Senior Design Project Report
Smart Car

Prepared by:

Abdul Majid
&
Isaac Rodriguez-Jimenez

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https://majidabdul4578.wixsite.com/mysite

Faculty Advisor: Dr. Farid Farahmand
Industry Advisor: Peter Oliver
Client: The Switch Vehicles

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Abstract

The goal of this project is to design a smart vehicle that is relevant to the most popular products in the automotive technology industry. We have utilized affordable hardware components to produce a more affordable smart vehicle system compared to those already available in the market. Since cell phones are a major part of millennial students' culture, we came up with the idea of controlling basic components of an electric vehicle with an Android cell phone. The smartphone is connected to the vehicle through Bluetooth, so that an app on the smartphone can turn the vehicle on and off, control the vehicle forward and backwards, and turn the lights on and off. Safety is our main priority, thus our group has developed an object detection system for the blind spot area on the passenger's side per the request of our industry advisor. If an object is detected, it will alert the driver with lights, so that he/she can have enough time to avoid the detected object.

1 Introduction

Our client Peter Oliver, cofounder of Switch Vehicles, builds electric vehicles and provides classes to high school students in order to educate them about those vehicles. Peter's goal is to come up with new ideas and designs for Switch Vehicles, so that students can also learn and expand their horizons through vocational classes. Most of the employees that work at Switch Vehicles do not have experience in the field of electrical engineering, so in order for the Switch Vehicle's autonomous component to be developed. Peter has allowed groups of electrical engineering students to take part in the process of designing and testing said component. In order, for the vehicle to be considered autonomous, it is necessary for the vehicle to be operated without a driver sitting in the vehicle. In addition, the vehicle must have some kind of object detection system. Our team has designed a basic object detection system with a few functionalities. This elementary system can scan the blind spots of the Switch Vehicle and give warning with a liquid crystal display if an object is detected. Our group designed and tested two components of the Switch Vehicle. One of the components is the control for the vehicle with an application on an Android phone. It allows the user of the vehicle to move it forward/backward, turn light on/off, and to switch the vehicle on/off. The other component we focused on was the object detection system which is used to detect objects in the blind spot area and in case of detection, it alerts the user with a light. This project is intended to lay the foundation of this autonomous vehicle for future Sonoma State students that will continue to work on this system.

Figure 1: Switch Vehicles frame work [1]

1.1 Project Background

There are many complex electronic components used in vehicles today. Many of those allow the user to control various aspects of the vehicle. In some cases, the vehicle manufacture requires the buyer to pay more for these features. Features like these include remote start, blind spot detection system, parking aid, and others. In the very beginning of our project, Peter Oliver from Switch Vehicles offered us his guidance and resources. With the vehicle at our reach we had planned on testing a motor controller in order to research methods of replicating the inputs which are needed to simulate a throttle pedal. The motor controller we had planned on using is an Alternating Current Induction motor controller created by a company called Curtis [16]. Having these resources would have given us the opportunity to apply our knowledge on an item that is currently on the market. Unfortunately, we lost contact with Peter Oliver and as a result lost our available resources. In order to continue our project with the same objective, we decided to recreate an educational kit that can not only be used independently with a test board, but can also be applied to a Switch Vehicle. Switch Vehicles already had an existing educational kit, but we decided to recreate one that would mimic our intended project on a Switch Vehicle. In other words, the work we performed on the redesigned educational kit is parallel to the work that we would have done on a Switch Vehicle. Since we were able to get some initial testing done with the ACI motor controller, we decided to use the inputs collected from the ACI motor controller as inputs for our test board in order to mimic the functions we had planned to have on the vehicle.

Figure 2: Students learning about the vehicle [1]

Last year, Sonoma State had a student working with Switch Vehicles. This student, was able to successfully control the basic functionalities of the Switch Vehicle with a computer. In order for this to function the student had to physically connect his computer to the ACI motor controller. Similarly, our group was able to control the basic functionalities of the vehicle, but with an Android phone instead. We are appreciative of his work because it contributed to our initial understanding of the ACI motor controller functionalities.

1.4 Problem Statement

Switch Vehicles did not have anything to make their vehicles stand out from the crowd of automotive manufactures in terms of modern technology. Our goal was to design a system that could control the basic functions of the electric vehicle from Switch Vehicles. Some of those basic functions include turning on the vehicle and moving it forward and backwards. In addition, the vehicles lights can be turned on and off. We made this possible by using wireless technology to send commands from an Android phone to a Bluetooth module. We also used sensors to detect objects and alert drivers to avoid collisions. The Switch Vehicles Company offers this educational kit at a much lower cost, to teach about their technology. The problem with this education kit, is that it does not model the vehicle well and it was not energy efficient. In order to implement our project, we designed a new educational kit that can be connected to the vehicle or used with a test board. Our ultimate goal was to successfully complete our project as a new product with extensive documentation which Switch Vehicles could be proud of having to present to high school students for educational purposes.

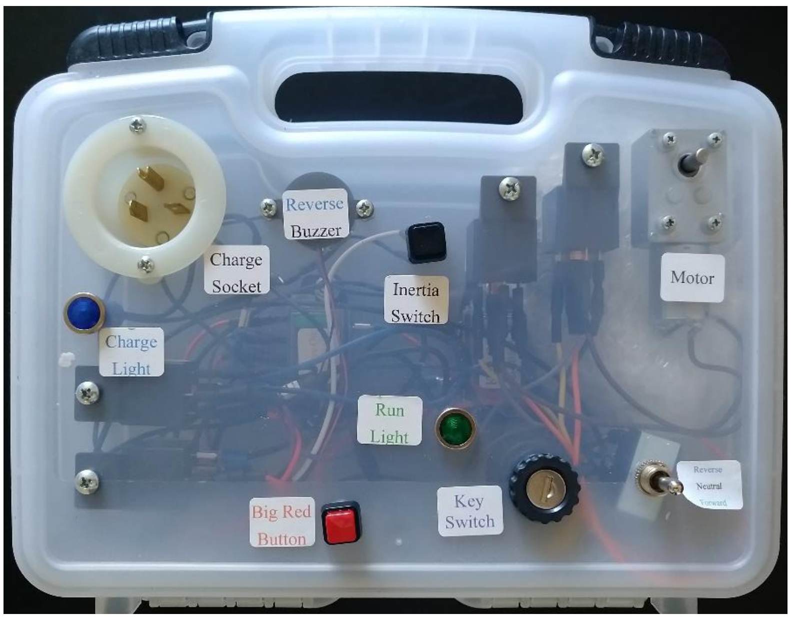

Figure 3: Switch Vehicles Educational Kit [1]

1.5 Literature Review

Viper is one of the leading brands in vehicle security and remote start products [11]. Their products allow the user to add keyless entry to their vehicle along with optional features such as remote start, alarm, and control relays. Another cool feature is that Viper has created an app called SmartStart. This app allows the user to conveniently view the status of the vehicle, control the Viper system, and receive alerts from the vehicle on their phone. Depending on which Viper system the user selects, their phone will use bluetooth or cellular service in order to communicate with the Viper system in the vehicle.

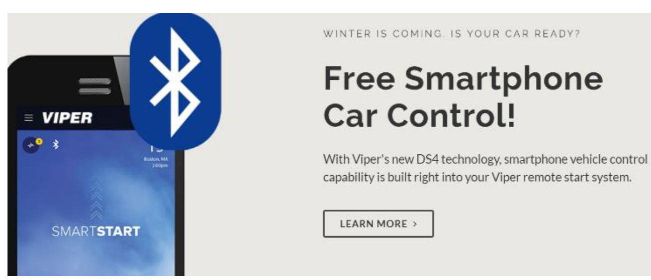

Figure 4: Viper vehicle security systems [11]

Another leading brand similar to Viper is Compustar. Compustar also sells alarms and remote start systems for vehicles that do not come manufactured with such. Like Viper, Compustar has an app called DroneMobile. DroneMobile also has the capability of locking and unlocking the vehicle, turning the vehicle on and off, and it offers security features [12]. Both brands have their own apps which allow users to interface with their system. Unfortunately, Viper does not have the ability to track the vehicle's location like DroneMobile can. On the other hand, Viper can connect via Bluetooth between the system and the smart phone, which is something DroneMobile cannot do. In order for DroneMobile to work the client is responsible for the required data plan's monthly charges.

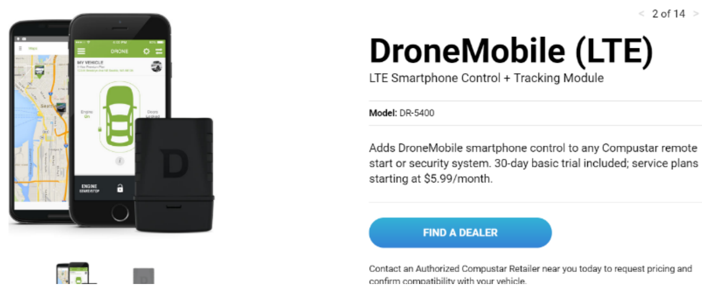

Figure 5: Compustar's DroneMobile [12]

Although our system is designed to perform similar functions as Viper's and Compustar's, it is unique because it is specifically designed to work with an electric vehicle and the Viper and Compustar systems are only compatible with gasoline powered vehicles. Our system is not designed for security, however, like Viper's and Compustar's ours is capable of turning the vehicle on/off and can also power relays on/off. On the other hand, they all have something different from each other. Viper can use Bluetooth instead of cellular data. Compustar can track the vehicles movements using GPS. Finally, in our system, we can control the velocity of the motor and monitor the blind spot.

1.2 Marketing Requirements (MR)

MR.1 Bluetooth connectivity can reach up to 15 feet.

MR2. The app will work with majority of Android phones.

MR3. Comprehensive documentation will be provided, so other students can benefit from it.

MR4. The system has a minimalistic construction design that allows it to be universal and portable.

MR5. The system will control the basic functionality of the vehicle such as: turning vehicle On/Off, turning headlight On/Off, switch between Forward/Reverse mode and move the vehicle up to 10 MPH.

MR6. There is a 24 pin connector and harness that connects to 4 relays on the vehicle in order to control the four basic functions above. The connector and harness also runs wires to the LIDAR and Curtis Motor Controller. LIDAR will measure the distance of an object in front of the vehicle. The wires available to the motor controller will control throttle.

MR7. The system will consume 1 watt or less under normal conditions excluding LIDAR.

MR8. An efficient voltage regulator is used in order to power our components with 5v.

MR9. A main power switch is used in order to turn off the system that will utilize the 12v car battery.

MR10. Each major component of the system such as an Arduino will be connected to a fuse panel with an appropriate rated fuse.

MR11. LCD will be used to display relevant data, such as vehicle status.

MR12. LCD will be turned off by default in order to conserve energy. A switch is available in order to turn on and off the LCD

MR13. Button will be used to scroll through LCD information.

MR14. A LIDAR sensor will be used to detect an object in the blind spot of the vehicle.

MR15. This system outputs 4 enable lines for relays, a zero to five variable voltage, and a zero to five thousand variable resistance and input the data lines for the LIDAR sensor

1.3 Engineering Requirements (ER)

ER.1 Bluetooth module and Arduino will communicate via TX and RX to provide at least 15 feet of range unobstructed. [**MR1**]

ER2. The app will be designed using MIT App Inventor. Specifically designed to work with most Android smartphones. [**MR2**]

ER3. Documentation will be written about all aspects of the project using MS Office and comments on the code will be comprehensive to people who are not familiar with coding jargon. [**MR3**]

ER4. The system will be in a (10” x 6” x 4”) enclosure which will make it portable and easy to use in different vehicle. [**MR4**]

ER5. A relay module controlled by the Arduino will be used to power 4 basic functions of the vehicle. [**MR5**] [**MR6**] [**MR15**]

ER6. The Arduino will use a PWM output to generate 0 to 5 volts in order to simulate a throttle pedal at the input of the Curtis motor controller. [**MR6**] [**MR15**]

ER7. The Arduino will also control a digital potentiometer in order to output a variable resistance between 0 to 5KΩ and them to generate a variable voltage. Just in case **ER6** does not work. This solid state potentiometer has 100 steps and has a maximum resistance of 10KΩ making each step size 100Ω. [**MR5**] [**MR6**] [**MR15**]

ER.8 The power consumption of each device will be measured in order to avoid consuming more than 1 watt at 12 Volts. [**MR7**] [**MR8**] [**MR9**]

ER9. The voltage regulator will be tested and proven an efficiency of at least 70%. [**MR8**]

ER10. A toggle switch will be used to introduce power into the system once it is connected properly. 18 gauge wire will be used between the external connector to the switch and from the switch to the fuse panel. [**MR9**]

ER11. The fuse panel has a 12v input that distributes the voltage and protects the circuitry by limiting the current to 0.1 or 0.25 Amps with fuses**.** [**MR10**]

ER12. LCD will use I^2C in order to display vehicle status. That includes the gear the vehicle is in, if the lights are on or off and if the vehicle is on or off. [**MR11]**

ER13. The LCD will use a latching switch that will turn on and off the display. [**MR12**]

ER14. A momentary push button has been used in order to trigger an interrupt. The purpose of this interrupt is to display other relevant data that is not shown by scrolling. [**MR13**]

ER15. This LIDAR sensor is connected using I^2C. This is one of our major components that uses 5v and 45ma during continuous operation. [**MR14**] [**MR15**]

2 Implementation

Figure 7 is the system view of our project. We will be using two Arduinos' connected to a sensor and a display. We chose the Arduino because of its popularity and ease of use. Since one of the purposes of this project is to provide documentation, the Arduino is a good foundation to start on because many students may already be familiar with it. In this case, we have what is called a primary/secondary relationship where the top Arduino sends commands to the bottom Arduino

Figure 6: Proposed Implementation on actual vehicle

2.1 Design Approach

This is the system view of our project. We will be using two Arduinos' connected to a sensor and a display. We chose the Arduino because of its popularity and ease of use. Since one of the purposes of this project is to provide documentation, the Arduino is a good foundation to start on because many students may already be familiar with it. In this case, we have what is called a primary/secondary relationship where the top Arduino sends commands to the bottom Arduino.

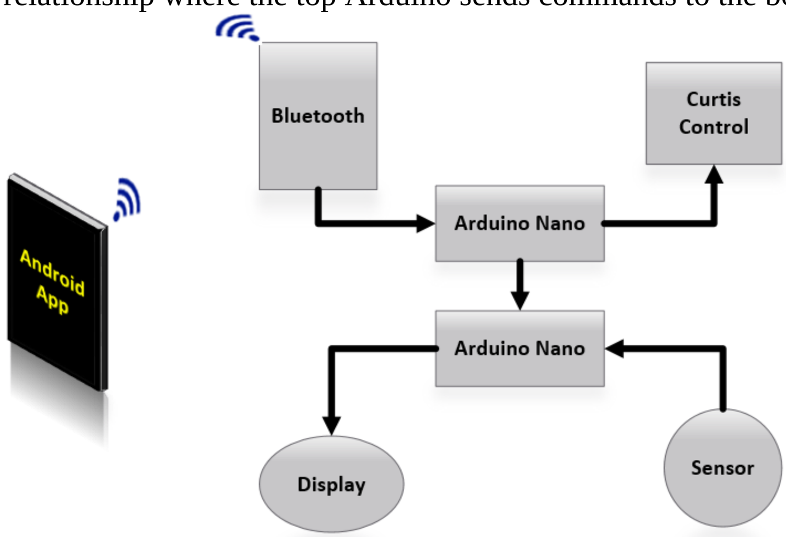

Figure 7: Main system overview

After further testing, this design might change a bit in order to accommodate the Digital Potentiometer. We actually do not know, what kind of accelerator pedal we will be given. There are 3 main types of accelerator pedals that output a resistance, a 0 – 5 voltage, and a serial output. Once we receive this component, we can decide what we will use to mimic the accelerator pedal. For the meanwhile, we will design a 0 – 5 voltage output and a 0 – 4.8KΩ output.

2.1.2 Curtis Control

This block in our basic system overview refers to the circuitry we designed in order to fool the Curtis Motor Controller into thinking a person is giving it inputs, such as a throttle pedal or engaging the transmission. The Curtis Control consists of 3 components, the relay module, the 0 – 5 volt output and the 0 – 5 KΩ output. These three components enable our system to turn on and off the vehicle, to engage forward or reverse, to turn on and off the lights and control speed of the motor. A big chunk of this project lies in this block, therefore we spent a many hours making sure this part met our expectations.

- Relay Module: This is a set of four electronically controllable switches. These output 5v directly from the source. It is important to use the power from the source and not the Arduino Board because the Board is not capable of supplying enough current to power the relays on the vehicle. In particular, our system turns on the same relays on the vehicle that turn on and off the vehicle, engage forward and reverse and turn lights on and off.

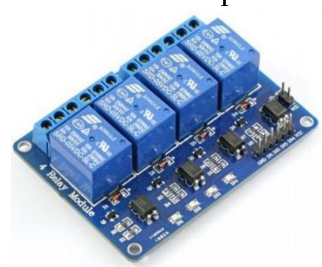

Figure 8: Relay module [2]

- 0 – 5 volt output: The Curtis Motor Controller accepts different types of inputs that control the throttle input. One of those inputs is 0 – 5 volts. In order to extract 0 – 5 volts from the Arduino, we used PWM. PWM is a digital signal that changes its frequency in order to interpret data. In this case, we designed a circuit that takes advantage of this. As we feed this changing signal into our circuit, our output voltage changes with it linearly.

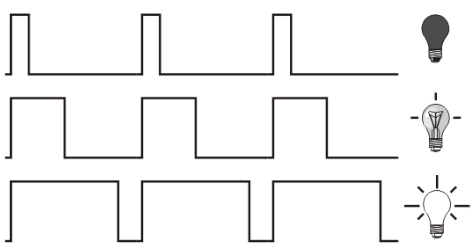

Figure 9: PWM Duty cycle [13]

- 0 – 5 KΩ output: This is another type of input that the motor controller accepts that allows us to mimic the throttle pedal. In this case, we needed a way to electronically control the resistance. In a non-electronically way, we could have used a potentiometer. A potentiometer allows us to manually vary the resistance using a knob. Similarly a Digital Potentiometer allows us to vary the voltage in small steps. Our devices allow for increments of resistance on average of 46Ω with 100

Figure 10: Digital Potentiometer IC [14]

increments. This means that our maximum average resistance is 4600 Ω. This is okay because our maximum resistance input is 4.8KΩ.

2.1.2.2 Primary Controller

This Arduino Nano is an embedded system that uses open-source software. The board is able to read inputs, such as different sensors, and is able to write outputs to do different things, such as an LED or a monitor. It does so using an easy to use platform designed for anyone to use. There are many different types of boards that Arduino produces. In this case, we chose the Nano because of its low operating current and its small foot print.

As mentioned above, the primary controller is considered the primary embedded system, because the direction of control goes from the primary nano to the secondary nano which will be mentioning next. The primary nano gets commands from an Android phone by reading from the Bluetooth module using a serial interface. After the nano gets the commands, the nano performs those actions by either the relay modules or the PWM/resistive output. Using our harness, our system controls the test board which was designed to replicate the vehicles inputs.

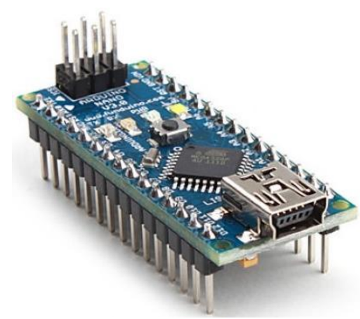

Figure 11: Arduino Nano [4]

2.1.2.3 Secondary Controller

The secondary controller, also an Arduino Nano, has two functions. It displays the status of the relay module and reads the information from the LiDAR sensor. Using these two the secondary Arduino can display a message asking the user to check their blind spot if the LiDAR detects an object in a certain range of the vehicle's blind spot.

We have several reasons to use two embedded systems. The Arduino Nano only offers one serial interface and our system needed two serial interfaces. One serial interface is for transmission between an Android phone and Bluetooth module. The second serial interface is between the LiDAR sensor, the LCD and the secondary Arduino. Another idea we had that we were not able to implement due to time constraints was to shut off the secondary embedded system. We wanted to turn off the secondary embedded system in order to save energy when the vehicle was off. When the vehicle was off, we were only concerned about the Bluetooth connection and Curtis control, we did not need to display anything or use the LiDAR.

2.1.2.4 Our App

To send commands from our Android phone, we used an open source cloud-based tool known as MIT App Inventor 2. MIT app inventor provides a lot of tools to make the GUI of your app more user friendly. Buttons can be replaced with pictures to make it easy for users. MIT app does not require any coding, it is as simple as putting pieces in a puzzle together. Although there is no coding experience needed, connecting blocks does need some logical thinking in order to make your app working properly. Below is an example of a block of MIT app that sends the character ‘A’ from an Android phone to Bluetooth module:

Figure 12: App Inventor [5]

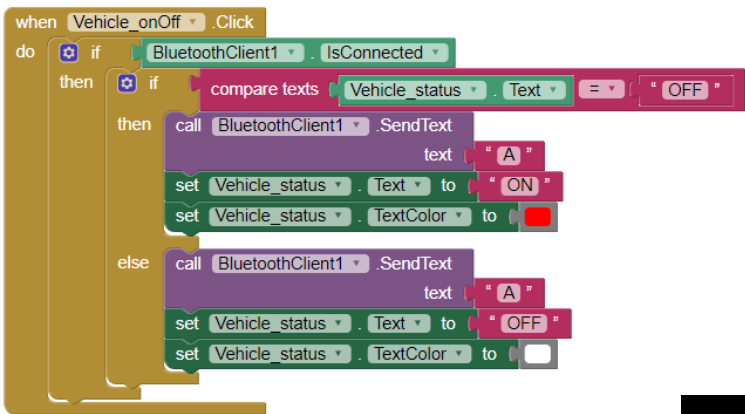

Figure 13: App Inventor code block

Figure 13 is the block code. This block sends character ‘A’ to turn vehicle on or off and it also changes the status of on or off on the LCD. The color of status in app to show the status of vehicle. For example, if the vehicle is off the status says OFF in white color. On the other hand, if it is pressed then it says ON in red color.

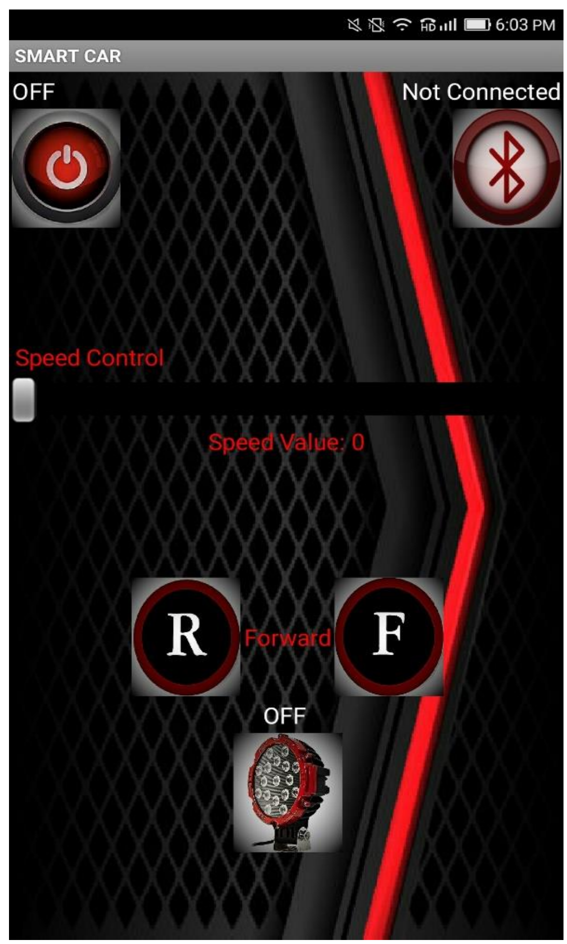

Figure 14: Final App GUI

Figure 14 is the graphic user interface of our final app. It consists of five buttons and one slider. The first button on top right corner is used for Bluetooth, so when the user presses the button it will show different Bluetooth devices and then the user has to select which module they want to connect to. The second button on top left is used for vehicle on or off. The third and fourth buttons in the middle are used for selecting reverse or forward. R is used to select reverse direction, while F is used to select forward direction. The last button on the bottom is used to turn the lights on or off. Lastly, the slider is used to change the speed of a motor. Since our

Arduino Nano is an 8 bit system, the slider sends analog integers from 0-255. The values increases the width of the PWM which increases the speed of the motor.

2.1.3 Project Schedule

The Project Schedule is very important because it helped us stay on track and communicated our progress to our advisor. On Figure 6 you can clearly identify the tasks that were be completed by each group member. Following this timeline was crucial to our success in completing this project because it showed what and when something needed to be done. Looking at this schedule you can see how some tasks took longer than others. In addition, it is evident where we encountered challenges and needed further advising.

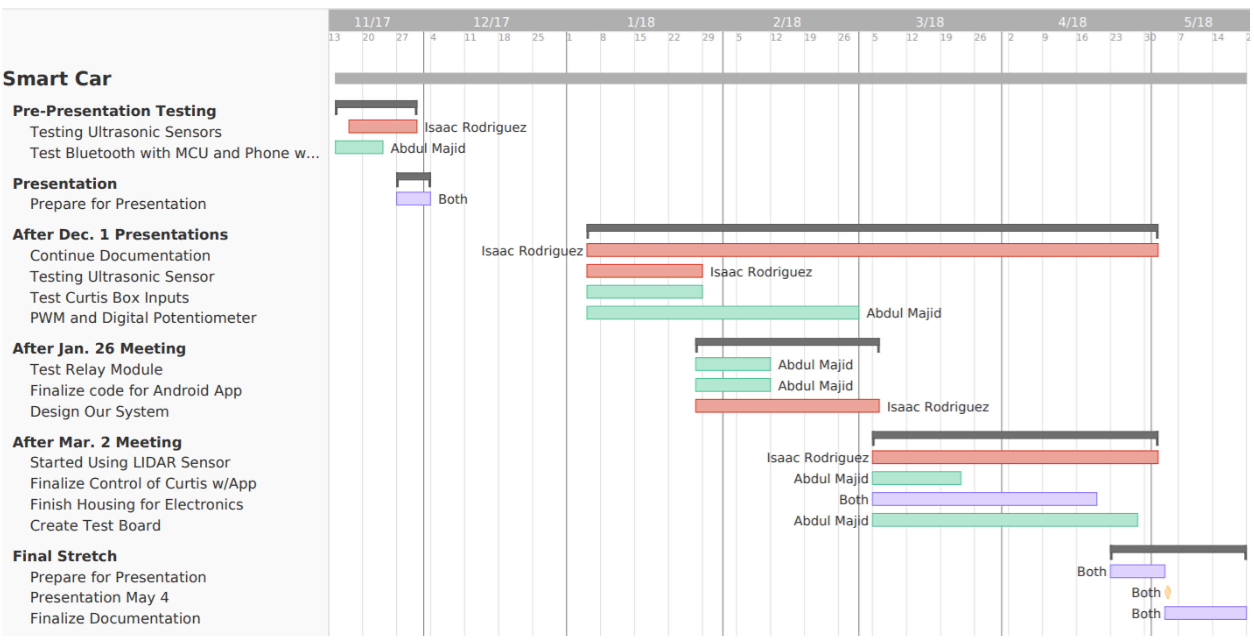

Figure 15: Project schedule

2.2 Hardware Design

To start off we used an Arduino shield in order to allow us to use the screws to connect wires. The shield also has hole which allowed us to bolt on the entire board onto our case. After many different test, we went through many different Arduino boards trying to find one that will meet our needs. Some were too powerful and consumed too much energy and some just did not do what we wanted. In the end, we found that the Arduino Nano was the best choice because of its affordable cost and its very small power consumption.

Figure 16: Arduino Nano shield [16]

2.2.2 Primary Arduino Nano

This is the circuitry used for the top Arduino. As you can see here, there are several components used in order to make this work. The Bluetooth module is used to get data from the smart phone and then the Arduino reads it. We also have the relay module I mentioned earlier. A couple things not mentioned, were that the 12 volt source come from outside our system and through our harness. We use a toggle switch in order to decide when to let 12 volts in.

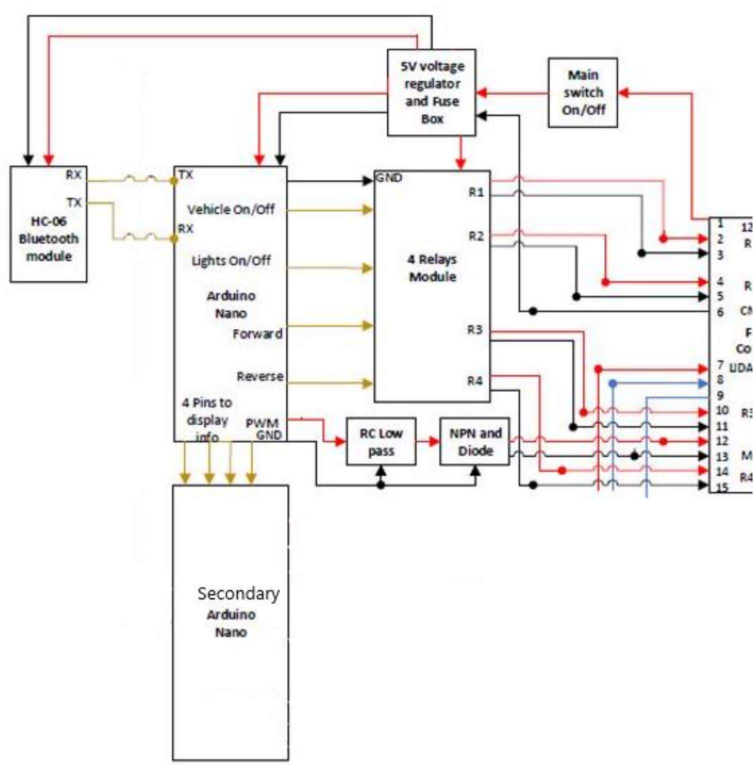

Figure 17: Primary Arduino Nano

2.2.3 Secondary Arduino Nano

In this figure you can see the circuitry involved in the primary Arduino was omitted. This omission was done with the purpose of highlighting several things. As you can see, it appears that the LiDAR is missing. That is because the LiDAR sensor is outside our system and its lines are SDA and SCL which come from the sensor, to the harness and into our system. Another thing is the LCD screen and it's on/off switch which is completely independent of the embedded system. .

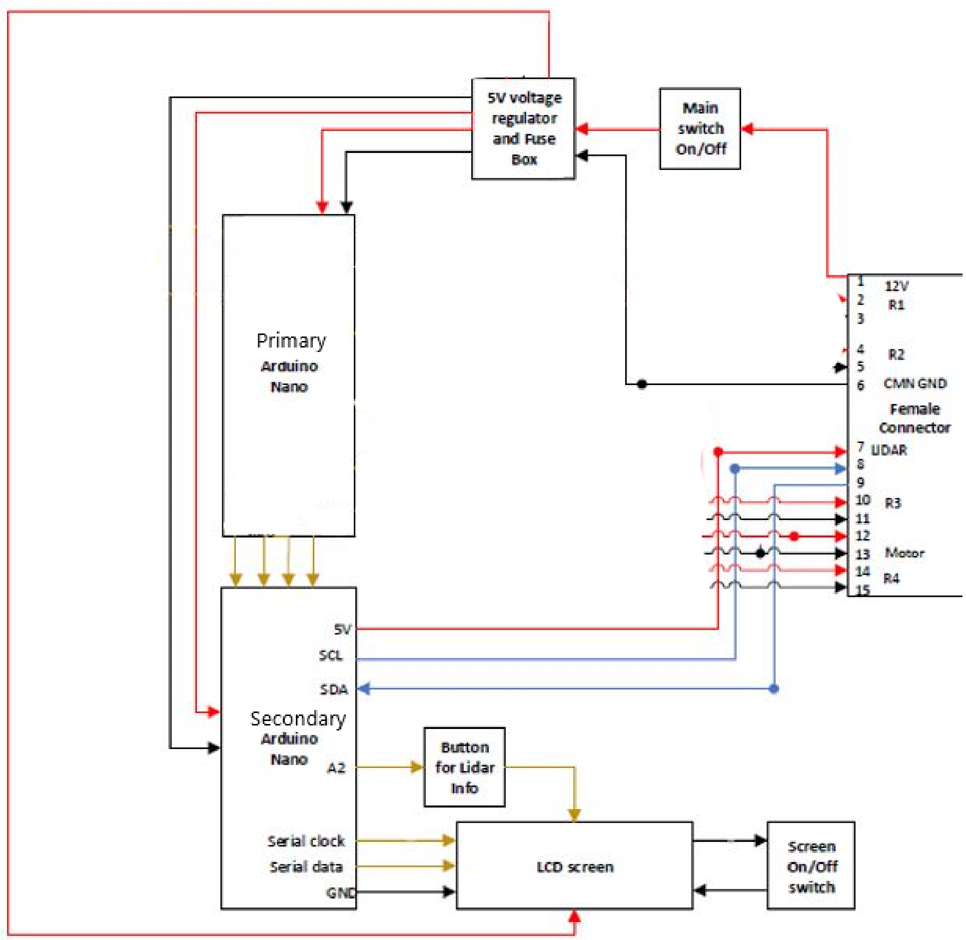

Figure 18: Secondary Arduino Nano

2.2.4 Test Board

In order to test our main system, we have used a test board to show that our system works as we promised. The test board consists of the following components: one 12V bulb, three 12V LED's, a LiDAR and one 12V CPU fan. For the vehicle's on or off state, we used a 12V bulb. For headlights on or off, a powerful 12V bright white LED was used. For forward or reverse state, we used two orange color 12V LED's. A LiDAR is used to detect an object and display information through LCD that is connected to our secondary Arduino Nano. Lastly, to control the speed of motor we used 12V CPU fan. All these components were glued to a clear Acrylic plastic stand and for all the wires we used a wire connector to connect each component with our main system. Below is the detailed circuit view and a picture of the test board. This test board has the same input the Curtis motor controller has.

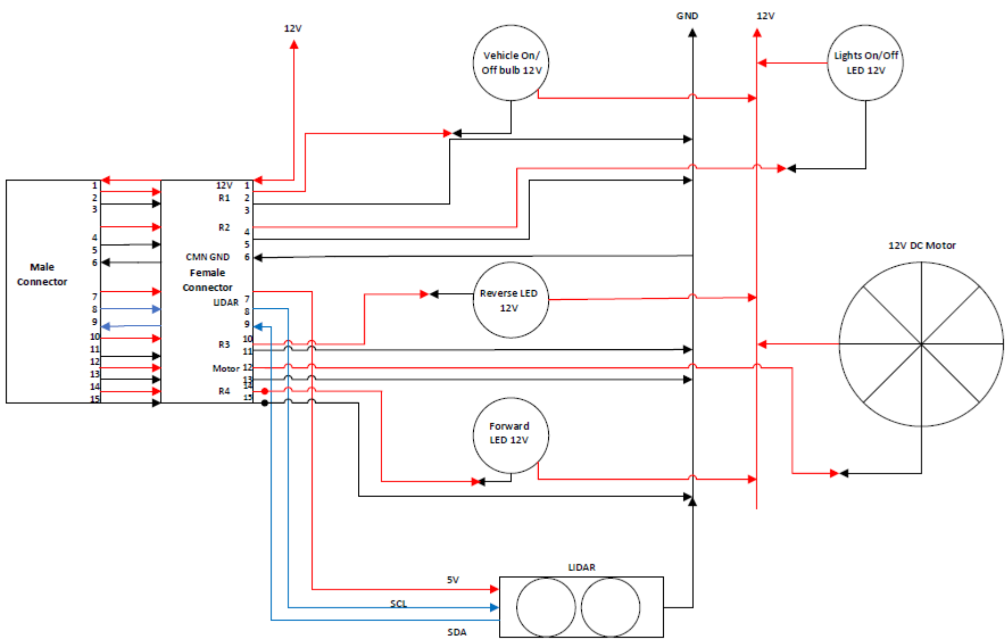

Figure 19: Test board circuit

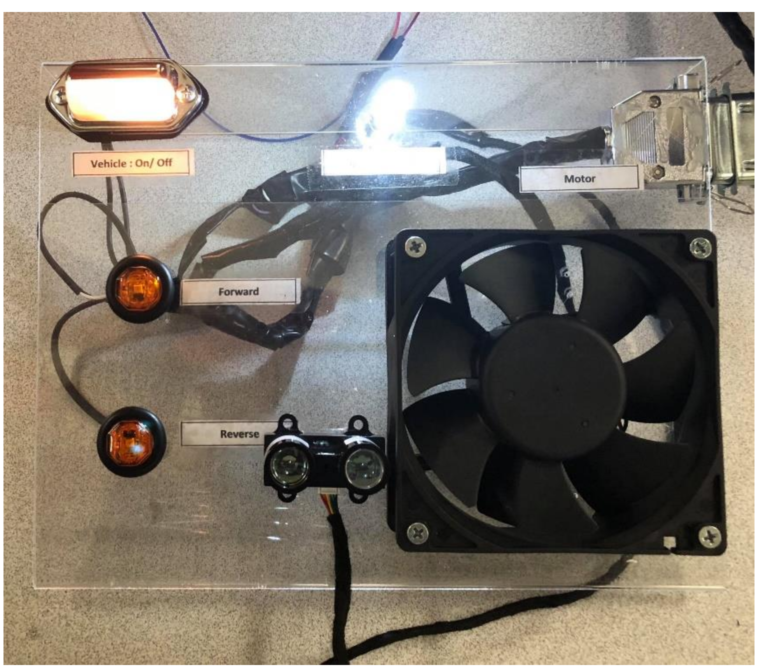

Figure 20: Test board

3. List of Tests

T1 (ER1)

Test connectivity indoors with walls and outside without obstructions. Plot distances in meters to see how far we can separate the receiver and transmitter without losing signal.

Part I Indoors no Obstructions

Procedure

The first part of this test is done indoors. We conducted this test in a large room (40ft x 25ft) without obstructions. The purpose of this test was to verify we could successfully pair and transfer data between the receiver and the phone 20ft, 30ft, and 40ft away in an enclosed space. All distances were measured by a measuring tape. These trials were conducted 30 times each while the Bluetooth module was sitting on a table on the same plane as the phone.

Results

- After 30 consecutive times, we can verify that at a stable connection is possible up to 40ft.

Things to Consider
This test was done in the Senior Design Room, possible reflections of Bluetooth signal can affect our results
The tests were done across the room at the same position for each distance tested.

Part II Indoors with Walls

Procedure

This second part of this test is done indoors but with walls in between the Bluetooth module and the phone. The purpose of this test was to verify we could successfully pair and transfer data between the receiver and the phone 10ft and a wall then 20ft and a wall in an enclosed space. We conducted this test using a classroom. The Bluetooth module would be placed inside the room. All distances were measured by a measuring tape. These trials were conducted 30 times each while the Bluetooth module was sitting on a table on the same plane as the phone.

- The first trials were done by placing the Bluetooth module in a classroom 10ft away from a wall and seeing if we would pair and transfer data on the other side of the wall.

- The second set of trials were done the same way as the first but now moved the phone 10ft from the wall.

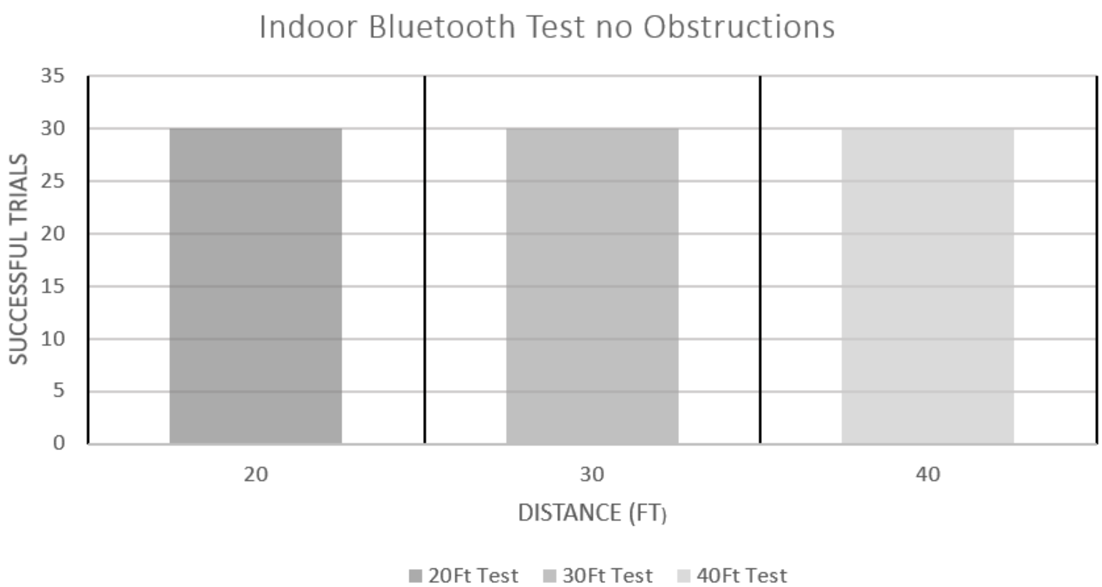

Figure 21: Bluetooth connectivity test 1

Results

- After 30 consecutive times, we can verify that a stable connection is possible on the other side of the wall when only 10ft away from the receiver 100% of the time.

- Similarly, we found that at 10ft away from the wall the Bluetooth module was 90% reliable after 30 consecutive trials.

What went wrong	
Occurrences	Error
3	Bluetooth module would not show up to pair

Table 1: Bluetooth connectivity error

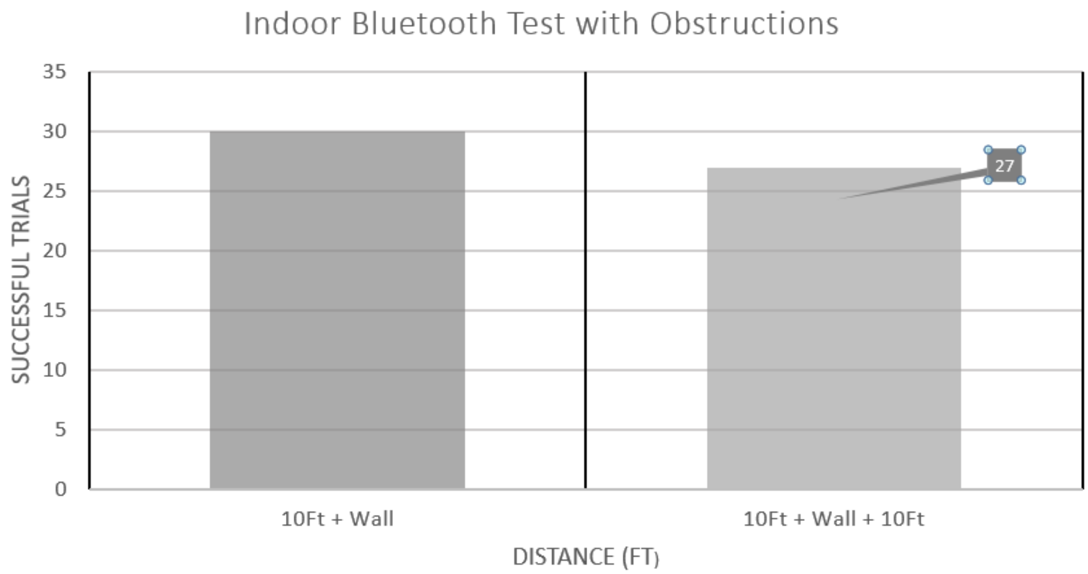

Figure 22: Bluetooth connectivity test 2

Conclusion

In these tests, we fully expected our Bluetooth module to pair in the first trial of our 2 different experiments. Part II was an interesting experiments because we don't expect to operate our project behind walls. A few things to note would be that could have influenced our results.

- Part I — We are in doors, the Bluetooth module was susceptible to multipath from reflection, diffraction and scattering.
- Part II — We are not sure what is inside the wall so results will vary with different walls.

Overall this test was a success because it proved that our engineering requirement was met. We showed that our Bluetooth module could provide connectivity at 15ft reliably.

T2 (ER2)

Procedure

This test is to show that we are able to successfully send data from the phone to the Arduino.

Results

This test was proven by being able to turn on and off relays by pressing buttons on the Android phone.

Conclusion

This test was successful because we have been able to consistently send data to the Arduino without any problems.

T3 (ER4)

Procedure

This test consists of evaluating the difficulty of transporting our system. Since this test was based on personal opinion, we decided to ask a couple people to tell us how difficult our system transport. We asked them to pick up our system from the floor and set it on a table. Then we asked them to plug in the harness and secure it with the provided clips. Finally we asked them to remove the harness and place it back on the ground.

Results

When the person initially picked up our system and set it on the table. We asked them if it was too heavy or hard to pick up. The three people we asked to conduct this test said it was easy to pick up and not heavy at all.

The next part was to see what these three people thought about when connecting the harness to our system. Two people said it was a little difficult to connect the harness to the system because it was hard to hold down the box and try to secure the clips around the harness connector. The third person said it was easy to connect but the clips where hard to get around the connector.

Finally we wanted to know what they thought about when disconnecting our harness from the system. Everyone said it was easy to disconnect.

Conclusion

Out team believes that our system has an acceptable weight. The only thing that we think we could have improved on, was finding a more suitable connector that used a different style of clips that holds the harness to the system.

T4(ER5)

Procedure

Testing will show we can power on and off the car, turn off and on the lights and change the gear from forward to reverse to neutral using relays.

Results

We were able to successfully control the relays using the Arduino. We believe that the module we are using has a built in driver in order to separate the 5 volts from our system and the 12 volts from their system.

Conclusion

This test was done many months ago and the relay module has held up very well. Something we noticed is that each relay consumes a slightly different amount of current.

T5 (ER6)

Procedure

This test will show how one step on the slider in our app increases the output voltage. Similarly we will show how voltage changes across the whole slider.

Results

The way this circuit works is by taking a digital signal and converting it into an Analog

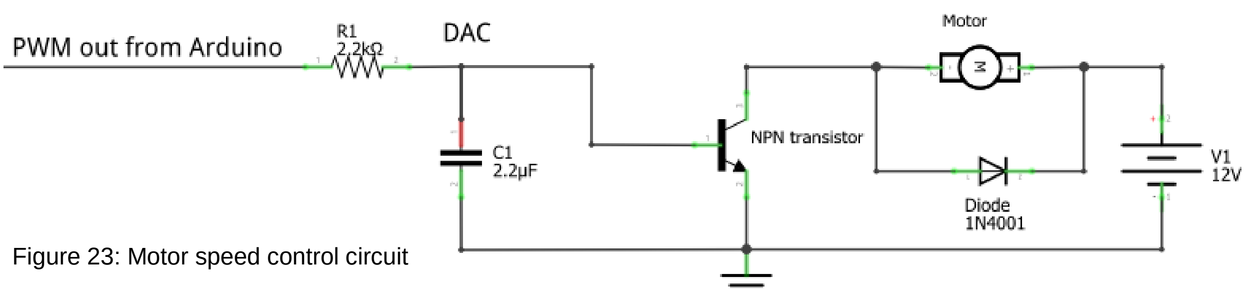

Figure 23: Motor speed control circuit

signal. The Arduino has a digital signal output that we are using. That signal is fed into an RC filter that removes high frequencies generated by the PWM. The transistor is then used as a valve to control the speed of the motor by controlling the flow of current to ground.

This table shows how different RC combinations gives different RC time constants. Combinations 1, 3 and 5 are used to display graphs below.

#	RC Combinations		Time Constant (s)
	Resistors (K-Ohm)	Capacitors (μ-Farads)	
1	2.178	0.462	0.001
2	4.575	0.462	0.002
3	9.68	0.462	0.004
4	2.178	2.275	0.005
5	4.575	2.275	0.01
6	9.68	2.275	0.022
7	2.178	10.15	0.022
8	4.575	10.15	0.046
9	9.68	10.15	0.098

Table 2: RC combinations

Combination 1 on the left show the yellow digital signal and the blue analog signal. Comparing the blue signal with the graphs below. We can see how increasing the RC time constant slowly lowers the peak voltage of the analog signal.

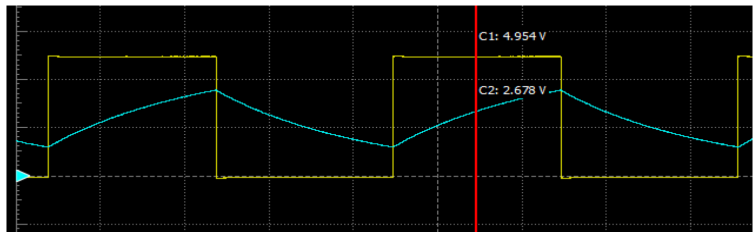

Figure 24: RC combination 1

Combination 3 uses a time constant of 0.004 seconds. The use of different time constants causes a different affect at the output. Using a bigger time constant that is displayed on the left, (combination 5) makes the motor speed up slowly. Compared to combination 1, the motor speeds up faster.

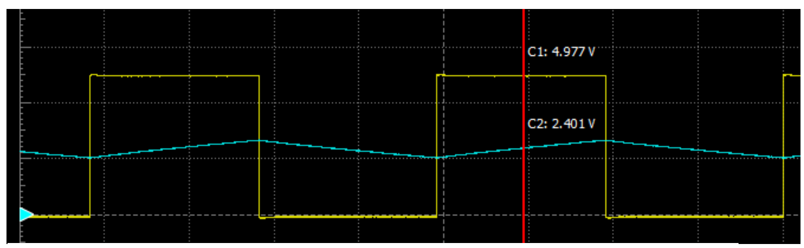

Figure 25: RC combination 2

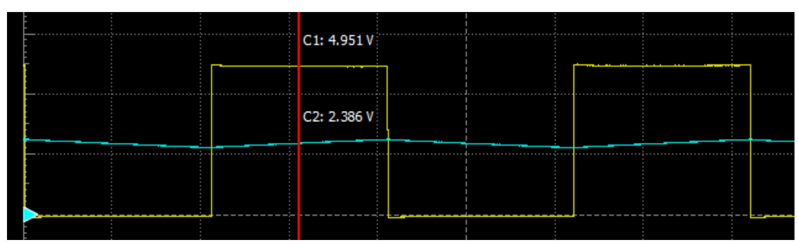

Figure 26: RC combination 3

This table shows how in 1 time constant the capacitors charge to 63.2%.

Figure 27 below shows visually how changing the Time Constant affect how long it takes the capacitor to reach full charge.

Time Constant(τ)	Charging Cap (%)	RC Combintaions		
		RC#1	RC#3	RC#5
0	0	0	0	0
1	63.2	0.001	0.004	0.01
2	86.5	0.002	0.008	0.02
3	95	0.003	0.012	0.03
4	98.2	0.004	0.016	0.04
5	99.3	0.005	0.02	0.05

Table 3: RC combinations time constant

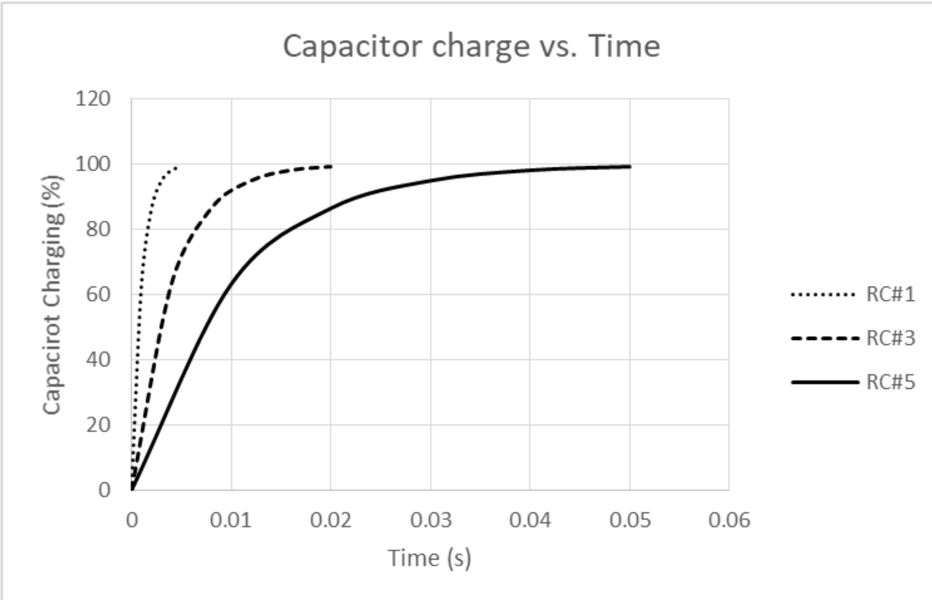

Figure 27: RC time constant response

On Figure 29 and Table4 you can see how increasing the step value on the cell phone app will affect the output voltage. On the right, we have a table with all the points that were collected. Similarly those points are displayed visually on the graph below.

Duty Cycle (%)	Input(0-255)	Output(0-5VDC)
0.00	0	0
7.93	20	0.34
16.26	41	0.76
24.20	61	1.15
32.53	82	1.56
40.47	102	1.96
48.41	122	2.35
56.74	143	2.76
63.88	161	3.12
71.82	181	3.51
79.76	201	3.91
88.09	222	4.32
96.03	242	4.72
100.00	252	4.92

Table 4: Duty cycle vs. output voltage

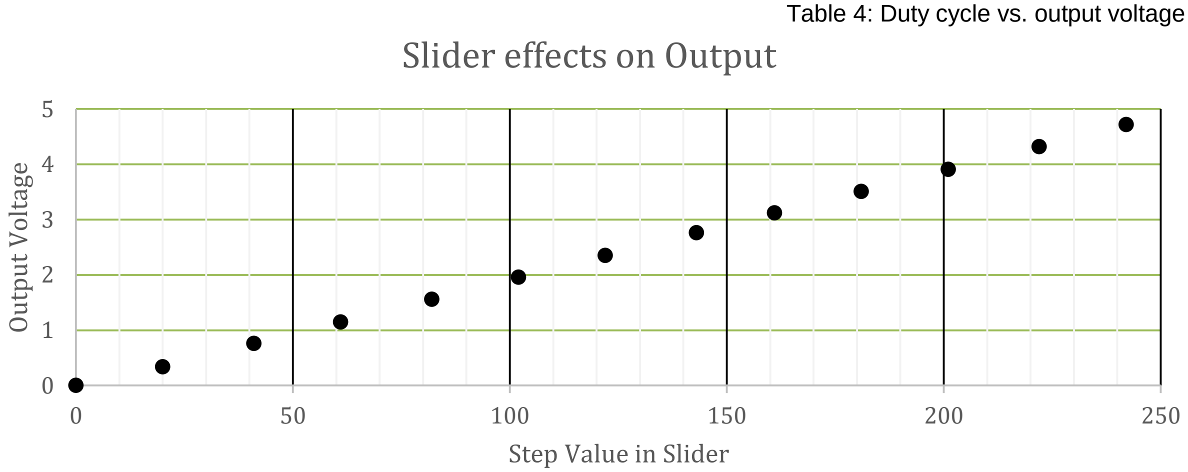

Figure 28: Slider effects on output

Conclusion

This test was pretty involved because it required us to be very meticulous with our 0 – 5 volt output. We needed to be sure that this worked very well because this project is heavily influenced by this part of the project. The 0 – 5 volts controls the throttle to the motor controller. This tells the brain of the motor controller to move the car at a certain speed, therefore we were careful to design this piece with our desired results.

T7 (ER7)

Procedure

To begin, our target resistance was 0 – 5KΩ. So what we did, was place 2 digital potentiometers in parallel. Doing that allowed us to cut the resistance in half and double the maximum amount of current that passes through each device. Each digital potentiometer requires 3 data lines that we shared between each IC. As we increment the count delivered to each IC, the resistance output increases by 50 ohms.

Results

This is the circuit built to output 0 – 5KΩ. It produces a linear output. Each step size is calculated to be 50 Ohms with 100 steps. We measured the output at different steps and plotted them.

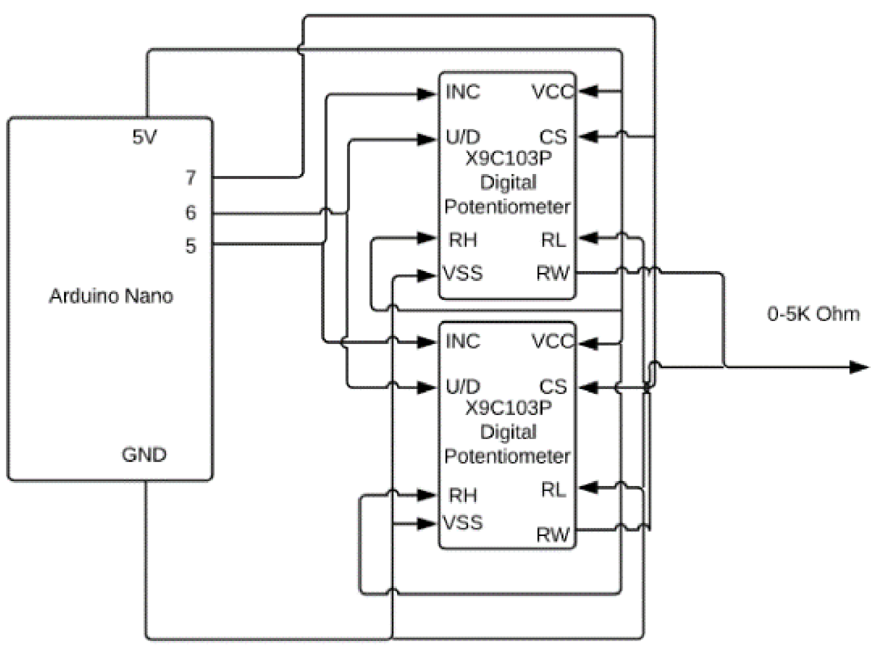

Figure 29: Overview of Arduino and digital potentiometer

This circuit diagram, shows how both ICs share inputs and outputs in order to deliver 5KΩ.

When one digital potentiometer is used, we got the following results.

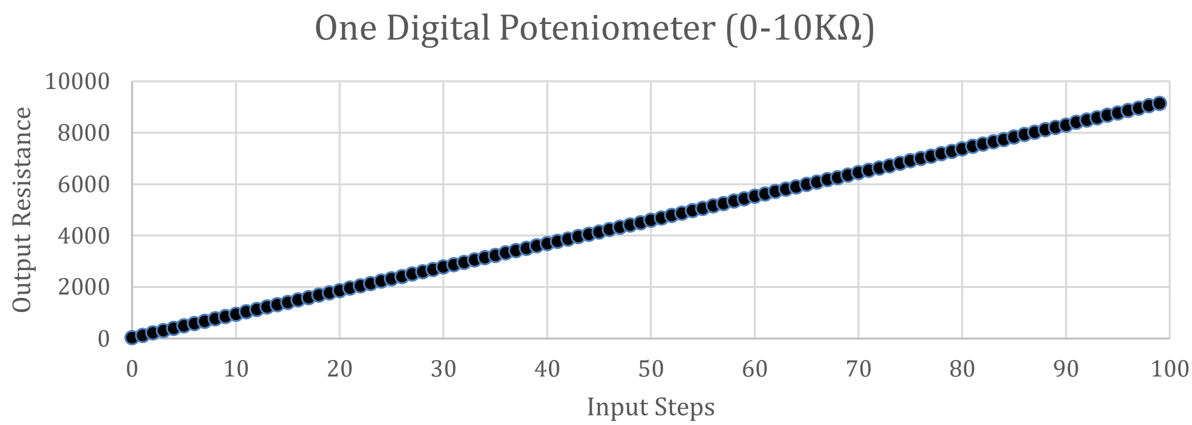

Figure 30: Digital Potentiometer changes resistance as the slider moves in the app.

With both digital potentiometers we got the following results.

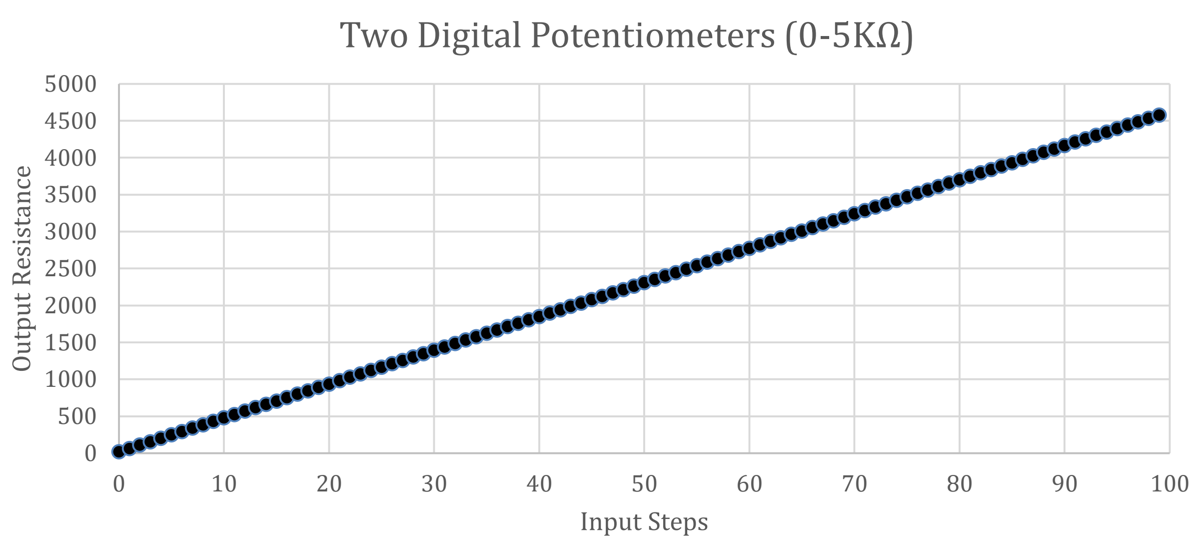

Figure 31: Using two digital potentiometers in parallel to get half the resistance.

The values we measured were different than the ones we calculated. When one potentiometer was used, each step size was roughly 92 Ohms. Similarly when 2 digital potentiometers were used in parallel, each step size was 46 Ohms. This makes sense because 46 plus 46 adds to 92. Something we noticed was that a single potentiometer did not reach its maximum stated value of 10KΩ. It reached 9140 Ohms. Using 2 potentiometers the max value was 4580 Ohms.

Conclusion

This test is important because it is an alternative output to the 0 – 5KΩ. Most modern motor controllers accept 0 – 5 volts or 0 – 5KΩ. Interestingly both devices have the same of error of $100(1 - {}^{9140}/_{10000}) = 8.6\%$. When we combine both potentiometers the error is reduced slightly to $100\left(1 - {}^{4580}/_{5000}\right) = 8.4\%$.

T8 (ER8)

Procedure

The power consumption will be put into different tables where the scenarios will change showing what major components are connected.

Results

This project first started with the Arduino Due. 2 Arduino Due were used to control our system. After realizing that the power consumption was too high, we decided to figure out a way to reduce the power consumption. At the beginning we were consuming about 8 watts. This was a combination of using powerful embedded systems, using indicators that required a lot of current and using the onboard linear voltage regulator. We decided to reduce our computing power. We started with the Arduino Due, then the Arduino Uno and Mega, followed by 2 Uno's, and finally 2 Arduino Nano. We kept going down in stages because we were trying to find a board that will work with our current code and also be the most efficient.

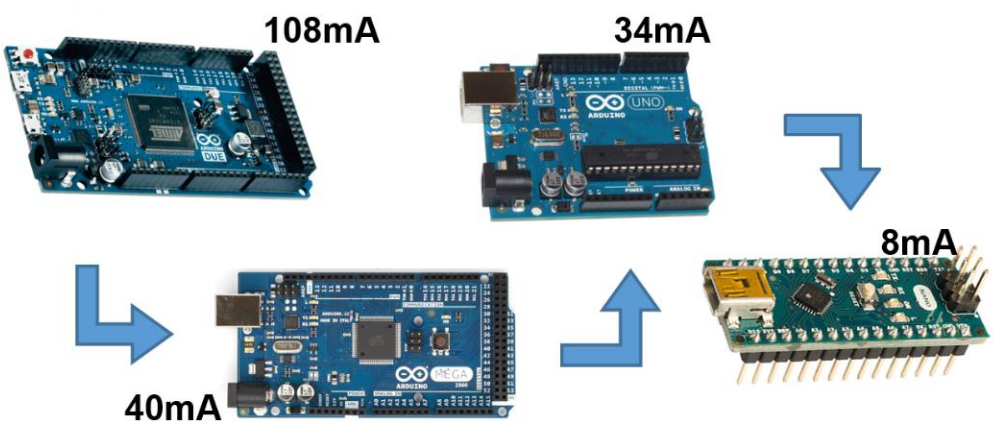

Figure 32: Different Arduinos and their power consumptions

Nothing Connected					Power (mW)			
Voltage	Due	Mega	Uno	Nano	Due	Mega	Uno	Nano
5V	108mA	40mA	34mA	10mA	540	200	170	50
12V	61mA	70mA	50mA	10mA	732	840	600	120

Table 5: Different Arduinos power consumptions

From the chart above you can see we dropped from 540 mW to 50 mW per board. We are using 2 boards, so we jumped from 1080 mW to 100 mW.

The next thing we did, was check the Bluetooth consumption. We found the Bluetooth to consume 3mA when paired and not transmitting. When the Bluetooth was paired and transmitting, it consumes 20mA. We got these values by comparing the values on the top table and the bottom table.

Bluetooth Active using Arduino Mega			**Power**
Case	Voltage	Amps(mA)	Watts(mW)
Not Transmitting	5	43	215
Transmitting	5	61	305
Not Transmitting	12	73	876
Transmitting	12	90	1080

Table 6a: Commands combinations and Arduino power consumption

Finally we measured or consumption of the relays, we found that they consume on average 45mA per relay.

Bluetooth Active and Relays w/Car on			Power	
	5V	12V	mW @ 5v	mW @12v
Forward, Lights ON	91mA	137mA	455	1644
Reverse, Lights ON	96mA	141mA	480	1692
Forward, Lights OFF	137mA	198mA	685	2376
Reverse, Lights OFF	141mA	201mA	705	2412

Table 6b: Commands combinations and Arduino power consumption

Bluetooth Active and Relays w/Car off			Power	
	5V	12V	mW @ 5v	mW @ 12v
Forward, Lights ON	140mA	201mA	700	2412
Reverse, Lights ON	144mA	205mA	720	2460
Forward, Lights OFF	181mA	258mA	905	3096
Reverse, Lights OFF	183mA	260mA	915	3120

Table 6c: Commands combinations and Arduino power consumption

We found the average consumption of the relays by subtracting certain values in the table above.

Conclusion

In our optimal case, when our system is sitting idle. We are consuming 0.033A. This means that the LCD display is turned off and the LiDAR is not connected. In terms of power, we are consuming 0.396 Watts which is way less than the 1.92 watts than the Switch Vehicle's Educational kit.

Figure 33: Switch Vehicles educational Kit power

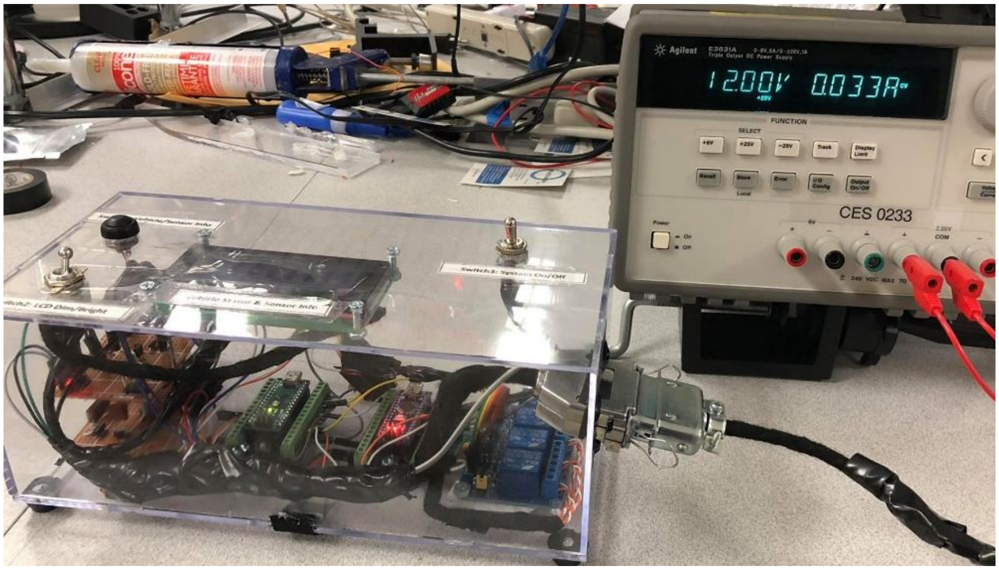

Figure 34: Our system power consumption

With the LiDAR connected, our system consumes 0.936 watts. The LiDAR runs at 5 volts with 45mA. This means that we are still under our budget for power consumption. This test was very successful because we were not sure at the beginning if we were going to be able to reduce the power consumption to less than 1 watt.

T9 (ER9)

Procedure

The power output will be compared to the power input to see what efficiency the regulator provides.

Results

The onboard voltage regulator provided us with a 41.66% efficiency. More than half of the power we consumed was generated into heat. We decided to look into a more efficient voltage regulator. We found a company called Dimension Engineering that sells very good regulators. We tried to see how efficient this new regulator was. It was a switching regulator that increase efficiency as we increased the amount of amperage we pull out of it. Our test started at 45mA. Interestingly, the efficiency was very similar to the onboard regulator. After increasing the amperage to 115mA, the efficiency increased to 74%.

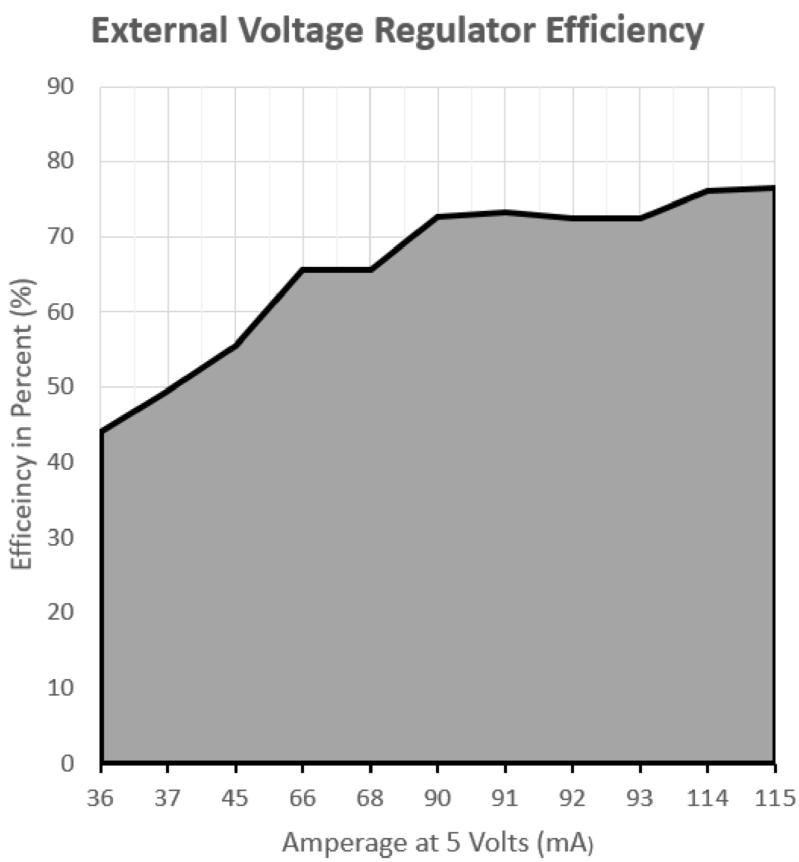

Figure 35: External voltage regulator efficiency

Conclusion

Our team thinks that if we would have pulled more current. The switching regulator would have reached its designed efficiency of 83%. This test was a success because it allows us to show how much we have improved in terms of power consumption.

T10 (ER10)

Procedure

This can easily be tested by measuring the voltage at the source and comparing it to the voltage at the fuse panel in our system.

Results

We were successful in bringing in 12 volts into our system by using our harness. From the harness the 12 volts goes straight into the toggle switch. Then it leads into the 5v regulator. Finally it is distributed by the fuse panel. We measured the voltage and current before and after the toggle switch to make sure that the switch did not pass any current.

Conclusion

This test was successful because we wanted to make sure that our switch was not leaking any current. This is important because we do not want to consume energy when we are not supposed to.

T11 (ER11)

Procedure

We will measure the amperage used by each device and make sure it does not exceed 250mA.

Results

Part of this test has already been done in test 8. Provided below is a table with max current draw of each device used. Each device has its own fuse. Not listed here is the second Arduino because that is assumed to be the same as the first.

Device	Current mA
Arduino Nano	10
LiDAR	45
LCD	26
Relay Module	141
Bluetooth	21

Table 7: Device Current Consumption

Conclusion

Each device tested was well below the 250mA rating for the fuse. Therefore we felt confident, that this size fuse was enough for our needs. The purpose of this fuse is not to save the components but to reduce the risk of creating a fire just in case something where to happen.

T12 (ER12)

Procedure

In order to test the LCD, we have put different text messages on the LCD through the Arduino.

Results

The LCD is works well. The only problem we have is when the LiDAR is not connected the LCD does not work. This is because both the LiDAR and LCD are using I2C. The LiDAR and LCD are sharing the same pins. The LCD and LiDAR have a unique address which allows them to share pins, but the problem with this is that the Arduino requires all the devices on the same bus to be connected in order for this to work.

Conclusion

The LCD works as designed but the I2C communication is a little tricky to work with. If it had been the LCD by its self, the I2C would have worked fine.

T13 (ER13)

Procedure

We have added a latching switch that between the power to LCD backlight LEDs and their grounding point. This simple test requires us to see if we are able to turn off the backlight of the LCD in order to save power.

Results

Yes, we are able to successfully make the backlight of the LCD turn off while still being able to display on the LCD. The amperage required for keeping the LCD running with the backlight off is 3mA. Turning on the LCD backlight increases the amperage to 26mA. By simply adding this switch, our system saw a reduction of amperage of 23mA which at 5v is 115mW.

Conclusion

This test was done in order to reduce the power consumption as much as possible. The LCD backlight has no use if the user is not looking at the screen, therefore we came up with this idea to allow the user to choose if they want the backlight on or off.

T14 (ER14)

Procedure

An interrupt was used I order to tell the Arduino to scroll through the LCD information. In this case, pressing the button changes the screen to display the LiDAR readings. The way this interrupt is set up, is that it is looking for a falling edge. By simply having the interrupt pin pulled up to high we can introduce a ground to make the pin low and read a falling edge.

Results

The button does work this way, but it might require a few presses before the LCD scrolls. We believe this is because the code for reading the button does not have a proper de-bouncing code.

Conclusion

This button can be made to display more information if needed. It has successfully worked for the past weeks.

T15 (ER15)

Procedure

In this test we are going to characterize the LiDAR sensor. This is important because it helps us understand how the sensor works and what to expect from it.

Results

This device is the LIDAR-Lite V3 distance measurement sensor. It is made by Garmin and is classified as a CLASS1 laser product, which means that it is safe to use under normal conditions [14]. The website from where this sensor was bought advertises that it can read distances up to 40 meters which is 131 feet [15]. In our case, we only need to read the blind spot. Which means we are only using a fraction of the operating range of this sensor. The blind spot that we calculated on our personal vehicle was between 10 and 20 feet.

Figure 36: LiDAR sensor

Part 1 Sensor Accuracy

Here we wanted to see the outputs of the LiDAR and compare them to measured values we took. We used a 25ft measuring tape to measure the distances. We took a large poster board and put it in front of the sensor at the distances measured below on table 9. We calculated the error by using the formula $\left(\frac{|actual\ value - measured\ value|}{actual\ value}\right) \times\ 100 = error.$

Measured (Ft)	Sensor Output	Error
1	37cm => 1.21ft	21% over estimate
2	57cm => 1.87ft	6.5% under estimate
3	80cm => 2.62ft	12.66% under estimate
4	113cm => 3.70ft	7.5% under estimate
5	141cm => 4.62ft	7.6% under estimate
6	177cm => 5.80ft	3.33% under estimate
7	205cm => 6.72ft	4.00% under estimate
8	242cm => 7.93ft	0.87% under estimate
9	271cm => 8.89ft	1.22% under estimate
10	304cm => 9.97ft	0.30% under estimate
11	343cm => 11.25ft	2.27% over estimate
12	373cm => 12.23ft	1.91% over estimate
13	401cm => 13.15ft	1.15% over estimate

Table 8: LiDAR Outputs and Error

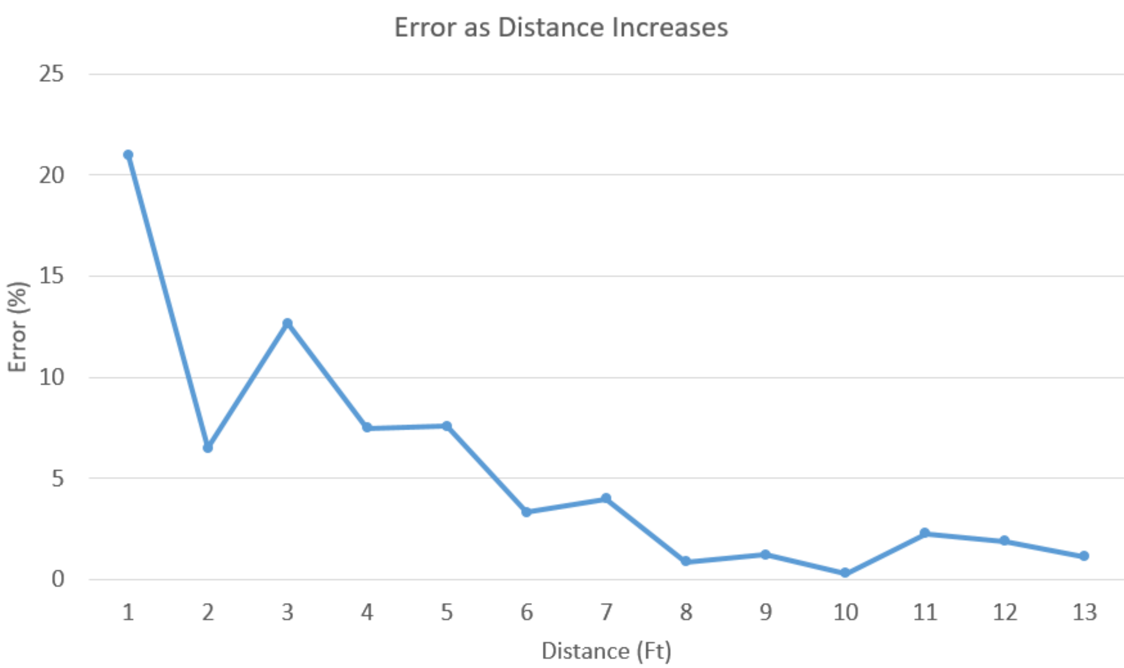

Figure 37: LiDAR linear error as target gets farther away from sensor.

As we can see on the table 8 and figure 37, the sensor is very inaccurate under 5ft. It is not until 8ft that the sensor has an acceptable error.

Part 2 Beam Width and Height at certain distances

When trying to calculate the angle of the beam width of the LiDAR, we found that it does have a typical angle. We found this out by measuring the beam width and height at different distances. In order to find the beam width and height, we used two large poster boards. We placed the LiDAR in a fixed position for every test. We then measure 5 feet directly in front of the sensor and placed some tape on the floor perpendicular to the sensors field of vision. We used this tape to mark our 5ft line. We then used one of the large poster boards and moved it along the tape on the floor until the sensor detected it. Once the poster board was detected, we moved the poster board very slightly back just outside of the LiDAR's field of vision. We did the same thing on the opposite side using a different poster board. We now measured the gap between the poster boards and called that the beam width. Next was figuring out the beam height. We used a ruler put it flat against both boards like a bridge between gap. We moved the ruler from the base of the board upwards until the sensor noticed it. We moved the ruler slightly out of the field of vision of the LiDAR and marked the location on the board. Next, we did the exact same thing but this time moving the ruler down from the top until the sensor recognized it. Finally, we marked that location and measured the distance between the marked locations and called that our beam height. We repeated this test at all our measured distances. These are the results of the following procedure:

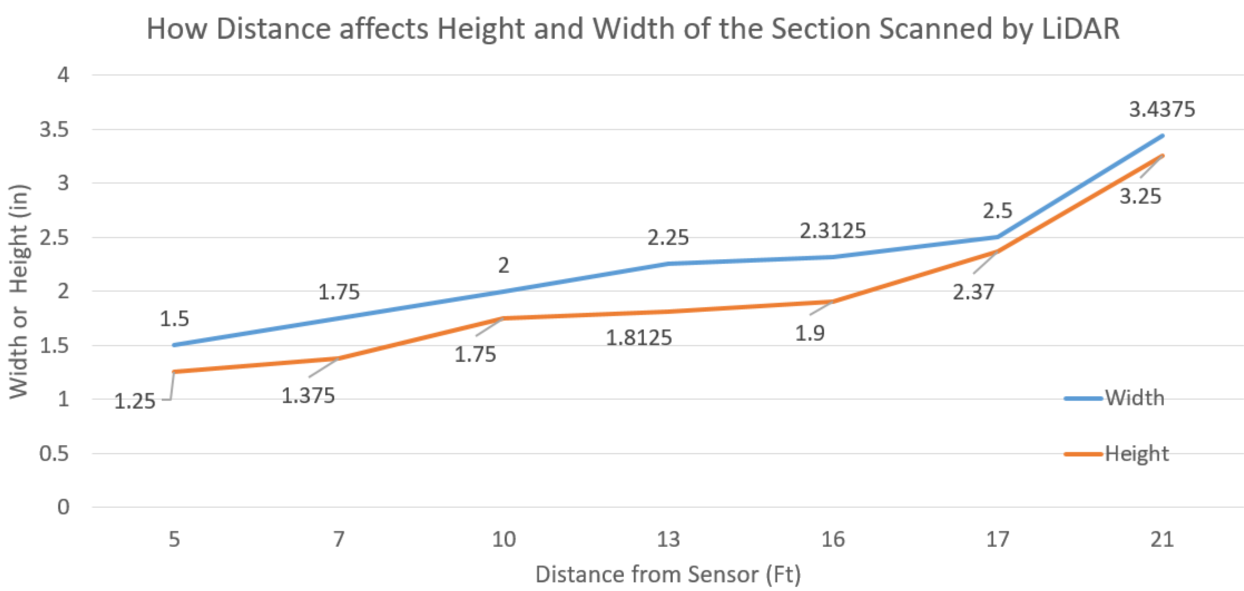

Figure 38: LiDAR height and width of detection zone dependent on distance.

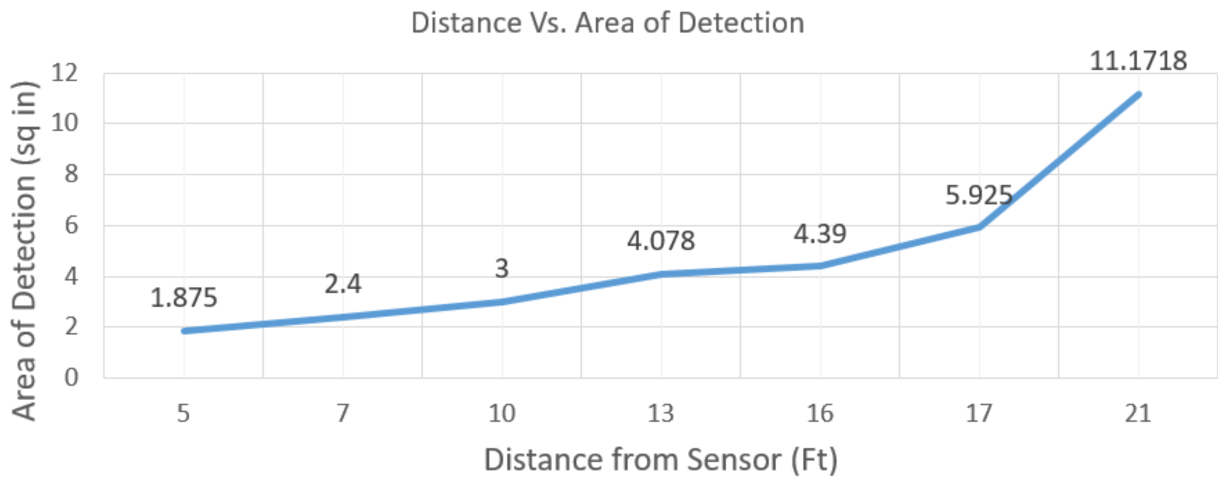

Figure 39: LiDAR Area of Detection based on Distance

According to the datasheet of the LiDAR Lite, the beam divergence is said to be 8 miliradians [17]. In figure 41 we calculated the beam divergence using the width and distance from sensor. 8 miliradians is 0.458 degrees. We can speculate that the beam angle of the LiDAR should be 0.916 degrees. Below on table 9 our average beam angle is 0.939 degrees. If this is true we would have an error of 2.3%.

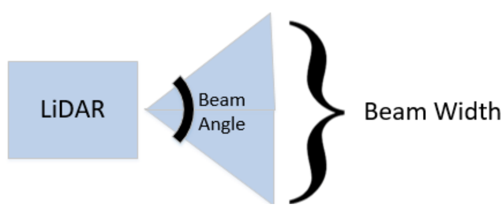

Figure 40: LiDAR Beam Angle and Width

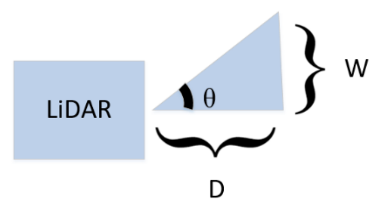

Figure 41: LiDAR Beam Angle Calculations

Beam Angle Calculations using Width				
Distance from Sensor	D (inches)	W (inches)	θ (degrees)	Beam Angle (degrees)
5 Ft	60	0.75	0.7161	1.432
7 Ft	84	0.875	0.5968	1.193
10 Ft	120	1	0.4774	0.9548
13 Ft	156	1.125	0.4131	0.8262
16 Ft	192	1.15625	0.345	0.69
17 Ft	204	1.25	0.351	0.702
21 Ft	252	1.7187	0.39	0.78
Average Beam Angle				0.939

Table 9: Beam Angle Calculations

Using the error equation found in part 1, we have found the error of the beam angle using 0.916° as our actual beam angle.

Error in Beam Angle using Width.

Measured (Ft)	Beam Angle	Error
5	1.432°	56.33% Overestimate
7	1.193°	30.24% Overestimate
10	0.9548°	3.88% Overestimate
13	0.8262°	8.98% Underestimate
16	0.69°	24.67% Underestimate
17	0.702°	23.36% Underestimate
21	0.78°	14.84% Underestimate

Table 10: Error in Beam Angle using Width

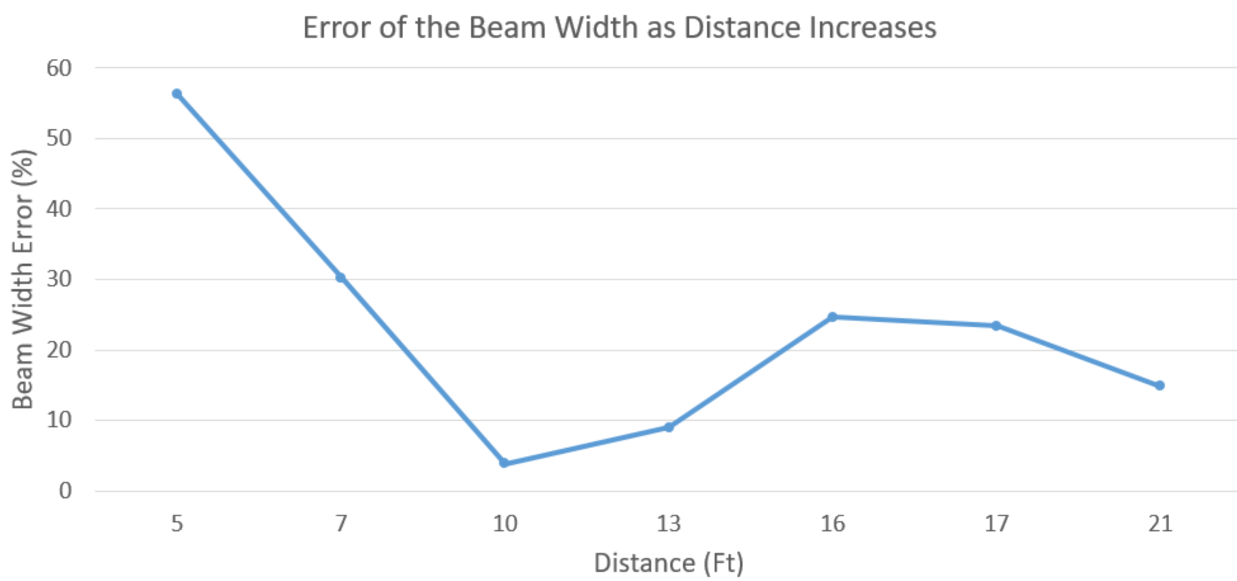

Figure 42: Error in LiDAR Beam Angle using Width

Now we will use the height to calculate the beam angle.

Beam Angle Calculations using Height				
Distance from Sensor	D (inches)	W (inches)	θ (degrees)	Beam Angle (degrees)
5 Ft	60	0.625	0.5958	1.1916
7 Ft	84	0.6875	0.4688	0.9376
10 Ft	120	0.875	0.4176	0.8352
13 Ft	156	0.90625	0.3323	0.6646
16 Ft	192	0.95	0.2836	0.5672
17 Ft	204	1.185	0.3323	0.6646
21 Ft	252	1.625	0.3689	0.7378
Average Beam Angle				0.8602

Table 11: Beam Angle Calculations using Height

Measured (Ft)	Beam Angle	Error
5	1.1916°	30.08% Overestimate
7	0.9376°	2.35% Overestimate
10	0.8352°	8.82% Underestimate
13	0.6646°	27.44% Underestimate
16	0.5672°	38.07% Underestimate
17	0.6646°	27.44% Underestimate
21	0.7378°	19.45% Underestimate

Table 12: Error in Beam Angle using Height

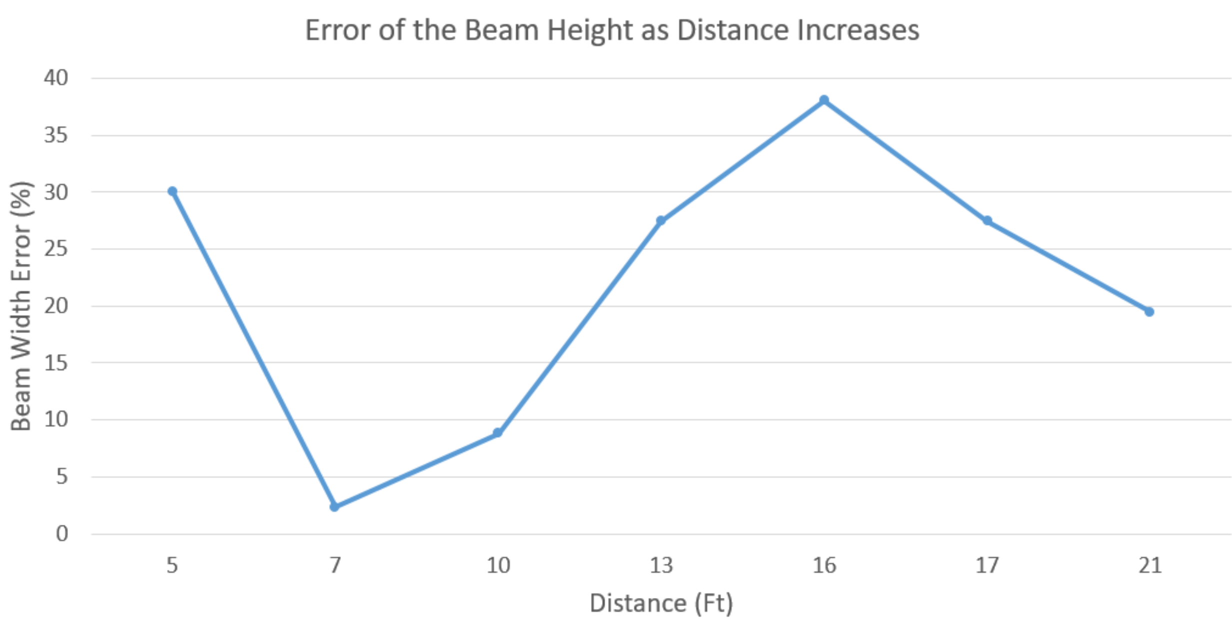

Figure 43: Error in LiDAR Beam Angle using Height

Conclusion

This test was a major part of our system because these is not a lot of information about this sensor. There are write-ups and labs on how to use it, but no one writes about how this sensor performs in terms of acquiring data. We were very surprise to find how sensitive this sensor is. It is difficult to characterize this sensor because there are many factors that can cause errors.

4. Ethics

The IEEE has provided ten ethical principles as parts of its efforts to promote professional responsibility and ethical practice among IEEE members. We have taken a couple that we feel have most impacted us during the development of our project. [18]

1. To be honest and realistic in stating claim or estimates based on available data

   This code of ethics is important to us since we were working with Switch Vehicles, it was necessary to provide the most accurate data and information possible.

2. To maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations.

   We consider this code of ethics important because we believe it is important to research in depth before taking the task at hand. In our project, we developed this knowledge by reading datasheets and testing different components.

3. To avoid injuring others, their property, reputation, or employment by false or malicious action;

   This code of ethics is important to mention even though we did not experience this first hand. Anyone is susceptible of being hurt by others.

5. Future Work

Future work would allow for safety features and energy efficiency. Finding a way for the Arduino to detect Bluetooth connectivity when it is present or absent is important because if bluetooth connection is lost, the Arduino needs to know in order to shut down all outputs and stop all motions of the vehicle. Another concept that needs more work is energy efficiency, which could be achieved if the primary Arduino allows the secondary Arduino to power on and off while sitting idle. Further work in this area is significant because if energy efficiency is achieved through the Arduinos then energy efficiency can also be achieved for the LiDAR and LCD which currently consume unnecessary energy when the vehicle is off.

Appendix A - Test plan

T1 (ER1)
Test connectivity indoors with walls and outside without obstructions. Plot distances in meters to see how far we can separate the receiver and transmitter without losing signal.

T2 (ER2)
This test shows that it was possible to have an app control things.

T3 (ER3)
This engineering requirement does not need testing.

T4 (ER4)
This test is designed to see how well the enclosure can be removed from the vehicle and how well it can be secured and connected back to the existing harness. This test assumes that all connections and implementation of our system have been installed on a vehicle.

T5 (ER5)
Testing will show we can power on and off the car, turn off and on the lights and change the gear from forward to reverse to neutral using relays.

T6 (ER6)
This test will show how one step on the slider in our app increases the output voltage. Similarly we will show how voltage changes across the whole slider.

T7 (ER7)
This test is needed to show how the resistance can be changed using the digital potentiometers.

T8 (ER8)
The power consumption will be put into different tables where the scenarios will change showing what major components are connected.

T9 (ER9)
The power output will be compared to the power input to see what efficiency the regulator provides.

T10 (ER10)
This can easily be tested by measuring the voltage at the source and comparing it to the voltage at the fuse panel in our system.

T11 (ER11)

We will measure the amperage used by each device and make sure it does not exceed 500mA

T12 (ER12)

The operation of the code will be tested using this LCD, therefore it must display data precisely where it needs to go and information should not be cut off.

T13 (ER13)

In this test, we will be analyzing the rigidity and effectiveness of the latching switch on the LCD.

T14 (ER14)

This will test is designed to see the responsiveness of the Arduino after multiple presses of the button to see if it can accurately scroll through the information.

T15 (ER15)

Characterization of the LiDAR was done in order to understand it better.

Appendix B - Circuit diagram

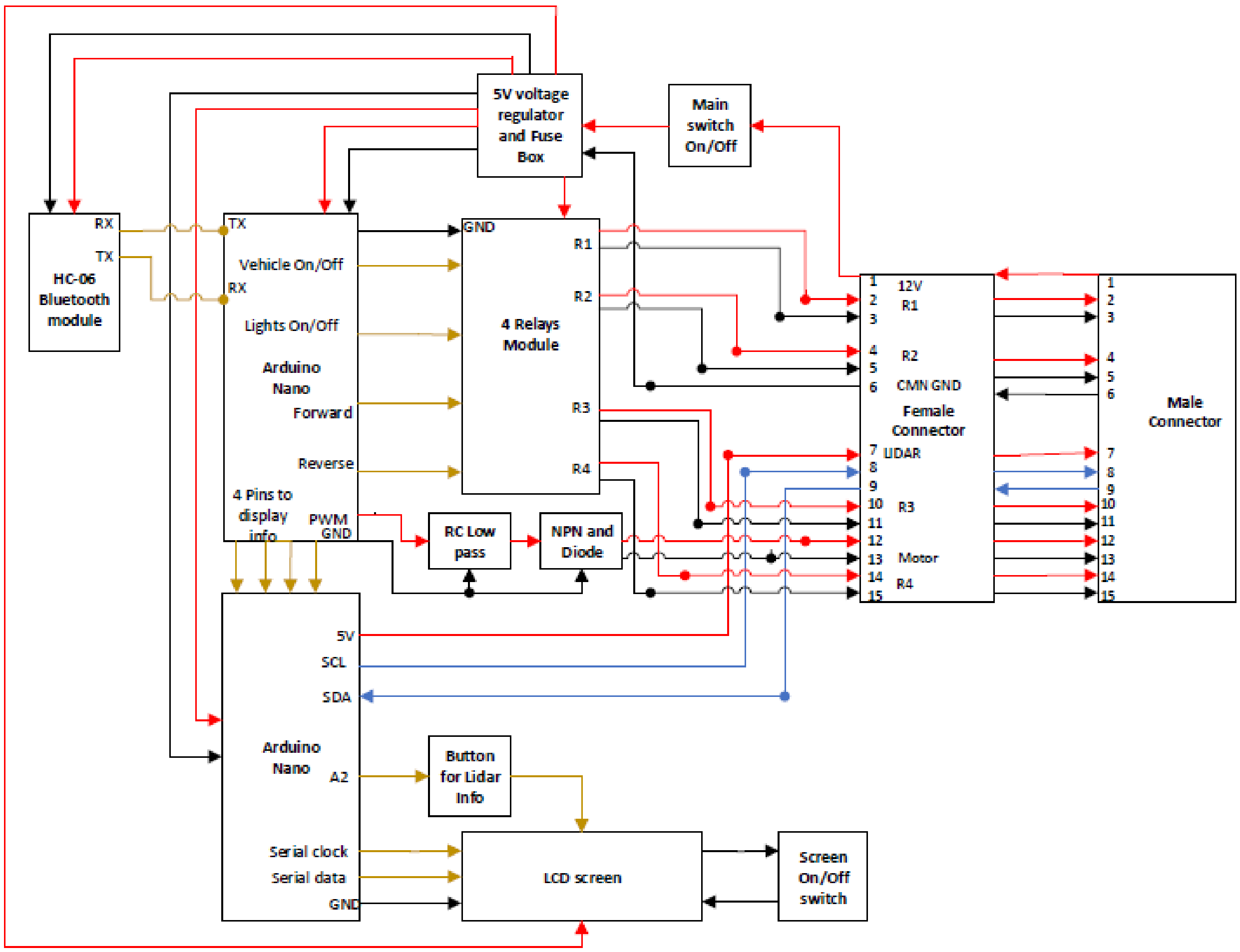

Figure 44: Main system circuit diagram

Appendix C - Flowchart

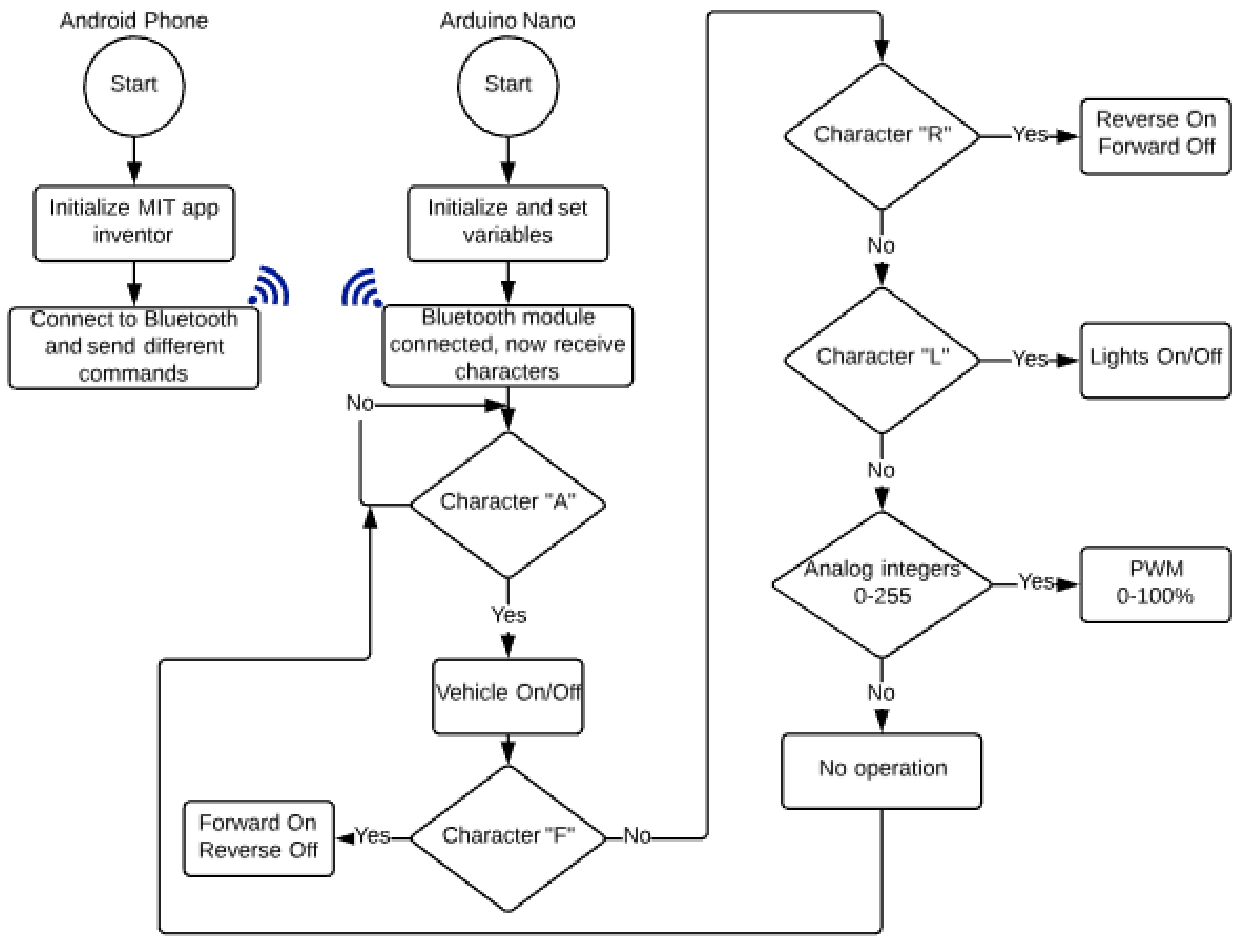

Figure 45: Flowchart for Android and primary Arduino Nano

Appendix D - Bill of Materials and Budget

These are the parts we used in order to build our project. We received $600 from source funding in order to complete our project. Half of this money was used on testing and the rest was used on building our system. As you can see, our system alone cost $180 without the LiDAR sensor. We are satisfied with our outcome because it is very affordable.

Parts	Quantity	Description	Price
Arduino Nano	2	Embedded System	$45
Arduino Shield	2	Screws down wires	$13
Wire Spool	1	To connect various components	$10
5 volt regulator	1	Convert from 12 to 5v	$15
Fuses	6	100mA fuses to protect hardware	$5
Fuse Holder	6	Holds the fuses	$5
LIDAR	1	Distance sensor	$120
LCD	1	Display	$13
Buttons and Switches	4	Control various aspects of the system	$15
Relay Module	1	Control lights, gear engagement and vehicle on or off	$10
Digital Potentiometer	2	Alternate input for motor speed control	$15
Bluetooth Module	1	Connects phone to system	$10
Miscellaneous	X	Estimated Cost from Parts used from Lab	$25
Total Cost			$300

Table 13: List of components and price

Appendix E - Acknowledgements

Over the past year, we worked hard to get to where we are now. This project has cultivated us from students to engineers. We feel that this process would have not taken place without the help of faculty advisors, such as Dr. Farid Farahmand, Shahram Marivani, and Ali Kujoory. We thank Switch Vehicle for inviting us to their lab and allowing us to perform our initial tests which were very important in starting our project. We thank them for providing the schematics and educational kit which helped us develop our project into what it is now.

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