MULTIDISCIPLINARY CAPSTONE PROJECT FOR ENGINEERING TECHNOLOGY

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Abstract

Teaching engineering design through senior project or capstone engineering courses has increased in recent years. In this paper we present the description of a multidisciplinary capstone senior design course that uses mobile robotics as the central theme for the projects. This course is offered for the Electrical Engineering Technology (EET) and Mechanical Engineering Technology (MET) majors at Georgia Southern University. The main goals for the course are: a) to give students the opportunity to participate in the development of a complete engineering project experience b) to take an active part as a member of a multidisciplinary team c) to develop scheduling, evaluation and control strategies in order to assure the successful completion of the project and d) to be able to understand and apply the professional aspects of the engineering project related to ethics, environmental, safety and sustainability issues.

Introduction

Most four-year engineering programs traditionally culminate with a capstone senior project course or workshop [1-3]. The main goal of these capstone courses is to offer students an opportunity to apply theoretical and practical knowledge acquired in the classroom to solve real-world engineering problems. The project courses also allow students to experience teamwork, practice project management issues, work under realistic project constraints (time, budget, and achievement of realistic goals and deliverables), and communicate information effectively, in oral and written forms, related to all aspects of their project [4-6].

Though the goals of these courses are the same, the extent and quality of the end result varies substantially from different schools and programs. Some senior project courses involve only design, simulation or research of a particular topic, while others require students to design and develop an actual working prototype [7-9].

In the Mechanical and Electrical Engineering (MEEE) Department at Georgia Southern University (GSU), a three-credit, two-semester (30 week) Senior Project course is required for students majoring in Electrical Engineering Technology (EET). The EET Senior Project course can also be taken as an elective course for students in the Mechanical Engineering Technology (MET) program. For this course, students are required to work in teams to design and develop an electrical or electromechanical prototype system for a specific application. During the first semester of the Senior Project sequence (Senior Project I), students identify and propose to work on an engineering problem of interest to them; evaluate different solutions to address the problem; develop the research, specification, schedule, and budget for the project; and study and evaluate the ethical, environmental, legal, and social issues related to their project. During the second semester (Senior Project II), students design, simulate, build and test the actual prototype, then present their results to the class.

Each year, between 15 and 25 students in the Engineering Technology programs at GSU start their senior project (about 80% are EET and 20% are MET majors). Some of the students already have an idea of the project they want to develop, a few of them already have started a project with a faculty advisor, but the majority

wait until the beginning of the semester to learn from the faculty advisors about possible projects to be developed.

In the last few years, students' interest in developing projects related to robotics has notably increased. As robotic systems have evolved in research and commercial applications, the number and complexity of these systems have also increased. These systems typically include subsystems with separate processors or controllers. The processors must communicate with each other to coordinate their activities. For example, a typical autonomous navigation system (mobile robot) consists of an interconnected collection of processors connected to a real-time controller. As these systems become more complex, the need for the students to work as a member in a multidisciplinary team becomes more critical [6, 10, 11].

In this paper the authors present their experiences incorporating the design and fabrication of an autonomous navigation vehicle as part of the Senior Project in the Engineering Technology programs at GSU. The goal of the autonomous navigation system project was to design and develop an autonomous vehicle which was mainly controlled using a Differential Global Position System (DGPS) receiver. The main characteristic of the proposed autonomous navigation system was that it could be easily divided into subsystems that, at the end, could be integrated as a whole system. The development of this type of complex system exposes students to a realistic engineering environment in which teams of engineers work independently to design and develop different parts of a complex system that ultimately must be integrated to successfully work as a whole system.

Senior Project Educational Objectives

The Senior Project I and II sequence fulfills the EET program and ABET's requirements for a capstone senior project by providing a two-semester senior project course. Based on ABET's educational outcomes, upon completion of the Senior Project sequence, students are able to:

- design and develop a multidisciplinary complex project;
- work in teams to find or propose and solve a problem in an engineering or technology field;
- understand and incorporate realistic constraints, including realistic design, implementation times and budget in the development of an engineering or technology project;
- develop a prototype of the proposed design and demonstrate a working prototype in accordance with the specifications;
- effectively communicate information relating to all aspects of the project in written and oral forms; and
- describe and demonstrate the concepts and importance of professional, ethical, environmental, and social responsibilities in the engineering field, and in particular relate it to their project.

To achieve these objectives, upon successful completion of the first semester (Senior Project I), students should be able to:

- describe fundamentals of engineering project management, and apply it to the proposed project;
- write a project proposal, identify the major tasks involved, and plan and develop task management, scheduling and cost management;
- identify a technical assistance group that will be available as a resource as they implement their project;
- research and write a report with all information needed to design and implement their project;
- describe and demonstrate the concepts and importance of professional, ethical and social responsibilities, demonstrated by

written analysis of an engineering ethics case study; and
- develop a project budget and project schedule that includes the economical and time constrains of the project.

Upon successful completion of the second semester (Senior Project II), students should be able to:

- design, simulate and debug the different parts of the system;
- implement and develop all the hardware and/or software prototypes related to their project;
- write documents of the project they developed with correct technical content, sufficiently detailed explanations and proper formatting, spelling, punctuation and grammar;
- write an analysis of professional, ethical, environmental and social responsibilities of the developed project;
- deliver a professional project report, with detailed information about the design, implementation and results of the developed project; and
- make an effective oral presentation of their project incorporating significant technical content and using standard presentation software in front of their peers, faculty and industrial partners.

Description of the Autonomous Navigation Vehicle

The general description of the project that was given to the students at the beginning of the course was:

"Students will design and implement a four-wheel drive autonomous mobile robot for outdoor patrolling and surveillance purposes. The autonomous navigation will be mainly controlled using a Differential Global Position System (DGPS) receiver. The robot should also be able to avoid obstacles encountered along its trajectory. The robot should be able to perform the assigned patrolling tasks in different parking lots on the university campus. The autonomous vehicle should be designed to operate in manual and autonomous modes. In manual mode a wireless remote control should be used to drive the vehicle. In the autonomous mode, using a laptop, the user specifies a set of waypoints (given as longitude and latitude coordinates) that the robot must visit. Then the autonomous vehicle will visit each waypoint navigating autonomously and avoiding, at the same time, any obstacles on its path, going from one waypoint to the next one in the same sequence as the waypoints were saved. The robot will use the DGPS as its main resource to control its movements and to navigate autonomously. Besides the DGPS, ultrasonic range finders (sonar sensors) and a digital compass will be used to detect obstacles and to help controlling the overall navigation of the robot".

Hardware Subsystems

In order to design and integrate the fully working autonomous navigation vehicle, the project was divided into a set of independent subsystems that allowed different teams to focus on a specific subsystem. Once each subsystem was tested and operating independently, all the subsystems were put together in order to integrate the complete system.

The autonomous navigation vehicle project was developed by ten EET and two MET students, divided into six teams of two students each. Each team was responsible for designing, building, testing and delivering a fully working subsystem capable of being integrated into the overall project. The project was divided into the following subsystems (Figure 1).

1) Mobile robot base (MET)
2) Motor controller (EET)
3) Remote control interface (EET)
4) Electronic compass and ultrasonic ranger interfaces (EET)
5) GPS navigation system interface (EET)
6) Main microcontroller and communication interfaces (EET)

In the next sections each one of the subsystem is explained in more detail.

1) Mobile robot base. The two MET students designed and constructed a robust mobile robot base that could be used in an outdoor environment. The base was made out of 1/8 inch thick aluminum platform. The bare base was 12.25 inches wide and 17.25 inches long. The sides were 2.125 inches high. The wheels were 6.75 inches in diameter and the ground clearance of the robot with the wheels mounted is about 2.3 inches. The base included four wheels, four DC motors and its drivers, and enough space to house all the other components of the complete system. Figure 2 shows the top and bottom views of the robot base. For the design of the base, the weight of the main components was carefully considered, such as the GPS receiver, the laptop computer and two 12V deep-cycle batteries. The students used SolidWorks software to generate a professional design of the vehicle base.

Figure 3 shows the completed vehicle with all the components. The frame on which the laptop is seated was constructed out of aluminum beams and joined with rivets. The overall weight of the robot was about thirty-five pounds.

2) Motor controller subsystem. The motor controller subsystem controls the operation of the four 24V DC motors with a gear ratio of 1:19. With no load, the motors will turn at about 265 rpm. At full speed the robot moves at about 5 mph. In order to control the rotation speed and direction of the DC motors, two small microcontrollers (ATtyni45) were used along with two pulse width modulation (PWM) drivers (LM18200). The drivers and DC motors used in the project are shown in Figure 4. The ATtiny45 microcontroller is an eight pin automotive microcontroller with an internal oscillator, which made the interface very simple. These microcontrollers worked very well for this type of application because of
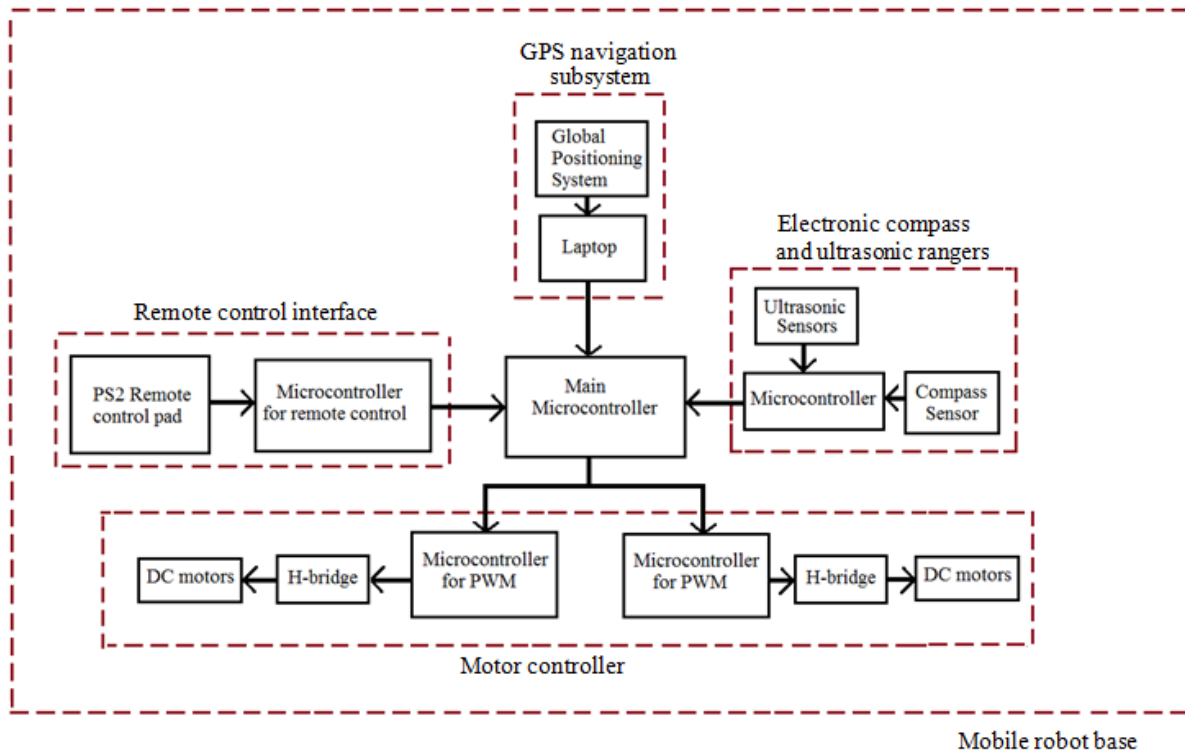

Figure 1. The Autonomous Navigation Vehicle Block Diagram.

Figure 2. Top and Bottom Views of the Robot Base.

Figure 3. The Robot Assembled.
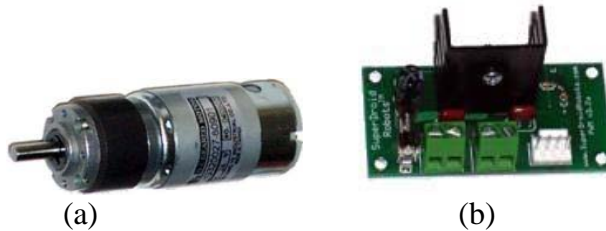

(a)   (b)

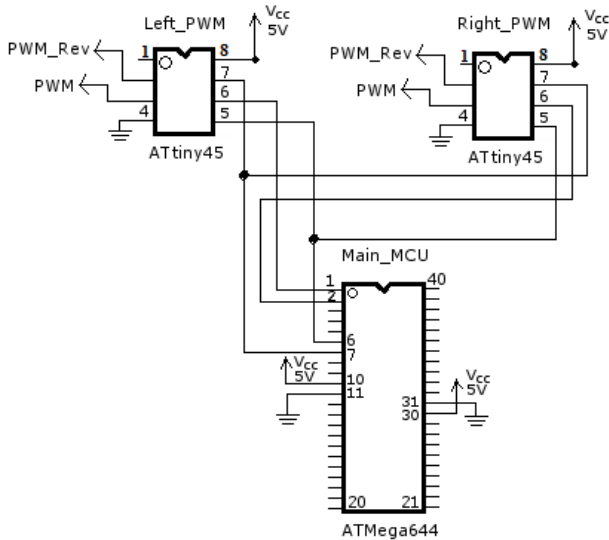Figure 4. (a) DC motors and (b) H-Bridge Motor Driver.

Figure 5. PWM and Main
Microcontroller Interface.

their small size and minimal external hardware needed. Figure 5 shows the circuit diagram of the connections of the two ATtiny45 to the main microcontroller. The connection to the main microcontroller is implemented using a 3-wire serial peripheral interface (SPI) communication channel that requires only RX, TX, and Clock signals. The data transmitted from the main microcontroller to the PWM microcontrollers are the pulse width modulation parameters. The PWM microcontroller outputs are the three signals required by the H-Bridge motor driver boards. The whole electrical system is powered by a 24V, 3000mA/h battery bank (two 12V deep-cycle batteries). Each motor sinks a current of

0.5A at no load. Once the load is added the current on each motor can increase up to 3 A.

3) <u>Remote control interface.</u> The mobile robot system had two modes of operation: manual and autonomous. In manual operation, a wireless remote control was used to allow the system to be easily moved to different locations. A wireless Playstation2 (PS2) remote controller was modified and used to manually control the operation of the robot when required. The PS2 communicates using a protocol similar to a Serial Peripheral Interface protocol. An Atmel 8051 microcontroller was used to build the interface of the main microcontroller to the wireless PS2 remote controller. Although the communication is performed serially between the PS2 pad and the 8051, the 8051 communicates the status of the buttons to the main microcontroller using an 8-bit parallel port, so the main microcontroller does not have to poll the serial interface to check if the serial data is ready. The wireless communication board is shown in Figure 6.

Figure 6. Remote Control Interface Board.

4) <u>Electronic compass and ultrasonic rangers</u>. A Hitachi HMB55 digital compass was used to measure the heading or angular position of the robot. The digital compass was required because the DGPS can only determine the angular position of the robot if the robot is moving. The digital compass functions by sensing the earth's natural magnetic field, and it outputs an 8-bit angular value with a resolution of 1 binary radian (1 brad) corresponding to a resolution of 1.4 degree per bit. In order to interface the compass to the main microcontroller a Basic Stamp 2 (BS2) microcontroller from Parallax was used. The BS2 relays the data to the main microcontroller via an 8 bit parallel port. Three Devantech SRF04 ultrasonic rangers (sonar sensors) were used to detect objects in the path of the robot; they also use the BS2 to interface to the main microcontroller. The sonar sensors are located in front of the robot and generate an interrupt signal to the main microcontroller if there is an obstruction in the path of the robot. This allows the navigation control program to decide whether to stop the robot or go around the object. The angle that the robot turns depends on the speed the robot is moving and the size of the object.

5) <u>GPS navigation subsystem</u>. A laptop computer with MATLAB software and a Trimble PROXRS DGPS receiver (Figure 7) were used to implement the autonomous navigation. The laptop was used to program the waypoints to be visited by the robot and read the robot's actual position in real time. This Trimble PROXRS GPS can work on the NMEA 0183 protocol as well as in the TSIP protocol, and has differential GPS capabilities allowing for a maximum positioning accuracy of up to 30 centimeters. In order to obtain maximum accuracy, the receiver needs a satellite differential signal, but this option requires a monthly subscription fee of about one $150.00 a month. The receiver also has a real time DGPS beacon selection, which was the differential signal option that was used in the project to control the

navigation of the robot. The main microcontroller (ATMega644) receives data from the DGPS (through the laptop) using an RS232 interface. Figure 8 shows the circuit diagram for the RS232 serial interface implementation that connects the laptop to the Main microcontroller. A MAX232 chip was used to interface the RS232 logic.
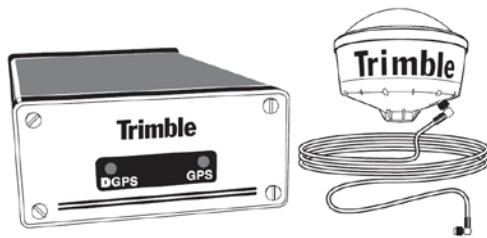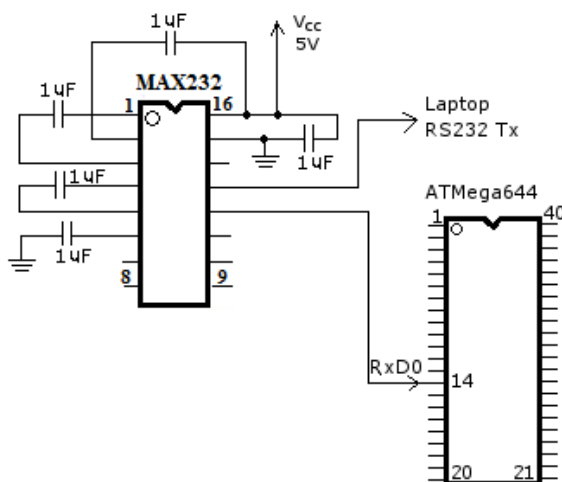

Figure 7. The DGPS Receiver w/Antenna.

Figure 8. RS 232 interface: laptop to main microcontroller.

6) <u>Main controller and communication interfaces.</u> The main controller of the system is an ATMega644 microcontroller, and was fully programmed in assembly language in order to improve memory optimization and execution speed of the program. The program was compiled, debugged and simulated using the AVR studio software, and then the executable file was downloaded into the chip using a programmer. The main microcontroller

communicates with four external devices, through their corresponding micro-controllers: a) the DGPS system through the serial port of the laptop computer; b) the wireless remote control pad trough an 8051microcontroller; c) the DC motors trough two ATtiny45 microcontrollers; and d) the electronic compass and three ultrasonic range finders through a Parallax Basic Stamp 2 (BS2) microcontroller. Figure 9 shows the implementation of the microcontroller interconnection board. The figure shows the main microcontroller (ATMega644), the Basic Stamp 2, and the two ATtiny45 microcontrollers.
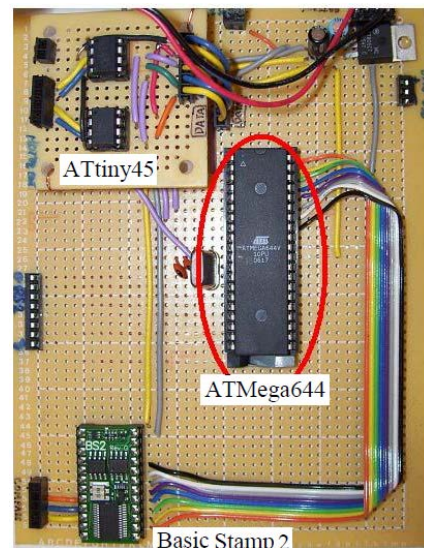

Figure 9. Main Microcontroller Card.

Navigation Control and System Integration

In order to integrate the different subsystems and control the navigation of the robot, two sets of programs were written. A) MATLAB programs were used to communicate with the DGPS receiver and convert coordinates from latitude and longitude values to Universal Transverse Mercator (UTM), and later to angle and traveling distance values; and to provide the navigation control commands sent to the main program. B) Assembly language programs were used to implement the main navigation control program and communicate with the

compass, remote control and DC motor interfaces.

A) MATLAB Programs

The GPS receiver has a standard RS232-DB9 connector that is used to communicate serially with an external device. This necessitated using a serial port in the laptop to connect the DGPS to the computer. All the programs on the laptop were written in MATLAB. The main reason for using MATLAB is that the toolboxes available make the serial communication programs and the coordinate translation easier to implement than to program them from scratch using C++ or Java. Figure 10 shows the flow chart of the "Distance and Direction" program, which is the principal program that controls the navigation of the vehicle. The main purpose of this program is to determine the distance and direction to travel given a destination point and its current position. In this program, the purpose of the "Is fix good?" block is to determine if there are enough satellites in view for the DGPS system and that there is a differential signal available in

order to set the data and operation to be valid. Figure 11 shows the flow chart of the MATLAB program used for selecting the "Driving Route". The Driving Route control program calls the Distance and Direction program as a subprogram. In order for the Driving Route program to be executed, at least one point must already be saved in the destination waypoints array. One of the important steps in the Driving Route program is the "Is the line busy" block; it is needed to avoid data collisions, since MATLAB would try to start sending the next batch of data to the microcontroller while still there is a previous transmission in process. Figure 12 shows the flow diagram for the control program that generates the PWM signals for the DC motors.

B) Assembly Language Programs

The main control program was written in assembly language for optimized size and execution speed, and contains two important subroutines that can be called up to control the navigation of the robot. The names of two
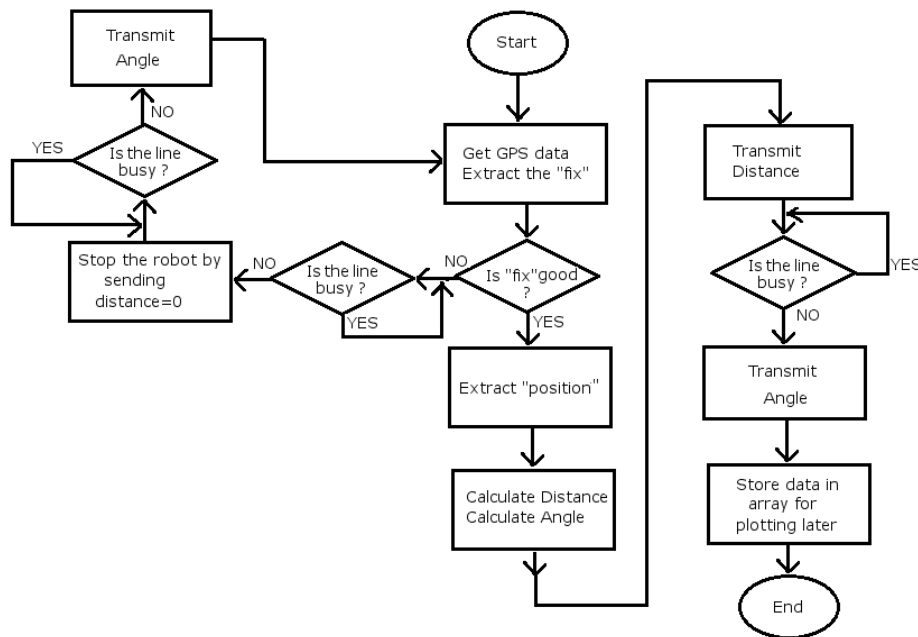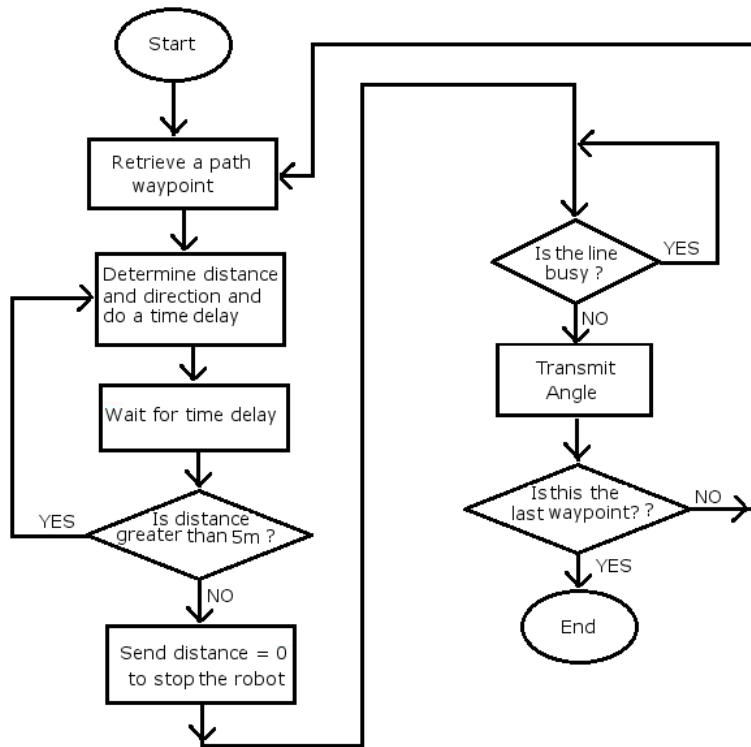

Figure 10. MATLAB Calculating Distance and Direction.

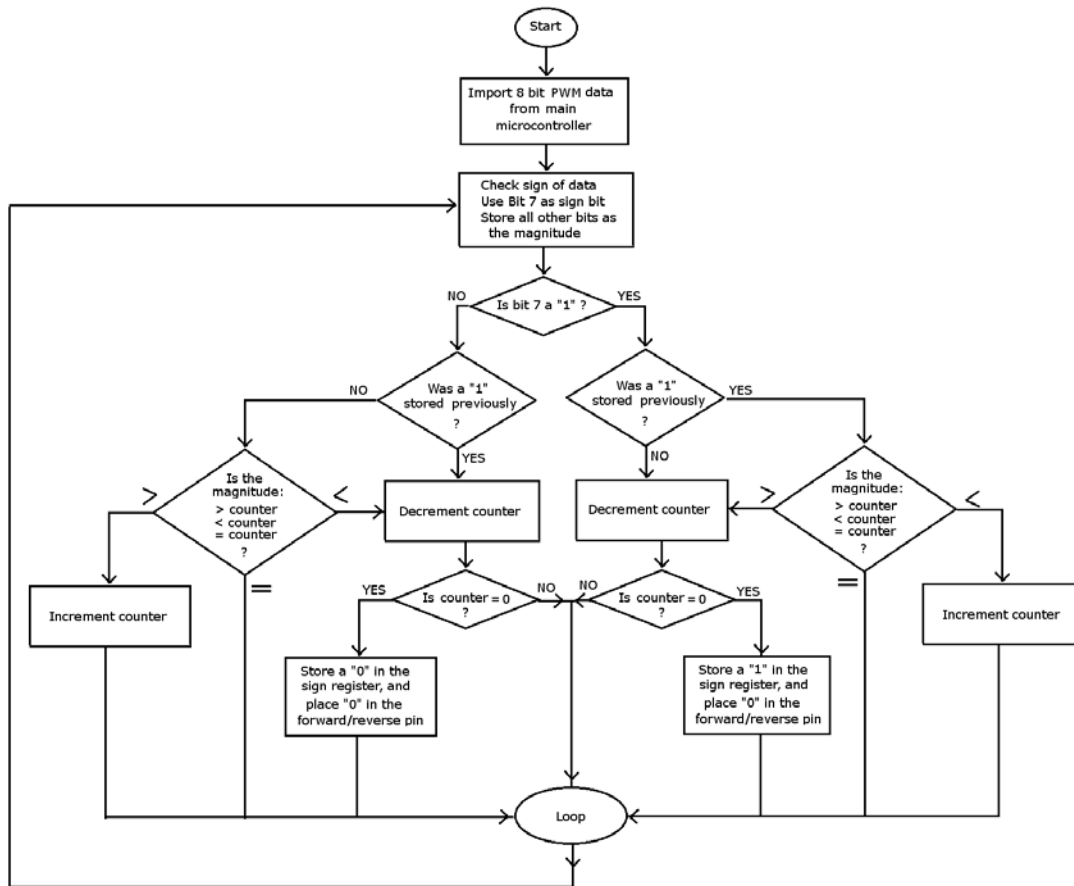Figure 11. Selecting Driving Route.

Figure 12. Control program for the ATtiny45 that generates the PWM signals for the motors.

subroutines are "Autonomous" and "PS2Buttons" respectively. Once one of the subroutines is called up, the program continues execution on the corresponding subroutine. At the end of the subroutine, the program returns to the main program in case the other subroutine needs to be executed. For instance, when thetriangular button on the control pad is pressed, the robot operates autonomously. Then, if no other button is pressed, the robot continues autonomous operation but continues to check whether any other button is pressed on the control pad. Once a button on the control pad is pressed, the robot stops its autonomous operation and functions manually by the particular remote control command (stop, go forward, go backwards, turn right, turn left) until the autonomous operation button is pressed again.

Course Assessment

Based on the project learning outcomes, the faculty used a variety of methods of measurement to collect data on the capstone design experience [12-16]. We can divide the assessment instruments into several categories. At the beginning of each semester students are provided with the specific rubrics for the topics the professors will use for evaluation of: a) the professional components that include ethical, environmental, sustainability and safety issues related to the project, b) the technical written report, c) oral presentations, d) project schedule and Gantt chart, e) project budget and parts list and f) the demonstration of the final product. They also receive rubrics for peer evaluation of teamwork participation, and evaluation of the course itself. The preliminary, formal proposals and project research reports are due during the first six week of the semester. Advisors provide a significant assessment to each team (feedback, not evaluation) based on this report, together with the observed performance in the weekly meetings. For the technical written report, targets of assessment include: format and organization, mechanics, illustrations, references, use of appendices. For the project implementation, targets include: identification of the problem, information gathering, and definition of the problem, development plan, execution plan, design verification, scheduling and technical level. For the professional components review, targets include the consideration of the following constraints: economic, environmental, sustainability, manufacturability, ethical, health and safety, social, and political. For the oral presentations, targets include: content, visuals, presentation skills, organization, attire, organization and handling of questions.

More specifically, for each semester the activities related to assessment are as follows:

I) For Senior Project I, during weeks one to six the design teams are formed, and the brainstorming process takes place to define the project and start generating ideas for possible design solutions. Students write a one page project proposal that describes the main technical characteristics of the project and the requirements of parts, equipment, and software in order to be reviewed and approved by the faculty advisors. Once the project is approved by the faculty advisors, the team has to write a formal project proposal that contains a more detailed technical description, the schedule for completing the project (Gantt chart) and an approximated budget for building the project. Also during these weeks, students receive lectures that provide basic knowledge of project management, project scheduling tools and project control techniques, as well as an introduction and awareness of ethical, environmental, sustainability and safety issues related to their projects in particular, and to the engineering field in general. Students learn about the value implications of their actions as professional engineers through discussion and written analysis of different engineering ethics case studies and the effects on the environment when developing or using some technologies [17,18]. From week 6 to 14, students do

the research of their projects and start the design, simulation, prototyping, etc. Teams receive continued advisement by having weekly meetings with their advisors, following the teams' progress very closely. Students are encouraged to report any problems that will affect or delay the progress of their project. The final oral presentations are performed at the end of week 14, and the final project plan report is submitted to the instructors during week 15 of the semester.

II) For Senior Project II, teams work full time in the implementation of their projects, making sure to follow the schedule for completing each part of the project on time. In order to do so, students meet once a week with their instructors to report their progress, and seek guidance for issues or problems that could delay or affect the completion of their project. During week six of the semester, each team gives an oral presentation of their advances in front of their instructors, other faculty, and peers. The presentations help teams assess their accomplishments in terms of what other teams have accomplished, and provide a motivating factor for the teams to continue working hard to stay ahead of the other groups. Final oral presentations are performed at the end of week 14, and the final comprehensive project report is submitted to the instructors during week 15 of the semester. Project demonstrations are performed at the end of week 15; faculty and industrial advisors participate in the evaluation process.

As part of our effort to continuously improve the course and to further our educational objectives, an assessment questionnaire was distributed to students at the end of each semester (Senior Project I and Senior Project II). The questionnaire was unannounced and the responses were anonymous. Table I reports the student's responses to the assessment questionnaire for Senior Project II. A score of four (4.0) is the highest and one (1.0) is the lowest. The average score in each category was computed over 22 responses (12 worked on the Autonomous Navigation Vehicle, and 10 worked on different projects). The overall evaluation of the Senior Project experience was 3.0 as shown in Table I.

Table I. Assessment Questionnaire Results.

Assessment Questions: (4 = highest score, 1= lowest score, and num. students = 22)	Average Score
1.- As a result of the course I can design, simulate, and debug components for a system.	3.0
2.- As a result of the course I am better prepared to work in team environment and propose and solve engineering related problems.	3.2
3.- As a result of the course I am better prepared to understand and incorporate realistic constraints, including realistic design and implementation times and budget in the development of an engineering or technology project.	2.8
4.- As a result of the course I can design and implement a prototype in accordance with given specifications.	3.1
5.- As a result of the course I am better qualified to submit written documents with correct technical content, sufficiently detailed explanations, and proper formatting, spelling, punctuation, and grammar of the developed project.	2.9
6.- As a result of the course I am better qualified to make effective oral presentations incorporating significant technical content using standard presentation software of the developed project in front of peers, faculty, and industry representatives	3.2
7.- As a result of the course I can write an analysis of professional, ethical, environmental, and social responsibilities of the developed project.	2.8
8.- Overall opinion of the course.	3.0

Conclusions

This paper has presented an overview of the capstone engineering design experience within an undergraduate senior project course designed to provide a broad engineering education to meet the needs of industry and society with a focus on mobile robotics. Although most learning took place outside the classroom, by enforcing a hands-on project base approach, students remained passionate about the projects and were highly committed to finish their assignments on time. The robotics capstone experience has been a successful approach to teach multidisciplinary design methodology and the initial goals proposed for this course were successfully achieved. However, at the beginning of the course, when the teams were formed and the different individual tasks were assigned, students felt that this was a very challenging project. Several times, students were frustrated because their initial designs and implementations were not operating as expected. However, with the guidance of the instructors, and perseverance of the students in debugging and testing, all the teams were able to complete the assigned tasks. At the end, students were able to integrate the different modules and the robot was able to successfully perform the tasks established at the beginning. Students were very proud and excited about the accomplishments they obtained working as a team and acknowledged that this was a great learning and working experience.

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Biographical Information

Fernando Ríos-Gutiérrez was born in México City. He graduated with a B.S. degree in Electrical Engineering (EE) from the National Polytechnic Institute, Mexico, and received M.S. and Ph.D. degrees in Computer Engineering from Tulane University. Dr. Rios–Gutierrez has taught in several universities in Mexico and the US and, from 2007 to present, he has been a tenure track Assistant Professor in the EE department at Georgia Southern University (GSU). Dr. Ríos-Gutiérrez has presented and published papers in the areas of engineering education, robotics, digital systems, and microprocessor applications.

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