Introduction

Strong evidence of volcanic activity on the long-believed volcanically dormant planet, Mars, was received by the National Aeronautics and Space Administration (NASA) (NYU Tandon, 2023). A request for proposal was issued by NASA for a Mars Rover Robot (MRR) to explore Olympus Mons, the second-highest mountain and largest volcano in the solar system; the data obtained by the rover will be studied to understand past volcanic activity on the planet and weigh the possibility of present-day volcanic activity.

NASA's request for proposal included a two-part mission. The first part involved collecting a rock sample and returning it to the start tile for analysis. The second part involved climbing the steep peak of Olympus mons and taking a picture from the top. NASA required the use of a sensor to aid the rover in precise navigation (NYU Tandon, 2023)

Requirements

VEX robotics components, a gyro and ultrasonic sensor, generic prototyping electronics, Arduino UNO board and IDE, and Fusion 360 were used in this project. The VEX components were used to make up the hardware and structure of the rover. Four 4-inch wheels were used to maintain stability on rough terrain, a 84 to 60 to 84 gear configuration with a motor in the center, and a 5/7 gear ratio so that the torque would be increased to traverse steep ramps. Flat plates were also incorporated in the center to contain the electronic components as well as to carry the rock sample. The robot must fit within a 15 in x 15 in footprint with no more than two motors used for the robot. The two types of sensors, prototyping electronics, and an Arduino UNO board (and Arduino IDE) were used to program the movement of the rover. A gyro, ultrasonic, touch or IR obstacle sensor could be incorporated in the design. Both gyro and ultrasonic sensors were used in our rover. Arduino IDE primarily uses C/C++, and the lab manual was used for additional help. The necessary libraries were downloaded from the lab manual. Fusion 360 was used to create a virtual representation of our design.

Procedures

3.1 Physical Construction

The physical construction of the robot started with a rectangular shaped body. A 10 in metal bar was used to hold the width of the robot and two 12.5 inch metal bars were then connected perpendicular in the inside of the robot with X inches spaced in between. Two chassis rails were then connected in between the two 12.5 inch metal bars, creating the base of the robot. Two 4-inch wheels were added with a 84 to 60 to 84 gear ratio to the motor that were attached to the bottom of the base of the robot on each side of the robot. Rubber bands were then added to each wheel to create friction. To secure the wheels from any damages that may occur, 12.5 in metal bars were placed on the outer walls of the robot. A metal bar was then added to the chassis rails perpendicular to the floor for the rock sample. The Fusion 360, 9V battery, gyro, and arduino UNO board and IDE were placed in the chassis rail and the ultrasonic was placed in front of the robot.

3.2 Software Setup

The Vex library was imported into the global area where Gyro and Vex were assigned. The triggerPin was assigned 11 and echoPin was assigned 10 and assigned to the ultrasonic sensor. Motors were also assigned to 4 and 1 on the arduino. In the setup area Vex, ultrasonic, and gyro were initialized.

The Robot used the gyro to check the initial angle and used the ultrasonic to check the distance between the robot and the wall. The ultrasonic sensor checks if the distance between the robot and wall is greater than five centimeters. If the distance is greater than five centimeters, that concludes the robot is not yet at the destination and will continue to move forward until the distance between the robot and the wall is less than five centimeters. At every interval where the ultrasonic checks the distance, the gyro would check the angle of the robot. It compares the current angle of the robot to the initial angle. If the difference between the two angles is off by 3 degrees left, the robot would turn to the right until the current angle is equal to the initial angle. If the difference between the two angles is off by 3 degrees right, the robot would turn to the left until the current angle is equal to the initial angle. When the robot is less than five centimeters away from the wall, the robot will back and start initiation a turn (Figure 1).

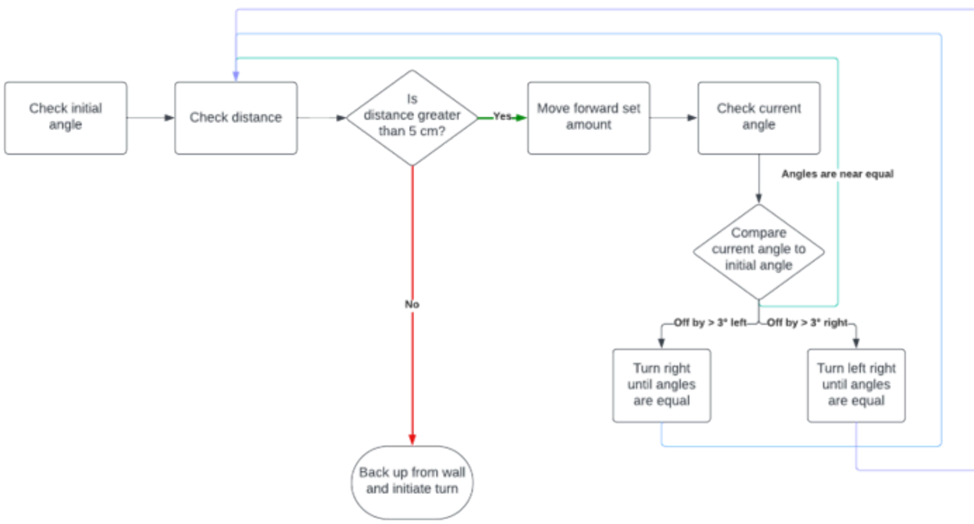


Figure 1: Code flow chart of the Robot Moving Forward

When the robot reached the wall, the robot checked the initial angle. Without the gyro sensor, the robot turned a set amount and then checked the current angle. If the difference between the current angle and initial angle is greater than 3 degrees left, it would turn right until the robot is turned properly. If the difference between the current angle and initial angle is greater than 3 degrees right, it would turn left until the robot is turned properly (Figure 2).

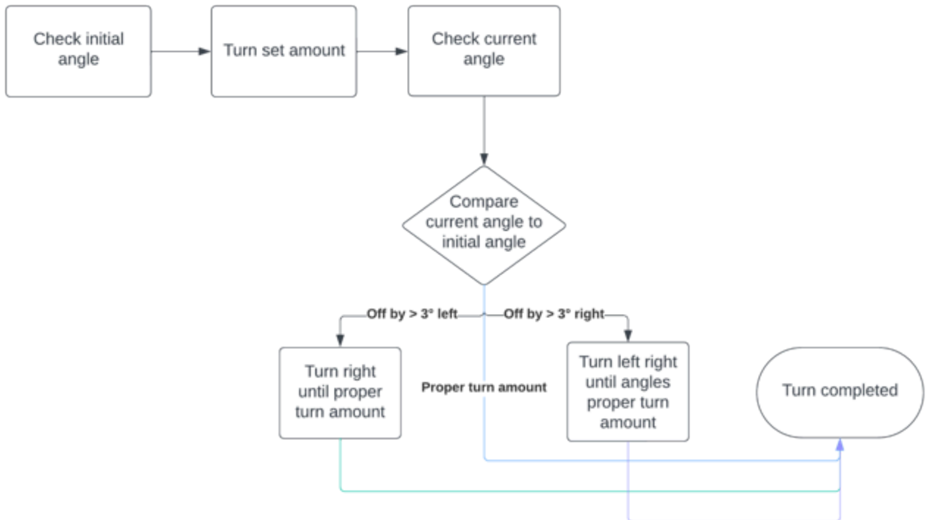


Figure 2: Code Flow Chart of the Turn Function

3.3 Software Troubleshooting

Milestone and Final Product Requirements

To meet the Benchmark A requirements, the robot had to reach the rock sample, but the rock did not have to be picked up. A Preliminary Design Investigation (PDI), which laid the groundwork for the project and outlined the project idea, inspiration, and goals, was also one of the requirements. An updated Engineering Notebook as well as an STL and 3MF (Cura Project file) of the company logo had to be submitted. Benchmark A was due at the end of Model Shop Session II.

To meet the Benchmark B requirements, the robot had to carry the rock sample, and return to the start tile. Moreover, a sensor had to be implemented and used to aid the robot's navigation. An STL and 3MF (Cura Project file) of the company logo had to be approved by the ProtoLab TA through the 3D printing submission portal on the EG website. An updated Engineering Notebook was also required to meet the requirements. Benchmark B was due at the end of Model Shop Session III.

For commissioning, the tasks for Benchmarks A and B had to be completed. Specifications for the robot had to be met. The highest point of the mountain had to be reached by the robot, and a complete stop had to be made at the peak. A print of an STL file of the company logo or extra credit print, as well as an approval from the ProtoLab TA were required. An updated engineering report had to be submitted for commissioning. A special login information was used to submit the deliverables for the project. The submission deliverables include: final presentation, final Arduino program, final circuit diagrams, initial sketch, all the drawings of the design (initial through final), a video walkthrough, final Microsoft Project schedule, final cost estimate, resume(s), final Engineering Notebook/project journal, and a Final Design Report (FDR).

Results

The Benchmark A requirements were successfully met by the deadline. Necessary library files were downloaded from the EG website, and the VEX library was included in the Arduino file. A while loop was used to turn the robot towards the rock, and a gyro sensor was used to navigate the robot. An initial cost estimate for the project was created (Table 1).

Table 1: Cost Estimate for Benchmark A

Resource	**Cost per Unit**	**Quantity**	**Cost**
Wire Motor 393	$16.99	2	$33.98
Assorted Electronics Components	$49.99	1	$49.99
7.2V Robot Battery	$34.99	1	$34.99
Miscellaneous	N/A	N/A	$49.22
Projected Labor	$50.00	50	$2,500.00
Total			$2,668.18

The robot was designed using CAD in Fusion 360 before being constructed. The CAD assembly consists of Vex C-Channels, a plate, four 4-in all purpose wheels, gears, two 393 motors, and a battery (Figure 1).

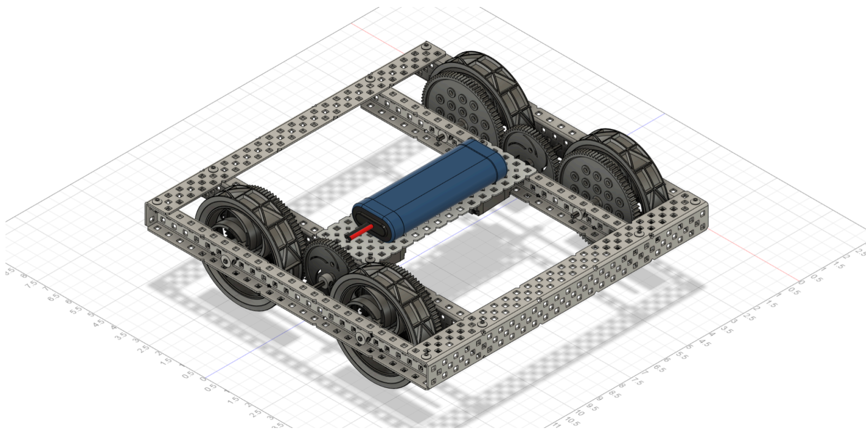


Figure 3: Initial Isometric View of the Robot in Fusion 360

The placement of the two 393 motors can be seen in the top view of the robot (Figure 2).

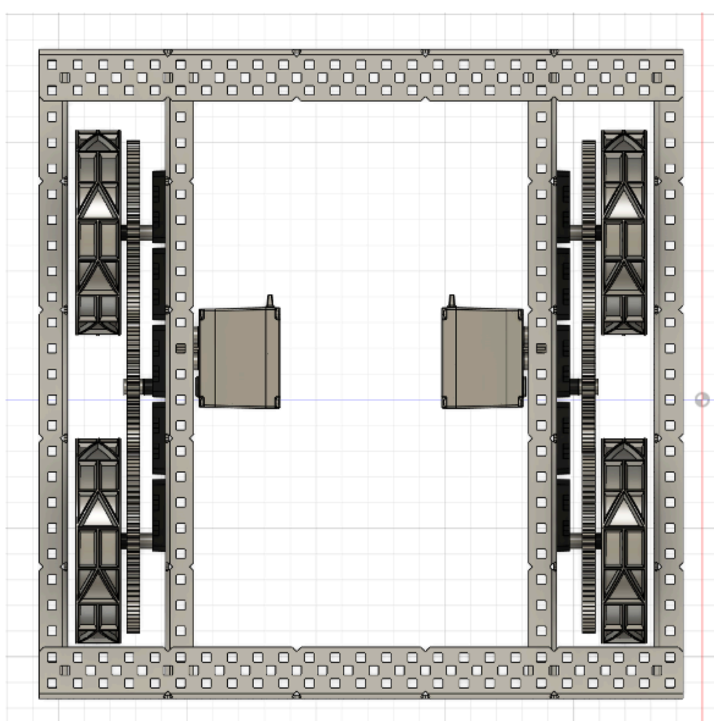


Figure 4: Initial Top View of the Robot in Fusion 360

The use of 4-inch wheels and the 84 to 60 to 84 gear configuration can be seen by the side view of the robot (Figure 3).

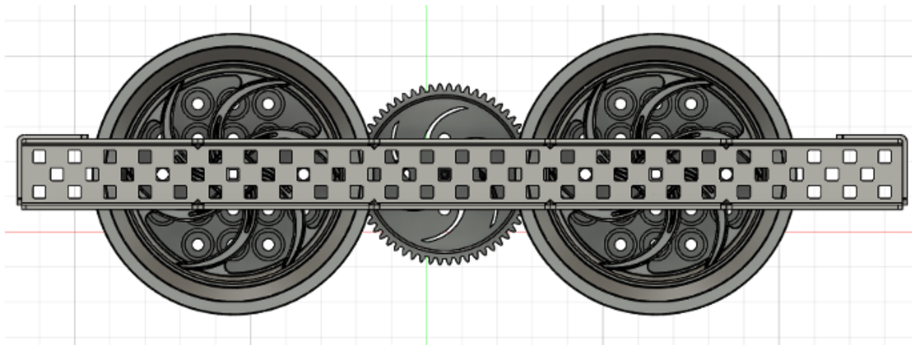


Figure 5: Initial Side View of the Robot in Fusion 360

The spacing between the gears and the wheels can be seen in the front view of the robot (Figure 4).

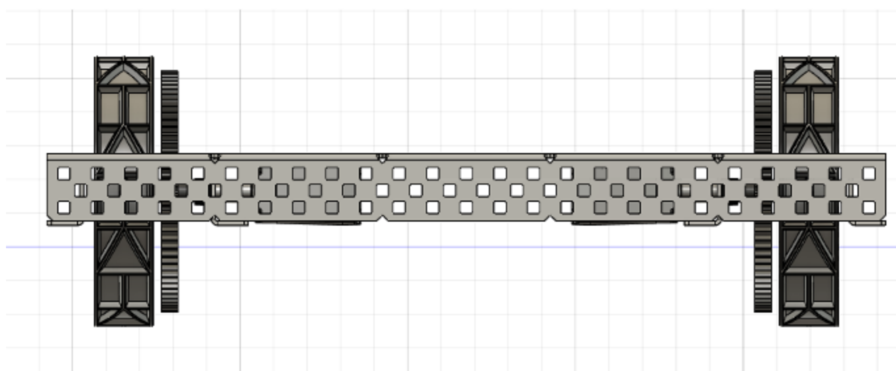


Figure 6: Initial Front View of the Robot in Fusion 360

The initial robot with the breadboard and Arduino UNO can be seen from a top view (Figure 5).

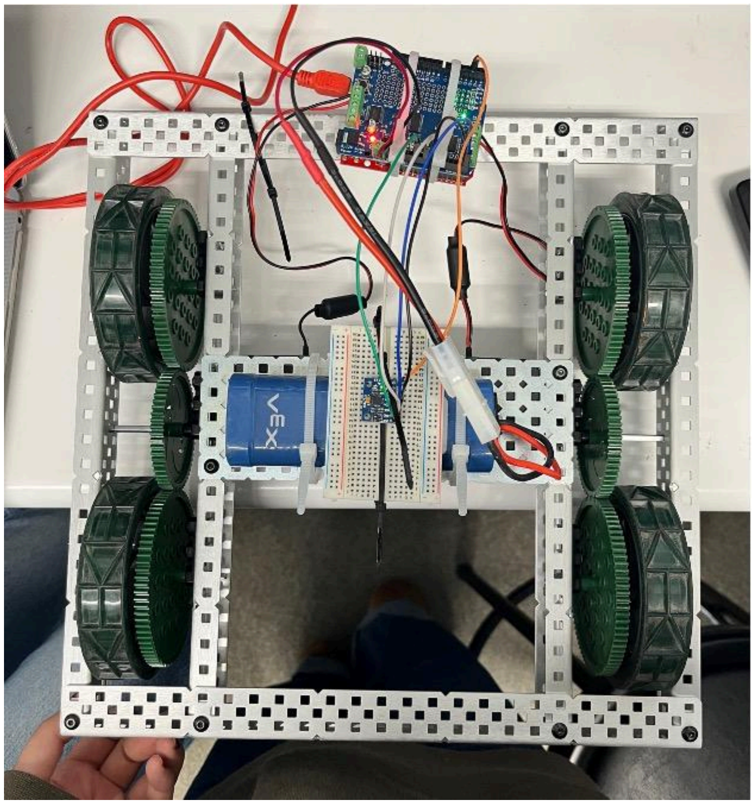


Figure 7: Initial Robot Drivetrain

The CAD sketch of the entire robot was created (Figure 6). The updated sketch shows the reduced width of the robot. It also shows the use of chassis rails, which were used instead of plates, to hold the Arduino UNO board, gyro and ultrasonic sensors, and battery.

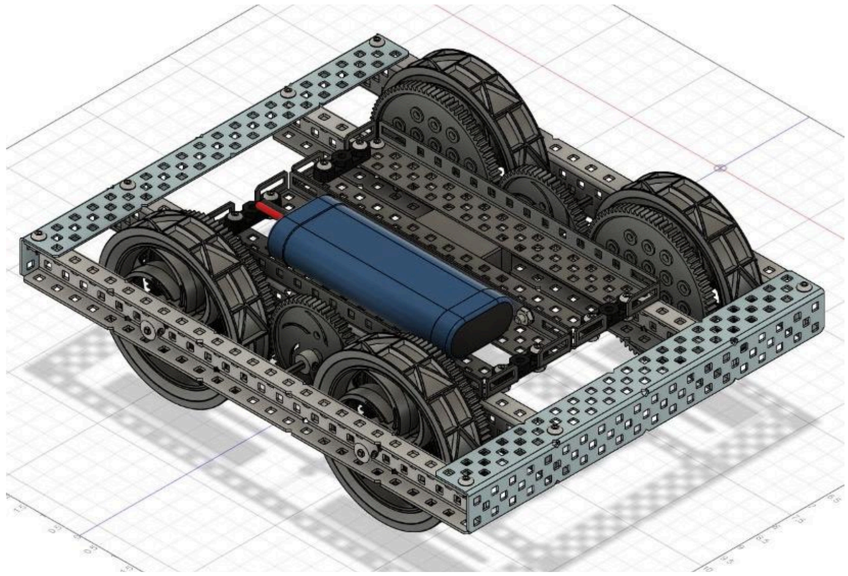


Figure 8: Isometric View of the Robot for Benchmark A in Fusion 360

The use of chassis rails is shown in the top view of the robot (Figure 7). The placement of the battery can also be seen.

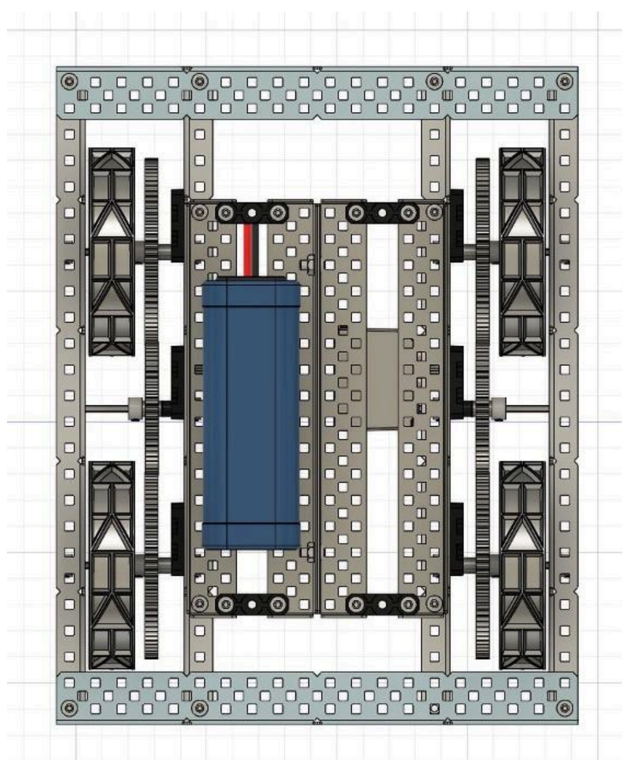


Figure 9: Top View of the Robot for Benchmark A in Fusion 360

The use of 4-inch wheels and the 84 to 60 to 84 gear configuration is also shown through the side view for Benchmark A (Figure 8).

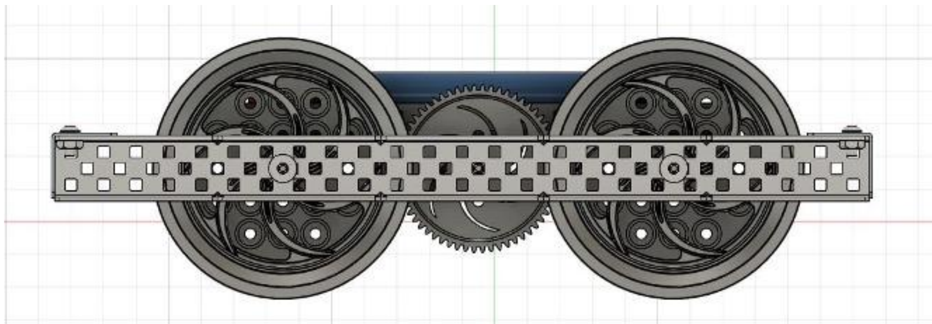


Figure 10: Side View of the Robot for Benchmark A in Fusion 360

The reduction in the width of the robot can be better seen by the front view of the robot for Benchmark A (Figure 9).

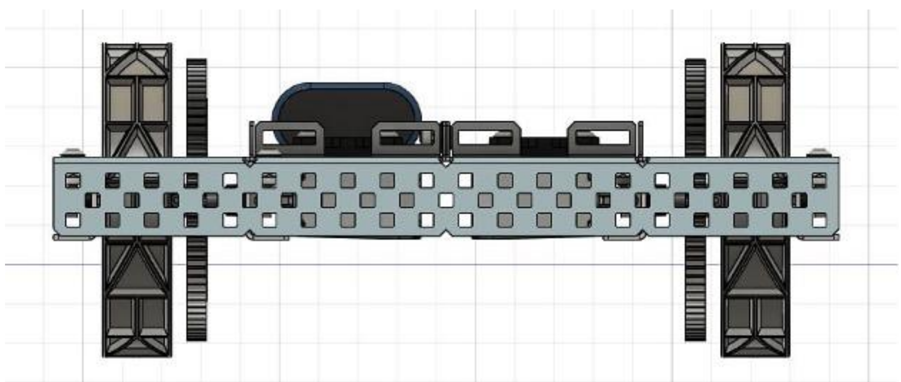


Figure 11: Front View of the Robot for Benchmark A in Fusion 360

The final Benchmark A robot can be seen from a top view (Figure 10).

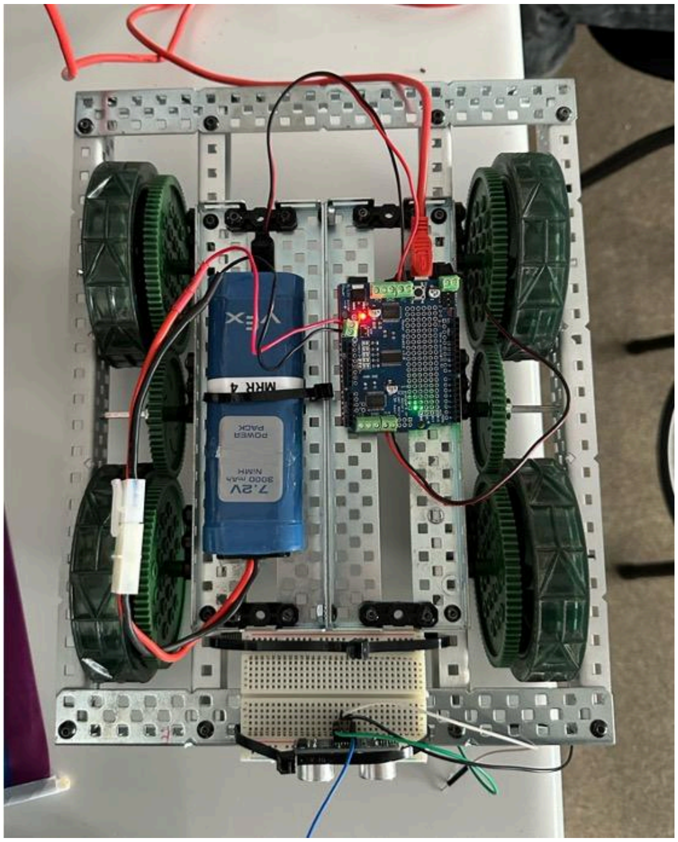
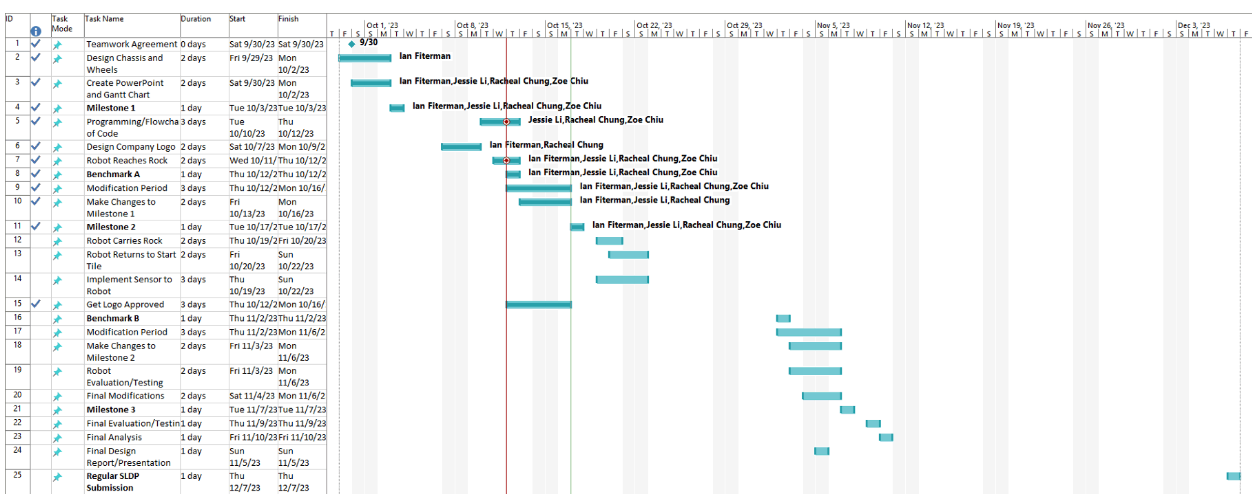


Figure 12: Robot Drivetrain for Benchmark A

The Microsoft Project file was created to keep track of future tasks (Figure 11). A red progress line was added to the file.



ID		Task Mode	Task Name	Duration	Start	Finish
1	✓		Teamwork Agreement	0 days	Sat 9/30/23	Sat 9/30/23
2	✓		Design Chassis and Wheels	2 days	Fri 9/29/23	Mon 10/2/23
3	✓		Create PowerPoint and Gantt Chart	2 days	Sat 9/30/23	Mon 10/2/23
4	✓		**Milestone 1**	1 day	Tue 10/3/23	Tue 10/3/23
5	✓		Programming/Flowcha of Code	3 days	Tue 10/10/23	Thu 10/12/23
6	✓		Design Company Logo	2 days	Sat 10/7/23	Mon 10/9/2
7	✓		Robot Reaches Rock	2 days	Wed 10/11/	Thu 10/12/2
8	✓		**Benchmark A**	1 day	Thu 10/12/2	Thu 10/12/2
9	✓		Modification Period	3 days	Thu 10/12/2	Mon 10/16/
10	✓		Make Changes to Milestone 1	2 days	Fri 10/13/23	Mon 10/16/23
11	✓		**Milestone 2**	1 day	Tue 10/17/2	Tue 10/17/2
12			Robot Carries Rock	2 days	Thu 10/19/2	Fri 10/20/23
13			Robot Returns to Start Tile	2 days	Fri 10/20/23	Sun 10/22/23
14			Implement Sensor to Robot	3 days	Thu 10/19/23	Sun 10/22/23
15	✓		Get Logo Approved	3 days	Thu 10/12/2	Mon 10/16/
16			**Benchmark B**	1 day	Thu 11/2/23	Thu 11/2/23
17			Modification Period	3 days	Thu 11/2/23	Mon 11/6/2
18			Make Changes to Milestone 2	2 days	Fri 11/3/23	Mon 11/6/23
19			Robot Evaluation/Testing	2 days	Fri 11/3/23	Mon 11/6/23
20			Final Modifications	2 days	Sat 11/4/23	Mon 11/6/2
21			**Milestone 3**	1 day	Tue 11/7/23	Tue 11/7/23
22			Final Evaluation/Testin	1 day	Thu 11/9/23	Thu 11/9/23
23			Final Analysis	1 day	Fri 11/10/23	Fri 11/10/23
24			Final Design Report/Presentation	1 day	Sun 11/5/23	Sun 11/5/23
25			**Regular SLDP Submission**	1 day	Thu 12/7/23	Thu 12/7/23

Figure 13: Microsoft Project for Benchmark A

The finalized PDI, updated Engineering Notebook, STL and 3MF (Cura Project file) of the company logo were submitted to meet the requirements.

The Benchmark B requirements were successfully met by the deadline. A vertical pillar was added to carry the rock, and a smaller breadboard was used to remount the ultrasonic sensor. Rubber bands were added on the wheels to increase traction. The rock sample was carried by the robot, and the robot was able to return to the start tile. An ultrasonic and gyro sensor were used to aid the robot's navigation. An STL and 3MF (Cura Project file) of the company logo were approved by the ProtoLab TA through the 3D printing submission portal on the EG website. An updated Engineering Notebook was submitted to meet the Benchmark B requirements. An updated cost estimate for the project was created (Table 2).

Table 2: Cost Estimate for Benchmark B

Resource	**Cost per Unit**	**Quantity**	**Cost**
Wire Motor 393	$16.99	2	$33.98
Assorted Electronics Components	$49.99	1	$49.99
7.2V Robot Battery	$34.99	1	$34.99
Ultrasonic Range Finder	$32.99	1	$32.99
Miscellaneous	N/A	N/A	$72.00
Projected Labor	$50.00	50	$2,500.00
Total			$2,723.95

The CAD sketch of the entire robot was updated (Figure 12). A vertical pillar was added to carry the rock, as shown in the sketch.

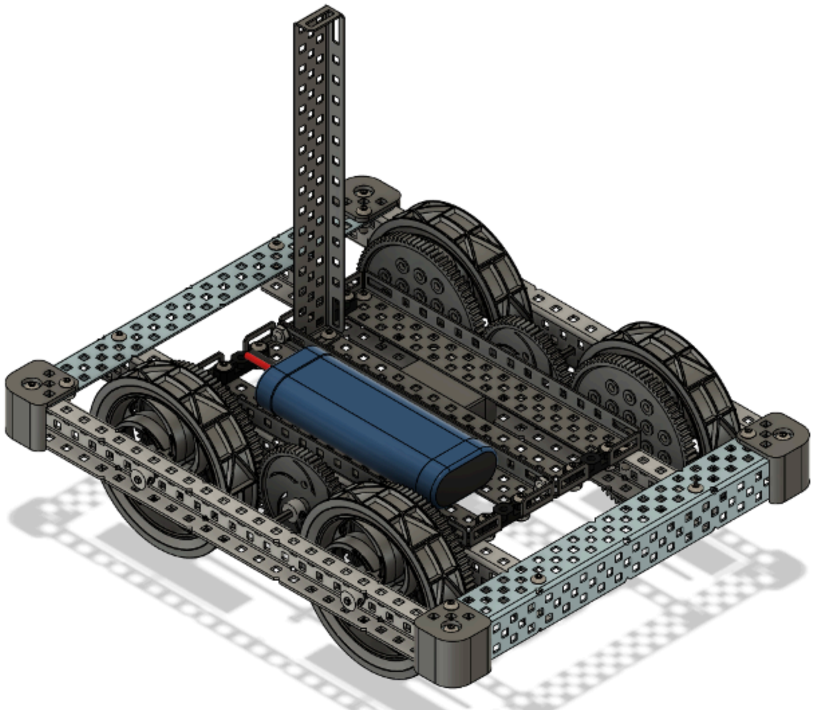


Figure 14: Isometric View of the Robot for Benchmark B in Fusion 360

The corners of the robot often got caught on the walls of the course so corner bumpers were designed and added to the four corners of the robot to prevent damage to the drivetrain and also to smooth the corners in hopes of not getting caught (Figure 13). These were not printed and instead a foam noodle was cut into small pieces to be taped and used as bumpers.

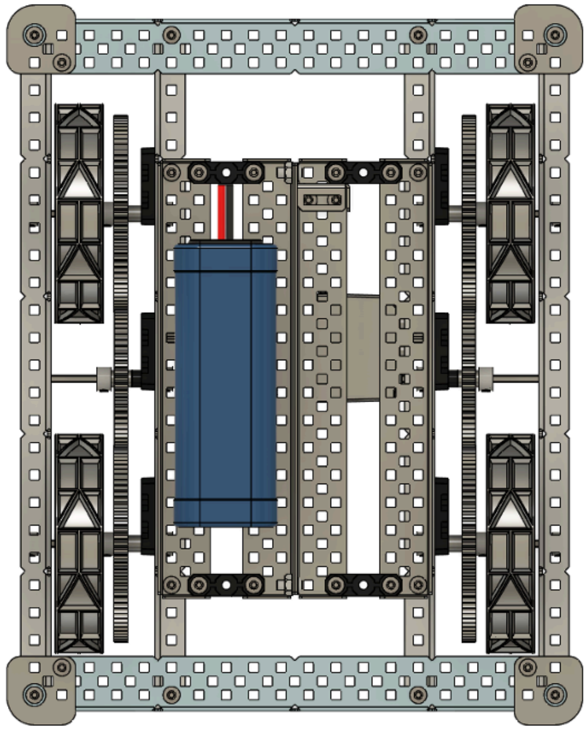


Figure 15: Top View of the Robot for Benchmark B in Fusion 360

The side view of the robot shows the vertical pillar that was added to the drivetrain (Figure 14). The use of 4-inch wheels and the 84 to 60 to 84 gear configuration is also shown through the side view.

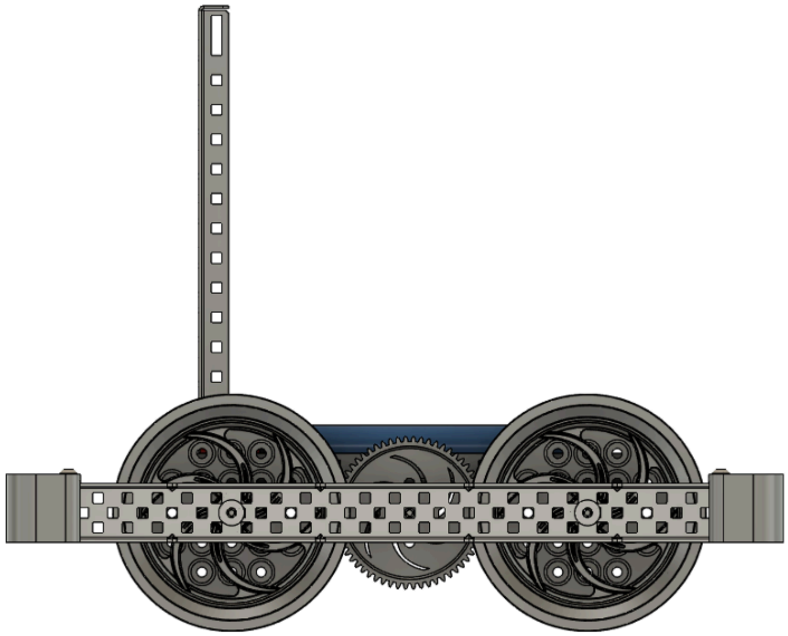


Figure 16: Side View of the Robot for Benchmark B in Fusion 360

The vertical pillar that was added to the drivetrain can also be seen at the front view of the robot (Figure 15).

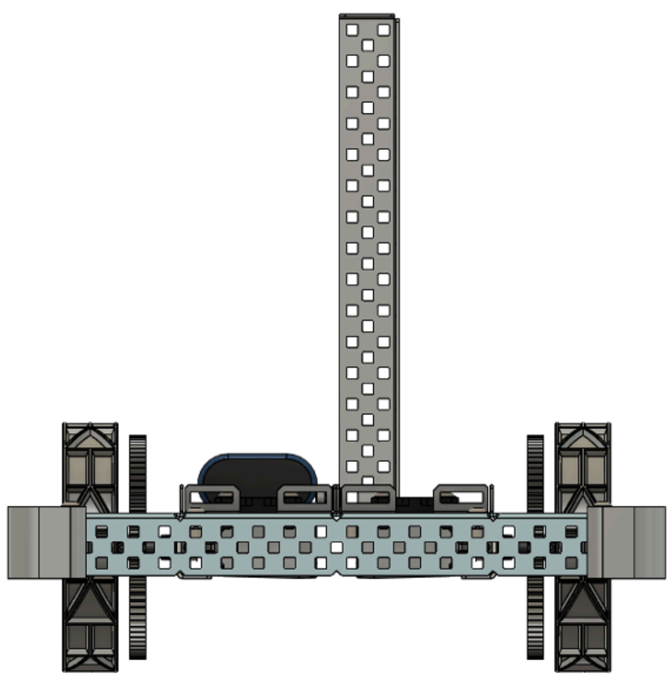


Figure 17: Front View of the Robot for Benchmark B in Fusion 360

As shown in figure 16, rubber bands were added to the wheels to increase traction. The robot would be able to climb up the ramp easily, with the help of increased traction. The ultrasonic sensor was mounted on the smaller green breadboard, and was attached to the front of the robot. Another small blue breadboard was used to mount the gyro sensor, and the breadboard was placed in front of the battery. Electrical tape was used to secure the connection of the wires together and to the breadboard. The foam corner bumpers were also removed as they still got caught on the inner walls of the course (Figure 16).

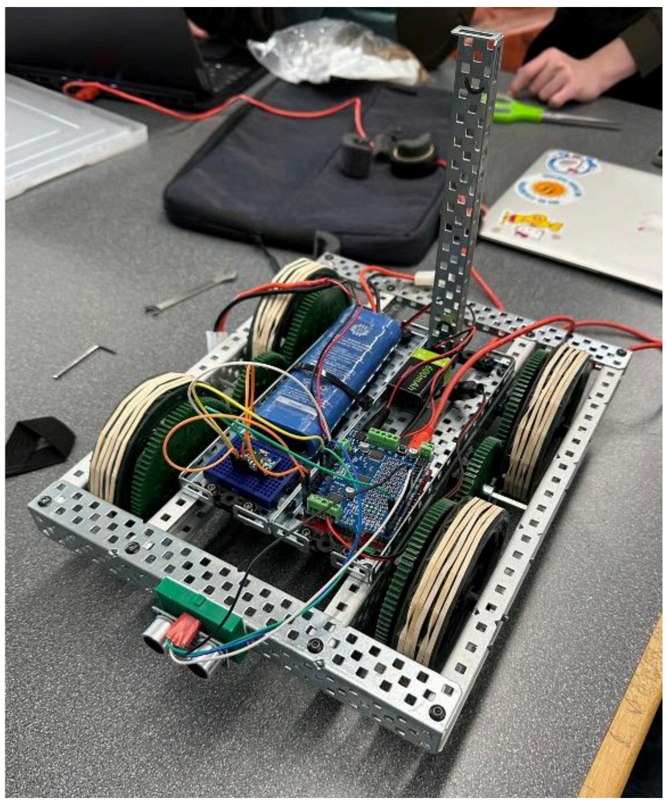


Figure 18: Robot Drivetrain for Benchmark B

The circuit diagram for the robot was created (Figure 17). The gyro sensor was not included in the diagram, but the wiring for the ultrasonic sensor is shown in the diagram. We did not have a schematic diagram for Benchmark B.

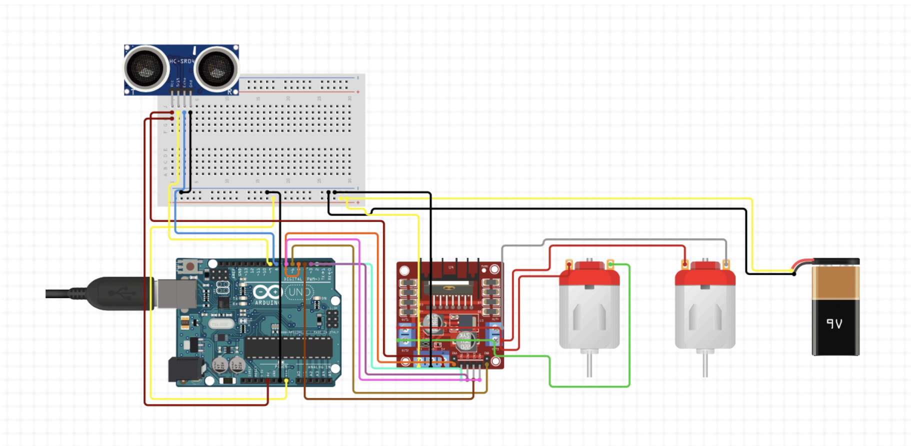
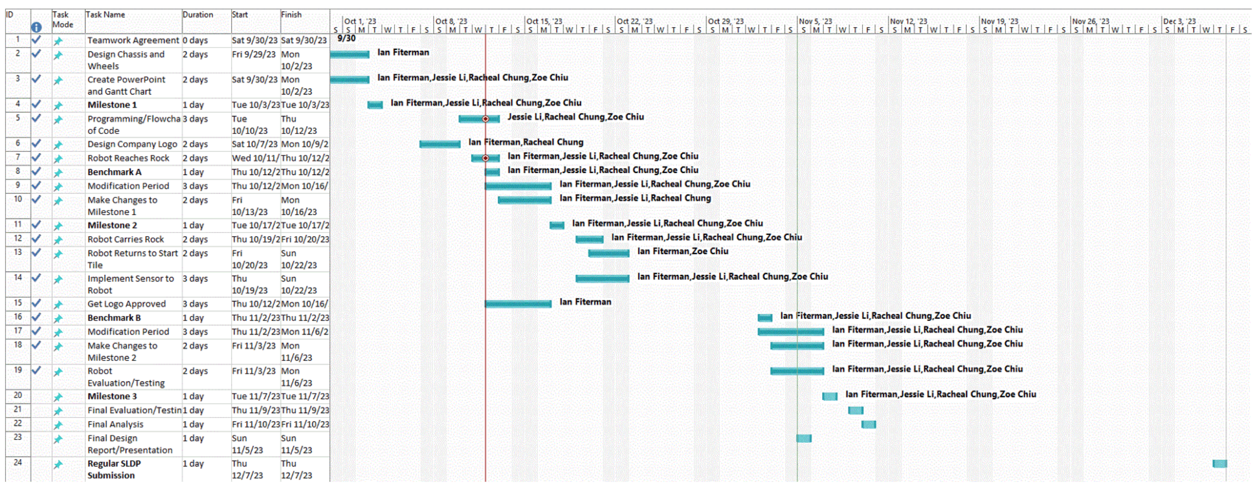


Figure 19: Circuit Diagram for Benchmark B

The original Microsoft Project file was updated and modified to keep track of future tasks, and also check our progress (Figure 18). A red progress line was added to the file.



ID		Task Mode	Task Name	Duration	Start	Finish
1	✓		Teamwork Agreement	0 days	Sat 9/30/23	Sat 9/30/23
2	✓		Design Chassis and Wheels	2 days	Fri 9/29/23	Mon 10/2/23
3	✓		Create PowerPoint and Gantt Chart	2 days	Sat 9/30/23	Mon 10/2/23
4	✓		**Milestone 1**	1 day	Tue 10/3/23	Tue 10/3/23
5	✓		Programming/Flowcha of Code	3 days	Tue 10/10/23	Thu 10/12/23
6	✓		Design Company Logo	2 days	Sat 10/7/23	Mon 10/9/2
7	✓		Robot Reaches Rock	2 days	Wed 10/11/	Thu 10/12/2
8	✓		**Benchmark A**	1 day	Thu 10/12/2	Thu 10/12/2
9	✓		Modification Period	3 days	Thu 10/12/2	Mon 10/16/
10	✓		Make Changes to Milestone 1	2 days	Fri 10/13/23	Mon 10/16/23
11	✓		**Milestone 2**	1 day	Tue 10/17/2	Tue 10/17/2
12	✓		Robot Carries Rock	2 days	Thu 10/19/2	Fri 10/20/23
13	✓		Robot Returns to Start Tile	2 days	Fri 10/20/23	Sun 10/22/23
14	✓		Implement Sensor to Robot	3 days	Thu 10/19/23	Sun 10/22/23
15	✓		Get Logo Approved	3 days	Thu 10/12/2	Mon 10/16/
16	✓		**Benchmark B**	1 day	Thu 11/2/23	Thu 11/2/23
17	✓		Modification Period	3 days	Thu 11/2/23	Mon 11/6/2
18	✓		Make Changes to Milestone 2	2 days	Fri 11/3/23	Mon 11/6/23
19	✓		Robot Evaluation/Testing	2 days	Fri 11/3/23	Mon 11/6/23
20			**Milestone 3**	1 day	Tue 11/7/23	Tue 11/7/23
21			Final Evaluation/Testin	1 day	Thu 11/9/23	Thu 11/9/23
22			Final Analysis	1 day	Fri 11/10/23	Fri 11/10/23
23			Final Design Report/Presentation	1 day	Sun 11/5/23	Sun 11/5/23
24			**Regular SLDP Submission**	1 day	Thu 12/7/23	Thu 12/7/23

Figure 20: Microsoft Project for Benchmark B

A software called Fritzing was used to create the final circuit diagram and the final schematic diagram. The two sensors that were implemented, the gyro and ultrasonic sensor, are shown in the figure below (Figure 19).

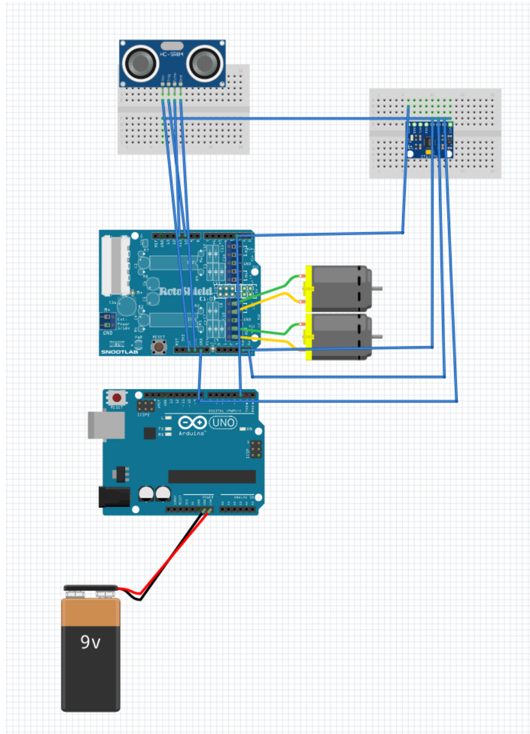


Figure 21: Final Circuit Diagram

The wiring is better shown through the schematic diagram that was created using Fritzing (Figure 20). Both ultrasonic and gyro sensors, as well as the two motors, are directly connected to the motor shield.

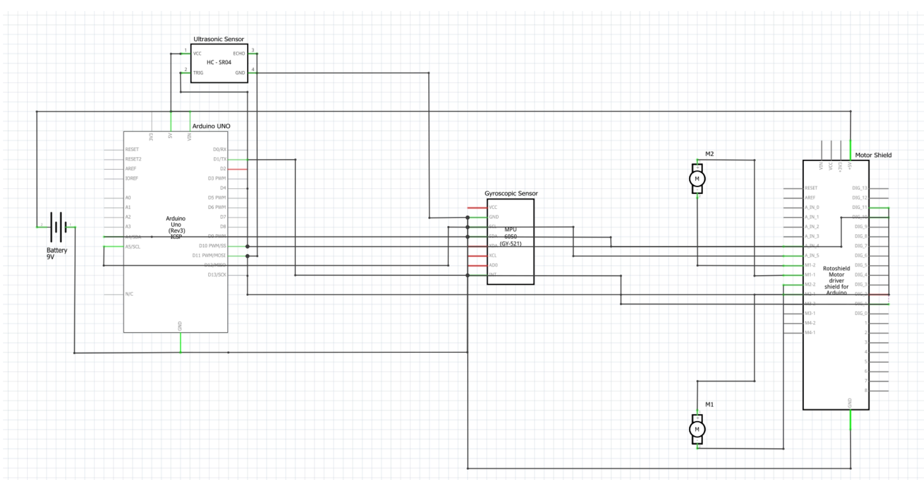
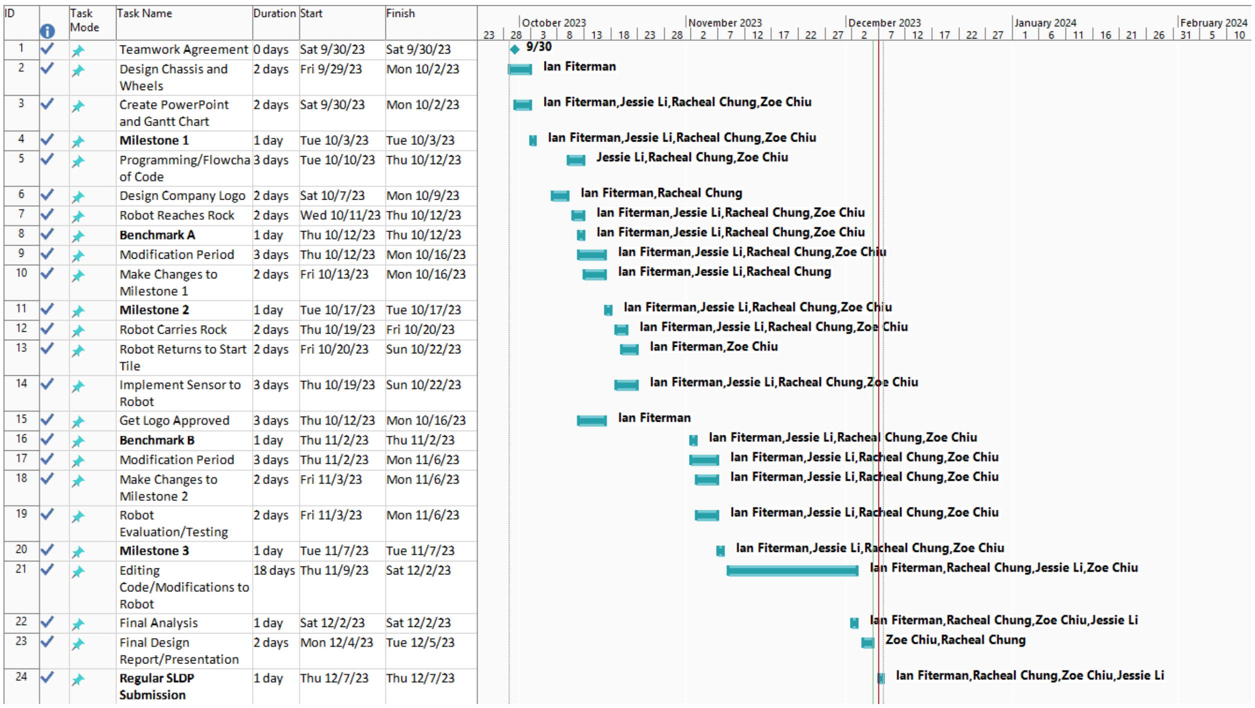


Figure 22: Final Schematic Diagram

The Microsoft Project file was updated based on our group's task schedule (Figure 21). A progress line was added by right clicking and checking the box for adding the progress line.



ID	Task Name	Duration	Start	Finish
1	Teamwork Agreement	0 days	Sat 9/30/23	Sat 9/30/23
2	Design Chassis and Wheels	2 days	Fri 9/29/23	Mon 10/2/23
3	Create PowerPoint and Gantt Chart	2 days	Sat 9/30/23	Mon 10/2/23
4	**Milestone 1**	1 day	Tue 10/3/23	Tue 10/3/23
5	Programming/Flowcha of Code	3 days	Tue 10/10/23	Thu 10/12/23
6	Design Company Logo	2 days	Sat 10/7/23	Mon 10/9/23
7	Robot Reaches Rock	2 days	Wed 10/11/23	Thu 10/12/23
8	**Benchmark A**	1 day	Thu 10/12/23	Thu 10/12/23
9	Modification Period	3 days	Thu 10/12/23	Mon 10/16/23
10	Make Changes to Milestone 1	2 days	Fri 10/13/23	Mon 10/16/23
11	**Milestone 2**	1 day	Tue 10/17/23	Tue 10/17/23
12	Robot Carries Rock	2 days	Thu 10/19/23	Fri 10/20/23
13	Robot Returns to Start Tile	2 days	Fri 10/20/23	Sun 10/22/23
14	Implement Sensor to Robot	3 days	Thu 10/19/23	Sun 10/22/23
15	Get Logo Approved	3 days	Thu 10/12/23	Mon 10/16/23
16	**Benchmark B**	1 day	Thu 11/2/23	Thu 11/2/23
17	Modification Period	3 days	Thu 11/2/23	Mon 11/6/23
18	Make Changes to Milestone 2	2 days	Fri 11/3/23	Mon 11/6/23
19	Robot Evaluation/Testing	2 days	Fri 11/3/23	Mon 11/6/23
20	**Milestone 3**	1 day	Tue 11/7/23	Tue 11/7/23
21	Editing Code/Modifications to Robot	18 days	Thu 11/9/23	Sat 12/2/23
22	Final Analysis	1 day	Sat 12/2/23	Sat 12/2/23
23	Final Design Report/Presentation	2 days	Mon 12/4/23	Tue 12/5/23
24	**Regular SLDP Submission**	1 day	Thu 12/7/23	Thu 12/7/23

Figure 23: Final Microsoft Project

Table 3: Final Cost Estimate

Resource	**Cost per Unit**	**Quantity**	**Cost**
Wire Motor 393	$16.99	2	$33.98
Assorted Electronics Components	$49.99	1	$49.99
7.2V Robot Battery	$34.99	1	$34.99
Ultrasonic Range Finder	$32.99	1	$32.99
Gyroscope Sensor	$20.00	1	$20.00
Miscellaneous	N/A	N/A	$90.00
Projected Labor	$50.00	50	$2,500.00
Total			$2,761.95

During the process of implementing sensors, two problems became a major issue in the designing and coding process. The wires that connected the sensors to the arduino often fell out of the breadboard causing misreadings. However, by using electrical tape it secured the connection between the sensor and the arduino. This made sure all the sensors worked properly and efficiently. Additionally, the gyro sensors were not working properly and needed to be replaced during Benchmark B.

When the robot traversed to the rock sample, the robot often shifted sideways and moved in a slanted path. This would cause the robot to bump into the walls of the obstacles and eventually get stuck at a certain area. To fix this problem, an “if” statement was implemented into the code. By initializing the gyro sensor, the sensor would check if the robot shifted either 3 degrees to the right or left and recenter itself to traverse in a straight line. With this implementation, the robot was able to get to the rocks sample and back to the starting tile without bumping into any of the obstacle walls.

Many issues came along the way with the gyro sensor, as it would output an unreasonable angle. This caused any turning to be off by a couple degrees. Using a trial and error process, these angles were random and often always in the negatives as they were supposed to stay within the ranges of 0 and 90 degrees. To achieve a consistent turn, a turn was added into the code with no utilization of sensors. Then by initializing the gyro sensor, the robot would check the angle and readjust itself. This made sure every turn was consistent.

Conclusion

The robot was successfully designed, built, and programmed to traverse the rocky course. Both benchmarks and commissioning were completed on time. The robot was able to utilize an ultrasonic and gyro sensor to travel in a straight path and turn consistently. The robot also successfully traversed ramp 2, ramp 3, and reached the peak. It completed all the required obstacles and the final total cost of the robot including labor cost was $2,761.95.

The robot could be improved by adding wheels with more traction rather than wrapping rubber bands over the current wheels as these rubber bands get worn out quickly, fall off, and get caught in the gears. Proper mounts for the battery, Arduino UNO, and breadboards could also be designed and 3D printed to allow for less movement of these pieces on the robot. The Keps nuts can be replaced with Nylock nuts to better secure the screws allowing for a more robust robot.