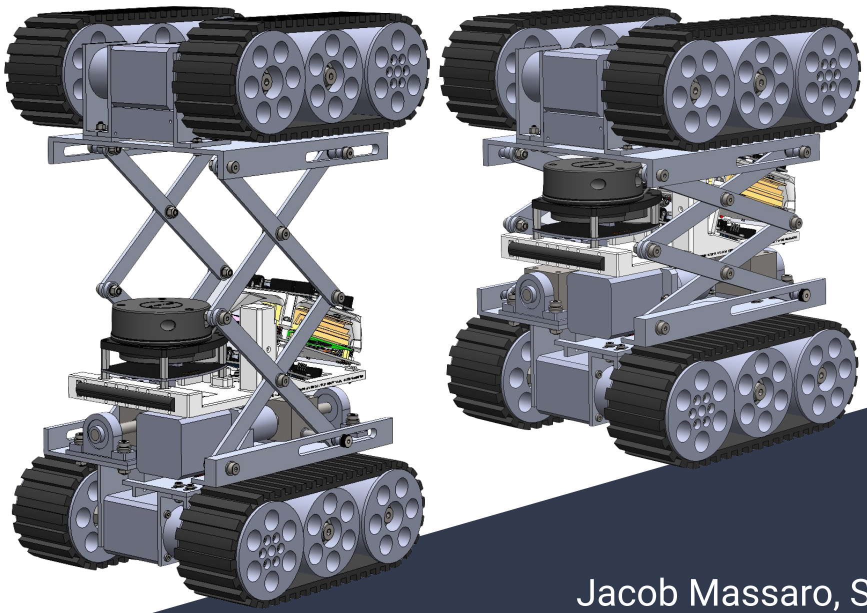
UCF Duct Inspection Robot



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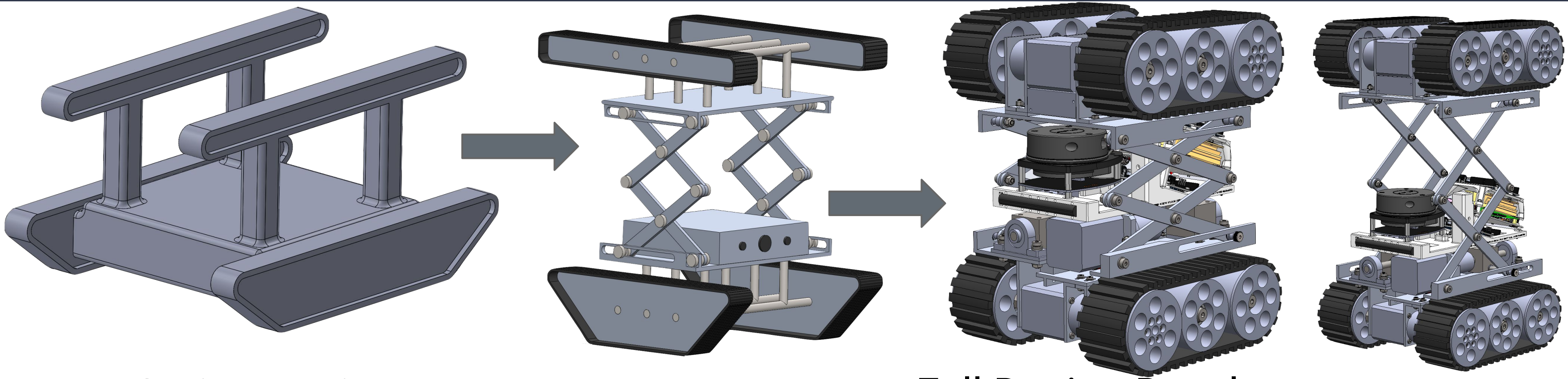
Sponsor: UCF Utilities & Energy Services

Introduction

- Project Client
  - The University of Central Florida *Utilities and Energy Services Department*
    - *Nate Boyd - Associate Director of Energy Services*
- Project Motivation
  - Design a device that improves the process of duct mapping and leak detection
    - HVAC Systems are large energy consumers
      - Improvements in efficiency can yield:
        - Utilities savings
        - Reduced environmental footprint

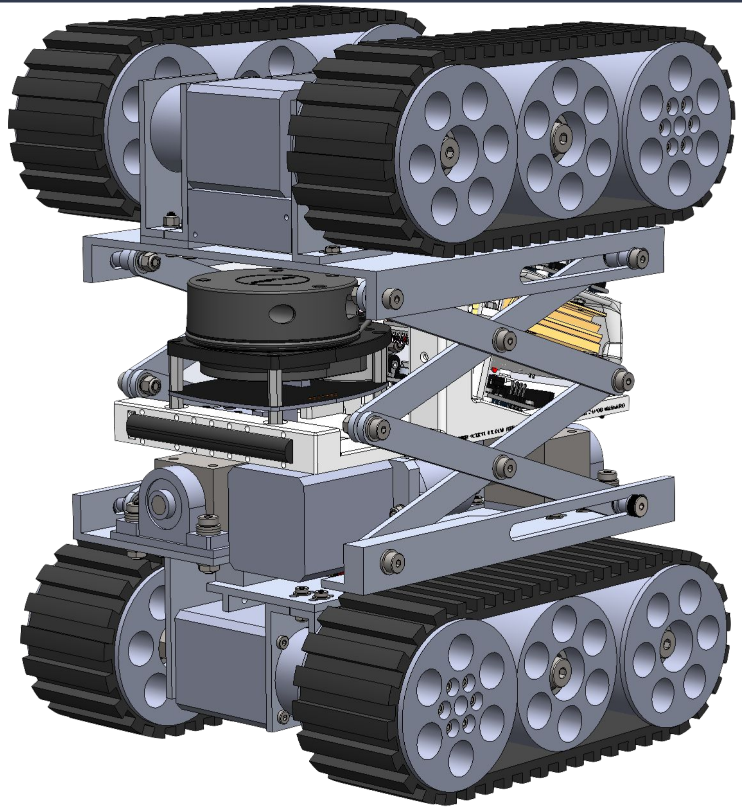
https://www.kisspng.com/png-furnace-hvac-control-system-air-conditioning-heati-3559013/

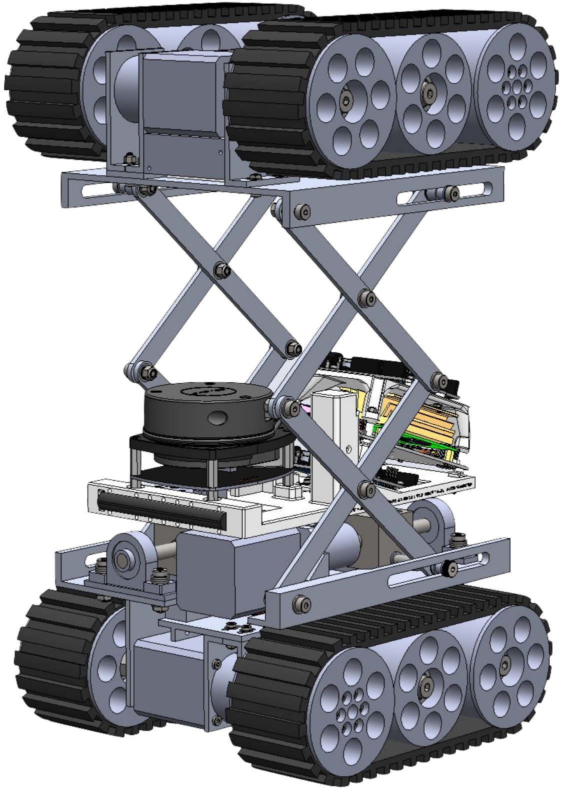
Design Process



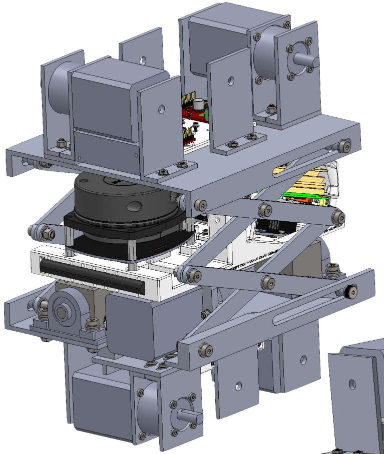
- Spring Design
    - 6061 Aluminum Frame
    - Track based drivetrain
    - Scissor Extension Mechanism
    - Lead Screw concept
    - Fathom ROV cable
    - DC Motors
- Fall Design Development
    - Ethernet-power sheath tether
    - Geared stepper motors
    - Round shaped wheel design
    - Developed lead screw mechanism
    - Motor Mounts
    - Computer System Mounts

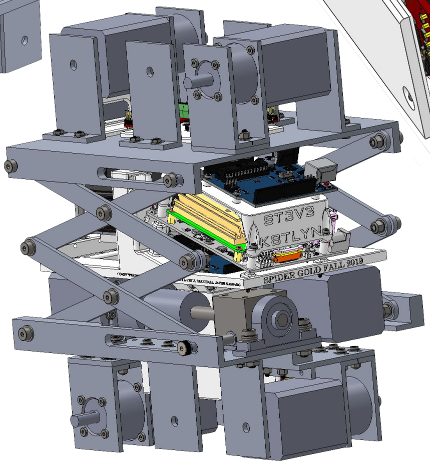
Final Design Models

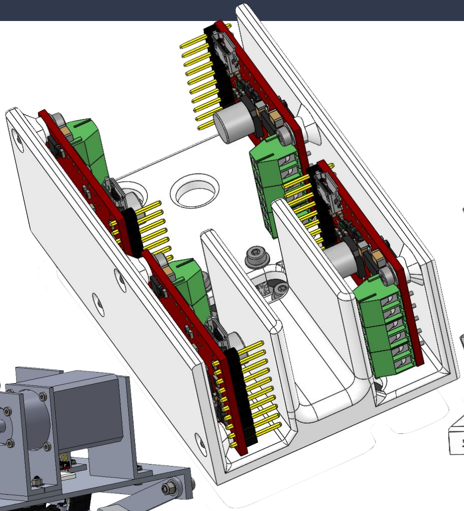


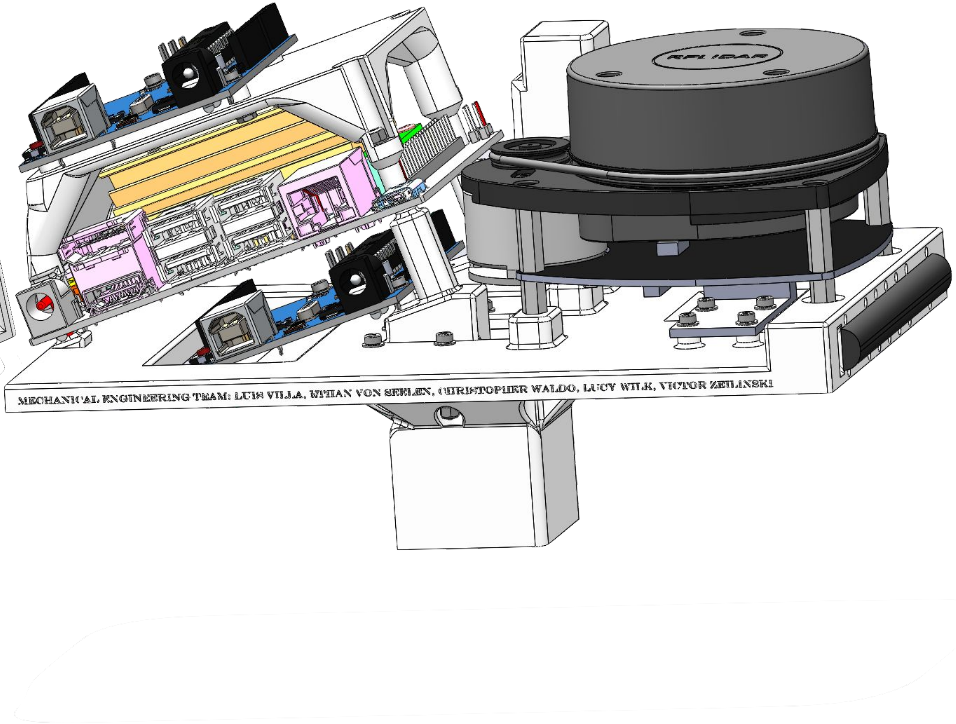


Final Design Models Cont.



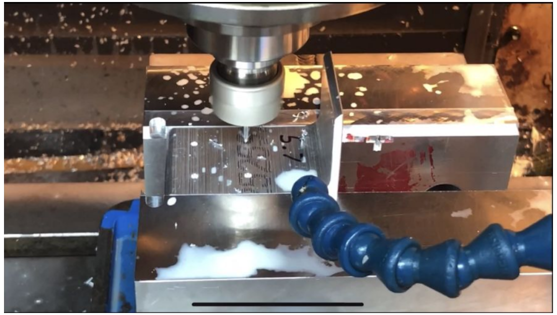


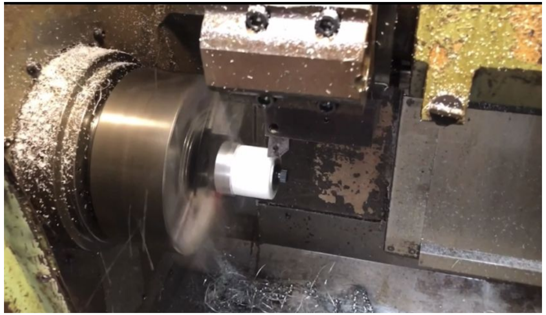




Manufacturing

- Custom manufactured 6061 aluminum and Delrin to match CAD model
- Process:
  - Technical drawings of each part made
    - SOLIDWORKS technical drawing
  - G Code created through Mastercam
    - SOLIDWORKS files converted to .dxf
  - Processes Used
    - Cutting
    - Milling
    - Turning
    - Grinding
    - Sanding
    - 3D Printing

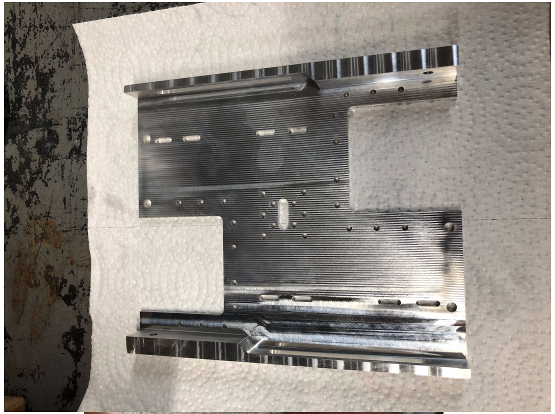
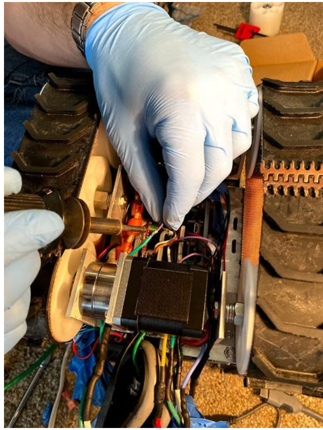
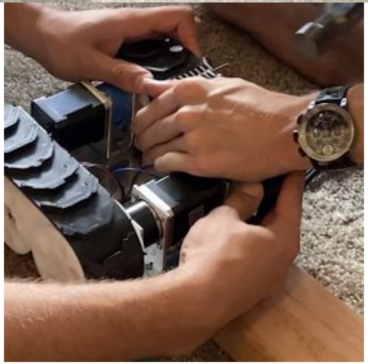




Assembly

- Positive assembly points
  - Detailed CAD model allowed for easy assembly
  - Labeled and bagged hardware
  - Slots allowed for adjustment in parts
  - Most electrical connections are soldered

- Negative assembly points
  - All bolts should have been loctited
  - Lack of adequate clearance to fix issues
  - Issues with stainless steel hardware
  - Electrical wiring/assembly (new process)
  - Lining up custom tracks


Technologies

- Ubuntu 18.04, ROS Melodic, Gazebo, NoMachine
- C++, C, Python, XML, HTML, CSS, JavaScript, Node.js
- Main ROS Packages
  - slam_gmapping: map
  - ros_bridge_suite: communicating bot to user
  - ros_serial: arduino to ROS

Hardware

- Nvidia Jetson Nano
- RPLidar A1
  - Point cloud data
- 2 Arduino Uno R3s
  - Bridge between Nano & Tics
- 6 Pololu Tic T500s
  - Control motors
- Logitech C270 Camera
  - Aid navigation & leak detection

Other Hardware

- Ultrasonic Sensors
- Infrared Camera

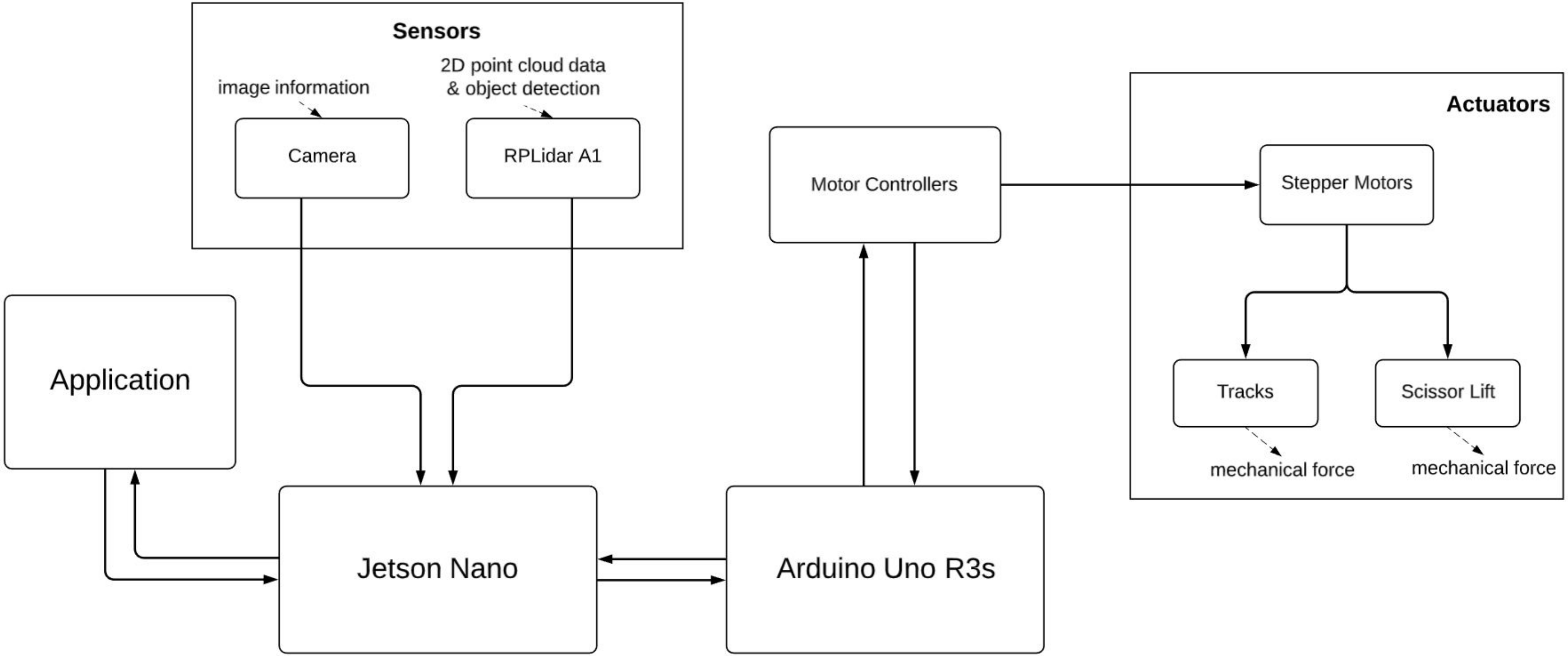
Jetson Nano

RPLidar A1

Pololu Tic T500

Arduino Uno
R3

System Overview

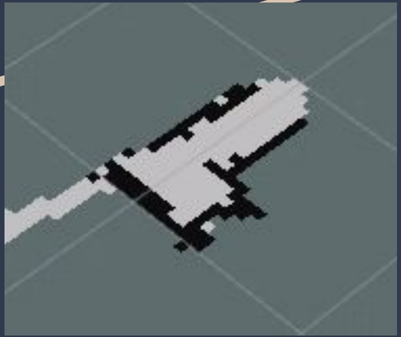


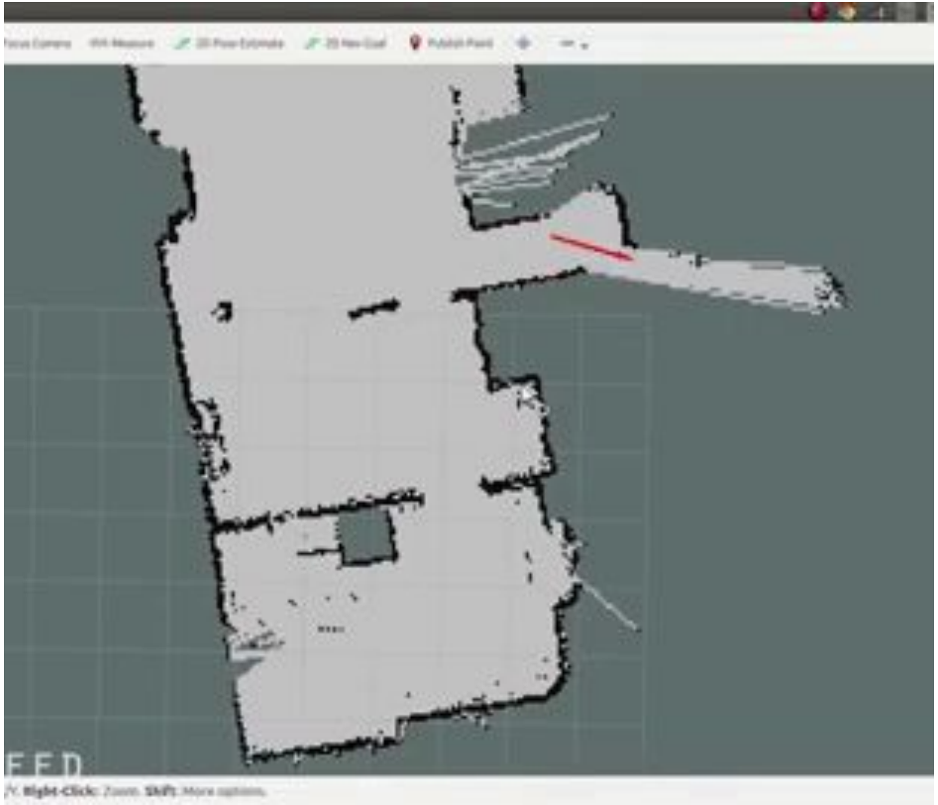
SLAM (Simultaneous Localization and Mapping)

- Updating a map of an unknown environment while keeping track of the robots location
  - Lidar SLAM algorithm
- Lidar emits infrared light and measures distance from the return reflection
  - Provides points to slam algorithm to compute estimate of its environment
- Use odometry data to find robots position within the map
  - Allows for more accurate maps

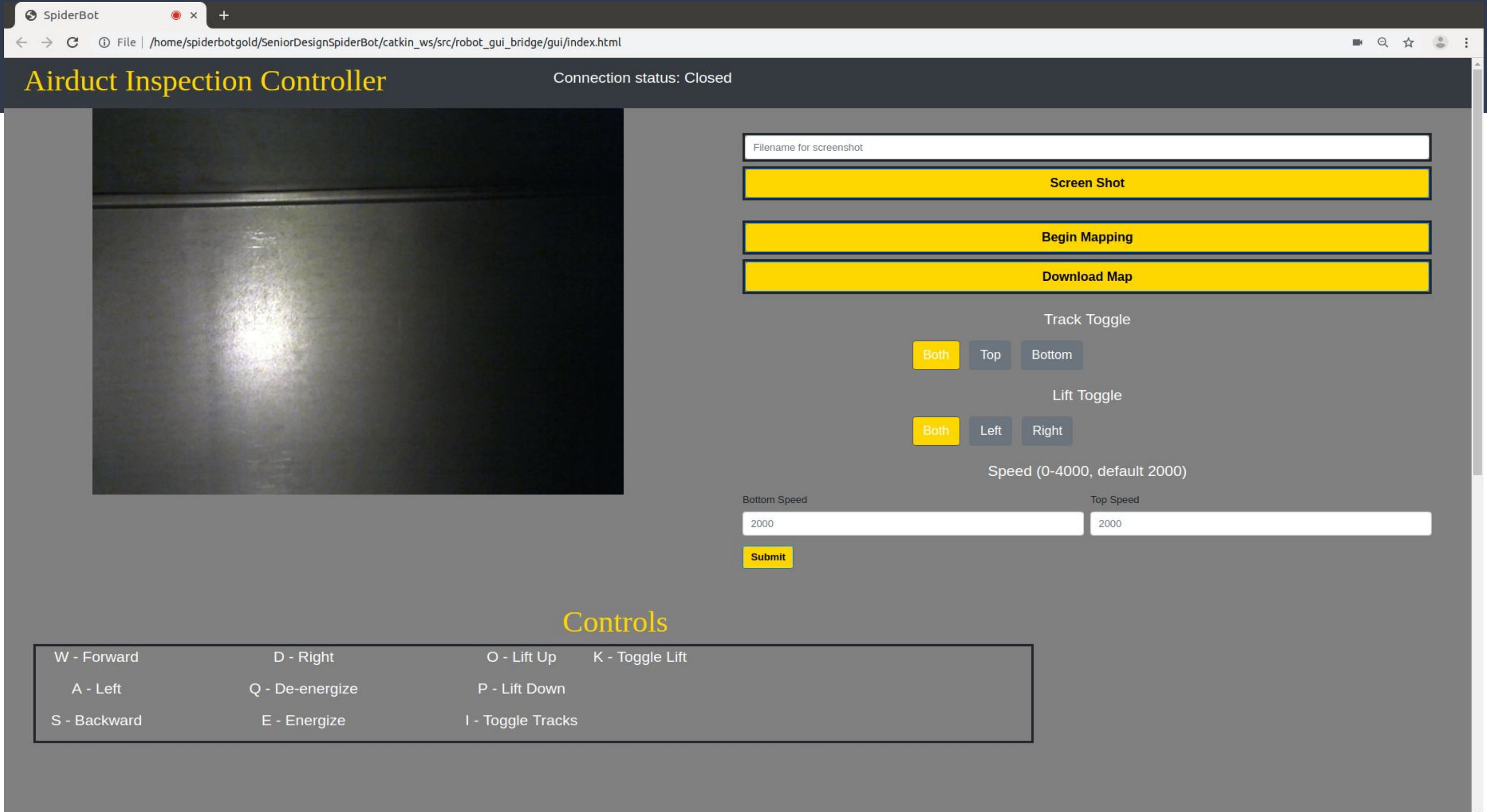
Mapping

- 2D SLAM using slam_gmapping
  - Saves map as image file
  - Image is converted to .PNG using a python script
  - Image can be imported to Revit
- Use odometry data from robot and RPLidar A1 to construct the map

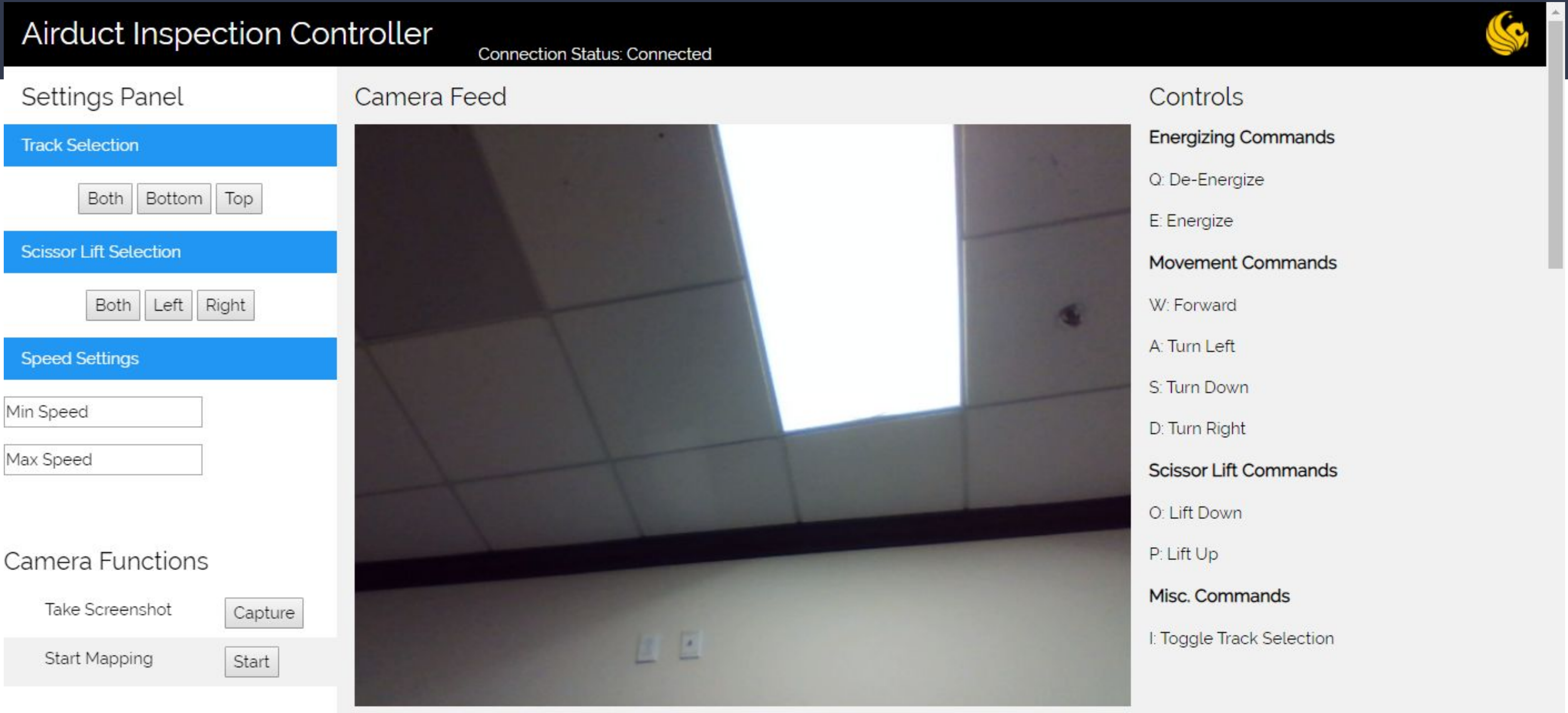




Control Application (stable)

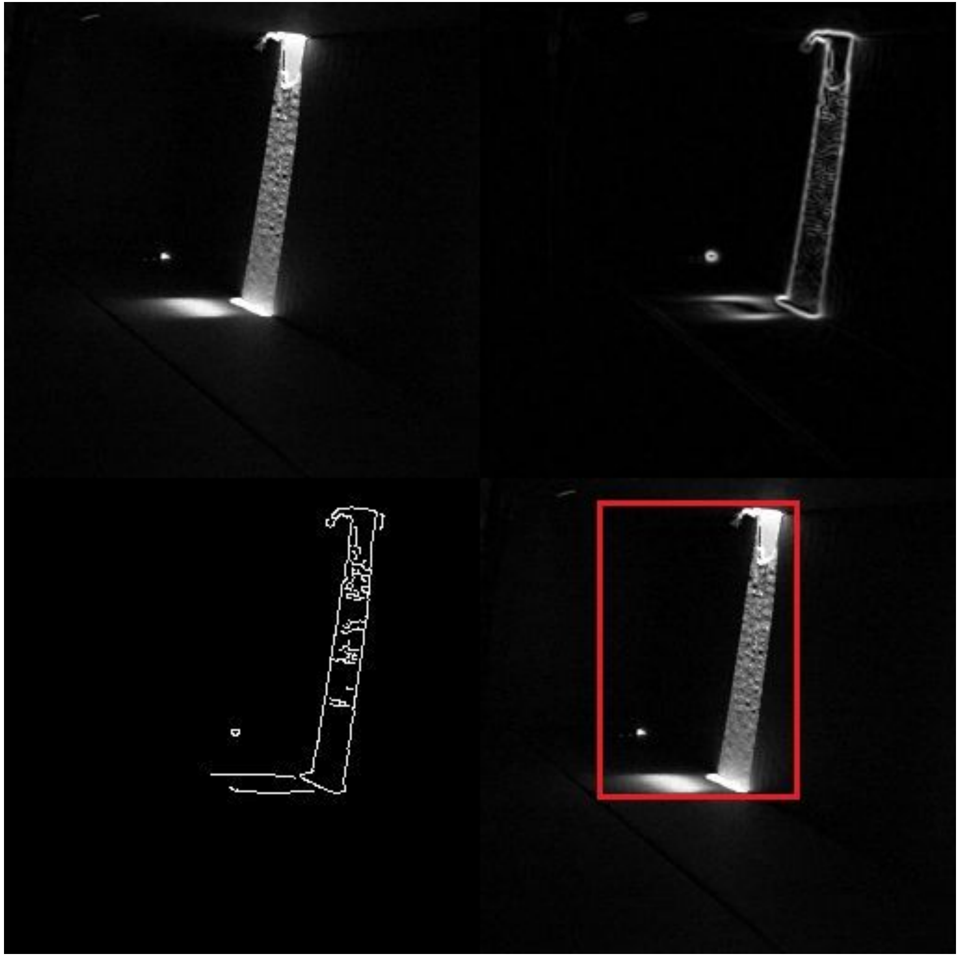


Control Application (latest)



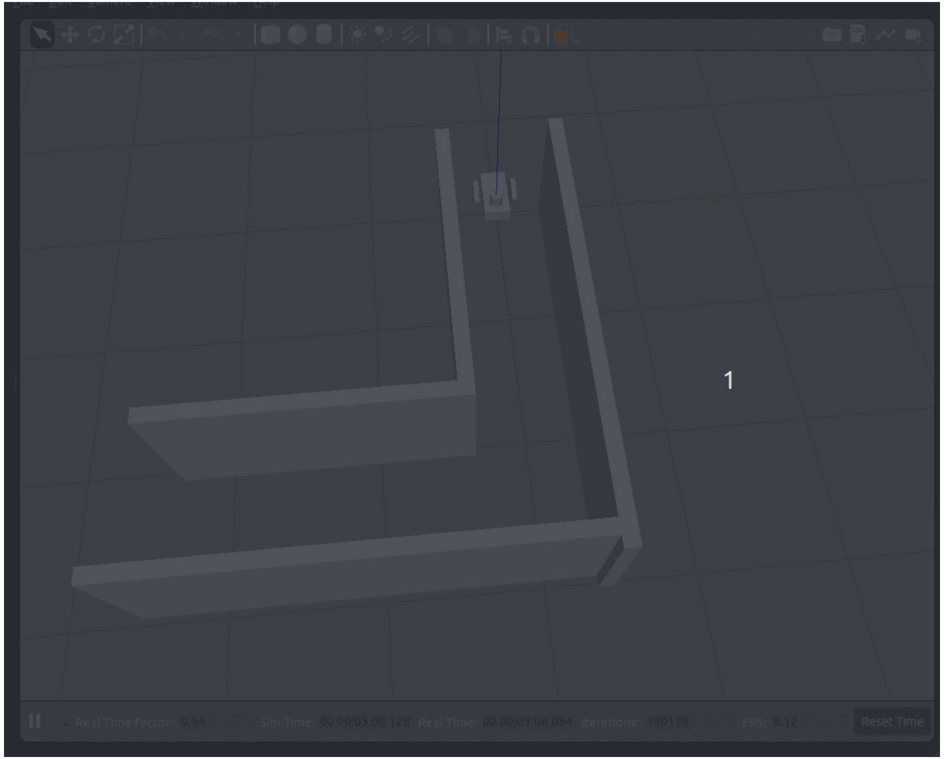
Leak Detection

- Areas where leaks are present will show drastic differences in light or heat signatures from rest of ducts.
- Canny edge detection algorithm with double threshold is used to detect these areas.
- Implementing a deep learning approach is difficult.
    - Large accessible training sets that match our constraints don't exist.
    - Luckily, the robot will be generating training images when it's run.



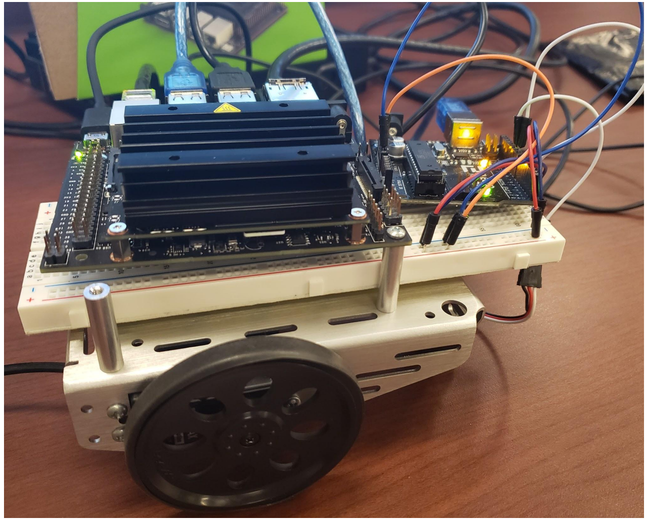
Simulation Testing

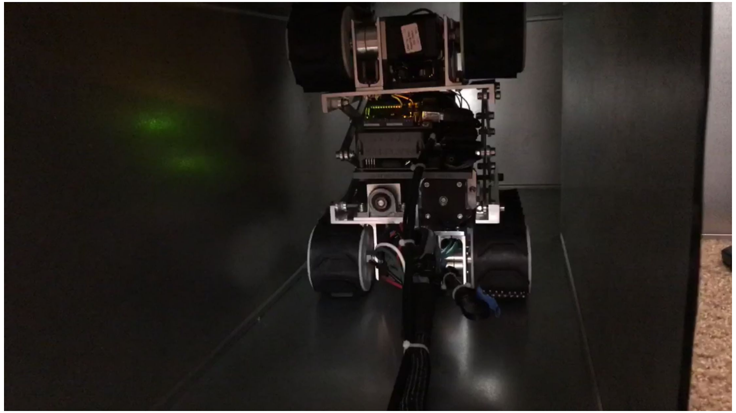
- Uses Gazebo simulator for Ubuntu
- Simulated model for map testing
- Similar drive system as track system
- Publishes laserscan data and odometry
- Uses gazebo_ros package to provide ROS integration



Physical Testing

- Robot for movement using Arduino and Jetson Nano
  - Started with dummy bot, which used similar differential drive system as our track system
- Test duct for final robot testing
  - Useful for testing accurate movement and mapping





Final Product Analysis

Metric #	Metric	Units	Marginal Value	Ideal Value	Result Value
1	Overall Dimension	in	8-10	8	12
2	Vertical Distance to Climb	ft	4	4 ≤	4 ≤
3	Tether Length	ft	100-150	150	85
4	Visual Sensors	Pass/Fail	Pass	Pass	Pass
5	Enivronmental Sensors	Pass/Fail	Pass	Pass	Fail
6	Mapping Sensors	Pass/Fail	Pass	Pass	Pass
7	Operating Temperatures	°F	45-80	45-90	45~80
8	Operators Required	# Persons	2	1	1
9	Live Video Streaming	mb/s	7	7-10	5-12
10	Max Device Speed	ft/min	15	30	10.52
11	User Serviceability	Pass/Fail	Pass	Pass	Pass
12	Manual Control	Pass/Fail	Pass	Pass	Pass
13	Autonomous Control	Pass/Fail	Fail	Pass	Fail

- Tested using our donated 12” square duct
- Measured these test runs with our metrics we made from last semester
  - Some passed categories include
    - Vertical distance to climb
    - User Serviceability
    - Manual Control
  - Some failed categories include
    - Overall dimensions
    - Maximum device speed
    - Tether length
- Budget
  - Proposed: $3,000
  - Actual: $2,742.20