Final Report for Project Lab 1

Dr. David Hemmert

The Decontamination Operation

Group 2: Error 404

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Abstract

This paper is an interim report that provides the outlines and designs on the progress of team Error 404 on how to build and program an autonomous rover to perform necessary tasks. The overall task of the rover is to travel along an aluminum adhesive path in the clockwise direction. On the path of the rover, there will be inspection station laid out on different locations. The inspection stations will contain contaminations in the form of metal washers. The rover will follow the path and move across each inspection station and will detect for the contaminations using an IR sensor. The rover is then tasked to collect the contaminations using an electromagnet and carrying them towards a disposal station located six inches away from the track. The rover currently has the ability to move in every direction using the DC motors that are attached to the Rover Chassis. It is still waiting to be tested on an aluminum track. The Electromagnet that will be used to pick up the contaminations has been designed and is currently waiting to be connected to the Rover Chassis. Each component involved in the design and completion of the project has been mostly completed. The components were not brought together into the rover in order to finish the final product.

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Introduction

The following report provides a detailed information and explanation of the progress for the outline and design of the autonomous rover. It also contains the detailed descriptions of each individual component that are being used to enable the rover to carry out its necessary tasks. The task of the rover is to follow along an aluminum adhesive path in the clockwise direction. Along the path. Several inspection stations are laid out which contain contaminations in the form of metal washers. The rover is tasked to follow along the path and stop along each inspection and access the existence of contaminants. Then the rover must pick up the contaminants from the surface by the use of an electromagnet and carry the contaminants to a disposal station that is located six inches away from the track. The Rover in use is the ROV5-2 chassis. Four IP sensors are attached to the front of the chassis in order to collect readings from the aluminum path for it to follow. IR sensors are being used to collect temperature readings from the inspection stations. The rover will receive IR signals from a box situated away from the track. The rover measures the temperature at the surface of each inspection station. Depending on the temperature reading, the rover will obtain certain frequency readings that will determine the tasks of the rover. The Basys 3 FPGA board is being used programmed with Vivado Verilog to enable the rover and the components to carry out the necessary tasks. This method of rover can be used for nuclear waste disposal purposes. It can be used to remove and replace metal fuel rods that are used in nuclear reactions. The IR sensors can be used to detect contaminated waste material and the electromagnetic functionality can be used to dispose of them. The IR sensor can also be used to measure the temperatures of the fuel rods that need to be extracted from a nuclear reactor. The final state of the Rover has been provided in Figure 1 below.

Due to the rise of Covid-19 cases, the lab was closed. This reduced the amount of time possible to spend in the lab or even finish the project. As a result, the overall project was incomplete. However, most of the components and equipment have been designed.

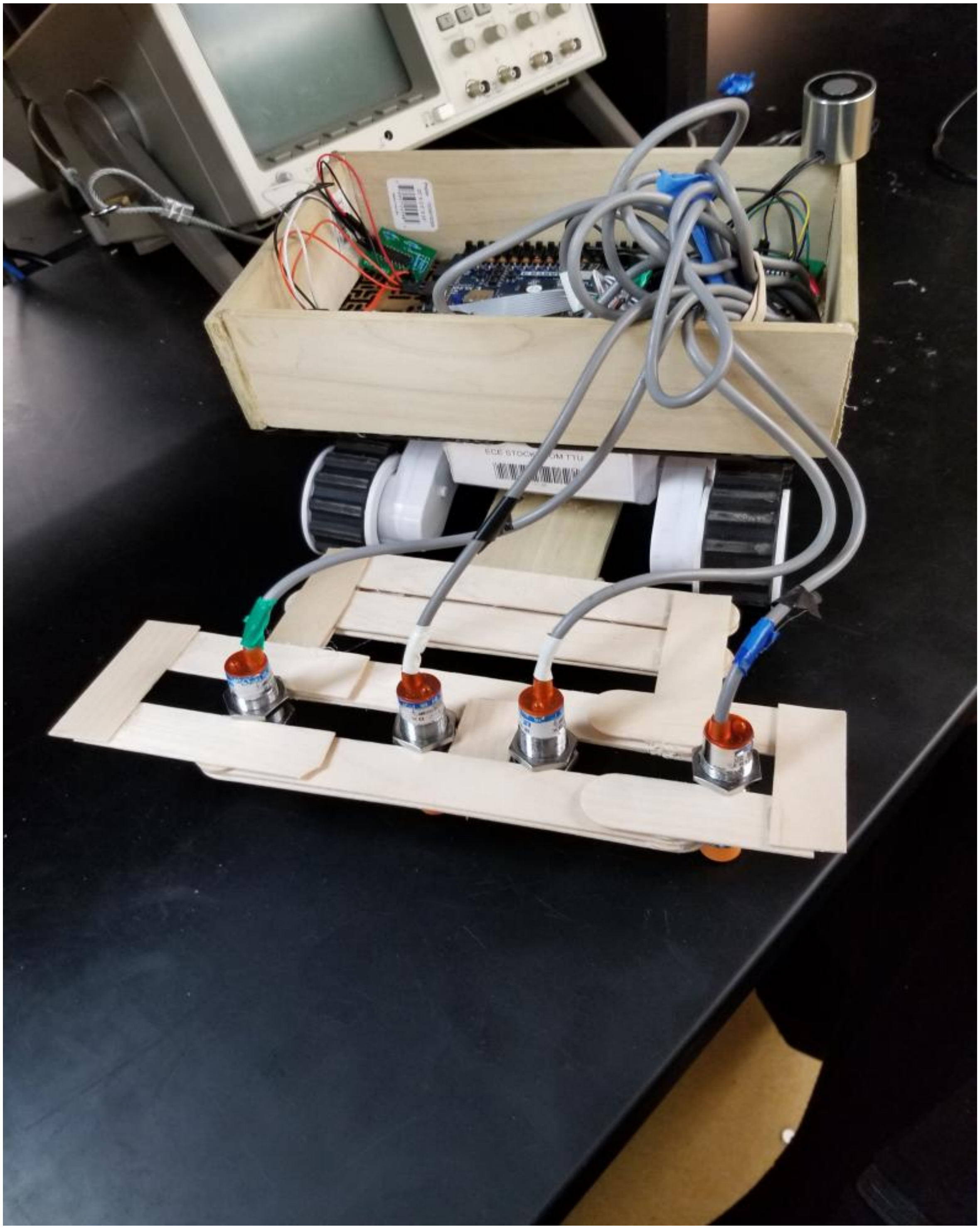

Figure 1: Final state of the Rover

Hardware

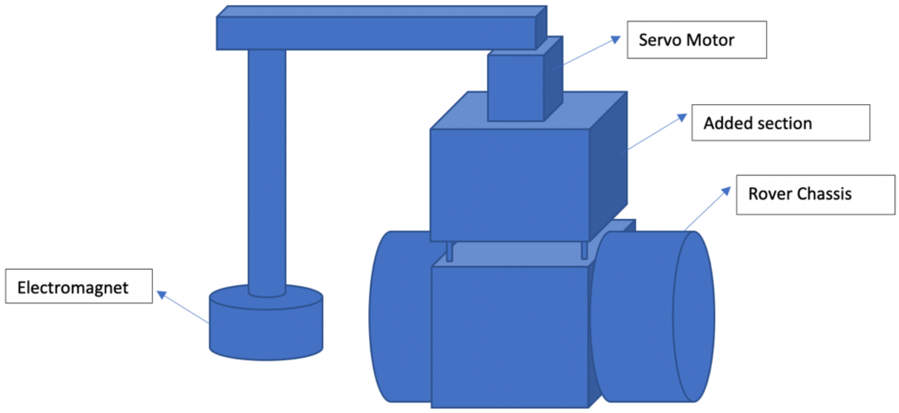

Figure 2: 3-D Design of Rover Chassis

IP Sensors (LJC24A3-T-Z/BX):

The rover is made to move along an adhesive aluminum track. This goal is obtained by the use of the IP sensors. Four LJC24A3-T-Z/BX IP sensors were connected along the front of the rover. Two sensors in the middle are used to make the rover move forward as long as it is over the metallic track. Once the sensors in the middle detect no further track in the forward direction, the two sensors on the sides turn on. The sensors detect which side has the metallic path to turn towards. If the left sensor detects the metallic path, the rover will move left. If the right sensor detects the path, it goes right. If all 4 sensors detect a path, the rover was programmed to move left.

IPS Circuit:

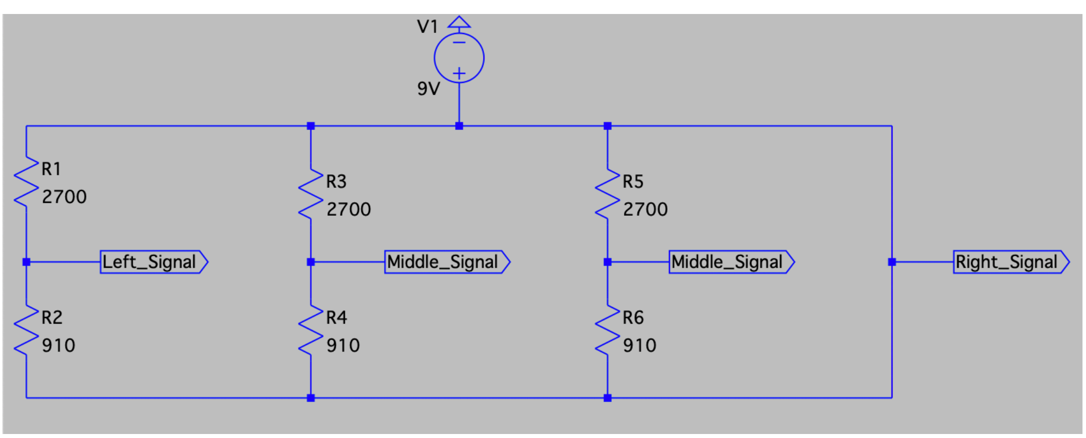

Figure 3: IPS circuit schematic

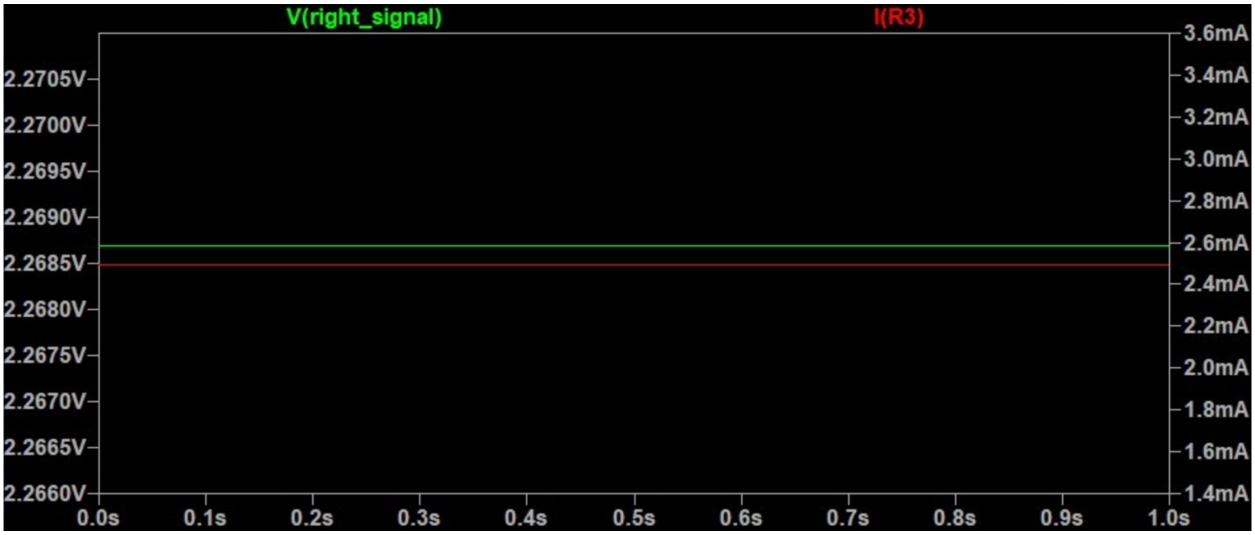

Figure 4: IPS Circuit Simulation

The circuit provides an output signal of close to 2.269V to each of the IP Sensors as shown on Figure 4 above and a current of roughly 2.5mA was provided as well. This signal is considered to be on High State. When the Rover is put on the aluminum track, the IP sensors detect the metal path, and the total voltage drops to 700mV. This is considered to be on the Low State. Voltage divider circuit with 2.7 kOhm resistors and 910 Ohm resistors are used to send the required signal to each of the IP sensors as shown on Figure 3 above.

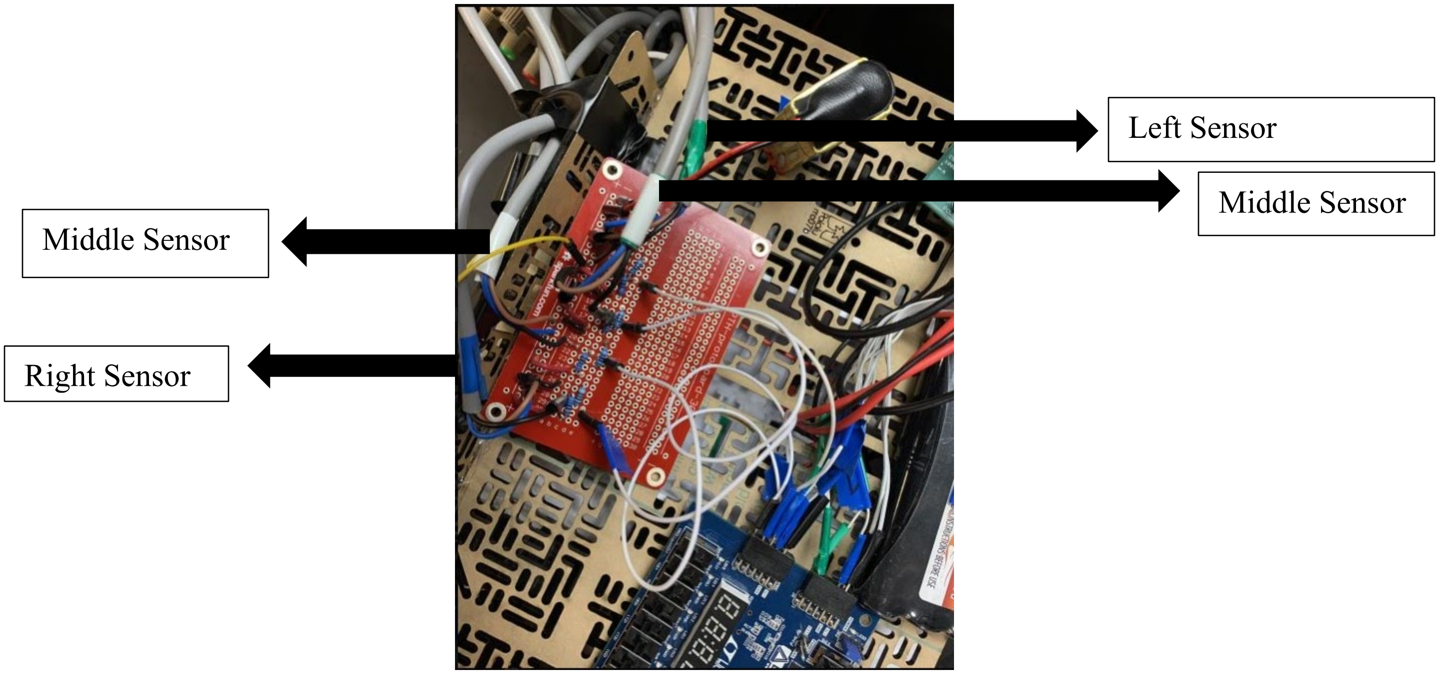

Figure 5: IPS Soldered Breadboard Design

Electromagnet (BDE 1212-12):

The electromagnet was used to pick up the contaminations from the inspection stations that would be laid out on different locations of the track. The electromagnet was to connect on the ROV5-2 Chassis by the means of an extended arm or pole. The extended arm or pole was connected with a servo motor. Once the contaminants were collected from the inspection stations, the electromagnet would rotate 180 degrees in the opposite direction using the servo motor where it would be able to drop off the contaminants at a designated disposal station. The operation of the electromagnet was determined by connecting it with a toggle switch. The Electromagnet would remain ON for the entirety of the project demo except for the times when it would turn OFF to drop the gathered contaminants on the disposal station.

The Electromagnet being used in this case is a bunting electromagnets BDE 1212-12 electromagnet. From the datasheet, it was learned that the Electromagnet would require 12V DC voltage in order to operate. However, on actual testing, it was found that the Electromagnet was able to meet the project requirements at 9V DC supply. As a result, a 9V battery was used for the power supply.

Electromagnet Circuit:

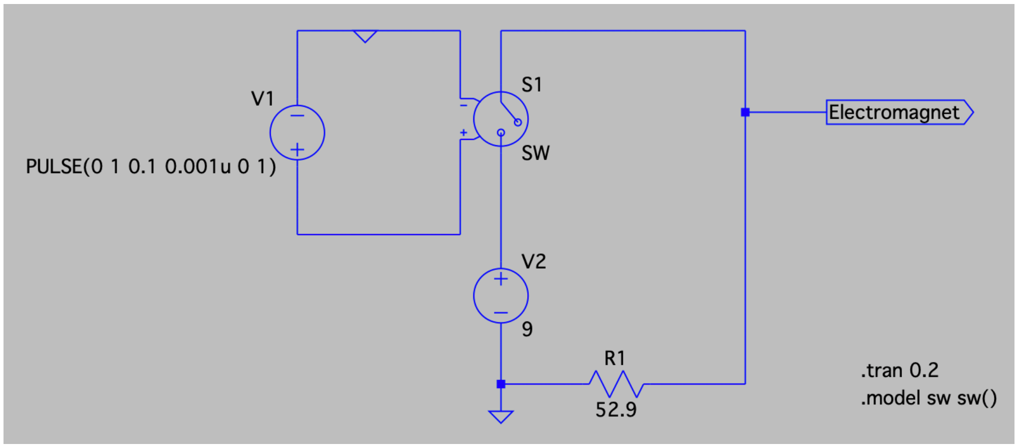

Figure 6: Electromagnet Circuit Schematic

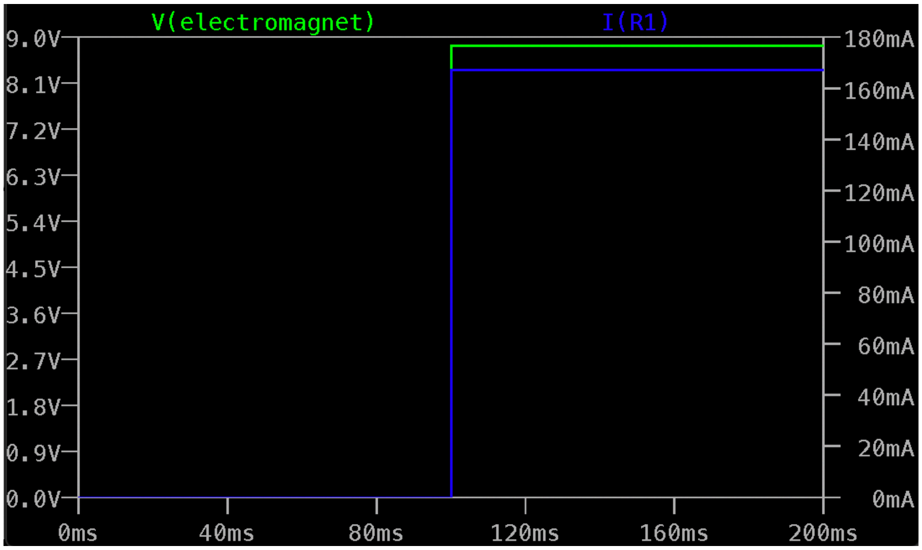

Figure 7: Electromagnet Circuit Simulation

The Electromagnet was operated using a simple toggle switch. The pulse of up to 9.0V can be seen at 100ms on Figure 7 which is the time delay for the switch. The electromagnet being used in this project requires roughly 170mA to function properly. On Figure 7 a current pulse is obtained at 170mA to prove that. The toggle switch is operated using a servo motor.

Servo Motor (Hitec HS-422):

The servo motor being used is the Hitec HS-422 servo and it was attached to the front-middle part of the rover chassis. The servo was connected to a pole or extended arm as shown on Figure 8 below. The arm would control the rotation of the electromagnet when it picked up contaminations and dropped them off. The servo disc would rotate in the anticlockwise direction. The operation of the servo was determined by connecting it with the Basys 3 board and programming it with Vivado Verilog. The servo was used for two purposes: To rotate the Electromagnet when the disposal station is detected, and the second purpose is to turn off the toggle switch that is used to operate the electromagnet. Once the servo rotates with the electromagnet, it turns OFF the toggle switch which also causes the electromagnet to turn OFF and the contaminants are dropped off at the disposal station. This function is showed in Figure 9 below.

Due to lack of time, and lab restrictions, the servo extended arm was not made. However, the concept of it was used to create a 3D design using AutoCAD to provide an idea about the servo worked.

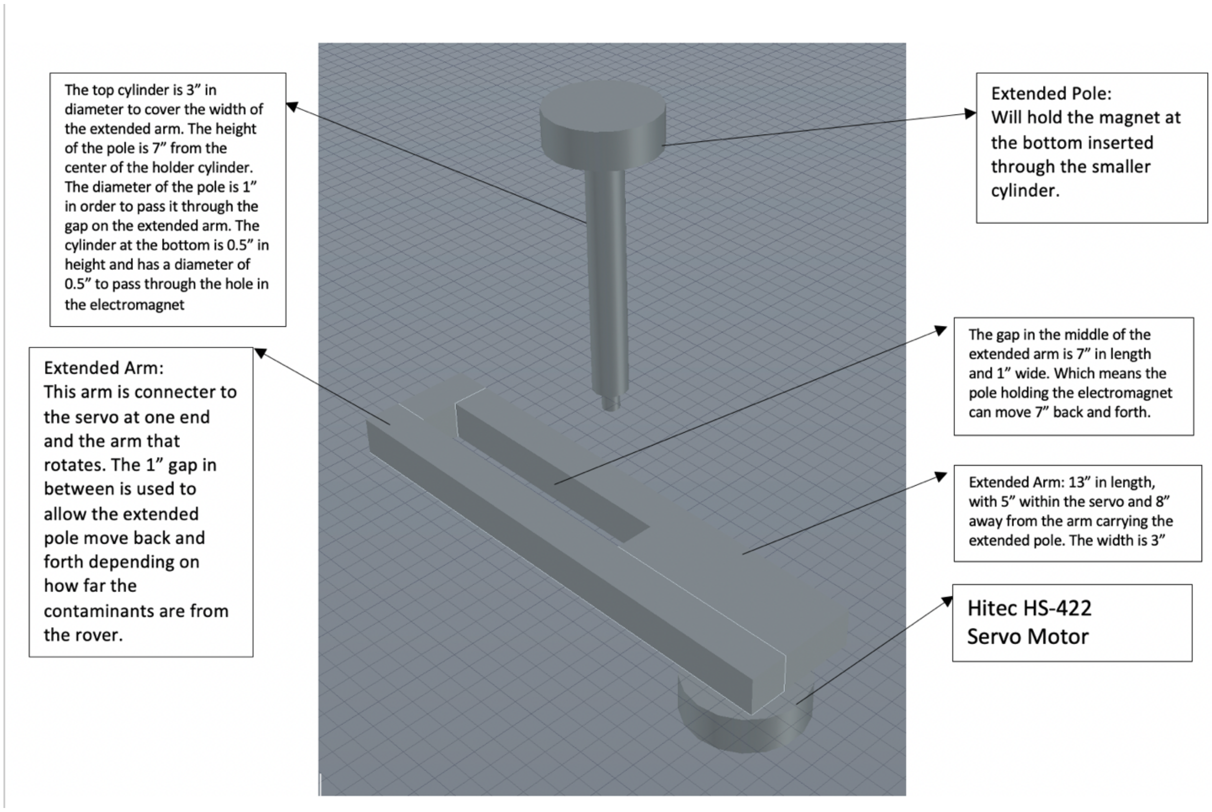

Figure 8: Servo Motor Extended Arm 3D Design

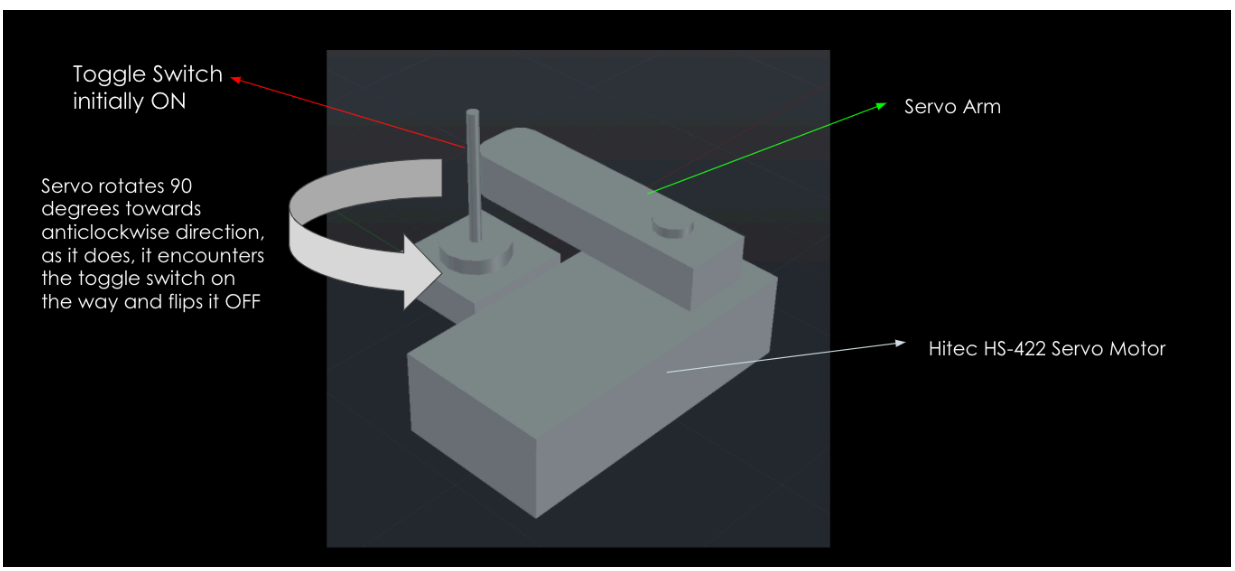

Figure 9: Servo Motor with the toggle switch (Not to Scale)

Servo Motor Circuit:

The Hitec HS-422 Servo Motor required 4.8-6V to operate. Approximately 5.14V was provided using a voltage divider circuit using a 4.7 kOhm and 9.1 kOhm resistors as shown in Figure 10 below. An IRF3708 MOSFET was used as a low-side switch to operate the servo motor. A 10 kOhm pull-up resistor was used along with the IRF3708 MOSFET. The CTRL wire of the servo motor was connected to the DRAIN of the IRF3708 MOSFET as shown on Figure 10 below. The GATE pin of the MOSFET was connected to the GPIO pin of the Basys 3 Board. A pull-down resistor with 10 kOhm was used to prevent the Basys 3 board from sending floating values into the circuit.

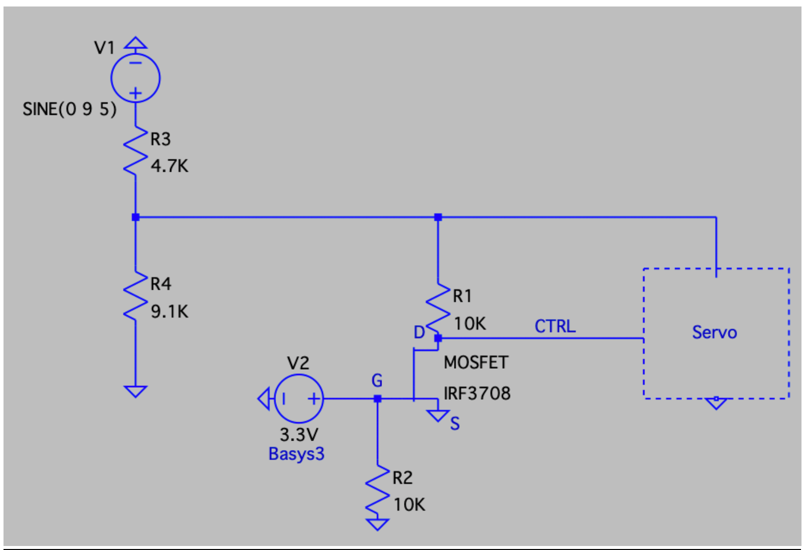

Figure 10: Servo Motor Circuit Schematic

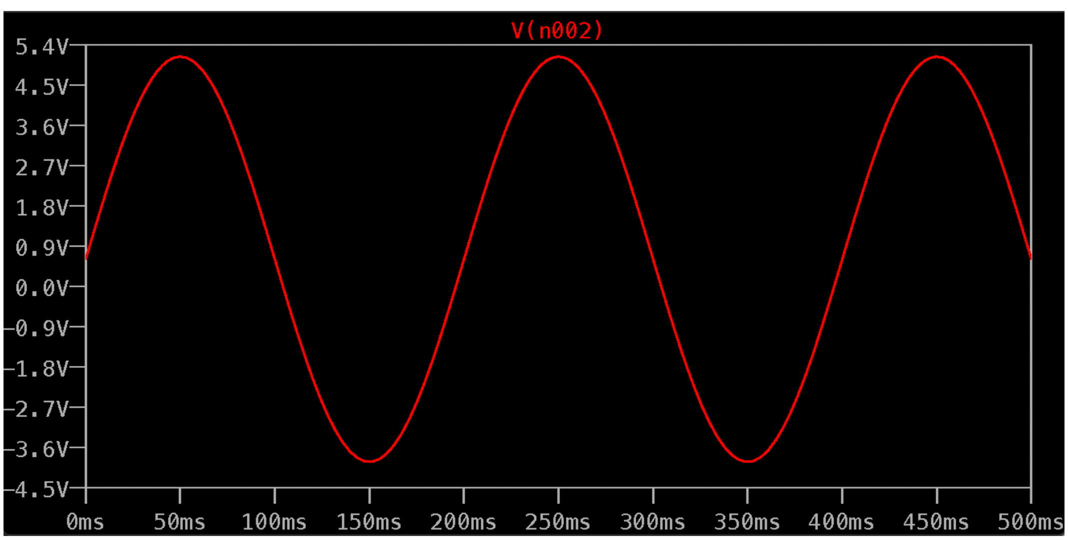

Figure 11: Servo Motor Circuit Simulation

Thermopile ZTP-148SRC1:

The ZTP-148SRC1 Thermopile was used to obtain the temperature readings. The temperature readings were required for when the rover analyzed the inspection station to detect contaminations. The ZTP-148SRC1 was always ON reading temperatures, and periodically outputs millivolt signals. The magnitude of the signal was dependent on the thermal resistance the thermopile faced. For example, on Figure 12 below, it was seen that 20 degrees Celsius (which would be the average room temperature) would have a typical resistance of 125 kilo Ohms.

Thermistor Resistance

Temperature (°C)	Minimum Resistance (kΩ)	Typical Resistance (kΩ)	Maximum Resistance (kΩ)
-20	925.2	975.8	1028.2
-15	696.2	732.2	769.3
-10	528.9	554.7	581.2
-5	405.5	424.1	443.2
0	313.5	327.0	340.8
5	244.3	254.2	264.3
10	191.9	199.2	206.6
15	151.8	157.2	162.7
20	121.0	125.0	129.0
25	97.0	100.0	103.0
30	77.9	80.5	83.1
35	63.0	65.2	67.5
40	51.2	53.2	55.1
45	41.9	43.6	45.2
50	34.5	35.9	37.3
55	28.5	29.7	31.0
60	23.6	24.7	25.8
65	19.7	20.7	21.6
70	16.5	17.3	18.2
75	13.9	14.6	15.4
80	11.8	12.4	13.0
85	10.0	10.5	11.1
90	8.5	9.0	9.5
95	7.3	7.7	8.1
100	6.2	6.6	7.0

Figure 12: Thermopile Temperature to resistance chart

Thermopile Circuit:

The thermopile ZTP-148SRC1 sent signals in milli volts. As a result, it cannot be read by the Basys 3 Board. So, the LM324-N amplifier was used to amplify the signal into a voltage that can be read by the Basys 3 Board. The circuit on Figure 13 below gives a demonstration of how that is carried out.

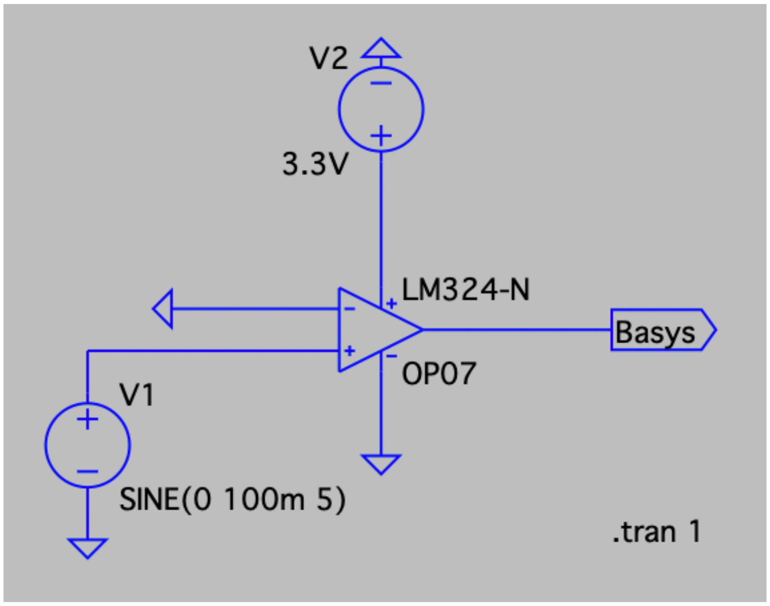

Figure 13: Thermopile Circuit Schematic

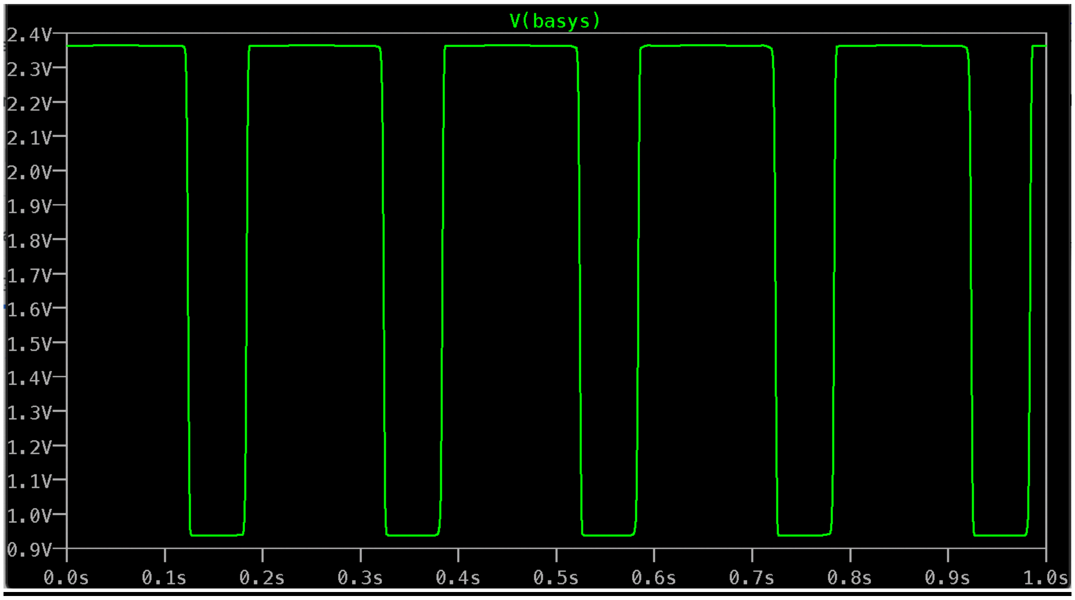

Figure 14: Thermopile Circuit Simulation

IR Sensor (OP505):

The IR sensor being used is the OP505 which is an NPN silicon phototransistor. This particular IR sensor operates at a current within the range of 2.15mA and 5.96mA. Its purpose is to receive IR signals at an angle of 25 degrees from a range of approximately up to 0.5 inches. The OP505 schematic along with an IR signal and a 2N2222 amplifying transistor is shown in Figure 15 below. The 2N2222 amplifying transistor is required as the OP505 receives signals in millivolts.

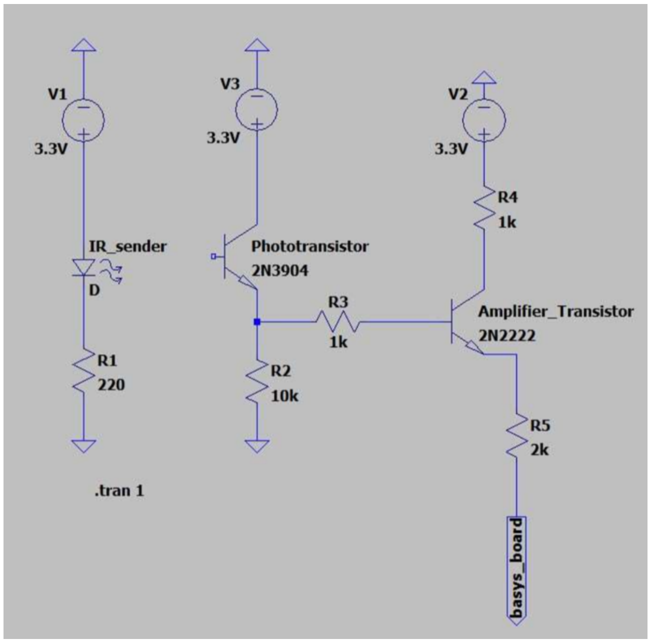

Figure 15: IR Sensor Circuit schematic

When the OP505 was tested, it was observed that the length and angle from which it could receive the signals was very limited as shown on Figure 16 below. As a result, readings from signals from the inspection stations were not obtained.

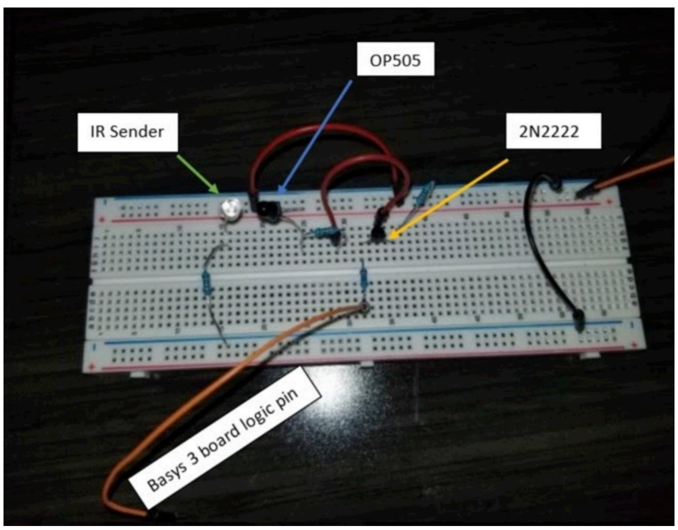

Figure 16: IR Sensor Breadboard Circuit

The TSOP382 IR receiver can be used to provide a solution for the aforementioned issue. It is both a photodetector and preamplifier. It can receive IR signals at any angle and from a greater distance. Figure 17 shows the TSOP382 with its pins. Pin 1 provides an output, Pin 2 is ground, and Pin 3 provides a voltage supply.

Figure 17: TSOP382

Comparator:

The LM339 comparator was used for this project. The purpose of the comparator was to compare an AC signal with a DC signal. At the same time, it was also tasked to limiting the amount of DC voltage supplied into the Basys 3 Board. Figures 18 and 19 show the circuit schematic and simulation for the comparator. Figure 19 consists of a square wave, and a sine wave. The square wave is the DC input signal into the Basys 3 Board, and the sine wave is the AC signal within the LM339 comparator. A 1 kOhm pull-up resistor was used to prevent any excess current from flowing through the circuit. The SNS_A and SNS_B are responsible for the AC signal. The SNS_A and SNS_B are both in the non-inverted terminal of the comparator. If the signal on the inverted terminal is greater than the signal on the non-inverted terminal, then the output is 3.3V, which means ON as it is on high state. If the signal on the inverted terminal is less than that of the non-inverted terminal, then the output is less than 1, which is read as low state by the Basys 3 Board. Causing it to turn OFF.

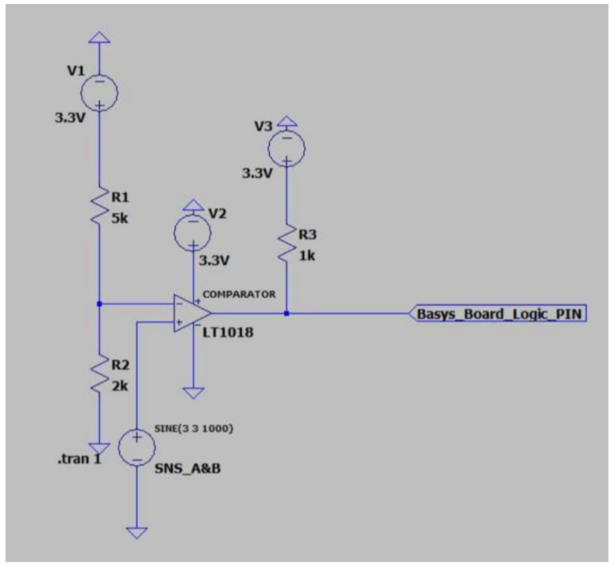

Figure 18: Comparator Circuit schematic

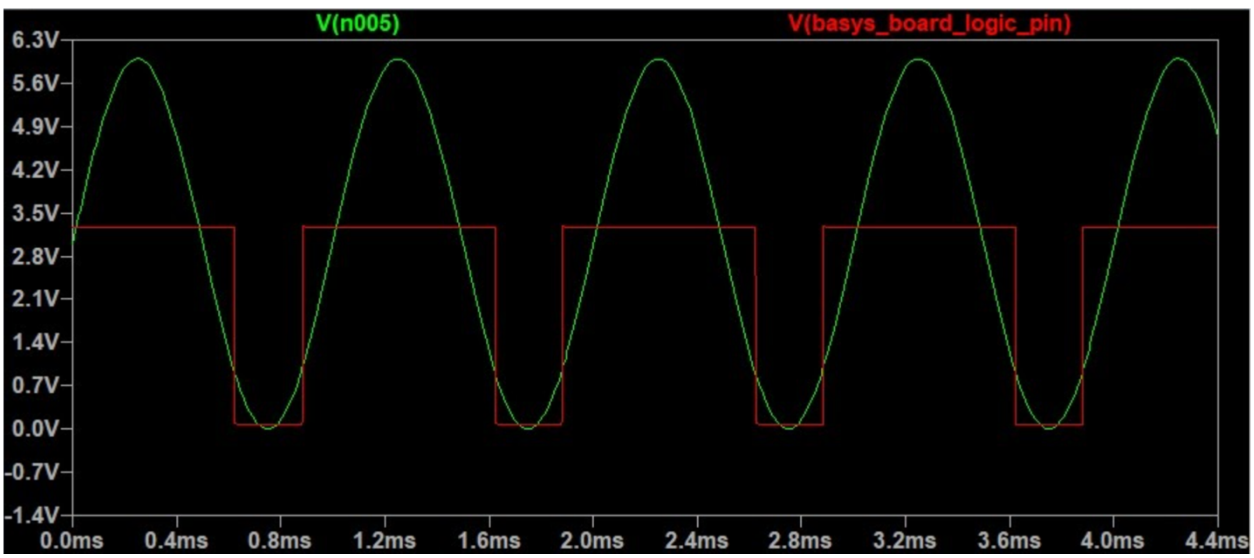

Figure 19: Comparator Circuit Simulation

PCB Comparator Circuit:

The PCB board was created and ordered using EasyEDA software. The schematic created using this software is shown on Figure 20 below. The software also allows the user to test and simulate the schematic before creating the footprint.

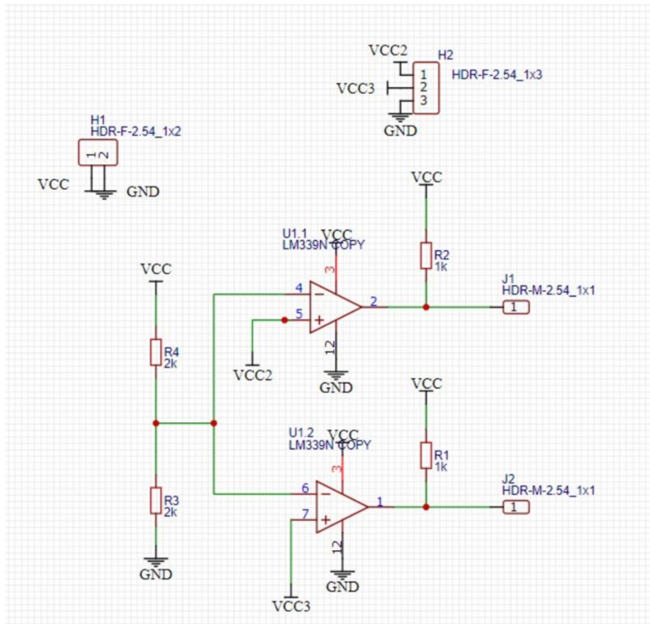

Figure 20: PCB Schematic

Figures 21(A) and 21(B) shows the footprint of the PCB. The PCB is double layered and is 80mm x 100mm in size. 21(A) provides the top view of the PCB while 21(B) provides the bottom view.

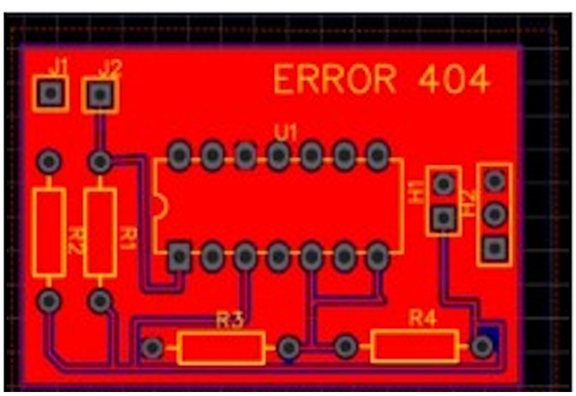

Figure 21(A): PCB Footprint(A)

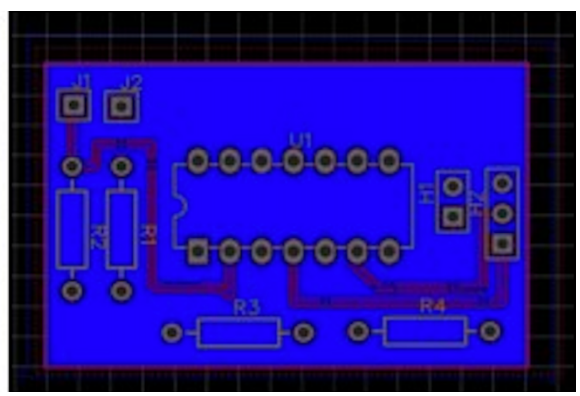

Figure 21(B): PCB Footprint(B)

Once the PCB was obtained, the comparator circuit was designed with its input to the H-Bridge and the output to the Basys 3 Board. Figure 22 shows the final printed board with the comparator.

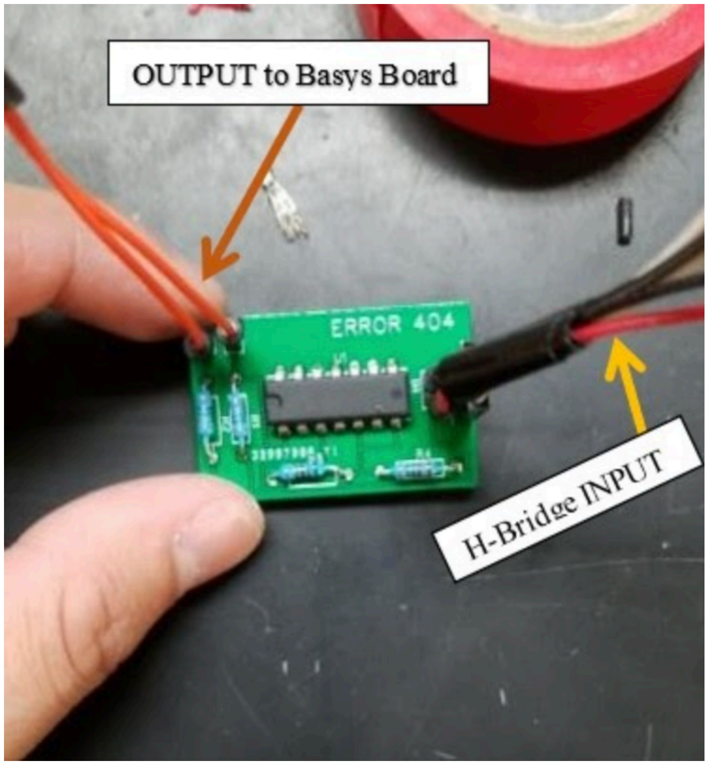

Figure 22: PCB Printed Board

Software

Inductive Proximity Sensors:

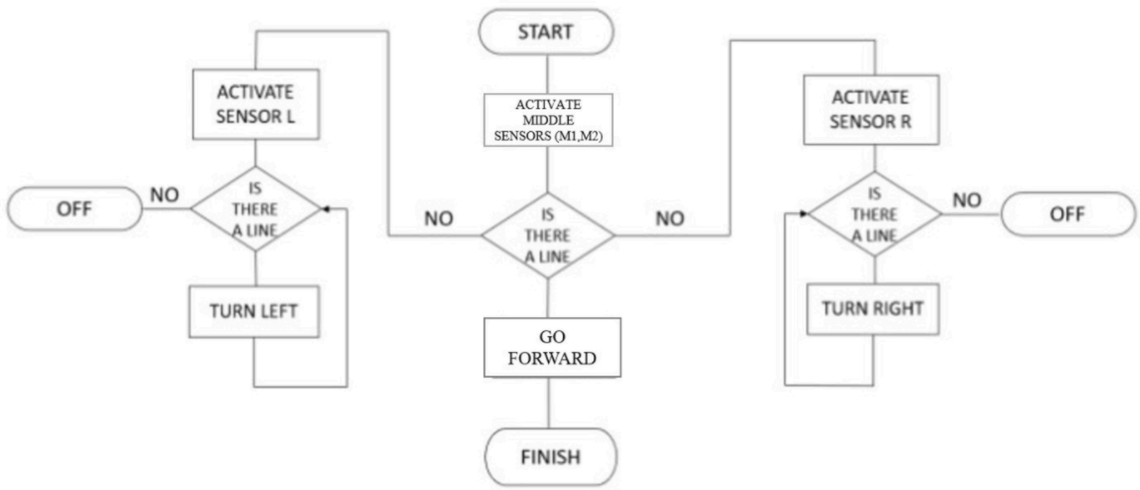

Figure 23: IPS Flowchart

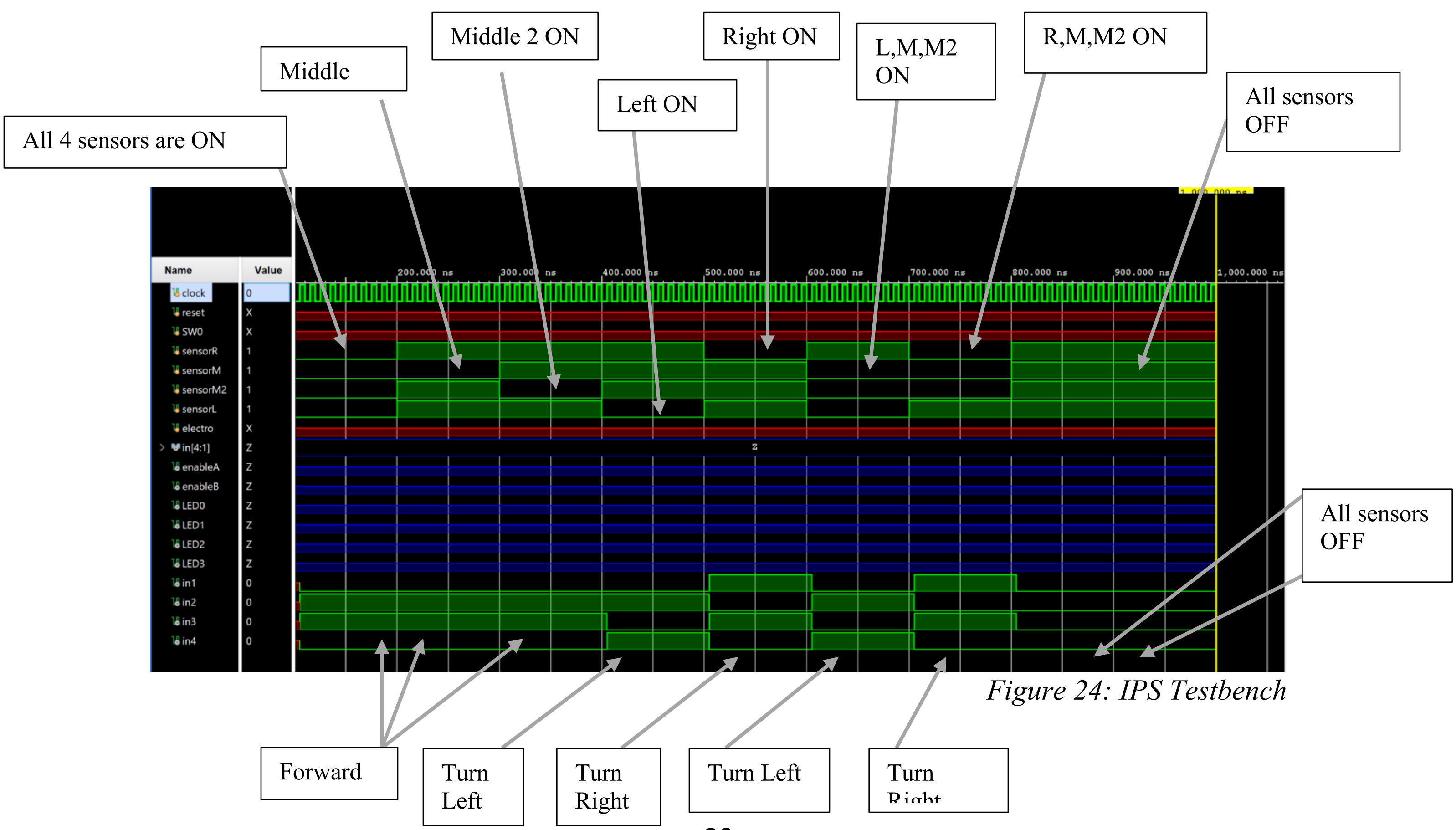

Figure 24: IPS Testbench

For this project, 4 IP sensors were used. M is middle sensor 1, M2 is middle sensor 2, L is left sensor, and R is right sensor. When M and M2 are activated, in2 and in3 are activated. This causes the Rover to move forward. To move left, the left sensor(L) turns ON activating in2 and in4. Finally, to move right, the right sensor turns ON activating in1 and in3. The ins are activated based on the direction of the rover's movement. For the sensors to turn ON, it needs to be on the low state, which is 0. And the sensors are off when they are in high state, which is 1. All these operations are shown in the IPS testbench on Figure 24 above.

Distance Sensor:

Figure 25: Electromagnet and Distance Sensor Flow Chart

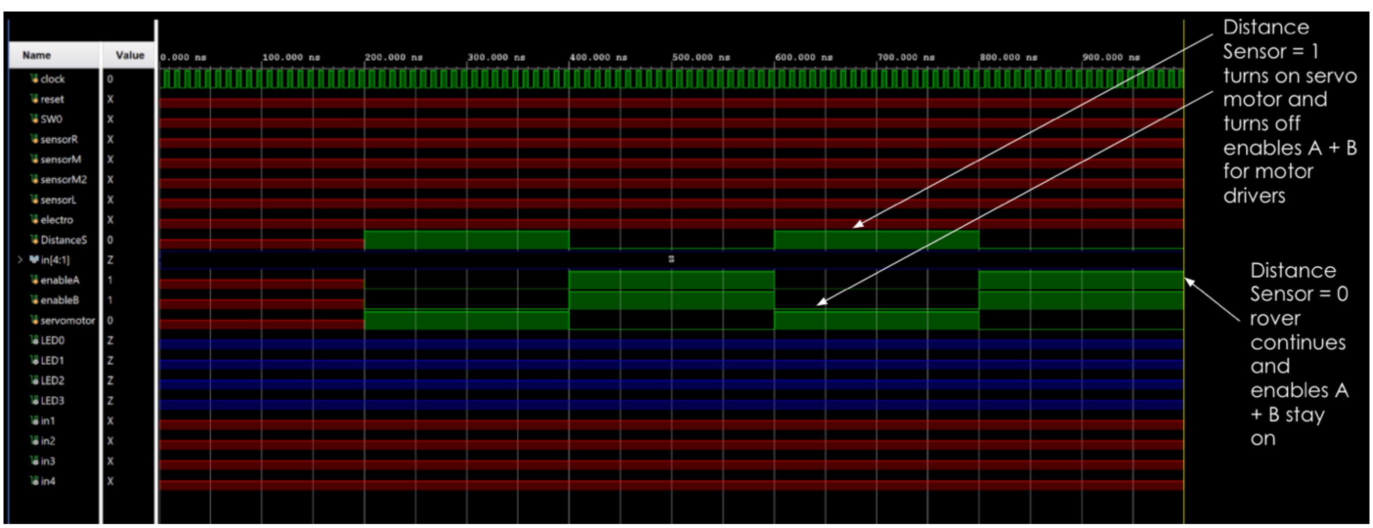

Figure 26: Servo for Electromagnet and distance sensor testbench

When there is an object in front of the Rover, the distance sensor reads 1. This causes the servo to read 1 as well. As a result, the servo rotates. The enables A and B turn OFF and the rover stops moving. The toggle switch responsible for the operation of the electromagnet is kept on the path of rotation of the servo arm. When the servo rotates and reaches the top of the disposal station, it clicks the toggle switch turning the Electromagnet OFF and causing all the contaminants to drop off. On the other hand, if there is no object in front of the rover, the distance sensor reads 0, which is low state. Hence, nothing turns On and the rover continues on its path. The operation of the servo testbench is provided on Figure 26 above. Figure 25 provides a detailed flowchart on how the electromagnet and the distance sensor operations are interlinked by the servo motor. The distance sensor determines if the servo motor will rotate or not, and the movement of the servo causes the electromagnet to turn OFF and drop the contaminants.

IR Sensor:

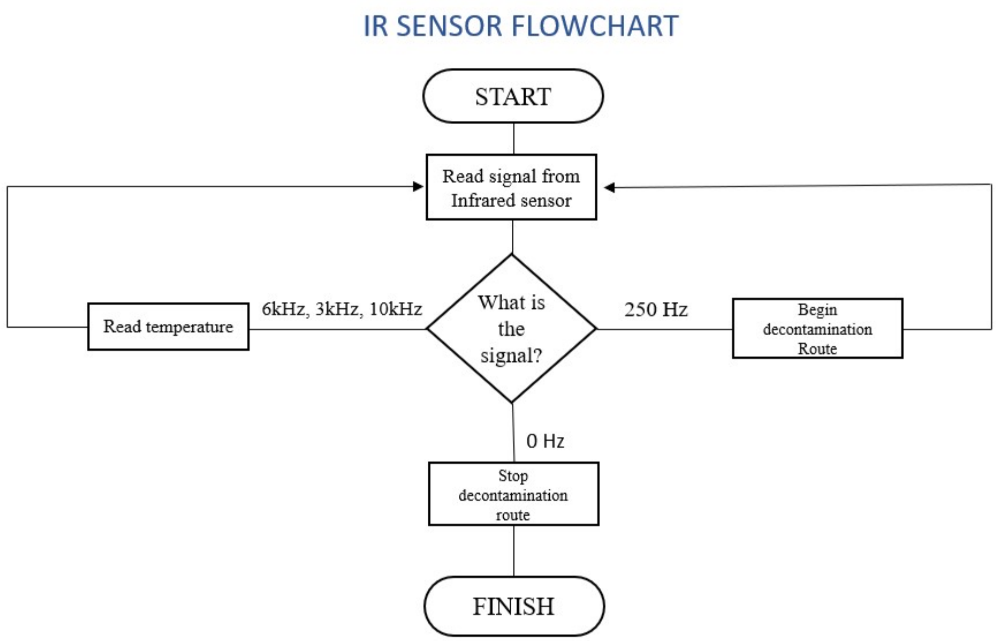

Figure 27: IR sensor flowchart

```
always@ (posedge clock) begin
if (IR == 1) begin
counter2 <= counter2 + 1;
positiveedge <= positiveedge + 1;
end
else if (IR == 0) begin
counter2 = 0;
positiveedge = 0;
end
end
```

Figure 28: IR sensor Code

When the IR sensor reads 1, the sensor begins to count the number of cycles. While doing so every positive edge in every cycle is calculated to count the frequency. From the flowchart on Figure 28, it is observed that the rover begins decontamination route when the frequency reading is greater than or equal to 250Hz. The IR signal reads temperature readings at 3kHz, 6kHz, and 10kHz. When the IR reads 0Hz, the rover stops.

Results and Conclusion

The overall project failed to meet its complete conclusion due to the unavoidable circumstances. However, Team Error 404 managed to complete the testing of most of the equipment separately. The 4 IP sensors were designed and tested and were put on the rover. They were tested along with the rover, and the rover moved perfectly. Issues were faced when all 4 IP sensors would turn on at a steep turn. This issue was resolved by instructing the IP sensors to cause the rover to move towards the left until the IP sensor positions were aligned with the aluminum path. The electromagnet was tested with an external 9V voltage supply. The provided voltage proved to be enough for the project's goals. A circuit simulation was designed and created with a toggle switch using LTSpice. However, it was not tested due to the lab being closed. The servo motor circuit was completed and designed using LTSpice. However, this too was not tested due to the circumstances. The servo arm that would hold the electromagnet was 3D designed using AutoCAD, but it was not printed. The IR sensor was successfully designed and tested. On further testing it was observed that the IR sensor range was too low. As a result, a solution to that was thought of, however, it was not implemented to a completion. As mentioned, most of the components were designed and implemented separately, but assembling it all on the rover and carrying out the final tests were still left. However, most of the project objectives were met to a successful fruition.

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LM324-N data sheet
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https://www.ti.com/lit/ds/snosc16d/snosc16d.pdf

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Ikram Haque, fellow classmate
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Mushfique Ahmed, former ECE student at TTU WCOE
Akhil Kapadia, TA

Equipment Support:

ECE stockroom

Appendix – Budget

Project Lab 1	Running Total (Main Project)			Total Estimate		
Direct Labor:						
Category or individual:	*Rate/Hr*	*Hrs*		*Rate/Hr*	*Hrs*	
MD Ridwan Rahman	15	90	$1,350.00	15	120	$1,800.00
Kevin Portillo	15	100	$1,500.00	15	120	$1,800.00
Michael Bolla	15	95	$1,425.00	15	120	$1,800.00
DL Subtotal (DL)		Subtotal:	$4,275.00		Subtotal:	$5,400.00
Labor Overhead	*rate:*	100%	$4,275.00	*rate:*	100%	$5,400.00
Total Direct Labor (TDL)			$8,550.00			$10,800.00
Contract Labor:						
Lab Assistant (Akhil Kapadia)	40	6	$240.00	40	10	$400.00
Friend(Ikram Haque)	15	0	$0.00	15	5	$75.00
Senior Friend (Mushfique)	15	2	$30.00	15	5	$75.00
Friend(Titus Karuri)	15	0	$0.00	15	5	$75.00
Instructor	200	0	$0.00	200	5	$1,000.00
Total Contract Labor (TCL)			$270.00			$1,625.00
Direct Material Costs:			$756.44			$800.00
(from Material Cost worksheet)						
Total Direct Material Costs: (TDM)			$756.44			$800.00
Equipment Rental Costs:	Value	Rental Rate		Value	Rental Rate	
Flush Wire Cutter (CHP 170)	$4.91	0.20%	$0.96	$4.91	0.20%	$1.01
Tweezers	$2.00	0.20%	$0.39	$2.00	0.20%	$0.41
Oscilloscope	$259.00	0.20%	$50.76	$259.00	0.20%	$53.35
Power Supply	$60.00	0.20%	$11.76	$60.00	0.20%	$12.36
Function Generator	$310.00	0.20%	$60.76	$310.00	0.20%	$63.86
Soldering Iron	$125.00	0.20%	$24.50	$125.00	0.20%	$24.75
Multimeter	$95.00	0.20%	$18.62	$95.00	0.20%	$15.58
IPS Sensors	$15.00	0.20%	$2.94	$15.00	0.20%	$1.77
Total Rental Costs: (TRM)			$170.70			$173.10
Total TDL+TCL+TDM+TRM			$9,747.14			$13,398.10
Business overhead		55%	$5,360.93		55%	$7,368.95
Total Cost:		**Current**	$15,108.06		**Estimate**	$20,767.05

Figure 29: Budget

The budget of the group was accounted for to keep track of the overall cost and expense of the project. The hours provided by each member of the group were added. That is under the DL subtotal. As a result, the **Total Direct Labor = $8,550.** For total contract labor, any kind of assistance from a friend, classmate, TA or the instructor was added. Therefore, the **Total Contract Labor = $270.** All the equipment obtained from the ECE stockroom or bought separately by each member was added under Direct Material Cost. So, **Total Direct Material Cost = $756.** Any equipment borrowed from the ECE stockroom were considered to be rentals and were put under the Equipment Rental Costs. **Total Equipment Rental Cost = $170.** At the end of the project, by adding all these costs up, we get **Total Cost = $15,108.06.**
The **Total Estimated Cost** was **$20,767.05.** Which means that the Total Cost was **$5,699** less than the original total estimated cost. So, project was completed within budget. Most of the cost was saved on Total Contract Labor and Total Equipment Rental Costs. All these values are clearly shown on Figure 29 above.

Appendix – Gantt Chart

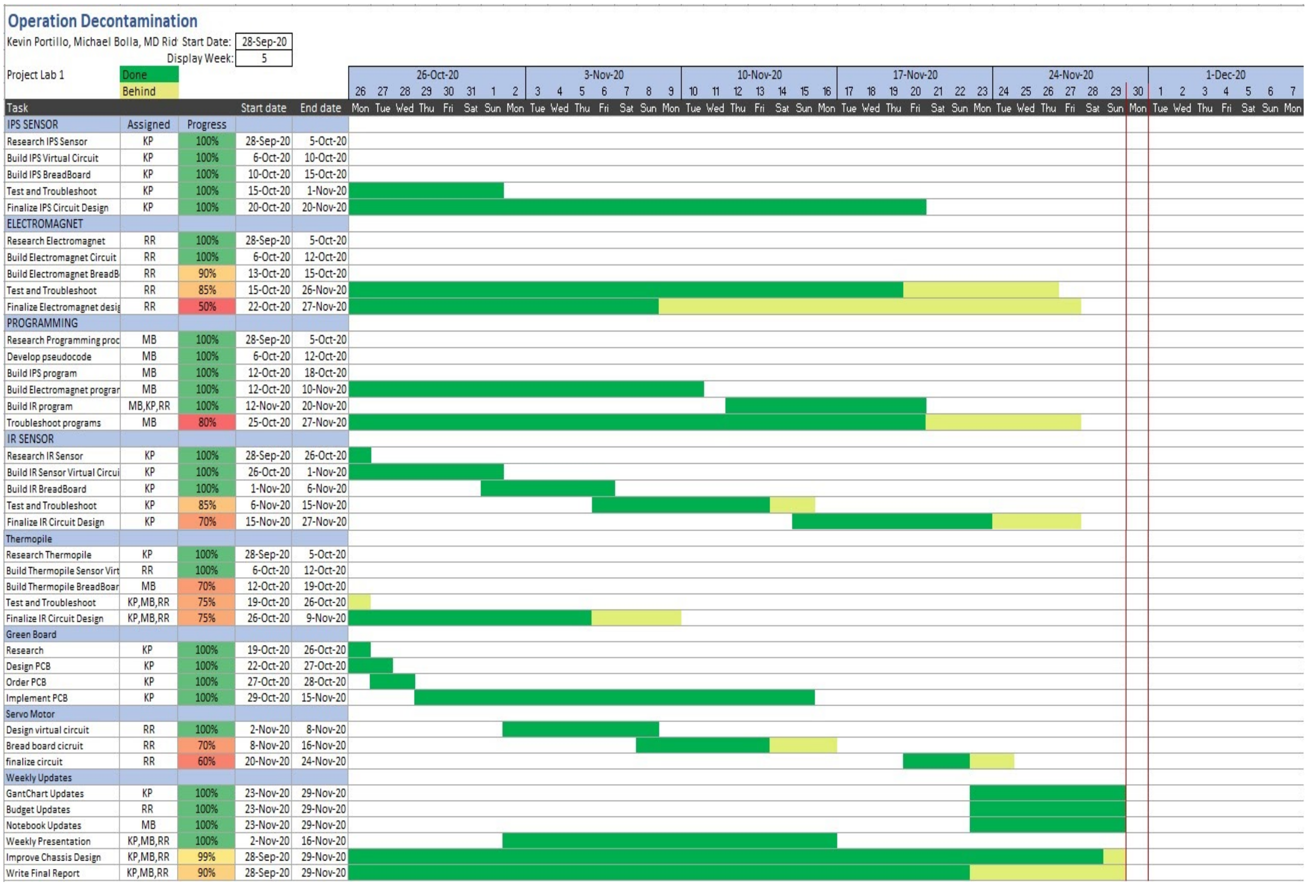

Figure 30: Gantt Chart

As shown on Figure 30 above. Most of the project objectives were met. The things that weren't completed were the physical representations and testing of components such as the Electromagnet, IR sensor, Thermopile, and Servo Motor. This was due to the unavoidable circumstance of having no access to the lab due to the increasing Covid-19 cases. Apart from that, all schematics and simulations objectives of each of the components were met. The final date for the Gantt Chart is considered to be the last day the project was worked on and presented.

Appendix – Code

IPS Code:

```
always@(posedge clock) begin
if(sensorL == 1 || sensorM == 1 || sensorM2 == 1 || sensorR == 1) begin
    width = 0;
    LED0_temp = 1;
    LED1_temp = 1;
    LED2_temp = 1;
    LED3_temp = 1;
    in1_temp = 0;
    in2_temp = 0;
    in3_temp = 0;
    in4_temp = 0;
    end
else if (sensorL == 0) begin //turn left
    width = 1048576;
    LED3_temp = 0;
    in1_temp = 1;
    in2_temp = 0;
    in3_temp = 1;
    in4_temp = 0;
    end
else if (sensorR == 0) begin //turn right
    width = 1048576;
    LED0_temp = 0;
    in1_temp = 0;
    in2_temp = 1;
    in3_temp = 0;
    in4_temp = 1;
    end


else if (sensorM == 0) begin //move forward
    width = 1048576;
    LED1_temp = 0;
    in1_temp = 1;
    in2_temp = 0;
    in3_temp = 0;
    in4_temp = 1;
    end
else if (sensorM2 == 0) begin //move forward
    width = 1048576;
    LED2_temp = 0;
    in1_temp = 1;
    in2_temp = 0;
    in3_temp = 0;
    in4_temp = 1;
    end
```

Figure 31: IPS Code

IR Sensor Code:

```
always@ (posedge clock) begin
if (IR == 1) begin
counter2 <= counter2 + 1;
positiveedge <= positiveedge + 1;
end
else if (IR == 0) begin
counter2 = 0;
positiveedge = 0;
end
end
```

Figure 32: IR Sensor Code