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Utilizing an Individually Built Mobile Robot in the Laboratory of an Advanced Digital Logic Design Course in Conjunction with a Final Class Competition

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Abstract

This paper describes the development and implementation of a series of laboratory projects utilized in a junior level, required course for computer engineering majors titled, "Advanced Digital Logic Design." Eleven of the 13 lab experiences are directly related to this project.

The first five labs are mainly construction labs where students are developing practical, hands-on skills and gaining familiarity with common prototyping practices. These skills include (a) utilizing a 3-D printer in order to create the chassis, wheels, and sensor mounts, (b) disassembly, modification, and reassembly of two servo motors, and (c) assembly and soldering two custom-designed printed circuit boards (PCB)—totaling approximately 50 components and 200 solder points. Once all the subsystems are complete, they are screwed together, along with a battery pack and front contact sensing bumper.

In the final six labs, the students systematically build-up the various digital designs needed in order to autonomously control their individually-built mobile robots. These labs include digital designs (a) to control the servos, (b) to play an accurate song on a small speaker, (c) to communicate with five infrared (IR) distance sensors in order to obtain range information, (d) to create a complex finite state machine (FSM), and (e) to navigate the robot through a set of obstacles. A 240 logic cell Complex Programmable Logic Device (CPLD) limits each student's design space and, consequently, efficiency of implementations is enforced. Milestones are graded throughout the semester in order to encourage proper progress toward the goal of participating in the final class competition; this event is where guests are invited and small prizes are awarded for the top three finishers.

This style of project-based-learning provides students with opportunities to gain practical skills and, with these skills, to increase students' confidence in their abilities to design and solve real-world problems. Additionally, I have found student motivation and interest to be high, which leads to increased rates of learning and accomplishment. Since the cost of the components is kept low (approximately $35), all students retain their respective robots and can continue working with them beyond the completion of the course.

Introduction

Providing students with practical hands-on skills in designing, fabricating, testing, and debugging are important objectives of the junior-level Advanced Digital Logic Design course. This three credit class is required for all computer engineering majors and it is an elective for both electrical engineering and computer science majors. The class meets three times a week with two, one hour lectures and one two hour laboratory. The number of students enrolled in this course over the last six years is shown in Figure 1 and has averaged around 15 students. Having small class sizes such as these makes it more feasible to give each student the help and attention needed in order to successfully complete each project. Each student works on his or her own robot, which assures that every student gains experience with all aspects of the project.

Year	2014	2015	2016	2017	2018	2019
# Students enrolled	15	16	14	12	21	14

Figure 1. *Student enrollment in Advanced Digital Logic Design over the last 6 years*

The lecture portion of this course breaks-down into three main areas:
1) Review of material covered in the first Digital Logic Design course, having been taken two years prior.
2) Learning the VHDL hardware design language.
3) Learning advanced material, including arithmetic circuits, advanced finite state machines, test benches, and testability.

The laboratory portion of this course breaks-down into three mains sections as well:
1) Robot Construction sessions.
2) Hardware projects not related to the robot and final contest.
3) Hardware implementations for the robot and final contest.

Construction Lab Details

One of the key objectives this course meets is to prepare junior students to successfully complete their respective senior design projects the following year. Students need to possess prototyping and debugging skills and should be familiar with the tools, techniques, and equipment available to them. In the first construction lab, students are familiarized with the department's 3D printers. As freshman, students take a one credit class in which they are introduced to solid works that can be used in order to make 3D models (they can be output and printed on our 3D printers). Although a few students typically are familiar with their use, nowhere else in the curriculum are students required to walk through the process of printing a 3D part. Each student is provided with the stereolithography file (.STL) for the chassis—and both the SolidWorks file (.SLDPRT) and stereolithography file for the wheels.

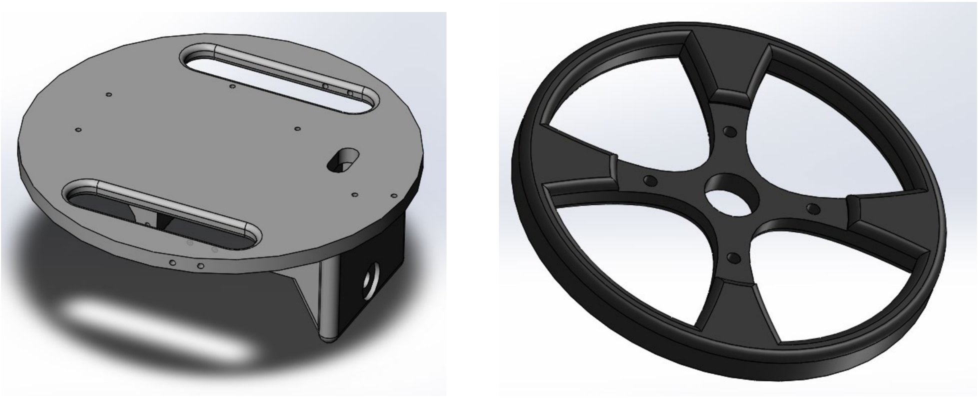
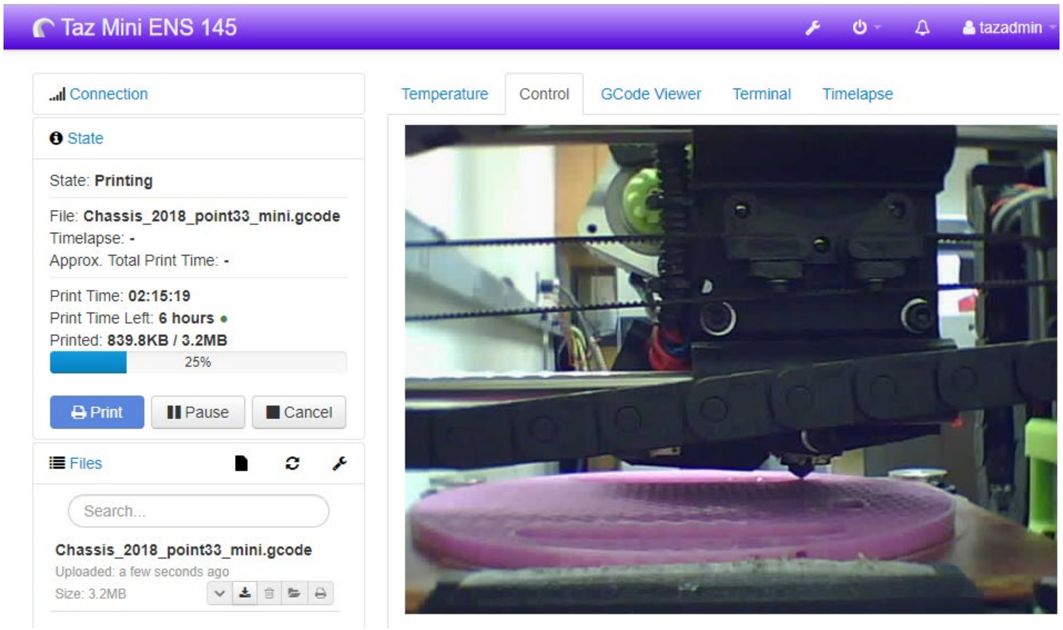


Figure 2. *SolidWorks renderings of the chassis and wheels given to the students.*

The above noted process allows students who desire to customize their respective robots the opportunity to do so with their wheels. These designs were derived from work accomplished in previous senior design and robotic projects on which I have advised and mentored students. The SolidWorks files are shown in Figure 2. Since a chassis required over five hours to print, a printing schedule was created. Doing so enables each student to be assigned a specific morning or afternoon (of a given day) on one of the three printers to which they had access. Within one week, all students should have had their chassis printed. Our printers are connected and controlled using network connected raspberry pi's running the OctoPrint software. This method allows students to watch the progress of their prints (even on their phones) through a web browser, providing a live video feed from a webcam (Figure 3). In case anything were to go awry, attentive students can stop the print and seek appropriate help.



State: Printing

File: Chassis_2018_point33_mini.gcode
Timelapse: -
Approx. Total Print Time: -

Print Time: 02:15:19
Print Time Left: 6 hours
Printed: 839.8KB / 3.2MB
25%

Chassis_2018_point33_mini.gcode
Uploaded: a few seconds ago
Size: 3.2MB

Figure 3. *OctoPrint providing live video feed of 3D printer progress*.

Students are responsible to print their main chassis and wheels and I 3D print five other smaller parts for them. These parts include the front and rear IR holders, the CPLD holder, the rear sensor holder, and two (each) of the IR rear Goggles. The various items are shown in Figure 4.

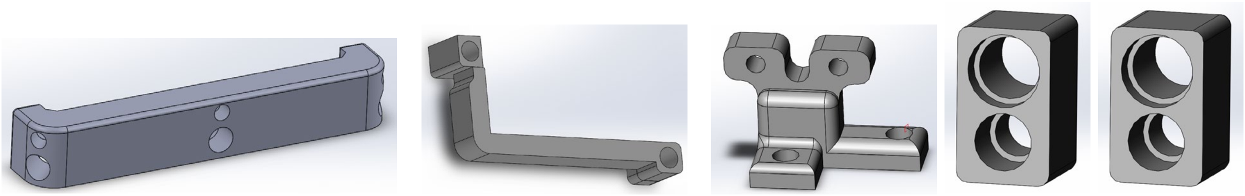


Figure 4. *Front IR sensor holder, CPLD holder and rear sensor holder and IR Goggles X2.*

In addition to giving instruction to the students regarding 3D printing their chassis, all students are given a six quart plastic storage box, a screwdriver, small pliers, and a small plastic storage box in which to keep their small parts. All students tape their respective names to the box, which eventually will be returned and re-used the following year.

Subsequently, I deliver a mini-lecture pertaining to soldering safety and techniques, then proceed to have students collect the needed parts and begin soldering-up the Printed Circuit Board (PCB), as shown in Figure 5. This PCB was custom-created in eagle and designed as a shield for the Altera MaxII 240 Complex Programmable Logic Device (CPLD) board. It provides all interface connections between the CPLD and two buttons, three custom IR sensors, a bumper, light sensor, 3 bit dip switch, a 4 digit seven segment display, 3 LED's, and a voltage regulator. The board was fabricated using OSH park and it is shown in Figure 5.

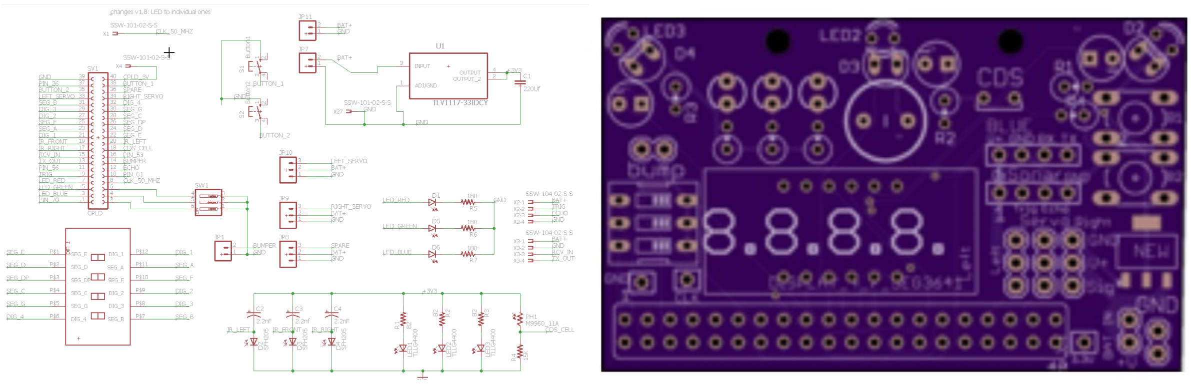


Figure 5. *Schematic and main printed circuit board.*

A detailed soldering manual is provided to the students in order to reduce mistakes and to provide key teaching opportunities so that all students, not only will understand what to do, but they also will grasp how and why the circuits were designed in the first place. Soldering-up all the parts continues for two (plenary) 2-hour lab sessions. Typically, one or two students will make a significant mistake(s) that will require re-work and help; but the vast majority of students complete an error-free, working-board on their first attempts. Figure 6 shows a finished soldered board.

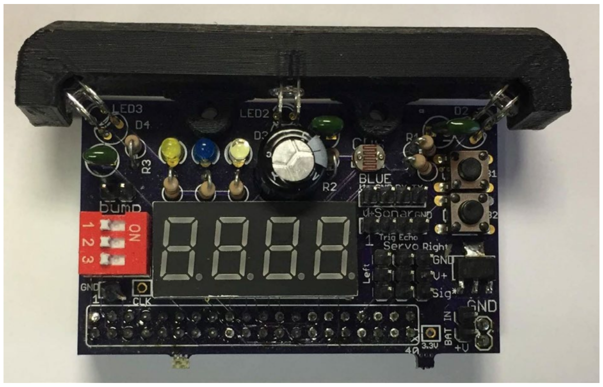


Figure 6. *Completed printed circuit board.*

Locomotion for the robot is provided by two standard servos that are modified for continuous rotation. Inexpensive metal gear servos (MG996R) have proven to be the easiest low cost servo for students to successfully modify. Again, I provide a detailed manual to students in order to help walk them through the process which involves disassembling the servo, removing the limiting pin from the final output gear, removing the potentiometer, and setting its neutral position. Once both servos are modified and their neutral points have been properly set, then the servos are re-assembled. Figure 7 shows a few of these key steps.

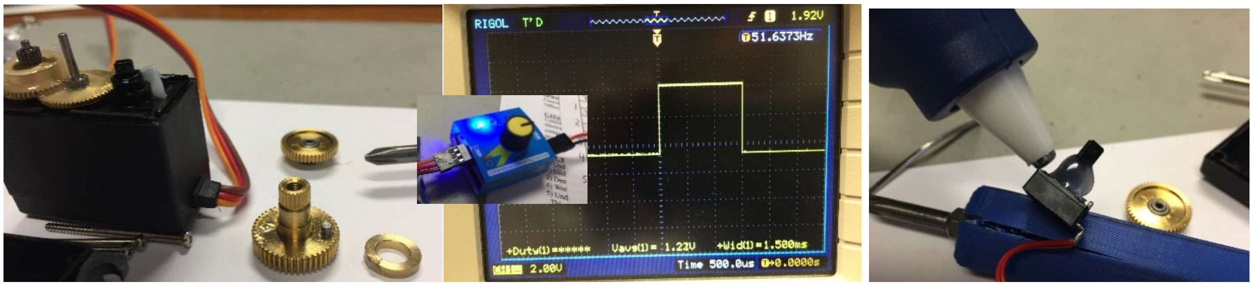


Figure 7. Key steps in modifying a standard servo for continuous rotation.

The fourth construction lab involves adding the bumper, batteries, and wheels to the chassis so the robot is ready for its first test. The bumper is an elegant design comprised of copper tape, attached to the front half of the robot, and a thin copper metal strip that is attached just beyond the front edge and held away from the robot with the rubber servo mounts (not otherwise used but provided with the purchase of the servos). Although the location of contact is unknown, any contact with the front of the robot will cause a short circuit to occur between the copper tape and copper strip. This forms a switch which, utilizing the built in pull-up resistors, is easily turned into a logic low, when the bumper makes any contact. Figure 8 shows the right edge of a finished robots bumper and Figure 9 shows the final finished robot from various angles.

Figure 8. *Copper bumper.*

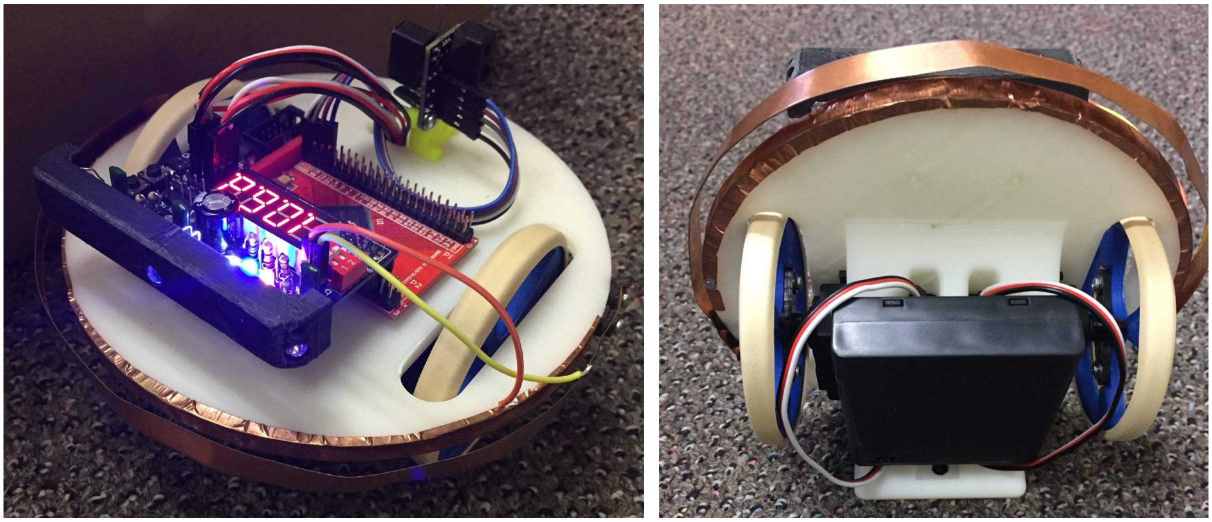


Figure 9. *Final robot top and bottom views.*

The fifth (and final) construction lab is scheduled for (a) debugging any mistakes (or similar issues) and (b) beginning the firmware development, which is the main focus of the course. The students are provided a functional test Program Output File (.pof) in order to verify that their hardware is soldered-up properly and working as expected. This is an important pedagogical step, since debugging bad hardware with potentially bad firmware is extremely frustrating and time consuming.

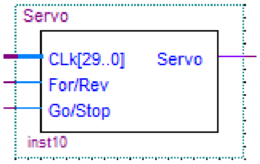
Firmware Lab Details

The next two laboratory sessions do not relate directly to the robot but, rather, support material being covered in the lecture portion of the course. The first of these involves a series of three different methods of hardware multiplier circuits that the students design and simulate in the Quartus II tool, using both block diagram and VHDL design entry methods. The second of these two laboratory experiences involves the students creating a simplified American flag on a VGA monitor. Using a burn-and-learn technique, the students develop closer and closer to what an American Flag should look like, through successive approximation. Figure 10 shows three of the steps through which students typically undergo while developing their solution.

Figure 10. *FPGA firmware developed VGA Monitor approximation of an American flag.*

Frequency-Based Design Lab

The remaining six laboratories directly support the robot and final class competition. Servo motors are controlled by a 50 Hz pulse that varies in width from less than 1ms to slightly over 2ms. The students design a fairly simple servo controller that outputs a short pulse (.65ms), causing the servo to spin in reverse, and longer pulse (2.6ms) causing the servo to spin forward and no pulse at all when commanded to do so. Figure 11 shows the block diagram and command table for this servo controller.



Go/Stop	For/Rev	Action
0	X	No pulse at all - GND
1	0 (Reverse)	650uSec pulse every 10-20ms
1	1 (Forward)	2621uSec pulse every 10-20ms

Figure 11. Servo Controller block diagram and command table.

The majority of this laboratory exercise is spent implementing a Music Synthesizer design. Lecture material, as well as a detailed handout, are presented to the students prior to the laboratory. This material includes Music theory concepts and a spreadsheet in order to help students convert a song of their choice to an efficient song ROM. The design itself utilizes the 12 standard notes of a piano's octave, a four octave clock multiplexer, seven note durations from whole notes to 1/16th notes, and detection of a rest (no sound). A digital square wave is output to a low cost speaker connected directly to the CPLD output pins and is loud enough to be easily heard without amplification. Figure 12 shows the block diagram for this design and the speaker itself.

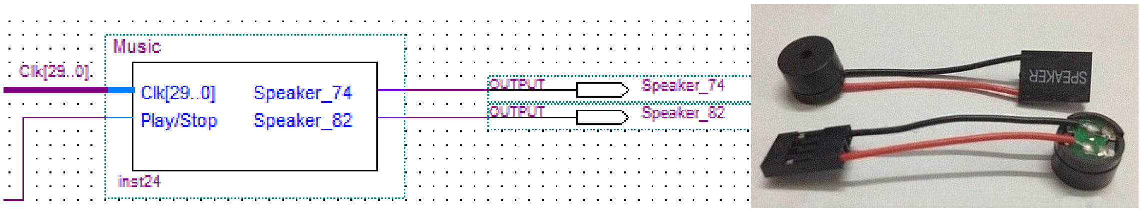
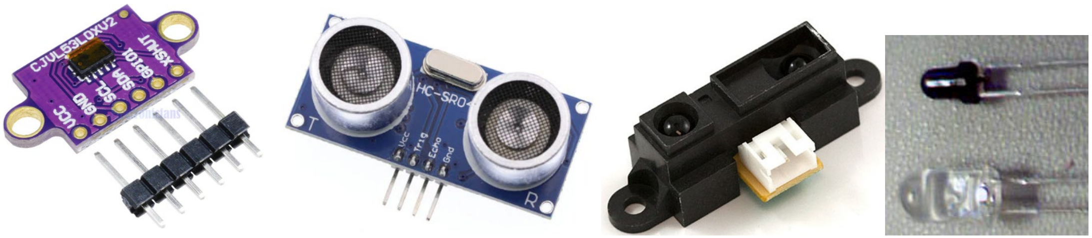


Figure 12. *Music synthesizer block diagram and small speaker used.*

Bumper Bot and IR Sensors Lab

In the subsequent lab, the students develop two new additional functions to their respective robots. The first is a simple Finite State Machine (FSM) that will direct the robot to drive straight forward until it hits its front bumper. If contact with the bumper is detected, then the robot should backup for a short amount of time in order to move away from the contacting object, spin for a short time, and then continue straight until the front bumper hits another object. This fun project allows creativity, since the amount of back-up and spin time is not fully specified.

The Infrared (IR) distance sensors are critical to the success of this project and will be discussed at length here. A variety of options exist for sensors that detect distance. Figure 13 shows a variety of affordable choices.



Name	Cost	Range (cm)	Key draw backs
VL53L0x	$2.51	3-120	Higher cost, I2C interface required, medium size
HC-SR04	$0.88	2-450	Large size, inconsistent, long range not needed
GP2Y0A21	$3.17	10-80	High cost, large size, Analog output
Custom IR	$0.36	1-30	Complex design issues

Figure 13. *VL53L0x, HC-SR04 Ultrasonic Sensor, GP2Y0A21 IR and custom built IR design.*

After substantial experimentation and development, the custom IR solution was adopted due to its low cost, small physical size, excellent short range performance, the production of 3-D printed directional guides, and the development of an elegant timing based measurement technique. This method took full advantage of the Bidirectional pins available on the CPLD board and provided an update rate of 95 readings per second. The transmitter portion of the circuit utilizes a high output (20ma), narrow beam (11degrees) IR emitter—in series with a 82 ohm current limiting resistor. This emitter provides a bright narrow beam of IR illumination for the robots' surroundings. The receiver utilizes a 2.2nF capacitor in series with an IR photo transistor that conditionally discharges the capacitor proportionally to the amount of reflected IR light it receives (which has been reflected back from its surroundings). Figure 14 shows the schematic for these IR sensors.

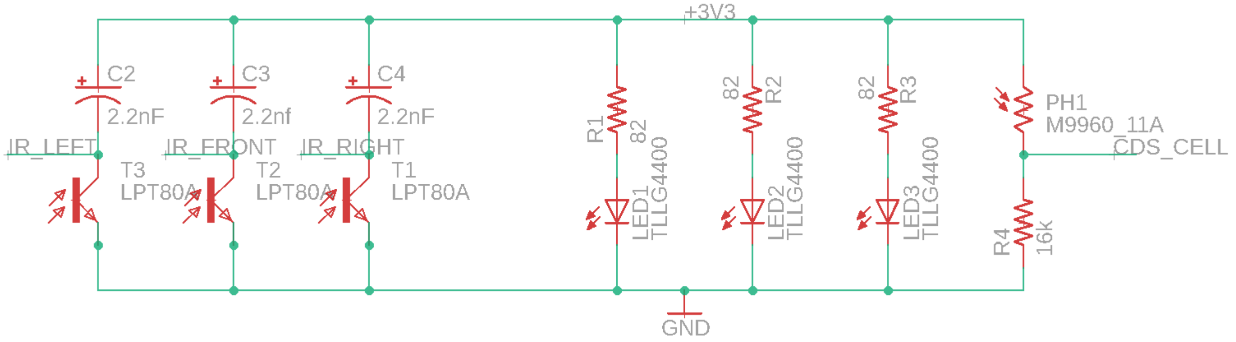


Figure 14. *IR photo transistors and IR emitters used in the front, left & center sensors.*

By making the bidirectional pin an output for one-half of the cycle, the capacitor is charged to a logic high. Then, the bidirectional pin is changed to an input, and the IR photo transistor discharges the capacitor. This time of discharge is measured using counters inside the CPLD and has proven to be stable and accurate. Calibration is needed and the students are required to provide this data in their lab report, along with at least two oscilloscope images similar to ones shown in Figure 15.

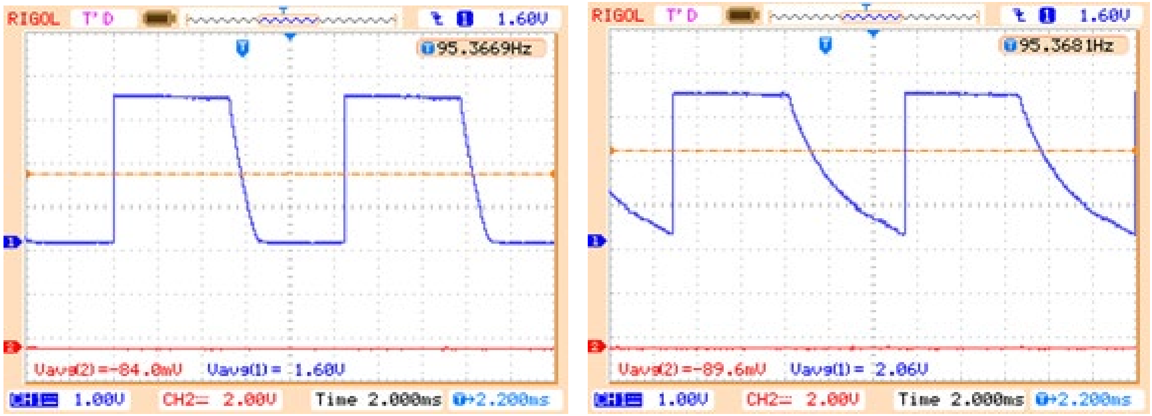


Figure 15. Actual Waveforms: Close object (left) more distant object (right)

The reflectivity of the wall or obstacle being sensed also affects the reading and, as a result, in the final contest cardboard and other light colored papers are used throughout the course. Black colored objects or other IR absorbing materials are therefore avoided. I highlight two key issues at this point. (a) Using black ABS plastic is a must for the IR 3D printed sensor holders and read IR goggles. Any other color conducts too much IR light directly from the emitter to the receiver, which basically blinds the sensor. (b) The other caveat is that the low switching threshold of the bidirectional input pin of the CPLD is susceptible to noise. A simple four-bit digital shift register filter helps to stabilize the readings around the switching voltage of this slow transitioning input. Each student develops the needed firmware in order to interface to these sensors and performs procedures in order to create calibration curves, as shown in Figure 16.

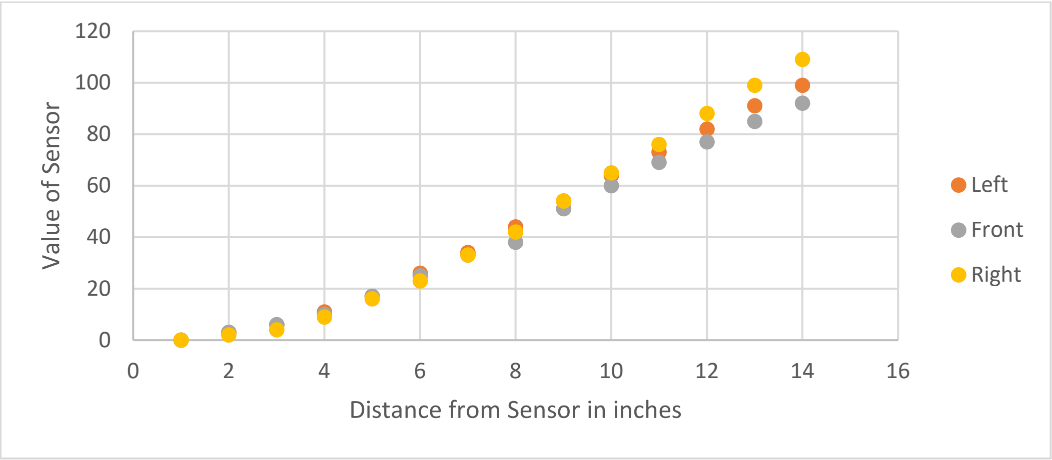


Figure 16. *Example values found for the three front sensors during calibration procedure.*

IR Wall Following Lab

In this lab, the bumper bot design is extended and improved in order to perform wall following. The front and front right (or left) 45 degree sensors provide the needed inputs to perform wall following. I make available only a short manual for this lab, which includes the state graph in Figure 17.

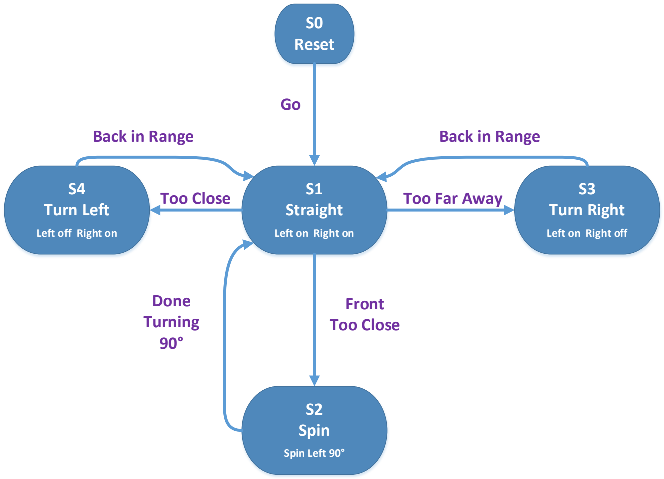


Figure 17. *Simplified wall following state graph.*

Notice that Figure 17 does not give the students details but is, rather, just notional. This latitude provides ample opportunity for each student to experiment with different values and ideas in order to achieve the required response. At this point in the semester, all students should be very proficient at VHDL design and be ready to assume the challenges of large Finite State Machine implementations. I firmly believe that providing this type of opportunity significantly encourages the development of debugging and encourages more thoughtful design strategies. Once the design is working well, then it is usually an easy modification to multiplex either the right or left 45 degree sensor into this block—so that the robot is able to follow a wall on either its right or left side.

Inside and Outside Box wall following lab

In order to successfully complete the final contest challenge, each robot must be able to navigate both inside and outside a box. Figure 18 depicts these desired maneuvers, where the red arrows represent the 5 IR distance sensor positions.

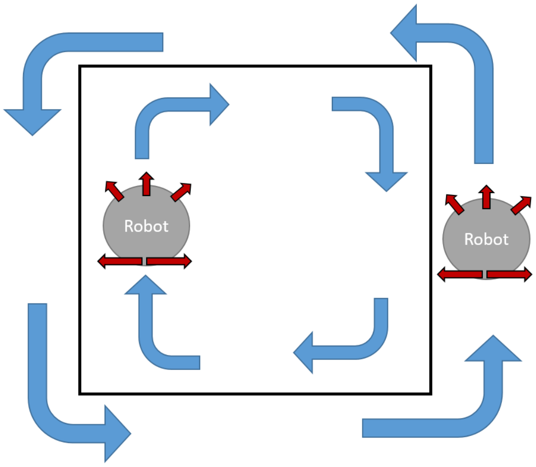


Figure 18. *Inside and outside box following maneuvers.*

The robot should be able to do this in both clockwise and counter-clockwise directions. Inside box following can be accomplished using only the front three IR sensors. Outside box following is more complex, since the 45 degree front sensor will lose the wall long before it should turn. This sudden loss of a wall must be quickly detected and the robot should remain moving in a straight-ahead-state, until the rear side sensor no longer sees the wall. Once this condition has occurred, then a 90 degree turn should be performed, which will place the robot in a good position to continue following the next side of the box. This lab has proven to be one of the most challenging in the course and success requires students to work diligently and to think deeply about their respective design choices.

Magnetic and Light Detection Sensor Lab and Testing Labs

A stop sign near the end of the final contest contains a strong magnet that the robot detects with a Hall Effect sensor. The addition of this magnetic sensor provides another opportunity for students to learn additional sensing options and become familiar with another common type of proximity detection technology. The Hall Effect sensor provides a digital on/off, indicating the presence and absence of the magnet. The students must include functionality in order to stop, while a human controlled "cardboard" bus passes in front of the robot. Figure 19 shows the Hall Effect sensor, contest stop sign, school bus, and the light dependent photo resistor.

Figure 19. *Hall Effect sensor, stop sign, school bus, and CDS Photo resistor.*

Three elements (the friends house, the T-Tunnel, and the church) in the final contest involve students navigating their respective robots through darkness. A Cadmium Sulfide (CDS) light intensity sensor (in series with a 15 K resistor) provides a digital input that is sufficient to detect darkness verses a lighted hallway. Since the sensor may give oscillating values near the entrance and exits of these contest elements, students must factor these oscillations into their respective designs in order to navigate robustly; experiencing success requires that robots not think multiple events have occurred—when only one dark/light event has actually happened.

The final lab is reserved for testing all elements of students' design and to be prepared for the final contest. At this point, I have the hallway set up with the boxes, other obstacles, and elements—identically to how it will be positioned in the final contest. I mark locations on the floor with masking tape, so that each obstacle can be repositioned, if something becomes bumped.

Final Robot Contest

The class occurs on the last Friday of the semester, providing maximum time for all students to complete their respective designs. The contest is divided into two rounds. The first round is a qualifying-demonstration-round, where two students at time run their respective robots down the course, without the most difficult elements present. One student calls a coin toss and, whoever wins, picks which side he/she desires to run (i.e., on either the left or right); the student who lost the coin toss runs on the opposite side. This qualifying round is intended to demonstrate that students' respective robots are capable of following a wall with various obstacles on either side. Typically, all students' successfully finish round one and are able to progress to the second and final round of the competition.

The main objective of the contest is to provide a friendly competition in which various elements earn points in proportion to their respective difficulty. The 2018 theme was, "Take a friend to church," and the basic course set up is shown in Figure 20. The respective robots earned points according to the rubric shown in Figure 21.

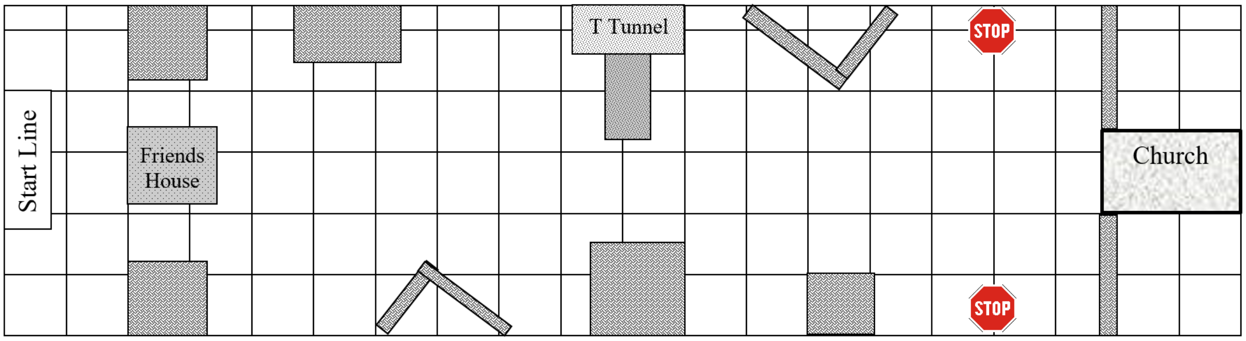


Figure 20. *Final robot contest hallway obstacle layout.*

Activity	**Value**
Pick up a friend *(enter friend's house earns 1 human touch)*	10 pts
Sound horn to pick up friend (stop & make some noise)	2 pts
Completely enter T-Tunnel	5 pts
Exit opposite wall of T-tunnel (earns 1 human touch)	15 pts
Switch over to the opposite wall on which the robot started	10 pts
Stop at the stop sign –wait for bus to pass before moving	7 pts
Completely enter the church	15 pts
Stop in the church	3 pts
Play at least 10 notes of a hymn while stopped in the church	7 pts
	(74 max)
Bumper touches	-1 pt each
Human touches	-15 pts
Total	
Number of earned human touches not used	
Tie breaker – which design used the fewest logic cells	

Figure 21. *Scoring rubric for final round of the class competition.*

A complete run earning maximum points, would first involve entering the "friends house," which is an island box uniquely positioned in all the course. The robot will then stop inside, honk the horn, then exit the friend's house, and progress down the course on the left hand side. When the robot enters the T-tunnel, it would exit out the center-end, not along the left wall. The robot then progresses down the right wall, stopping at the stop sign, and allowing the school bus to pass in front of the robot. Finally, the robot must enter the church box, stop, and then play at least 10 notes of a hymn of the operator's choice.

In order to encourage students to attempt the more difficult obstacles, I grant a "human touch" that allows them to pick up their robot and move it one foot in any direction of their choice and continue down the course. By allowing this potential benefit, I have found that more students are willing to attempt the more difficult challenges—rather than always "playing it safe." In the event that the robot completes the challenge without a human touch, this success serves as a credit to students' respective score. Finally, if two of more students earn the same score, then ties are broken first by whoever had the fewest unused human touches—and then by whoever's design used the fewest logic resources measured in logic cells (Lcells).

Assessment

This course is used primarily in order to assess ABET outcome (6), specifically: *"To conduct experiments, to analyze and interpret sensor data and to use these results to design appropriate solutions."* This outcome most often is best accomplished in a hands-on laboratory setting, which this project provides. All students conduct a number of experiments that are required in order to complete the laboratory projects; while this protocol is good, it is even better for students to conduct many experiments of their own invention—since they problem-solve with their robots in order to complete the final competition challenges. I believe some of the best learning occurs as students progress through multiple cycles of design, test, evaluate, and subsequently re-design. Seeing the consequences of their design decisions playing-out immediately in their respective robots' behavior provides many learning opportunities that pencil-and-paper-designs (alone) would not otherwise afford. These hands-on experiences also potentially build confidence in students' problem-solving abilities and also sharpen their debugging skills.

A fitting assessment of this criteria is the completion of the final competition challenges. Over the last seven years, 100% of the students have had their respective robots working at the final competition and are capable of autonomous navigation around simple obstacles. Typically, I will have two or three students who complete all available challenges and tie for first place. In these cases, the tie is broken by whoever uses the fewest "logic cells," with respect to the 240 available.

This objective was also assessed (in part) by an end of course survey that was conducted with the current class. The survey included four questions, using a Likert scale. The statement preceding all of these questions was, *"As a result of working through the labs and final robot project, respond to each of the following questions:."* The distribution of responses is shown in Figure 22 below.

Q1	I am more able to conduct experiments.
Q2	I am more able to analyze and interpret sensor data
Q3	I am more able to use the results of experiments and interpretation of sensor data to design appropriate solutions.
Q4	I feel more prepared to work on my senior design project next year as a result of working on my ADLD robot project.

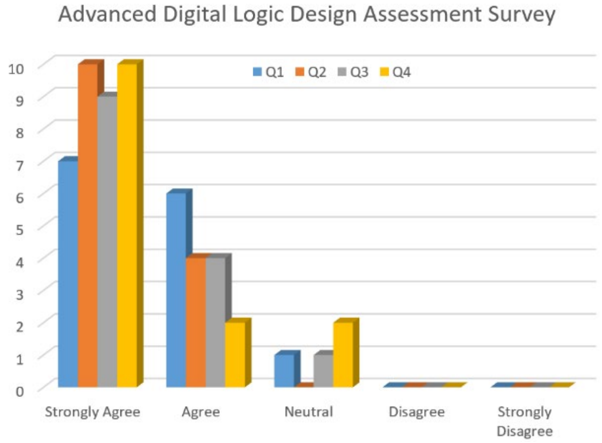


Figure 22. ADLD end of course assessment survey 2019.

The average student response on these four questions [who either "*strongly agree*" or "*agree*"] was 93%, with the most common response "*strongly agree*" in each respective case. The data supports the premise that this hands-on project contributes meaningfully to the successful completion of the course objective.

In the final required report regarding this robot project, students are asked to include one paragraph explaining their overall reaction. Students have consistently responded favorably to this assignment and below are a few salient comments made by students on their final written reports (i.e., that exemplify typical qualitative feedback).

"Not only was this project a lot of fun, I learned a ton through the process. The skills I developed in coding in VHDL and working with Altera hardware are going to look very good to potential employers. For example, I was looking at a Firmware Engineering job at Northrup Grumman and, at the top of their "preferred traits," was "experience with FPGA development utilizing VHDL and applied knowledge of Altera FPGA devices and their associated application environments." "LL

"It's also a confidence-builder and really cool, since we don't really get to do stuff that's this hands-on…" KD

"At times it was frustrating due to me not being familiar with the IDE. However, it stretched my mind and made me learn how to debug in a different way. It was a very satisfying project. When the robot works is seems like magic." CB

"This class is set up very well and I would keep it how it is. Hands-on experiences with FSM design is useful and the robot competition is a great avenue to spark creativity while having fun throughout the process." AW

I enjoyed this project very much. It was a good level of work that allowed me to invest some time but wasn't demanding enough that I felt I had to choose between this and other grades. I liked the free nature of it, which allowed me to explore my own solution to the problem." AC

Cost Considerations and Final Comments

Seven years ago, when I first proposed this project and requested funding from the school's Dean, I knew I needed to keep the cost of the project relatively low. Each of our laboratory classes charges a $100 fee (per student). These fees are needed in order to cover the cost of the laboratory equipment and consumables that are used in the respective labs. Since I seriously desired students to have ownership of their designs—and also to see projects completed from start to finish—I felt that allowing students to keep their respective designs would best accomplish these objectives. The cost of parts for each robot is shown in Figure, 23 arranged from most expensive to least. These costs include shipping and, in most cases, were bought in large quantities from AliExpress [5]. I have found the parts to be of sufficiently high quality but, since the shipping time is about 6 to 8 weeks, planning ahead is very important. At just $35 per robot, the Dean approved this expenditure and felt the remaining $65 was acceptable to maintain the lab.

Main PCB Board - Osh Park	$ 6.72
MG996R Servo Motor x2	$ 6.19
AA NMH Batteries x4	$ 6.07
EMP 240 MAXII CPLD	$ 5.76
USB Blaster & Cables	$ 2.75
3D Printed Chassis	$ 1.67
IR LED Emitter x5	$ 1.11
Four cell AA Battery Holder	$ 1.10
Sensor PCB – Osh Park	$ 0.97
Other 3D printed parts	$ 0.75
IR Photodetector x5	$ 0.66
4 Digit 7-segment Display	$ 0.29
2x20 Female Header 2.54"	$ 0.12
motherboard speaker	$ 0.11
Rubber Bands 2.5" x .5"	$ 0.10
DuPont Cables 10cm	$ 0.08
OH137 Hall Effect Sensor	$ 0.08
3 Position Dip switch	$ 0.07
Mounting screws	$ 0.07
1/4 watt resistors x9	$ 0.07
1x40 Male 2.54mm Header	$ 0.05
2.2nf Capacitor x5	$ 0.05
3mm LED x3	$ 0.03
LM 117 3.3V Regulator	$ 0.03
push Button switches x2	$ 0.03
CDS Light Sensor	$ 0.02
Total Cost per Robot	**$ 34.92**

Figure 23. *Parts list, with cost arranged from most to least expensive.*

Each year in the final report, I ask the students for feedback regarding various topics. One particularly helpful feedback-topic includes "*ideas for future improvement*." I consider all student feedback and then annually retain the best ideas, trying to incorporate these changes during the following year. This protocol has proven very helpful, has reduced student frustration, and improved the overall pedagogical process significantly. I also try to change a few small procedures from year to year, so that the contest remains fresh and unique to each class.

Most Salient Problems Faced

The most common hardware problems include: (a) Soldering in the LED's and photo transistors in the wrong direction. (b) Obtaining two servos that are significantly different in speed, so that a straight command causes the robot to curve to one side or the other. Students trading with a friend in class often has helped this issue. (c) Installing the correct USB blaster driver onto the Windows 10 machines, since driver signing has to be suspending (the older driver is needed and the newer driver causes machine crashes). (d) Since the parts must be ordered six weeks before the start of the semester, and sometimes students add the course later than this time frame, I may not have enough parts. I have learned to order a number of spares in order to anticipate this problem.

Conclusion

Overall, I believe this project is effective at providing engineering students with a meaningful learning opportunity. Hands-on soldering, construction, and debugging skills are all developed—and confidence is gained by a successful completion of a beginning-to-end project.

This course has proven effective in preparing students for their respective senior design projects the following year. Although it takes significant effort on the part of the instructor, the rewards are substantial—on multiple levels. I often tell students that I wish I could have taken a course that had included this type of project, when I was an undergraduate engineering student.

References

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[3] D Orser, K. Bazargan, J. Sartori, *"Harnessing State-of-the-art Internet of Things Labs to Motivate First-year Electrical and Computer Engineering Students"*, 2018 ASEE Annual Conference & Exposition, June 2018

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