and offer a structured course for education in mobile robot design. One of the major goals of this course was to expose students to industrial and commercial quality design, and bridge the gap between conceptual understanding and concrete implementations. After undergraduate students are able to apply abstract knowledge in concrete implementations, subsequent higher-level, theory-oriented courses have more relevance. As a byproduct of this course, some of the autonomous mobile robots implemented by our students have been able to compete in different IEEE sponsored robotic competitions.

2. Motivations and Background

Traditional approaches to system design in engineering disciplines have focused primarily on hardware design, whereas computing sciences have focused primarily on software design. With the introduction of robotic systems, it became possible to provide students with hands-on laboratory experiences to construct interdisciplinary and more complex systems. As robotic systems have evolved in research and commercial applications, the number and complexity of these systems have also increased. A significant portion of the design process must now focus on the integration of hardware and software. However, most senior design courses still emphasize just on the software writing or the hardware construction parts. In order to address both software and hardware issues, it becomes essential to apply a team-based approach.

Applications of robotic systems usually involve a large number of various types of sensors and actuators connected to a real-time controller. The rapid increase of such applications requires from the students a better understanding and knowledge of technology and how the different sensors and actuators work and they need to be able to correctly interface them to the controller. These applications serve as excellent case studies to motivate students and teachers. Also, fast computation speed is a major barrier for many real-time sensing and control applications, especially for sensors requesting a large amount of computation, such as obstacle detection and image sensors.

Modern robotic systems are equipped with advanced microprocessor-based embedded systems[6]. For example, an intelligent navigation system may use several electronic control units and hundreds of sensors and actuators to monitor and improve its performance.

Also, robotic systems that are designed for real-time applications such as navigation systems and process automation could be very expensive to develop. To be practical for a senior design class, the per-unit cost must be strictly controlled to fit within a typically constrained laboratory budget, since the cost of development of a platform for a mobile robot can become fairly expensive as the complexity of the sensors and control system are increased, it can reach thousands of dollars. For this reason, we had to find the best approach to follow in order to keep the cost of the robotic platform within the limits of the budget assigned to the course. In order to reduce the implementation costs we decided to use as much devices and systems that we already had available in our labs, such as sensors, electronic devices, laptops, microcontroller cards and simulation and programming, software tools. We also submitted internal equipment grants that have been used to acquire different sensors and actuators that allowed our students to design and implement more advanced autonomous mobile robots that were capable of participating in national robotic competitions. With the grant money, we were able to acquire for the senior design lab a differential GPS unit, a laser rangefinder, a digital video camera, different types of ultrasonic and infrared sensors, and a variety of DC and servomotors. Whit these basic components, several interesting robotic projects have been successfully developed and have been able to participate in different robotic competitions. In the following section we describe in detail the organization of the course and some of the projects developed by the students.

3. Class Organization and Teams Interactions

The typical senior design class consists of a group of 15-25 students that are separated into independent working teams. Typically the team size is 2-3 students, depending on the complexity of the project. Each team is responsible for the implementation of its own project. Each team's goal is to design, implement, and test an autonomous vehicle that is able to navigate in an unknown environment and perform a specific task.

Usually, the teams are advised by two faculty members. One advisor supervises the design of the robotic base, power supply and drive motor system. The second advisor is in charge of supervising the design and interfacing of the sensors and the navigation controller. A general block diagram of a typical autonomous vehicle is shown in Figure1. For each project the teams are responsible of:

a) Designing and implementing a mechanical base that includes: wheels, motors, motor drivers, frame and other components to ensure that the vehicle is capable of performing the desired tasks.

b) Designing and implementing infrared and ultrasonic obstacle detection sensors interfaces that are attached to the vehicle to provide environment information.

c) Writing and debugging the navigation and control program that is in charge of combining the information provided by the sensors, in order to control the vehicle. The various algorithms are written in assembly, C or Matlab languages.

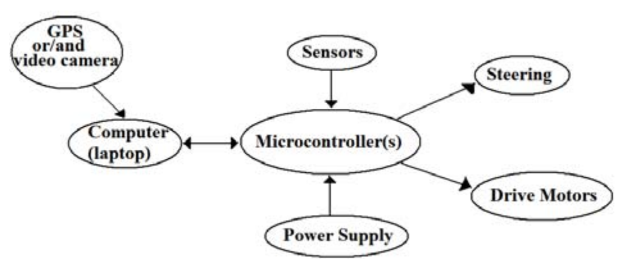

Fig. 1 Autonomous Vehicle Block Chart

Each team is asked to select a team leader based on his/her leadership and managerial skills. The team leader is the main communication channel between the students and the faculty members supervising the projects. The senior design is organized as a two-semester, 30-week long project. In the first weeks (1-5) of the first semester, students receive 3-hr/week lectures related to the theoretical background needed for the design of the different components of the autonomous vehicles, and 1-hr/week seminar related to the organization and development of the projects. In the following 3-4 weeks, each team performs research to define what will be the particular characteristics of their autonomous robot. From week 5 to8, students work in their projects proposals. By week 9, students should have selected their projects, and should present a preliminary written report and oral presentation of their progress. During the rest of the first semester students dedicate full time to do research and start the design of their projects. In the second semester students dedicate full time to the development of their particular project and the advisors are available at specific hours to provide advice and to answer any questions from the students. All teams and advisors meet 1-hr weekly during the second semester to discuss ideas, problems and to show advances for their projects. By week 4 of the second semester each team presents preliminary oral and written reports. Weeks 10-13 are dedicated to debugging, testing, interconnecting and final assembly of the autonomous vehicles. In week 14, final oral and written reports of the completed vehicles are presented to the class, advisors and other faculty and industry guests. The final public demonstration of the working project is performed on the last week of the semester. Many times, students are attracted to participate in a particular robotic competition (e.g. IEEE Regional Robotic Competition[2,3], Trinity College Fire Fighting Robot Contest[4], Intelligent Ground Vehicle Competition[5], etc). The teams design and implement their robots to meet the official competition rules and need to have their robot ready for the competition date. Due to budget constraints and dates, it is not always possible for all the teams to actually participate in a specific competition. However, in the last two years our students haves been able to participate in the 2008 and 2009 IEEE SoutheastCon contest and the 2009 and 2010 Fire Fighting Robot Contest.

4. Senior Design Educational Objectives

This course fulfills the EET department and ABET's requirements for a capstone senior design project, by providing a two-semester senior design option alternative to the traditional one-semester senior project. The contents of the course combines departmental expertise in digital system design, digital signal processing, power systems and control. Based on ABET's educational outcomes, upon completion of the senior design course students are able to:

a) Complete a design project that is interdisciplinary in nature, integrating the knowledge obtained in previous EET classes
b) Accurate communicate his/her project results, both in written report format and in oral presentation format
c) Understand how teams work and how to interact in a team setting. (Understand what is like to work in industry)
d) Appreciate the role of engineering in society, so that students take into account environmental, economical, social and ethical issues that are important in the development of an engineering project.

5. Course Assessment

The projects are evaluated in several stages, in a gradual and continuous way. In the weekly meetings, each team presents the evolution of their projects and receives orientation from the instructors. The objectives of these weekly meetings are also to have a close observation of the teams' progress and assure that each team member contributes to the teamwork. During the ninth week of each semester 30% of the final grade is assigned, after the students present their preliminary written reports and oral presentation of the results in their progress. Another 40% of the final grade is assigned to the students during week fifteen when they demonstrate their projects working in accordance to the specifications. The last 30% of the final grade is assigned based on the oral presentations, taking into account the quality and clarity of the presentation, and the completeness of the final written report.

6. Autonomous Vehicle Design and Implementation

Next we present a description of some of the robotic projects implemented as part of the senior design course. Pictures of the projects are shown in Figures 2 to 4.

In the following text we refer mainly to the robot shown in Figure 4, however with small differences most robots share the same characteristics.

Motors and Motor Control: All the robots use two DC motors controlled independently in speed and direction that implement the differential drive used for navigation. The direction and speed of the motors are controlled by two signals going into H-bridges. A 1-bit signal is used to control the speed of the motors by a pulse width modulation signal coming from one of the microcontroller ports. A second 1-bit signal is used to control the direction of the motor, either forward or reverse. The microcontroller receives a 2-bit signal from the main controller to indicate direction.

Steering System: An important action of the steering control is to make sure that the vehicle is traveling in the desired direction. In order to check if the vehicle is traveling in the correct direction a digital compass was added to verify the steering. The main purpose of the digital compass was control the movement of the vehicle by telling the microcontroller the direction that the vehicle is currently moving. The microcontroller takes data from the compass and sends it to the controller. Then, the controller analyzes the data and tells the vehicle to go straight, turn the wheels to the left, or to the right. The navigation algorithm says how much to turn from the current heading. From this value, the controller calculates the desired heading by adding the turn angle to the current heading. Also, the turn angle indicates what direction the wheels need to turn.

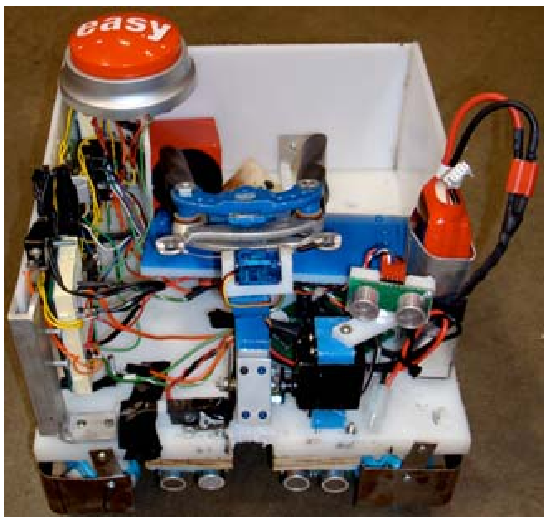

Fig. 2 SoutheastCon 2008 Competition

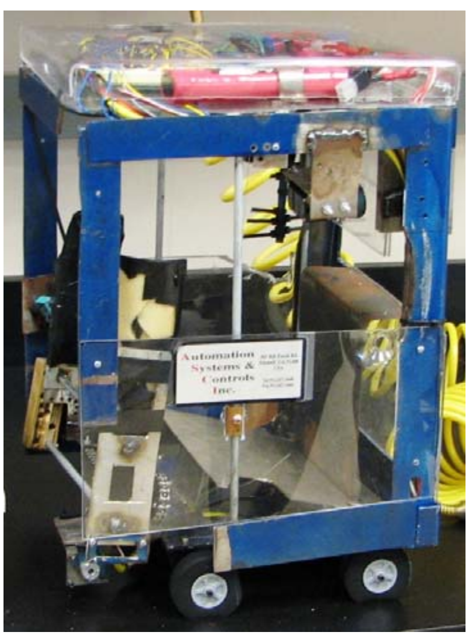

Fig. 3 SoutheastCon 2009 Competition

Wireless Drive, Remote Kill & Emergency Stop: Some of the autonomous vehicles are heavy, so they need a wireless driving system. The wireless controller is usually stripped out of a toy RC car to implement the RC features .

The Power Supply Module: Since the electrical components of the vehicle all require specific amounts of voltages, currents and power, a power supply module is constructed to provide these power requirements. The GPS and the laptop are powered using their own battery. The Power Supply Module also receives a control signal from the remote control to perform an emergency stop if required.

Connection between Microcontroller and Computer: The connection between the motor's microcontroller, a 68HCS12 MiniDragon development board [8], and the main computer was performed using the computer's parallel port. The parallel port was connected to one of the ports on the microcontroller using a ribbon cable. In Matlab, the Data Acquisition Toolbox gives the user the ability to communicate with the parallel port. By connecting the computer to the microcontroller, the navigation algorithm can use the data that comes in from the sensors and the compass to help control the steering of the vehicle[9].

Fig 4 .-GPS Controlled Robot Competition

7. Navigation Controller

The navigation controller is the brain of the autonomous vehicle; it takes inputs from the obstacle sensors, compass and GPS in order to decide the movements of the vehicle. Next we give a description of the operation of this system.

Obstacle Sensors: The purpose of the ultrasonic sensors is to gain information about how close a physical object is from the vehicle. Also, by using multiple sensors and the parallax method, it is possible to determine how far an object is from the center of the robot. It was determined that three sensors in the front and one in the rear of the vehicle will be sufficient to help in the control of the navigation. The three sensors SRF 04[7], located on the front are the main source for detecting the location of close physical obstacles.

Sensors and Data Processing : Using Matlab, students were able to implement a sensor's data processing algorithm to determine the presence of obstacles in front of the robot. First, the program calls a simple I/O command that captures data from all the sensors to have it available for manipulation. Next, the data is processed to find out which sensors are detecting obstacles. The next step is to collect the information provided by the compass and ultrasonic sensors to generate the correct speed and direction commands to the motors.

8. GPS Navigation Control

For some competitions the main navigation control needed is the GPS, and this is called the navigation challenge. To receive the GPS data, a Garmin differential unit[10] was used to get this input. From the GPS, the navigation algorithm obtains the desired angle the vehicle needs to travel in to get to the waypoint[11]. Using this angle as a desired heading, the navigation algorithm determines at what angle the vehicle needs to turn to get to the desired location according to the GPS[12,13]. Using the new angle as a starting point, the data is analyzed to check if the path at this angle is clear. If the path is clear, the vehicle turns at that angle. If the path is not clear, the navigation algorithm looks for the closest angle to the angle give by the GPS that gives a clear path. Once that angle is found, the vehicle turns at that angle. While the vehicle is turning, the algorithm is checking the sensors to see if there are any objects in the way. The algorithm also constantly checks the current GPS location to see if the vehicle is at the desired waypoint. If the current GPS location does match[14], the algorithm sets the desired location as the next waypoint.

Once all components of the vehicle have been installed and are working individually, they must all be integrated into a single system that will control the overall operation of the vehicle. Combining the various detection components into this navigation system provides the autonomous vehicle with the information needed to properly navigate through the unknown environment. The system will examine the data and come to an intelligent decision of which direction to take. The navigation control program is written in Matlab and uses the information provided by each input to determine the autonomous vehicle's direction.

9. Conclusions

Several autonomous vehicles were designed and built for the specific task of participating in the different robotic competitions, and to fulfill the senior design requirement for the students in our department. The participation in this course gave students real life team work experience. They experienced the application of theoretical information in different areas of knowledge to solve real life problems. This experience could later be used in their professional careers to solve similar problems in numerous other applications. The potential of real-world autonomous devices being able to control themselves is growing, and in some cases is very desirable. Throughout the process of designing and building the autonomous vehicles, the teams encountered many problems and made some mistakes of their own and they had to be identified and acted on accordingly. The top challenge for students and faculty members was to manage the schedule of each team, so that they were all ready to be put together by the end of the course. Based on the time constraints that we had, along with a limited budget, the final result that we obtained were better than expected. Overall, the projects integrated a variety of electrical, computer, and mechanical engineering techniques, along with computer science and mathematics. It also provided the students with a way to transfer theoretical knowledge into a practical application, been an invaluable final step in the electrical engineering technology program.

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