

# Functional Robot for ID and Retrieval

## Final Presentation

Senior Design Team 44



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# Agenda

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- Concept Generation
- System Architecture
- Design Review
- Prototype Hardware
- Test Methods and Results
- Objectives and Requirements Validation
- Lessons Learned

# Introduction

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## Problem:

- Our objective is to develop a robot that utilizes Noblis's orchestrated autonomy system and serves a specific task of our choice.

## Solution:

- We've chosen to create a robot with the ability to collect Carbon Monoxide data and integrate it into the Noblis disaster relief fleet.

# Requirements

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1. Frame Strength (Q)
2. Ground Clearance (Q)
3. Battery Life (Q)
4. Peak Motor Torque (Q)
5. Top Speed (Q)
6. Stay Within Budget (Q)
7. Path Planning (B)
8. Object Detection (B)
9. Information Exchange (B)
10. Establish Communication Server (B)
11. Send and Receive Json Messages (B)
12. Carbon Monoxide Sensitivity (B)

\* Q = Quantitative  
B = Binary

# Objectives

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- Maneuverability on pavement and grass + small gradients (<5%)
  - Does it get stuck (Y/N)
  - Motors do not overheat (Q)
  
- Weather Resistant
  - Electronics are dry in event of light precipitation (Y/N)

# Concept Generation

Concept Screening Table				
	Concepts			
Selection Criteria	Vinyl Chloride Gas Detection Robot	Transport Vehicle	Scout Robot	Mobile Arm
Cost-effectiveness	+	-	0	-
Viability	+	+	0	0
Beneficial	+	+	0	0
Functionality	+	+	0	0
Team Expertise	0	+	0	-
Scalability	0	0	0	0
Sum + 's	4	4	0	0
Sum 0's	2	0	6	4
Sum -'s	0	1	0	2
Net Score	4	3	0	-2
Rank	1	2	3	4
Continue	YES	YES	YES	NO

# System Architecture

Feature: Blind Spot Frame

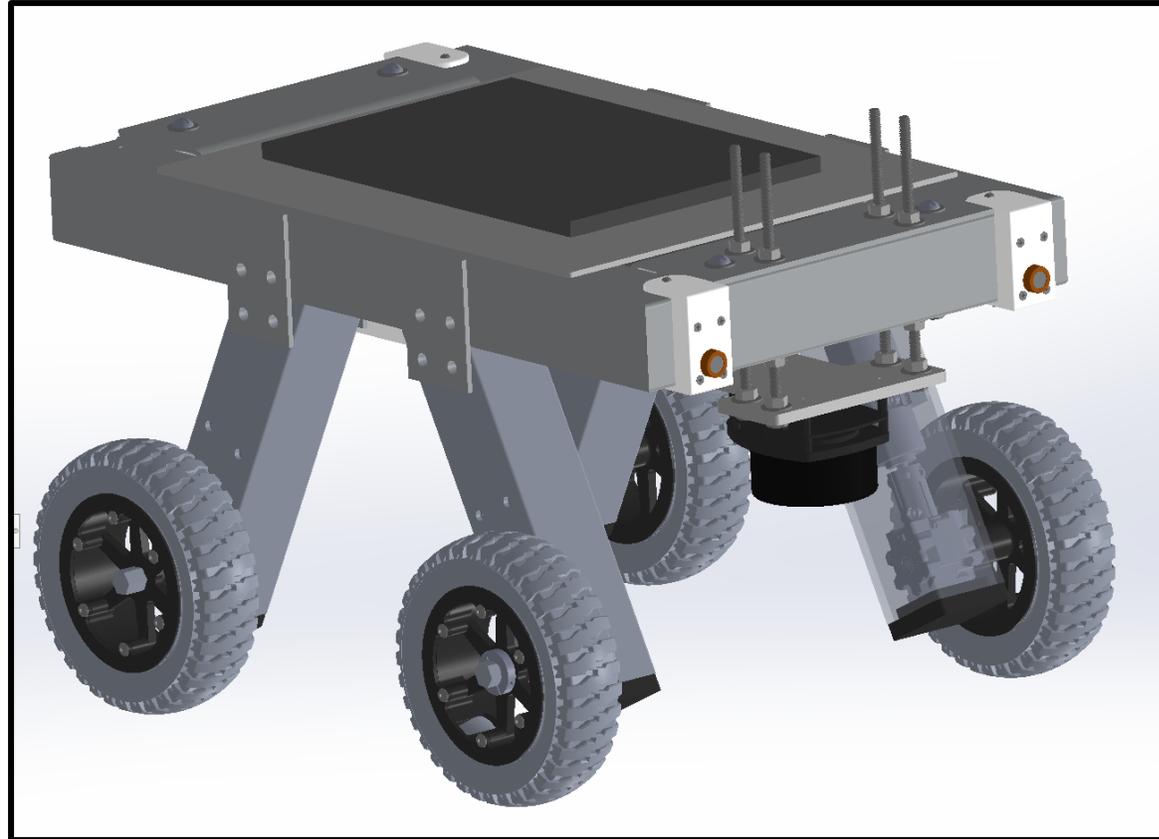
Benefits:

- Provides a clear view of the robot's blind spot
- Provides a high level of protection for the robot's sensors
- Provides a high level of strength
- Fulfills the object detection requirement



# Design Review

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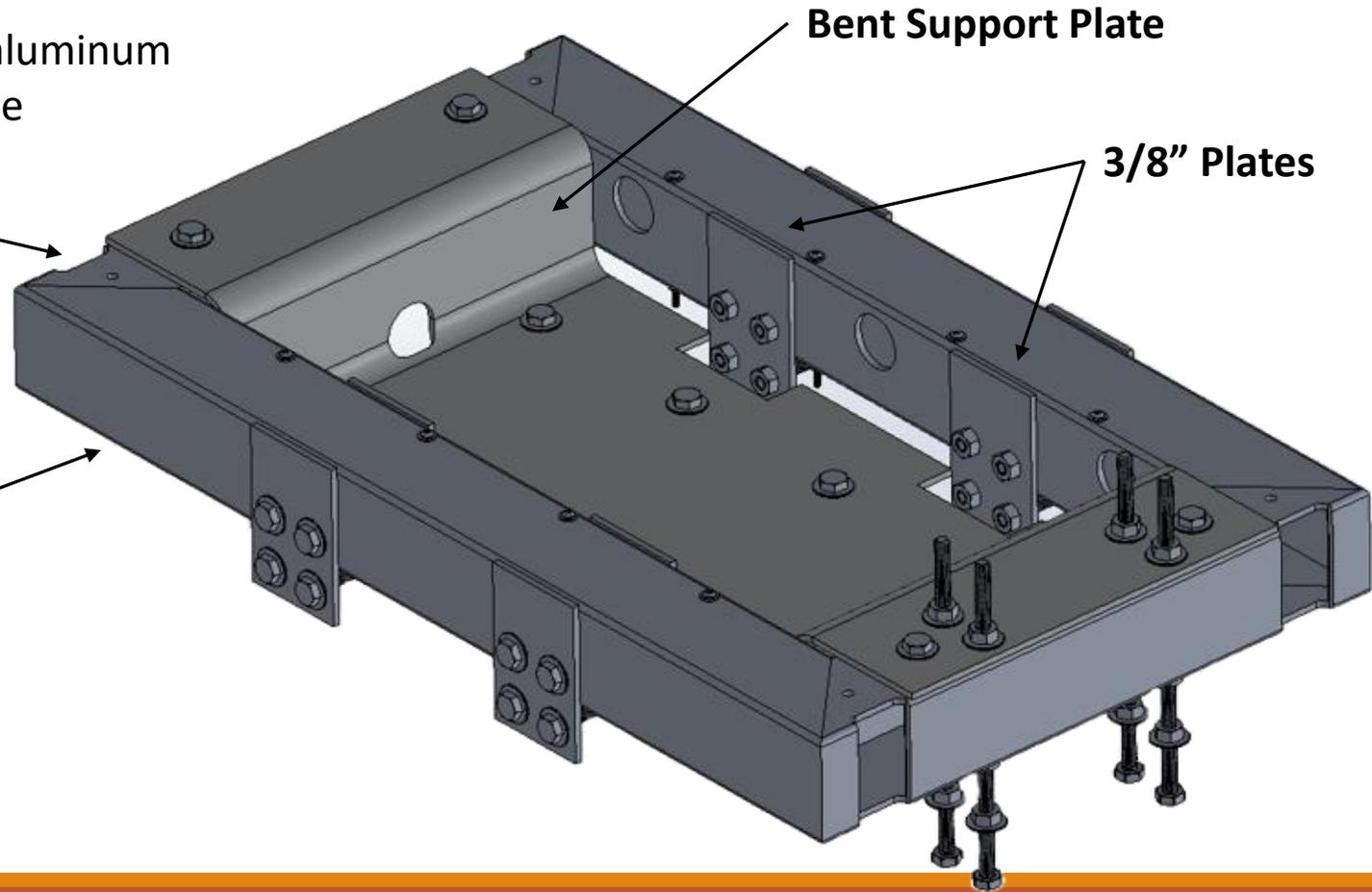


# Design Review Aluminum Frame

## Overview

The frame is made from 6061 T6 aluminum plate and square tube. Square tube components are welded together. Everything else is bolted together using 3/8" hardware.

**4" X 4" Square Tube Frame**



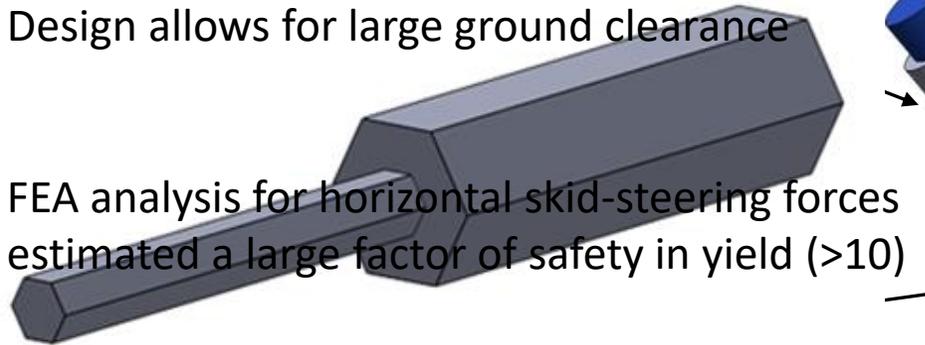
# Drive Train Assembly

- Leg is made from 6061 aluminum square tubing, which protects the motor from damage

Electric Motor

- Design allows for large ground clearance

- FEA analysis for horizontal skid-steering forces estimated a large factor of safety in yield ( $>10$ )



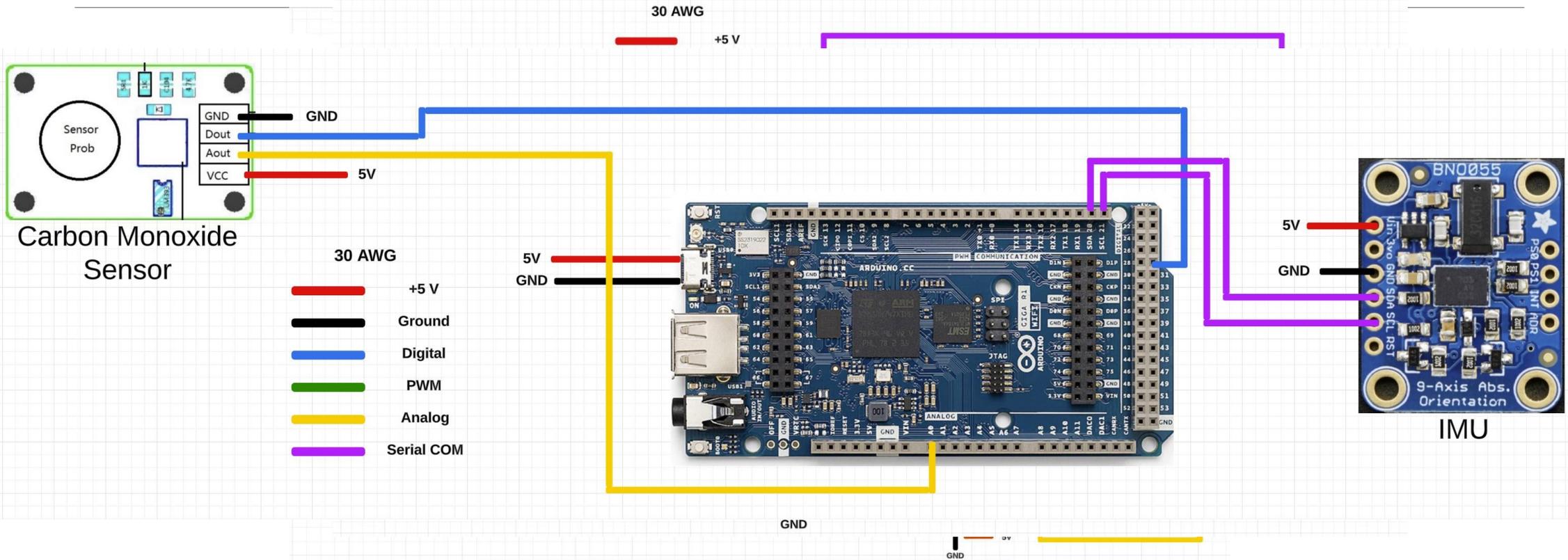
Custom Hex-Shaft



Whe

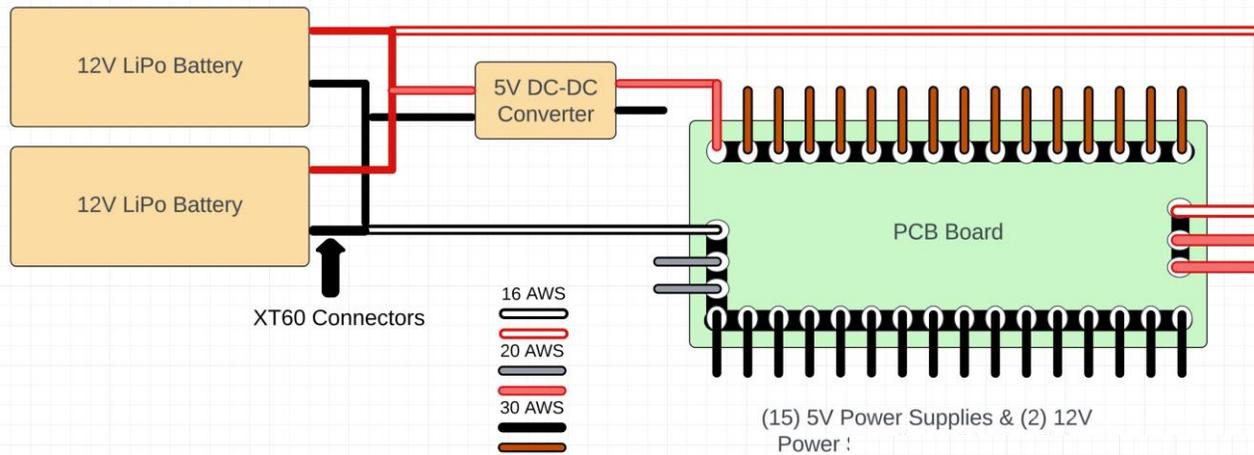


# Electrical Hardware



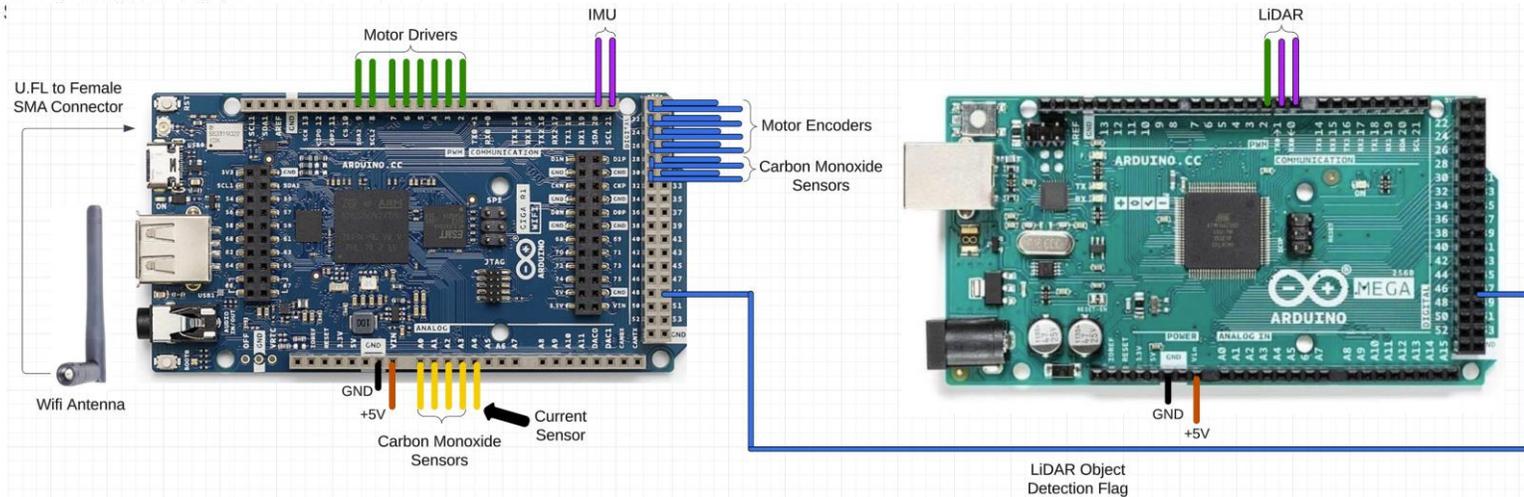
Motor - I2C Interface  
 LIDAR - I2C Interface

# Electrical Hardware Cont.



Power Supply

MCU Communication



# Prototype Hardware



# Frame Assembly

First, we used a band saw to cut a 12' piece of aluminum square tube into pieces that would make up the frame.

Second, we used the CNC machine to add features to our parts such as holes and angled cuts.

Third, we used the plasma cutter to create our flat parts out of a piece of 1/8<sup>th</sup> aluminum sheet metal.



# Frame Assembly

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Next, we used the press brake to bend the support plate into shape.

We then welded the four frame square tube parts together.

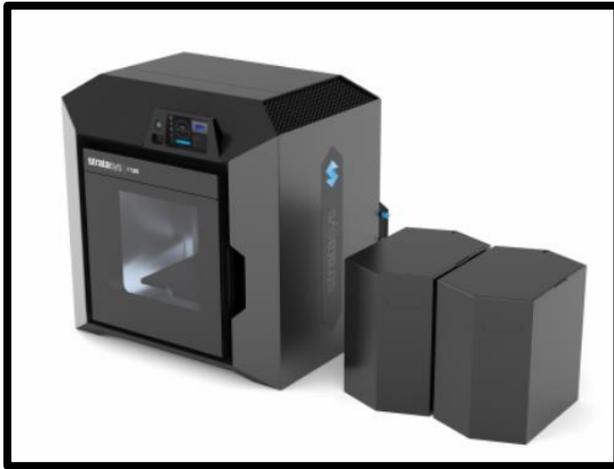
After deburring our parts, we assembled the metal frame.



# Frame Assembly

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To create our ABS components, we fabricated them using the Stratasys F120 3D Printer.

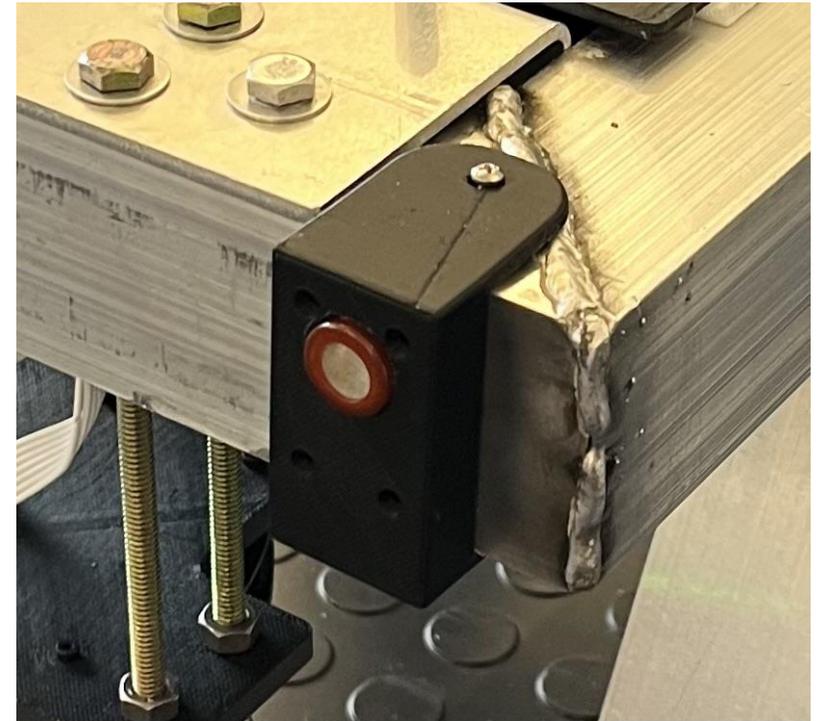


# CO Sensor

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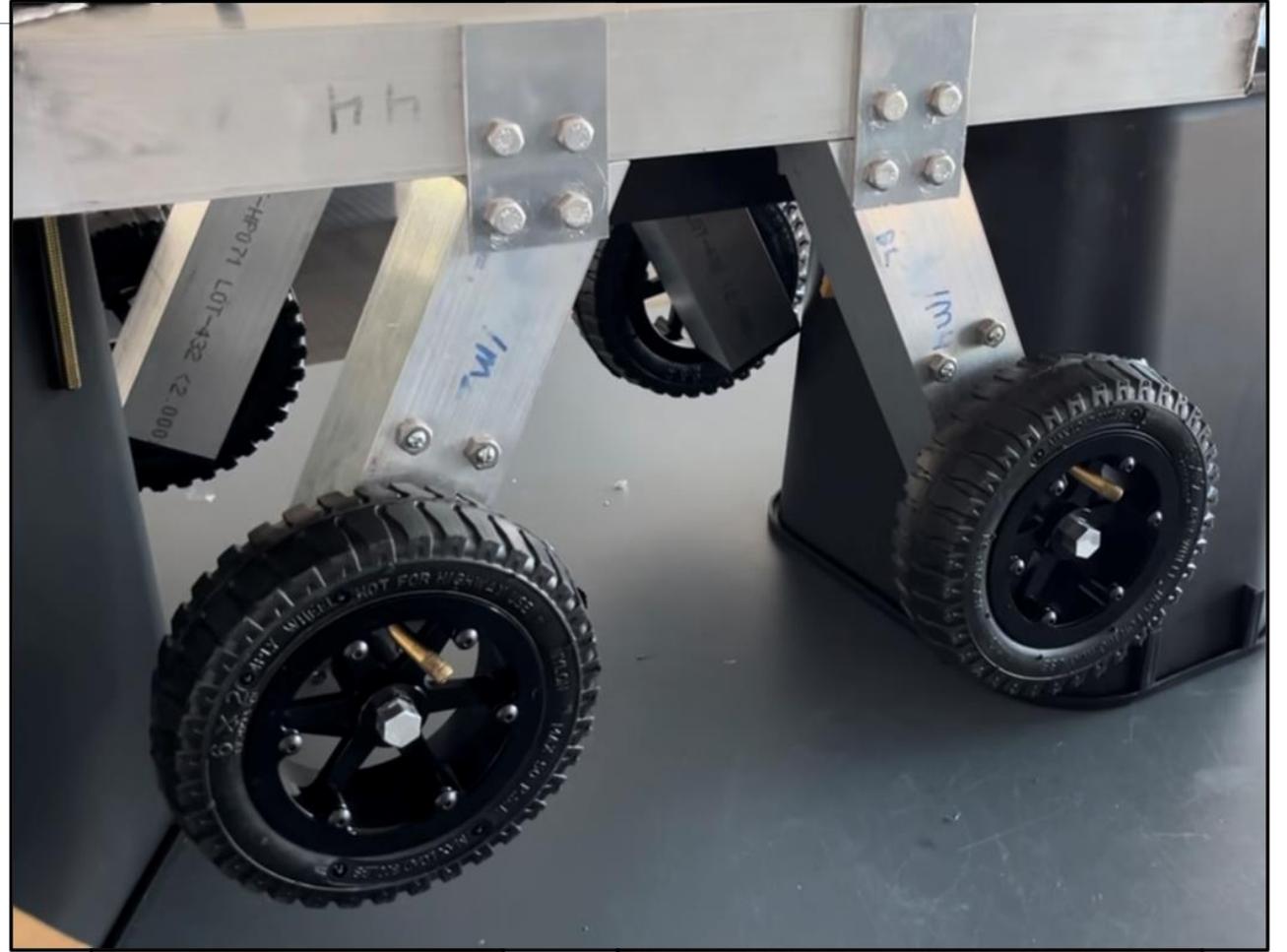
We 3D printed the mount for the CO sensor and screwed it in on the external frame. The sensor clicks in, and the circuitry is contained within the frame.

- Detects presence as well as concentration of carbon monoxide gas
- Operates in 10 – 50 deg C
- Has a concentration sensor range up to 10,000 ppm



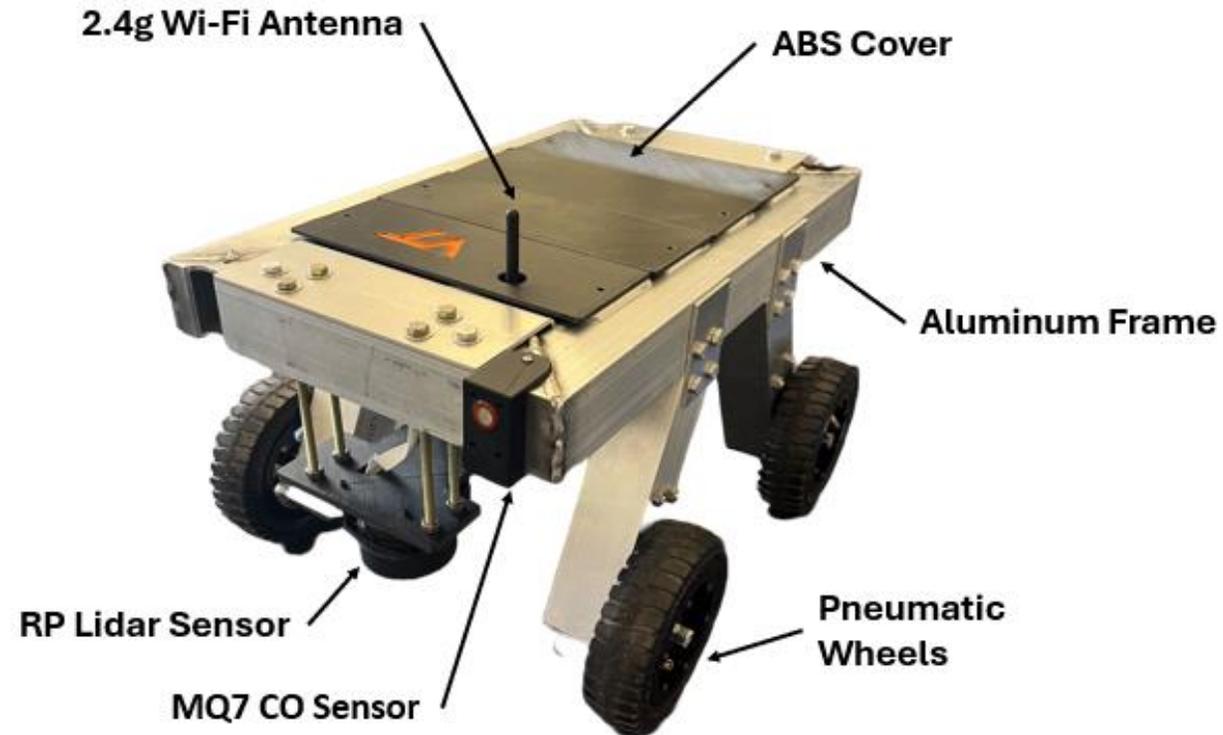
# Drive Train Assembly

- Hex shafts were machined using an aluminum rod and the manual CNC mill at Applied.
- Motor assemblies were inserted into the leg tubes.
- The wheels and shaft collars were attached, completing the drive train assemblies.

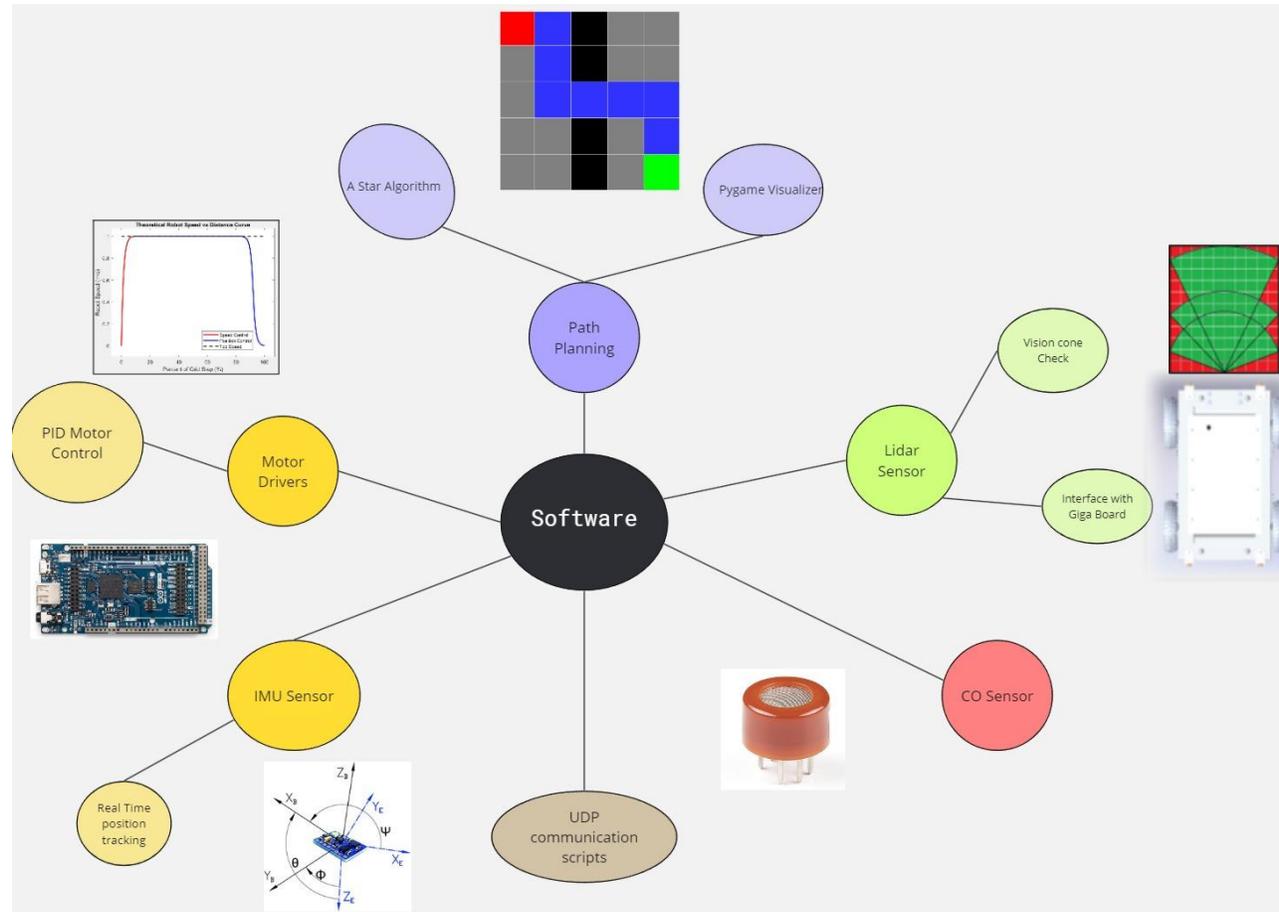


# Completed Physical Prototype

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# Prototype Software



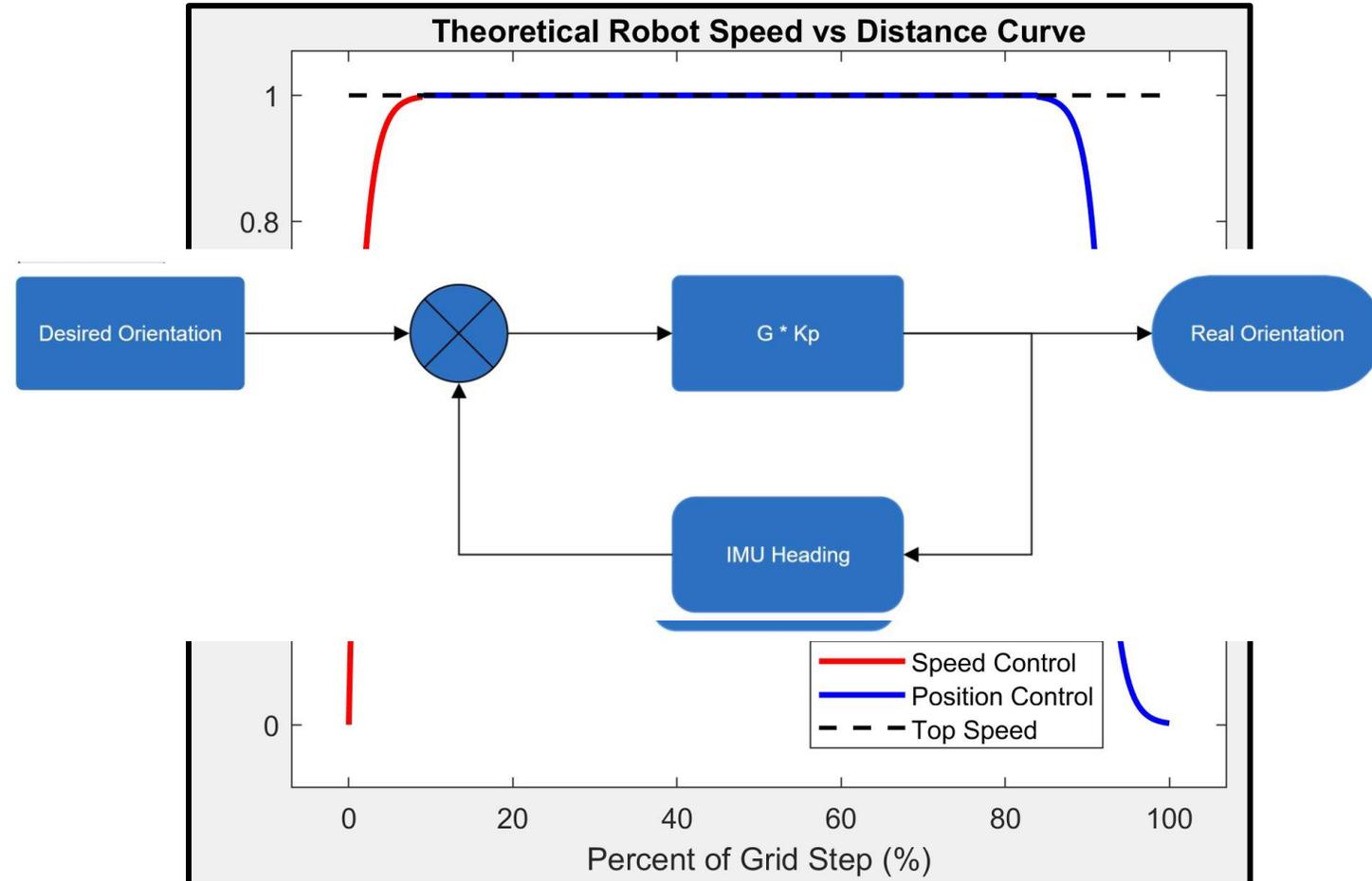
# Implementing Motor Control

First, we assembled the circuit, controlled motor ON/OFF, and confirmed we can accurately read encoder position and velocity in real-time.

Second, we added closed-loop, time-variant speed control for accelerations.

Third, we added closed-loop position control for predictable movements (autonomy) and deceleration control.

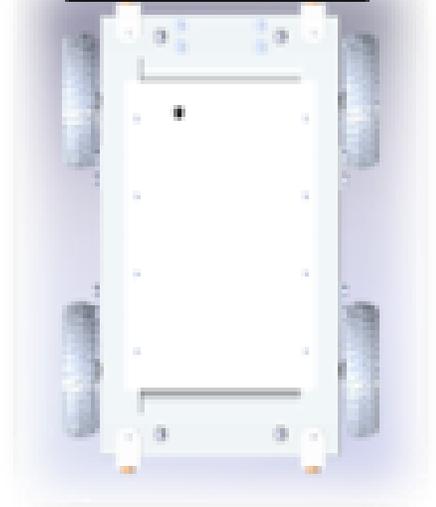
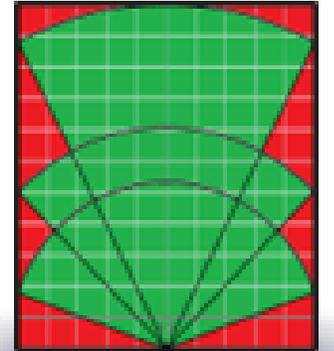
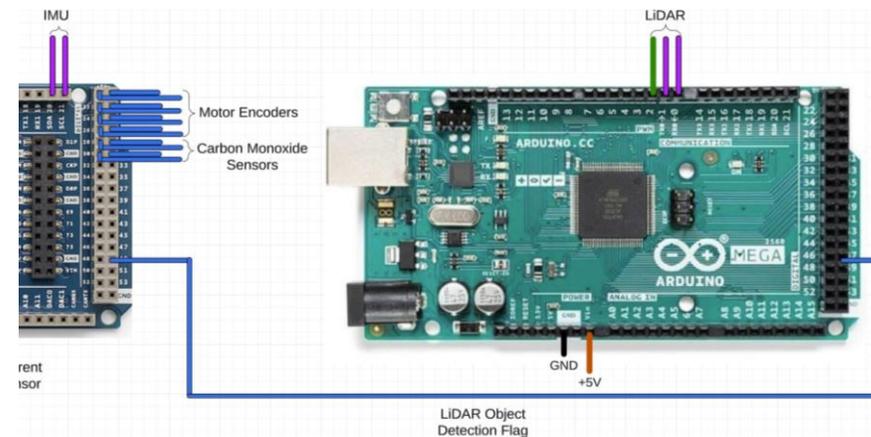
Last, we configured the code to run 4 motors with 4 different commands (forward step, 90 deg right/left, and emergency stop).



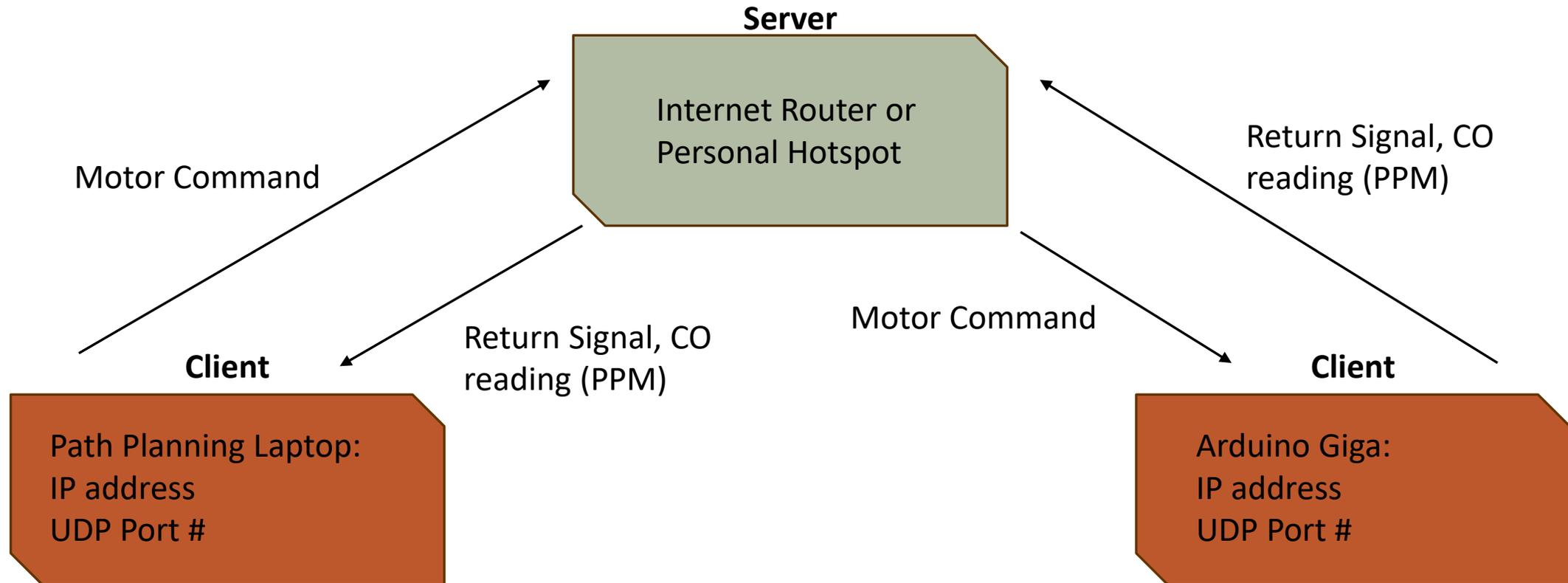
# Lidar Sensor

Script on Arduino Mega Board to repeatedly check for obstacles within a desired range

Utilize binary states of Clear and Not Clear to change pin state on Arduino Giga for communication with base computer

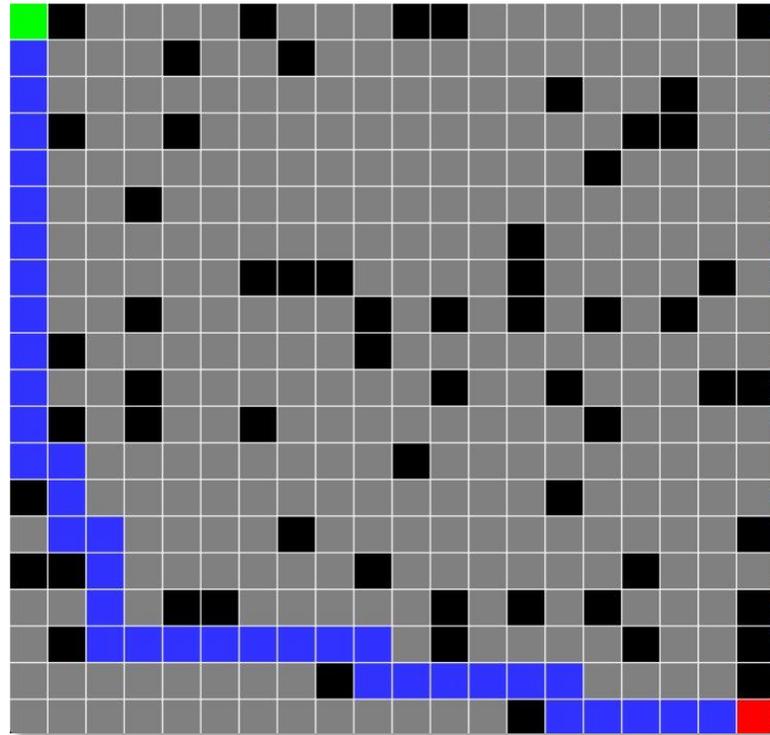


# Data Transmission: UDP Protocol

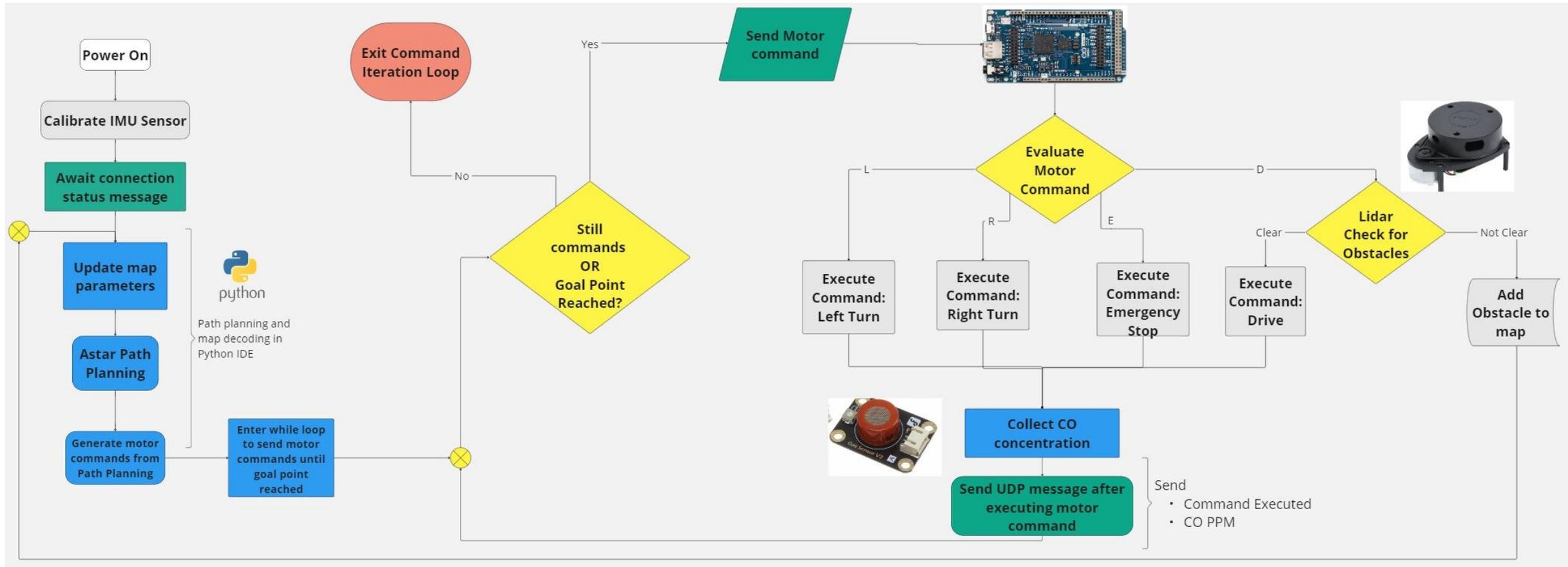


# A\* Path Planning

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# Software Flow Chart



# Test Methods and Results

# Battery Life Test

Prototype is required to operate for at least 30 minutes on one charge

Li-Po batteries may become damaged if voltage drops too low (< 9 Volts)

The robot was driven in a square pattern starting with two fully charged batteries

Voltages were recorded multiple times throughout the 30-minute test

Results were better than expected!

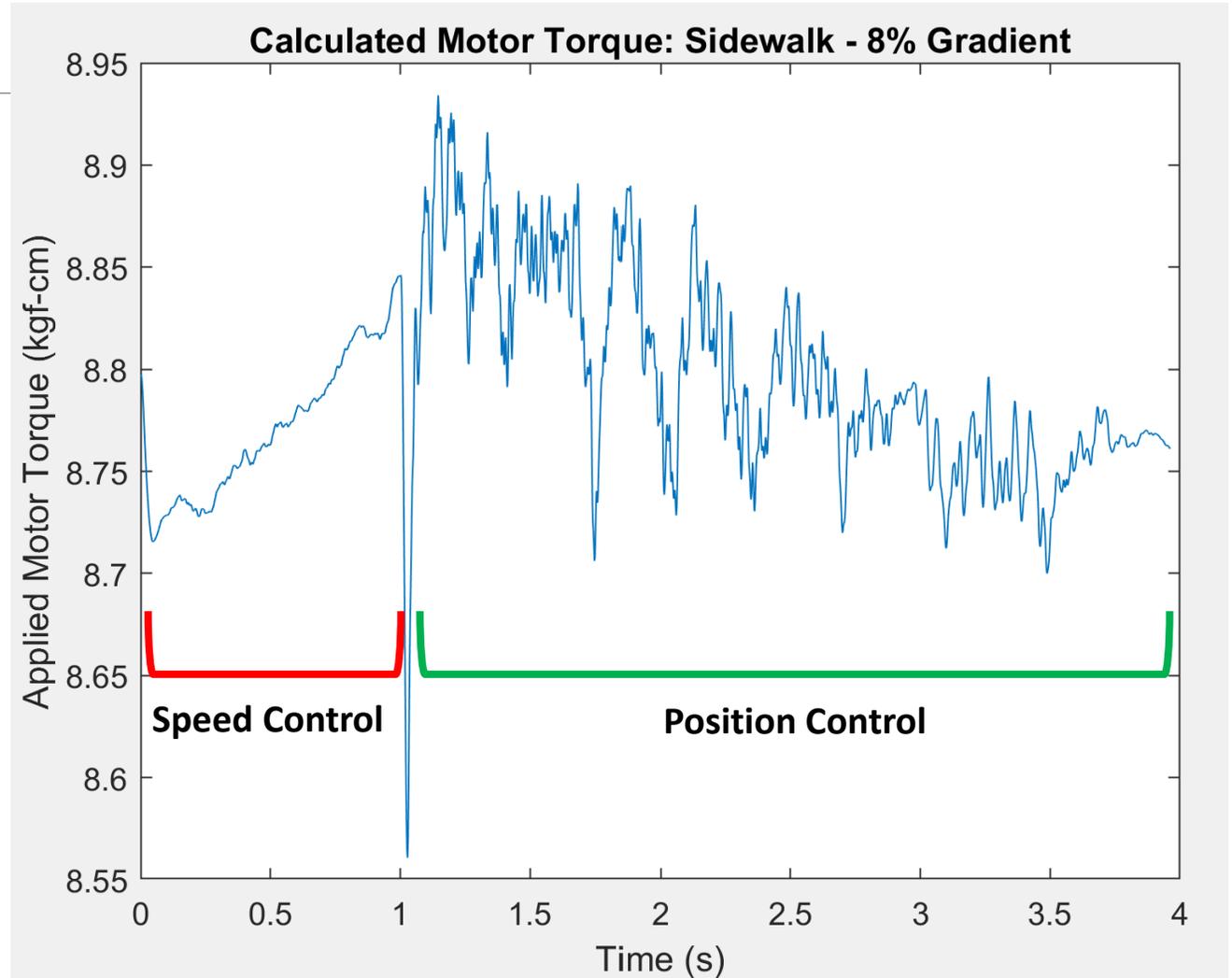
- Theoretical calculations assumed constant movement with peak current draw from motors

Battery Life Test Results					
	Time (min)	0	15	25	30
Battery 1	Voltage (V)	12.6	12.48	12.26	12.21
Battery 2	Voltage (V)	12.6	12.47	12.26	12.2

# Motor Torque Test

Speed and input voltage (PWM) were recorded for 'Forward' commands on different gradients and surfaces

Using the known Speed-Torque graph, we can calculate for motor torque



# Path Planning Test

## Goal :

- Receive accurate map of area
- Send list of commands to robot wirelessly
- Successfully navigate to the goal point

## Process:

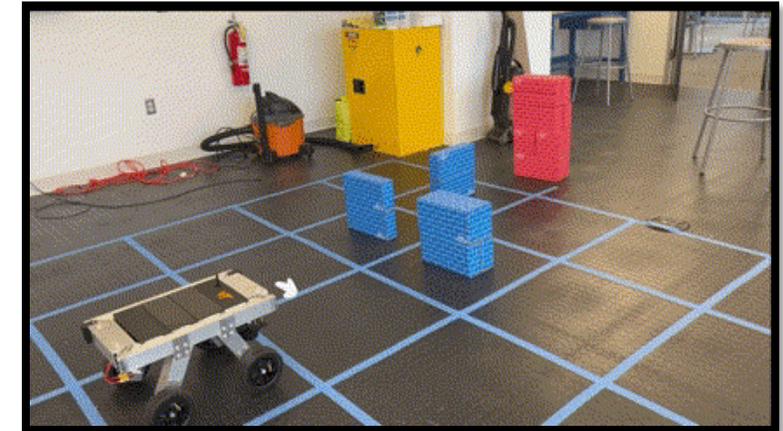
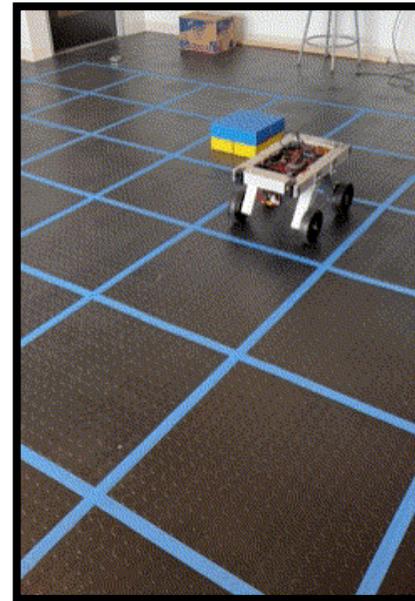
- Test various configurations of map & obstacles
- Verify that all commands are executed
- Send status message when goal point is reached or unreachable

## Result:

The robot *consistently* reaches the goal point when given an accurate map of the area. Utilization of A\* path planning algorithm is successful in this real-world implementation

## Requirements Validated:

- Path Planning
- Information exchange & establish connection server



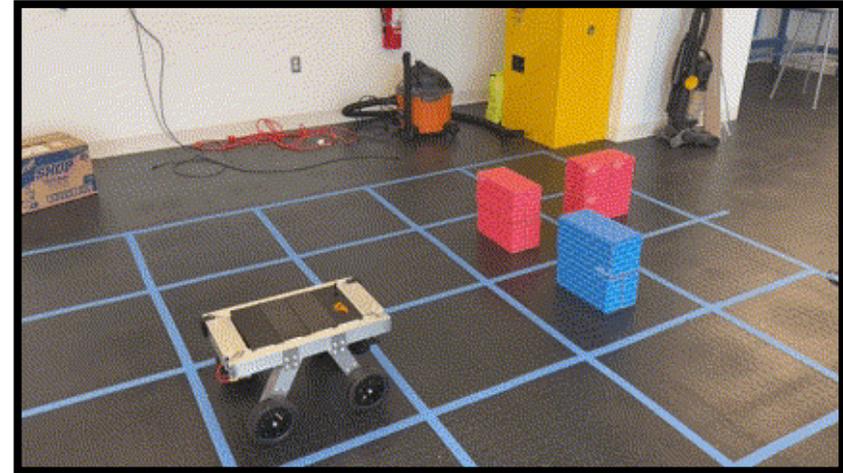
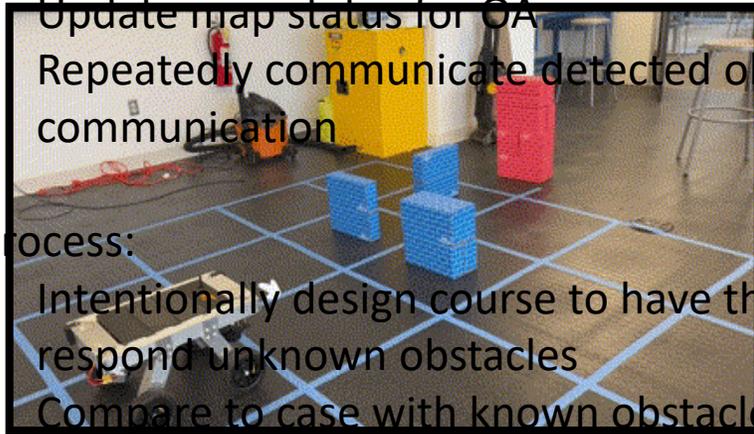
# Object Detection Test

## Goal:

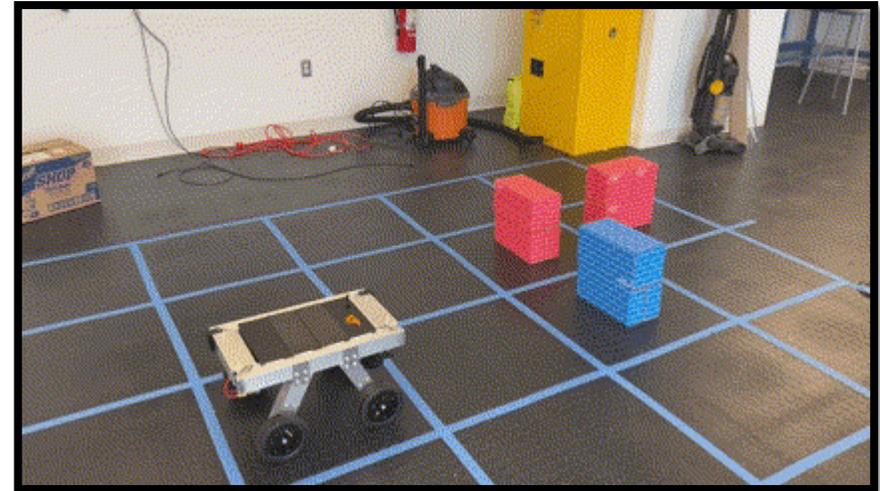
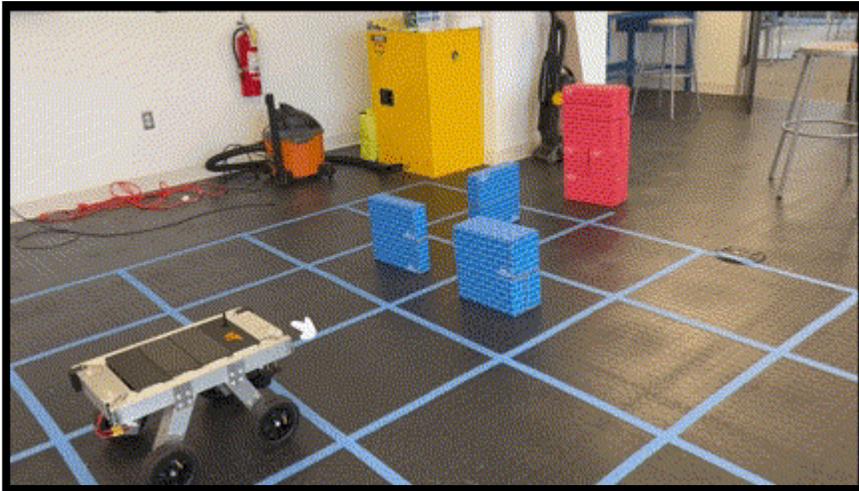
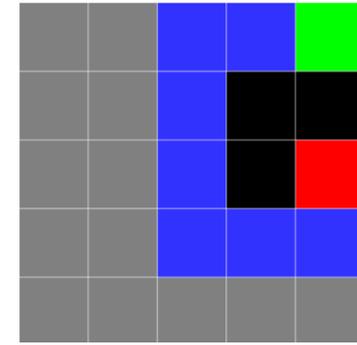
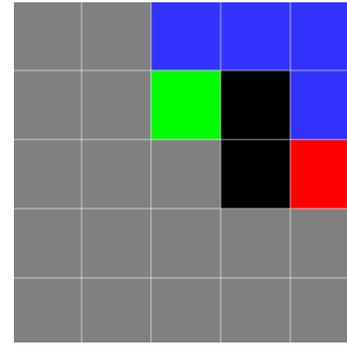
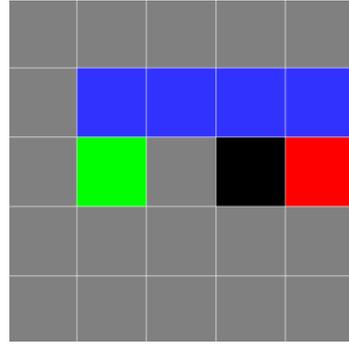
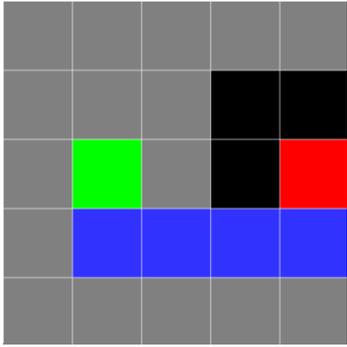
- Test ability to respond to unknown obstacles
- Recalculate path multiple times before reaching goal
- Update map status for OA
- Repeatedly communicate detected objects over UDP communication

## Process:

- Intentionally design course to have the robot have to respond unknown obstacles
- Compare to case with known obstacles



# Object Detection Test



# Results

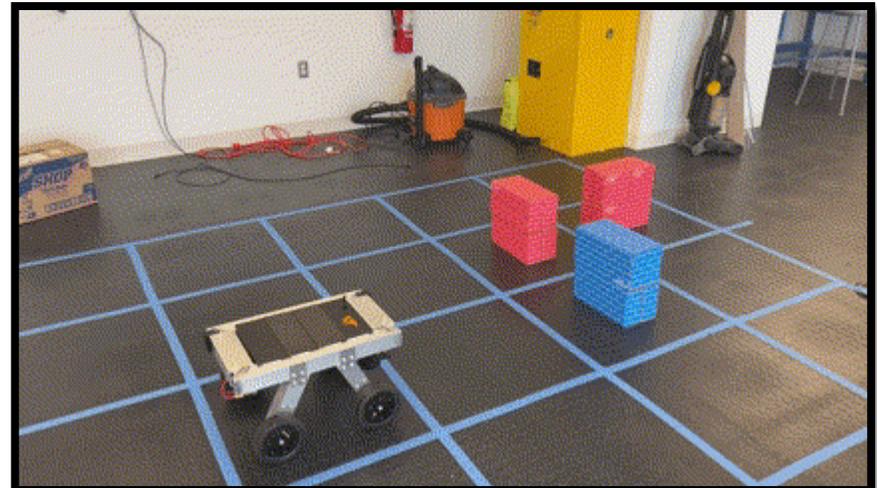
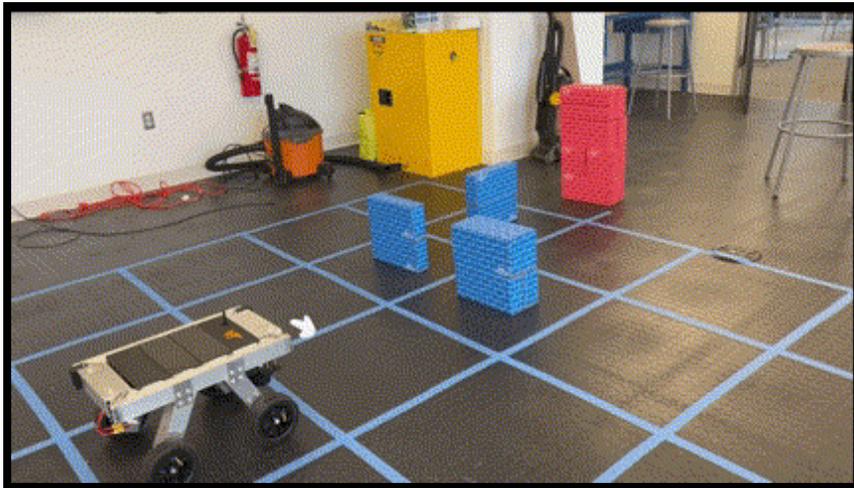
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Successfully reached goal point and responded to unknown obstacles

Times:

- Unknown: 2.55 min
- Known: 1.00 min

When using Orchestrated Autonomy, our robot can complete tasks faster.

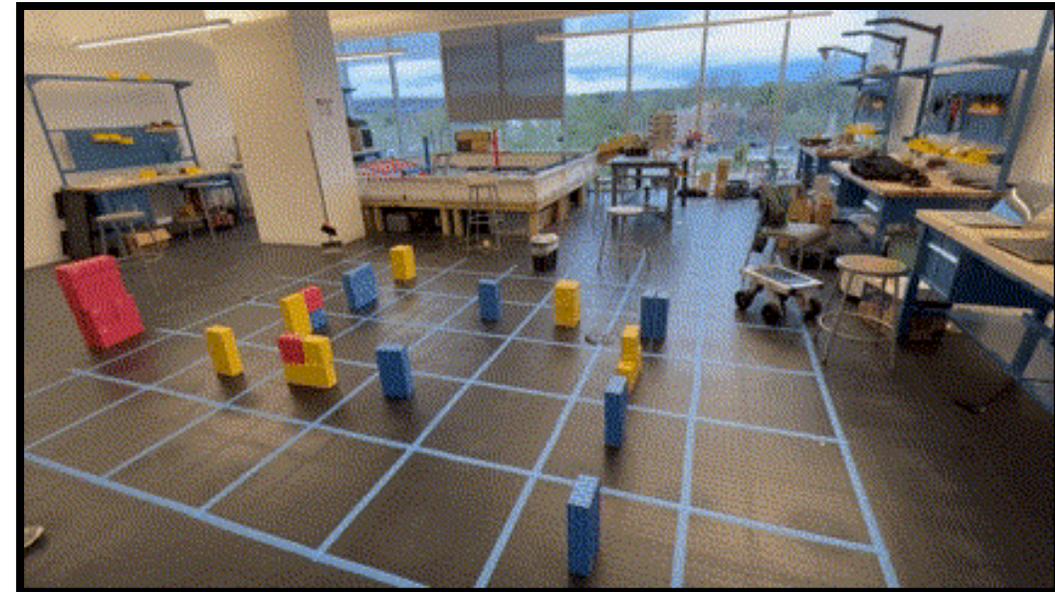
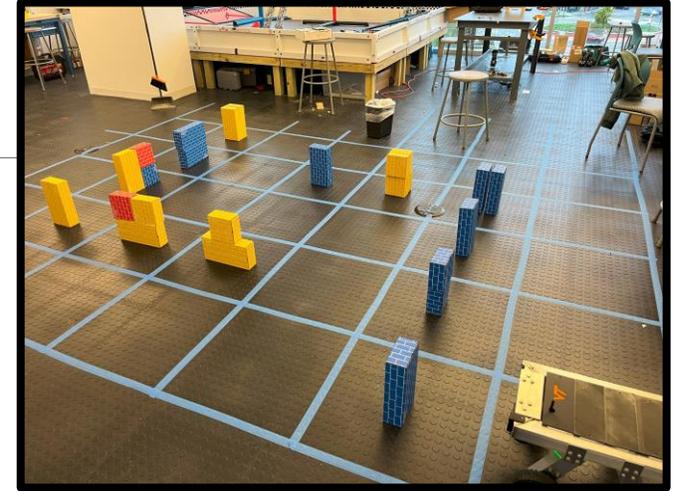


# Advanced Autonomy Test

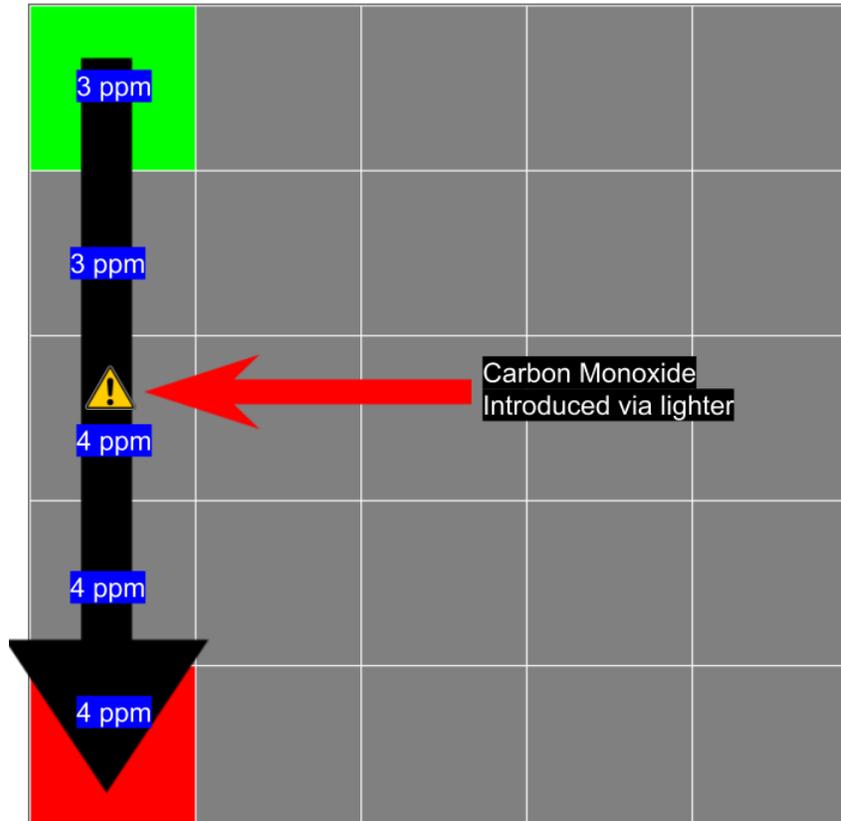
## Goal:

- Test an advanced scenario where all objects are unknown
- Validate RP Lidar sensor and repeated calls to A\* Path Planning Algorithm over UDP connection
- Reach the goal point in a maze and update the map with unknown obstacles

Results: The test was a success as it was able to detect all unknown obstacles and recalculate a path around them.



# CO Sensor Test



```
Path is Clear
CO VALUE:
3
1
Path is Clear
CO VALUE:
3
2
Path is Clear
CO VALUE:
4
3
Path is Clear
CO VALUE:
4
4
Path is Clear
CO VALUE:
4
5
Path is Clear
CO VALUE:
4
Reached goal point
New obstacles detected:
None
Flag Changed to:
False
Exiting main

In [2]:
```

# Objectives and Requirements Validation

# Requirement Validation

#	Design Requirement	Value	Validation Method
1	Frame Strength	Factor of Safety > 2	FEA (Pass)
2	Ground Clearance	> 5 inches	CAD Design (Pass)
3	Battery Life (Q)	> 30 minutes	Battery Life Test (Pass)
4	Peak Motor Torque	< 15.9 kgf-cm	Motor Torque Test (Pass)
5	Top Speed	> 1 m/s	Top Speed Test (Fail)
6	Path Planning	Y	Path Planning Test (Pass)
7	Object Detection	Y	Object Detection Test (Pass)
8	Information Exchange	Y	UDP (Pass)
9	Establish Connection Server	Y	UDP (Pass)
10	Carbon Monoxide Sensitivity	Y	Co Sensor Test (Pass)
11	Send and Receive Json Messages	N	File Formatting Unachieved (Fail)
12	Stay Within Budget	Y	Finished With \$1,105 Remaining in Budget (Pass)

# Objective Validation

#	Design Requirement	Value	Validation Method
1	Can maneuver on pavement and grass + small gradients without getting stuck	Y	Motor Torque Test (Pass)
2	Can maneuver on pavement and grass + small gradients without over heating	Y	Motor Torque Test (Pass)
3	Electronics are dry in event of light precipitation	N	Unachieved (Fail)

# Lessons Learned

# Fatigue Design

Two of our custom hex shafts underwent brittle fatigue failure due to large stress concentration factors where the different size hexes met

We recommend designing a new shaft that tapers down to the smaller hex to reduce the stress concentration and/or using a material with a larger fatigue strength such as steel, which also possesses a fatigue limit

Fatigue fracture design is just as important as designing for yield, especially in rotating parts which undergo stress cycles

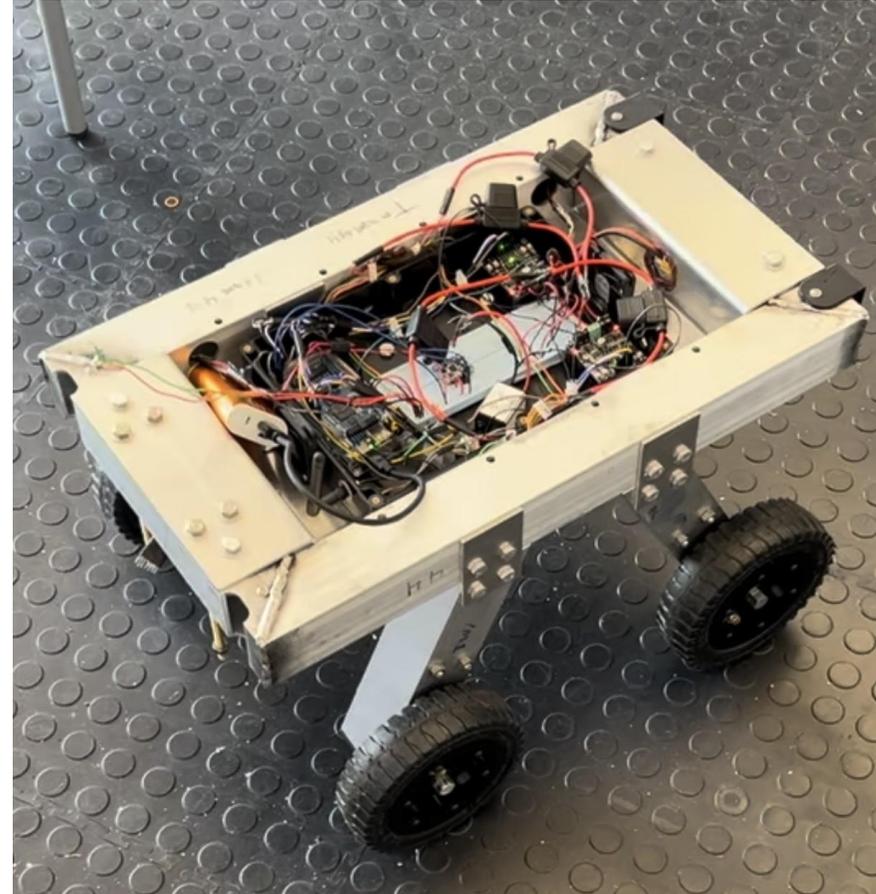


# Electrical Interference and Wire Management

Due to space restrictions for the electrical circuit, the team encountered issues where power wires produced electrical noise which disrupted the motor control and IMU positioning signals

These issues caused large setbacks on testing, but were eventually resolved

We recommend that in the future the electrical circuit continues to be reorganized, the breadboard be eliminated, and wires be soldered to a PCB board to reduce the chance of vibrations causing them to come loose



# Conclusions

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- General autonomy of desired task + compatibility with Orchestrated Autonomy were a success
- Certain features proved to be outside the scope of this year's project due to time:
  - Advanced LiDAR mapping
  - Continuous motion/high resolution path planning
- There is room for refinement, specifically in the robot's efficiency at completing its individual autonomy task, however the robot in its current form should prove useful to testing the limits of Orchestrated Autonomy

# Questions?

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