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Incorporating Robotics into Electrical Engineering Capstone

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This paper describes our experiences incorporating robotics projects into a two-semester Electrical Engineering Capstone course. The projects include multiple EE disciplines such as power, motor control, sensors, and routing software. Our first robotics projects in 2016 were based on the IEEE Region 5 challenge. Since that time, we have completed thirteen robot designs with six in progress. We typically assign the same project definition to multiple teams which enables end-of-semester "co-op-etitions" between the different design implementations. Some notable challenges encountered include determining how to seed the teams with early material, the expense of obtaining a competition field, and a propensity for the mechanical design and fabrication to take too much time away from the required electrical engineering course content. All teams present their projects at an end-of-semester in-person Senior Design Day event. During COVID-19 restrictions we also evaluated projects virtually using Zoom. The projects and associated competitions consistently draw a crowd both of students and design day attendees. It is our hope that our findings will benefit others who are considering the incorporation of robotics into their EE Capstone course.

Keywords: robotics, autonomous robot, electrical, capstone

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Introduction and Scope

This paper describes autonomous robotics projects which were designed as part of the two-semester Electrical Engineering Capstone sequence. Robotic projects incorporate several disciplines and require significant subsystem integration, so they are well suited to meeting the ABET requirements for Senior Design. We offer the students a choice of projects at the beginning of the course and have found robotics to be popular. Additionally, students see the career opportunities in the growing robotics industry[1] and enjoy the competitions like those popular at major universities[2]. The demonstrations and competitions at our culminating Senior Design Day event are very popular with both the students and attendees

Project Descriptions and Findings

IEEE Region 5 Robotics Competition 2017, 2020

IEEE Region 5 conducts annual robotics competitions[3]. Teams must submit an intent-to-compete in December and the competition is held at the Student Conference in in early April. This competition is open to student teams outside of Capstone and the competitions, which change each year, are quite challenging. We had two teams attempt this challenge[4] in 2017 which one team described as "…to create an autonomous robot that will navigate a maze and map it out while identifying dead ends and avoiding obstructions. At the end a manipulator will open a "barrel" and a sensor will read the object located within (a die) and display the number of "pips". Multiple components will be used to construct the autonomous robot." The teams had difficulty achieving a high-level of functionality by the time of the conference.

The 2020 competition was based on the concept of a trash collecting robot[5]. Due to high student interest, we formed four teams with four students each in the Fall of 2019. An immediate challenge was the competition field; the Lexan perimeter alone[6] is $799. While there are instructions for creating a low-cost field, the students expressed concern about the sensor response differing between the Lexan perimeter of the competition field versus the lower cost field. One team took it upon themselves to build a perimeter of painted 1" x 6" wood for all teams to use. For the flooring we purchased interlocking 3/8" x 24" x 24" foam tiles of the type used in exercise or child play areas. In all, we spent approximately $100 to build the practice field.

At the start of the project, we realized that we had no robotics components in our current recycled stock. We purchased four low-cost Arduino based kits which included an acrylic frame, ultra-sonic sensors, and four geared DC "TT motors" for approximately $30 each. The four teams were given two weeks to build and demonstrate the functionality of the kits. This activity worked well, and the kits have provided a good source of backup material. During the second semester of development, Spring 2020, the world was impacted by the COVID-19 pandemic. At this point two of the teams had largely completed the assembly of their chassis and were working to refine the trash collection. Two teams were still evaluating their construction methods. All teams had developed designs that were near the maximum 24” x 24” x 24” size allowed with geared DC motors to drive the wheels. Three teams used large NiMH battery packs; one team used a motorcycle style sealed Lead-Acid battery. For chassis construction, two teams used a mix of flat metal and modified plastic tubs, one team made extensive use of extruded aluminum rails, and one team’s design was almost entirely 3D printed. As a result, not only was the limited access to campus resources an issue for continuing construction, but there was no practical way to produce additional prototypes, leaving only one team member with access to the unit. The teams generally adapted by having the team member with the most suitable apartment or garage keep the prototype. The other team members would send software updates and occasionally they would meet off-campus for working sessions. Our students have access to full Zoom accounts and made heavy use of video conferencing.

The teams presented their robots during a virtual Senior Design Day using Zoom. The top performing robot was able to move about the field in a semi-directed way and collect much of the garbage. It was not able to accurately identify the type of garbage or place it into the proper bin. The remaining teams achieved slightly less functionality; the robots were all able to move and avoid collision with the perimeter. The sensors worked independently to identify the trash but were not integrated enough to enable autonomy. The sweeping/lifting mechanism to dump the trash into the bins proved to be mechanically very challenging.

In summary, the IEEE Region 5 challenges are appealing; they are well documented, there is high student interest, and the opportunity to compete at a regional level is a great one. However, for April delivery we must finalize the projects early in the Fall semester and the scope of the projects, albeit with different tiers of functionality, has been challenging from both an implementation perspective and a cost perspective. Other programs have had success with complex projects by having a series of courses prior to Senior Design. Two examples are the ADBL system implemented at SeoulTech[7] and the mechatronics curriculum at Ariel University Center[8]. In the following sections we discuss our attempts to balance the engineering challenge and content of our projects with the goal that each team will produce a highly functional robot within our current curriculum and six credit-hour limit.

Robo-Fetch 2020

This internal concept was meant to address some of the size and cost challenges of prior programs. The initial description provided to the students was “Create a ball chasing robot that will be able to retrieve a colored ping-pong ball thrown into a hallway [in the Engineering building].” Having no 3rd party requirements, we also provided a more detailed Product Requirements Document to the students. Key items were:

- Two wheel “tail dragger” chassis, 3D printed or fabricated from sheet/rod stock.
- > 20cm multi-segment tail, 3D printing preferred but any hinged solution is acceptable.
- Minimum battery life of 10 retrievals traversing the entire field. Battery must be able to be recharged in less than 15 minutes.
- Size, weight, max speed must be such that the danger to humans, furniture, walls, etc. is minimal.

Two four-person teams were formed based on the number of students who voted for this as their preferred project. They were in the middle of the first semester when the COVID-19 shutdown occurred. We changed the focus from a hallway in the engineering building to something they could test at home. We divided the foam tiles from the Trash-bot field so that each team could build a smaller 6’x 10’ “field” at their apartment. The original choice of ping-pong balls seemed inappropriate in non-enclosed area, so we switched to small “Gator skin” foam balls that are available in multi-color packs for children’s games.

One notable item was that one of the teams decided that they wanted to repurpose a hoverboard designed for a small child as the basis of their robot. Their rationale was that the price of the hoverboard was much less than the batteries, motor, wheels, and other chassis components separately. We discussed if the use of the hoverboard trivialized the design work. Controls, vision, and navigation tasks remained in addition to figuring out how to interface to a likely undocumented design, so this was deemed OK. We also had not anticipated a design capable of the speeds a hoverboard could reach. There was much discussion about how the speed could be limited, cutoff and safety switches, etc. In the end it was moot, the team was not able to purchase the hoverboard from the low-cost supplier that had made them interested in the first place. They switched to a more standard design with a bottom plate and two geared DC motors. Unfortunately, neither Robo-Fetch bot performed to the desired level on Senior Design Day.

Automated Floor Cleaning Robot 2020

In this project, we instructed the teams to start with a commercial vacuuming robot and replace the non-mechanical components to implement sensing and navigation. The Product Performance Criteria provided were:

- Self-map the house/room
- Auto-Dock when low battery, resume when charged

- Sense when the collection bin is full
- Sense when stuck
- Run for 90 minutes on a single charge
- Capable of alerting user when issues occur

Adding the requirement to have a working proof-of-concept by the end of the first semester helped the students to understand movement control. The students were advised of the complexity of navigation but were left to devise and implement their own design. One team wanted to implement cloud-based data storage and created a very complex vectorizing methodology for navigation. The other team was perfecting sensor implementations and allocated only a couple of weeks to implement navigation. The simple navigation could avoid some objects but did not complete the room mapping feature. This illustrated the challenge between providing help and design guidance versus allowing the students the explore and create their own solutions.

Sumo-Bots 2021

This project concept borrows heavily from the sumo-bot competition[9] objectives and rules. The rules provided a foundation for the robot car size and weight as well as the competition ring. Our 48" diameter ring was constructed by student workers using melamine board with a painted matte surface and border for less than $50.

We added requirements to demonstrate increasingly difficult tasks starting at the end of the first semester. The first demonstration was to push a stationary block from the sumo playing field. The second demonstration was to successfully navigate a 30-foot hallway, sense a black end-line, turn around, and return to the starting point. These tasks will be repeated at end of the second semester along with the sumo competition[a]. In the final competition[b], the hallway and block push demonstrations will be timed to see which car performs these tasks the fastest.

We started the teams with a basic robot car kit that included chassis, motors, motor driver, wheels, an Arduino Uno, and an IO breakout board. Our desire was for the teams of four students each to focus on sensor selection, electrical design, and coding tasks without devoting time to the mechanical design of the cars. A consistent car design allowed the component choices and coding algorithms to distinguish the designs in the competition.

At the end of the first semester, all four of the robot car teams successfully demonstrated the object push objective. One team successfully completed the hallway navigation objective, while the other three teams partially completed the objective.

Providing nearly complete robot car kits as a starting point appeared to have caused the student teams to "make what they had work", as opposed to evaluating alternate, likely better, implementations. While we used a very low-cost kit, we believe our experience in extending a base design is similar to others such as the AmigoBot used at Georgia Institute of Technology[10].

In the future, our objective is to take advantage of our makerspace resources to provide a basic chassis design. This chassis with a selection of available sensors, motors, wheels, and controllers should allow students to get prototypes robots up and running quickly. We will have the students demonstrate earlier in the first semester the car movement, field boundary, and object detection capabilities, allowing time for the students to analyze and evaluate alternate component options.

Pen-Bots 2022

The goal of this project is to create line drawings by having the robot move over a blank surface with a pen. This project provides an alternative to the more traditional robot car designs by requiring the use of stepper motors instead of geared DC motors. The requirements specified increasingly more complex drawings over the course of the two semesters. As of this writing, this project is just beginning with two teams of three students assigned in Spring 2022.

Subsystems for Robotics Projects

Typically, robotics projects can be divided into four sub-system categories: sensors, controllers, actuators and power[11]. While there are mechanical design and assembly aspects of the projects, as an Electrical Engineering Capstone course, we have tried to focus teams on the electrical and coding work.

Sensors allow the robot to gather input from the physical world. Projects have used cameras for vision, optical sensors for line/boundary detection, and ultrasonic sensors for object detection. Encoders, gyros, and accelerometers have been used for movement. Pressure sensors have been used for arms and grippers.

Controllers process the input from the sensors and determine actions based on an algorithm. The controller output drives actuators to turn the decisions and responses into actions. There are a wide variety of controllers available for robotics projects. Some of the attributes that are important to controller selection are: the number of I/O's, the processing power, the number of cores, and interrupts, power, and cost.

Actuators allow the robot to interact in the physical world. Typically, our projects have used geared DC motors for motion control (wheels and tracks), stepper motors for robotic arm movement and servos for

[a] Sumo-bot Trial Run https://youtu.be/JdZDMYMciCI a

[b] At Sr Design Day https://youtu.be/oLXu6Bq5N_o

grippers. The types of motors used have varied depending on the precision of the movement or motion required. Power consumption, size, and cost are key factors in selecting motors for a robotics project.

In addition to hardware subsystems, robotics projects can have multiple software subsystems. The coding responsibilities in a robotics project should be divided among the team members. Initially teams tend to have one member responsible for "software" but we have found it is better to have each team member deliver both hardware and software whenever possible. This may include writing software as well as selecting components that have mature software libraries available. Code to manage the various sensor inputs can usually be subdivided into areas of responsibility for different team members. Similarly, motors and actuators will have sub-routines for the control of these components. Multiple algorithms are often required to complete the various tasks. For example, in the Sumo-bot project, the code necessary to navigate a hallway is different than the code used in the block push and sumo competition. These different coding routines can be divided among the team members for implementation.

Key Lessons Learned

We summarize our key lessons learned as follows:

- Specifying a portion of the mechanical components necessary to construct the robot helps keep the focus on the electrical design and coding aspects of the project. If available, this is a great opportunity to collaborate with a makerspace resource.
- Expectations must be clearly set when seeding teams with nearly complete kits. The kits can inhibit their exploration of better suited implementation options.
- Constraining the Bill of Materials cost is essential and helps meet the ABET requirements. The students must evaluate trade-offs between the cost of sensors, actuators, and controllers to find the best balance for their project's objectives.
- Performance requirements should be documented to exercise each of the anticipated subsystems with an increasing level of difficulty.
- Each student's subsystem should include hardware and software when possible. Navigation is an often-overlooked component of autonomous operation.
- Multiple teams implementing the same robotics project creates an opportunity for collaboration and sharing of best practices and can ease the coaching and evaluation burden on the instructors.
- A friendly competition between robotics teams has had a positive impact on the students' motivation and engagement. While we do not use the competition directly for grading, it does provide a useful comparison for assessing the fulfillment of the design objectives.

Our goal with these projects is to provide a better learning experience where the students achieve as much as the team dynamics allow on their own merits. Our graduates need to think independently, solve problems, test, and adapt to live up to their best potential as engineers.

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