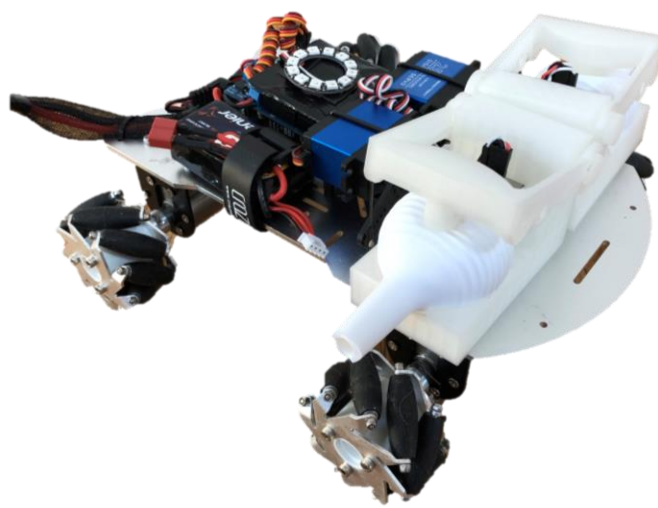
ALV+IN

An Intelligent Stereoscopic Olfactory System for Autonomous Localization of Volatile Organic Compounds

INTRODUCTION

Electronic noses, or e-noses, are still a very new concept in modern research. And while few working prototypes exist, the implications of such devices are huge. Currently, one of the few types of electronic noses is used to determine a person's blood alcohol content. Harnessing odor-tracking technologies could lead to increased food safety, workplace safety, and even early disease detection. In a humanitarian setting, such a device could be used to assist in natural disaster recovery efforts.



ENGINEERING GOAL

The purpose of this project is to design, build, and test a proof-of-concept electronic-nose (e-nose) driven robot to locate concentrations of an odor such as rubbing alcohol using a list of readily available materials. To do this, I will devise a stereo-olfactory system to "sniff" the surrounding air while measuring concentrations of a particular odor. The robot will be able to consider previous data and make smart decisions while moving autonomously to seek the scent. Additionally, the robot's sensors will be interchangeable to sense multiple odors. This proof-of-concept will use rubbing-alcohol as the odor due to its low risk factor; other substances may be considered during the testing phase.

CURRENT APPROACHES

There are two main algorithm methodologies used in odor source localization attempts: **chemotaxis,** using the orientation and movement of an odor (following a gradient), and **anemotaxis,** referring to the direction and current of a fluid.

In the most successful approach documented, conducted by a group from the Center for Robotics and Intelligent systems (Monterrey, N.L., Mexico), a robot utilizes **genetic programming** and a **sweeping spiral** to survey an environment before tracking and locating the odor source. The group found that saturation of the robot's sensors and a constantly moving odor plume make it difficult to accurately locate an odor.

BIO-INSPIRATION

CANINE OLFACTORY SYSTEM

Unlike humans, dogs have a uniquely shaped olfactory system which allows for passage of odorous molecules in through the main nostril and out through small slits on the side of their noses. This allows for continuous sniffing.

In addition, a dog will inhale and exhale three to five times whenever they catch a scent, stirring the odor molecules in the ambient air to determine the composition and/or source.

In order to combine both of these important functionalities into one robotic system, the robot's synthetic nose will include a pump-like system which exhales when pressed and inhales when released. This will mimic the stirring of odor molecules.

THE ROBOT

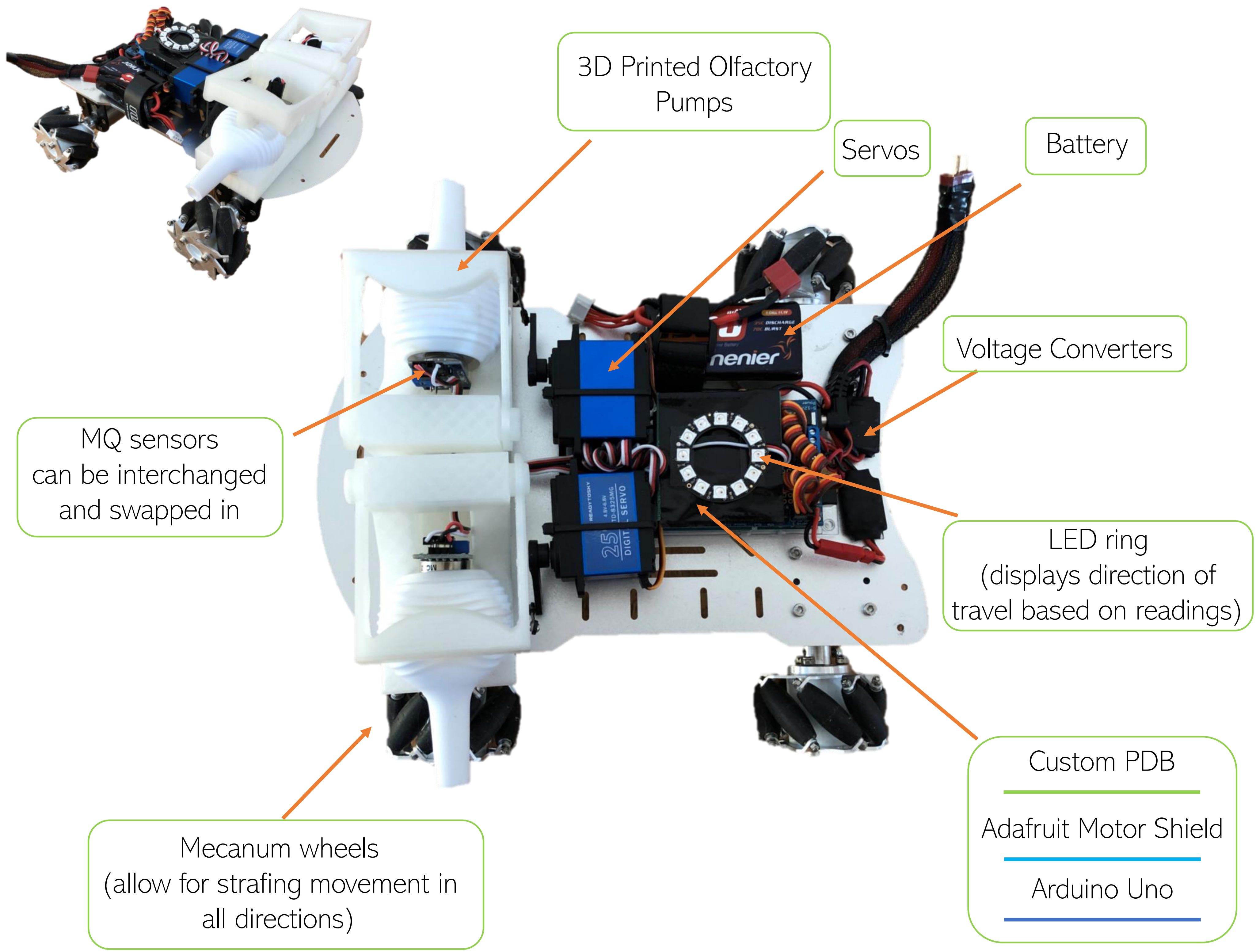
DESIGN CONSTRAINTS

- Autonomous robot which must move on its own
- Take readings of airborne molecules (alcohol, butane, etc.)
- Determine path of travel based on sensor readings

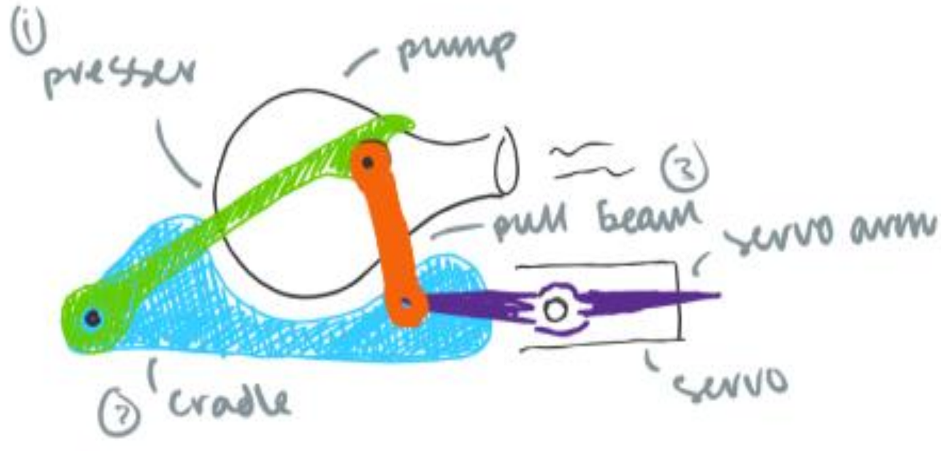
COMPLETE LIST OF MATERIALS

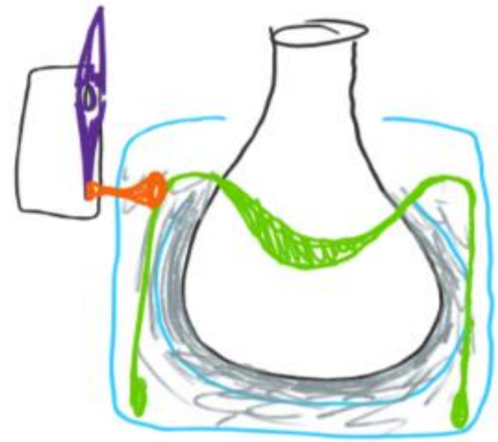
Mecanum Wheel Base Kit
2x 6V digital servos
Arduino Uno
Adafruit Motor Shield
Adafruit Neopixel LED ring
2x Step down converter
Dean power connector
12V lipo battery
4x 20mm aluminum standoffs
2.5*6 cm carbon fiber plate
Rubbing alcohol

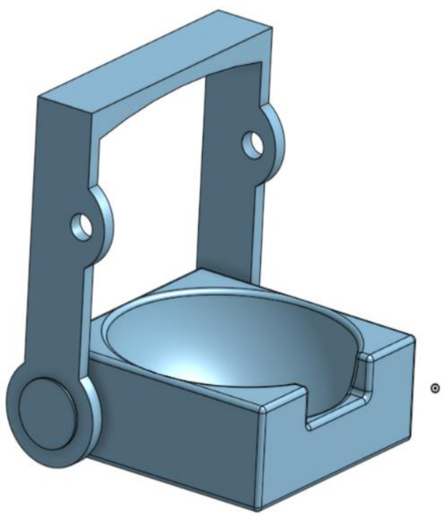
Zipties
4x ball linkage
2x 5 cm linkage
2x 3D printed olfactory pump systems
2x rubber pumps
2x MQ sensors (types vary)
Dupont connectors
Custom PDB (90-degree connectors)
Solder + soldering iron
Double sided silicon tape
Butane lighter

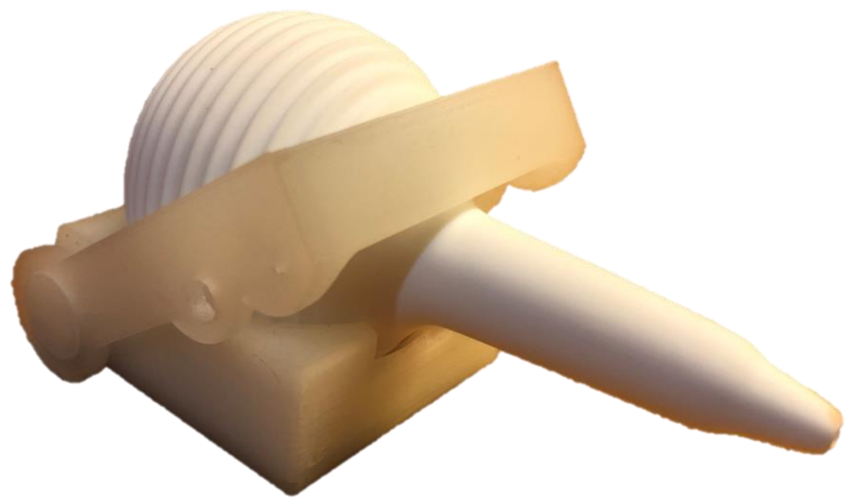

3D Printed Olfactory Pumps
Servos
Battery
Voltage Converters
MQ sensors can be interchanged and swapped in
LED ring (displays direction of travel based on readings)
Custom PDB
Adafruit Motor Shield
Arduino Uno
Mecanum wheels (allow for strafing movement in all directions)

THE OLFACTORY SYSTEM PROTOTYPE V1



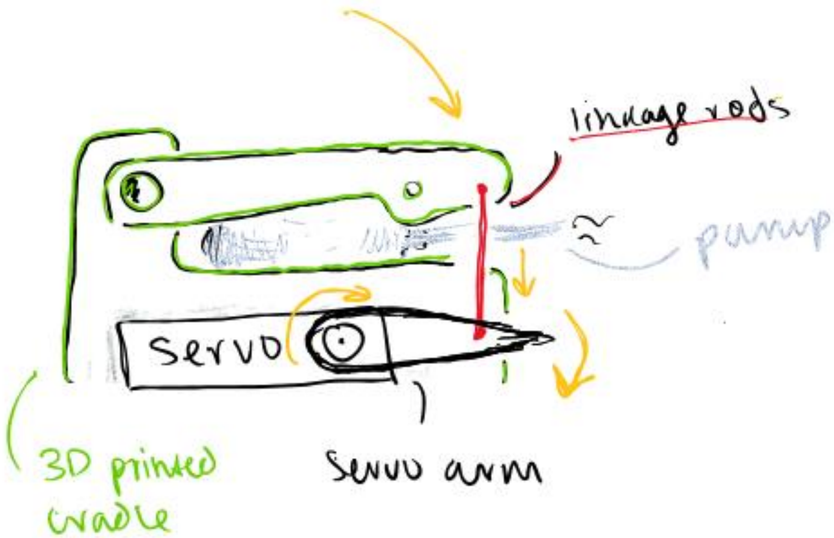




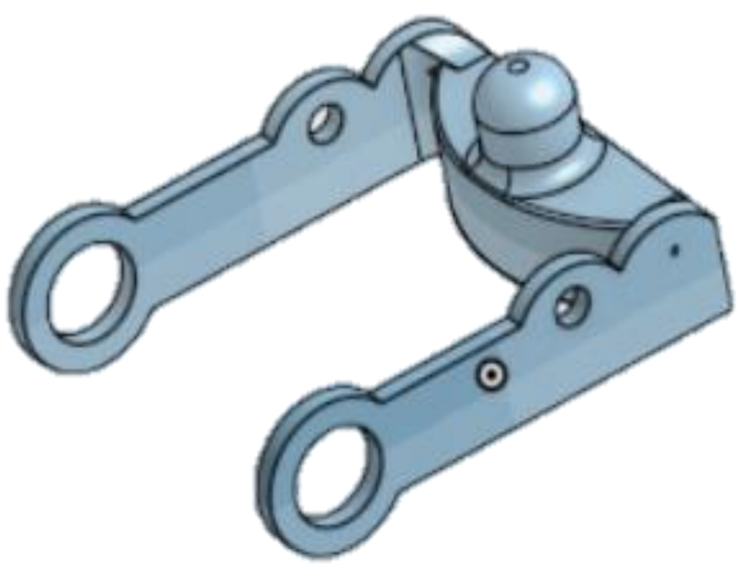


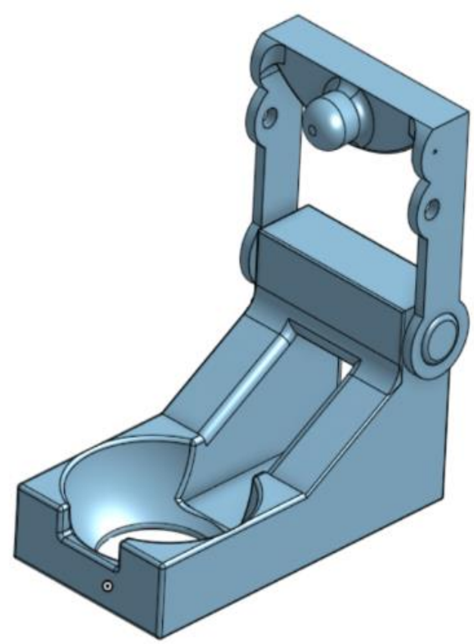
The robot nose prototypes were designed using CAD software and 3D printed.

THE OLFACTORY SYSTEM PROTOTYPE V2

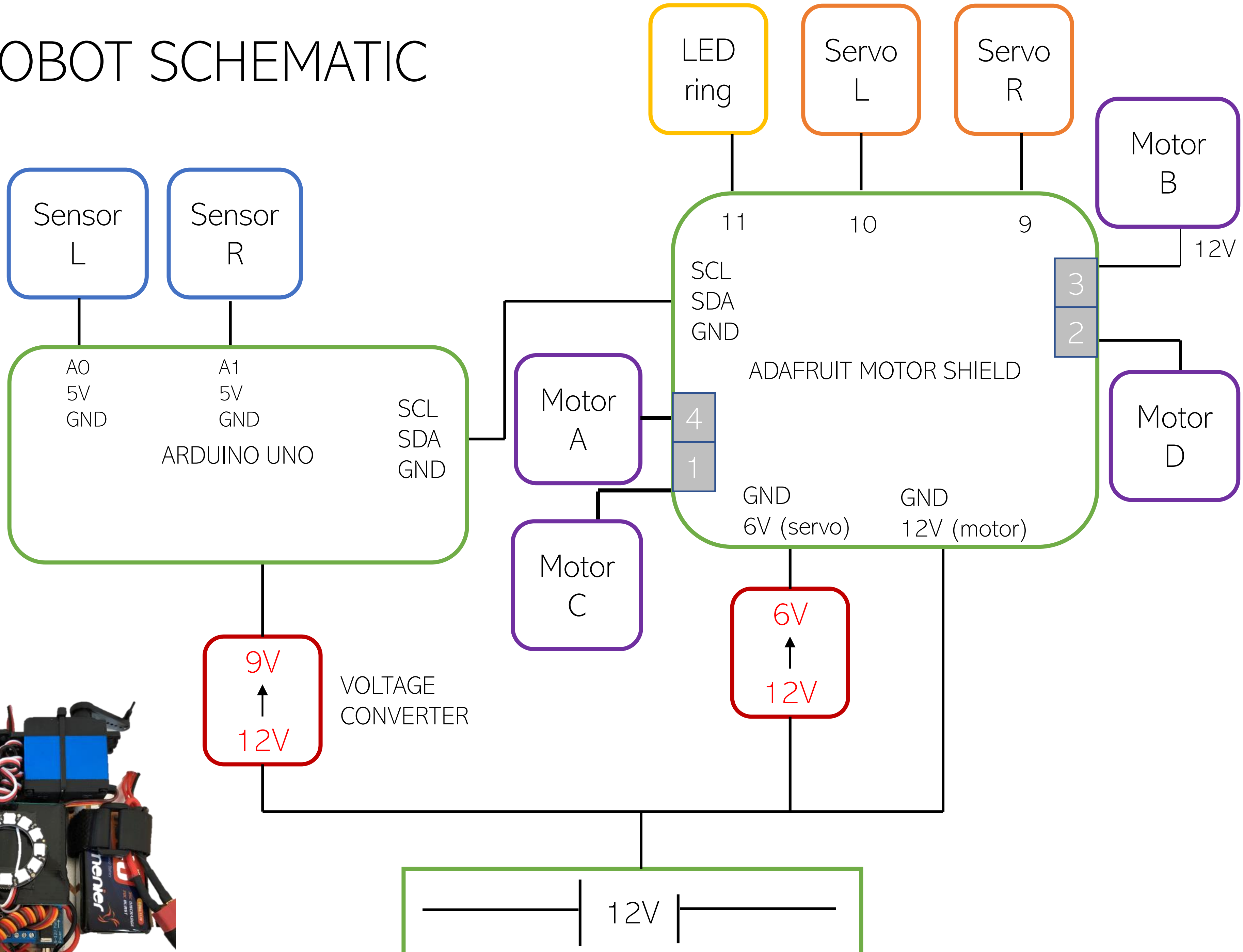


This 3D printed olfactory pump system was designed to hold a small pump and press into the pump's center, mimicking an inhale-exhale function. The design consists of a base piece (in which the pump rests) and a jaw piece, which is driven by a servo and clamps onto the pump base.





ROBOT SCHEMATIC



THE LOCALIZATION ALGORITHMS

DETERMINE NEXT ANGLE

$$\theta = \frac{90 \times K\,(R - L)}{\max(L, R)}$$

Where
K = Weighted constant
R = Right sensor value
L = Left sensor value
θ = Next angle

The next angle is computed for the current reading, as well as two previous readings. These are then averaged for the resulting angle. In this way, ALV+IN uses previous readings to assess the next direction of travel.

```
    return avg (90 * K0 * sgn(R0 - L0) * abs(R0 - L0) / max(L0,R0),
                90 * K1 * sgn(R1 - L1) * abs(R1 - L1) / max(L1,R1),
                90 * K2 * sgn(R2 - L2) * abs(R2 - L2) / max(L2,R2));
}
```

DETERMINE NEXT STEP LENGTH

$$l = 1.0 - \frac{Q0 \times (R + L)}{2 \times \max(L, R)} - \frac{Q1 \times (R + L)}{2 \times \max(L, R)} - \frac{Q2 \times (R + L)}{2 \times \max(L, R)} - \cdots$$

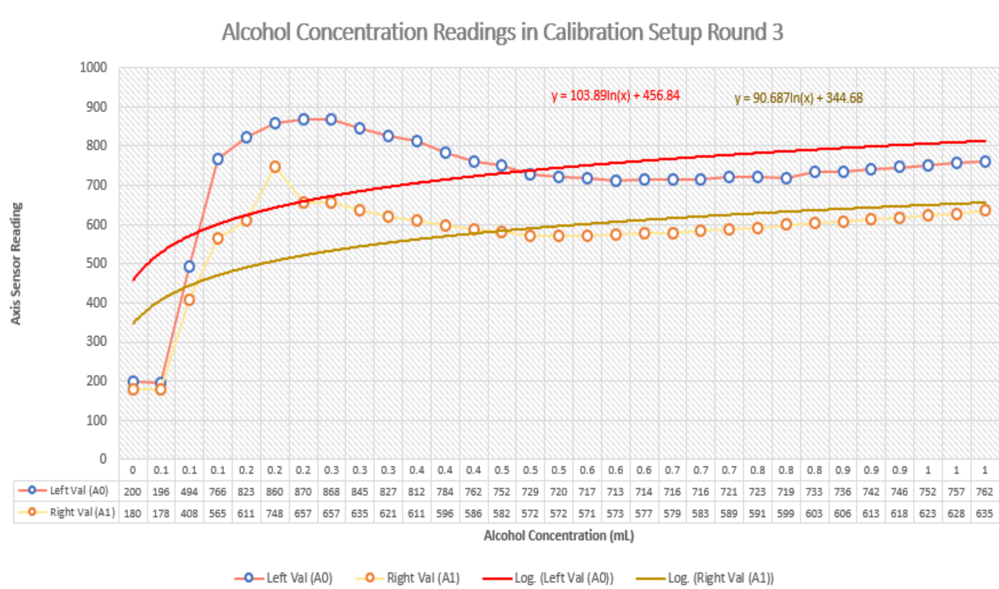
Where
$Q(n)$ = Weighted constant
R = Right sensor value
L = Left sensor value
l = Step length

To determine the next step length, an algorithm subtracts up to four weighted normalized average readings from 1, then multiplies the result by 12 inches (1 foot).

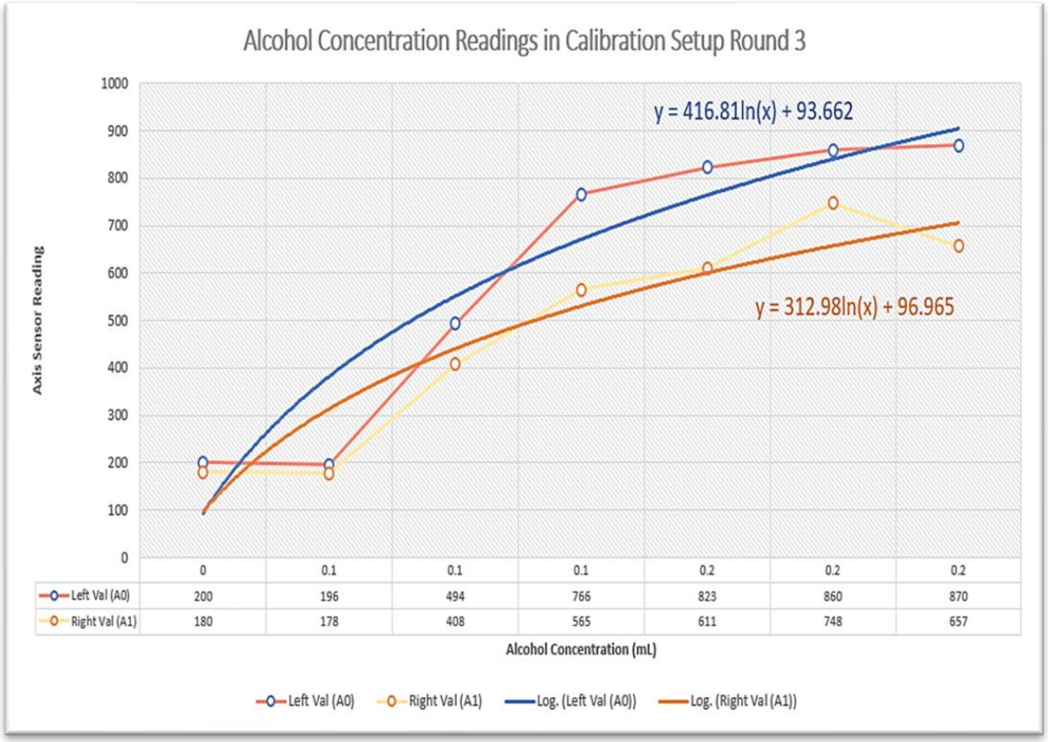
```
double computeNextStepLength() {
    return 1.0 -
        Q0 * ((double)(lastReadingLeft(0) + lastReadingRight(0)) / (2 * (double)MAX_READING)) -
        Q1 * ((double)(lastReadingLeft(1) + lastReadingRight(1)) / (2 * (double)MAX_READING)) -
        Q2 * ((double)(lastReadingLeft(2) + lastReadingRight(2)) / (2 * (double)MAX_READING)) -
        Q3 * ((double)(lastReadingLeft(3) + lastReadingRight(3)) / (2 * (double)MAX_READING));
}
```

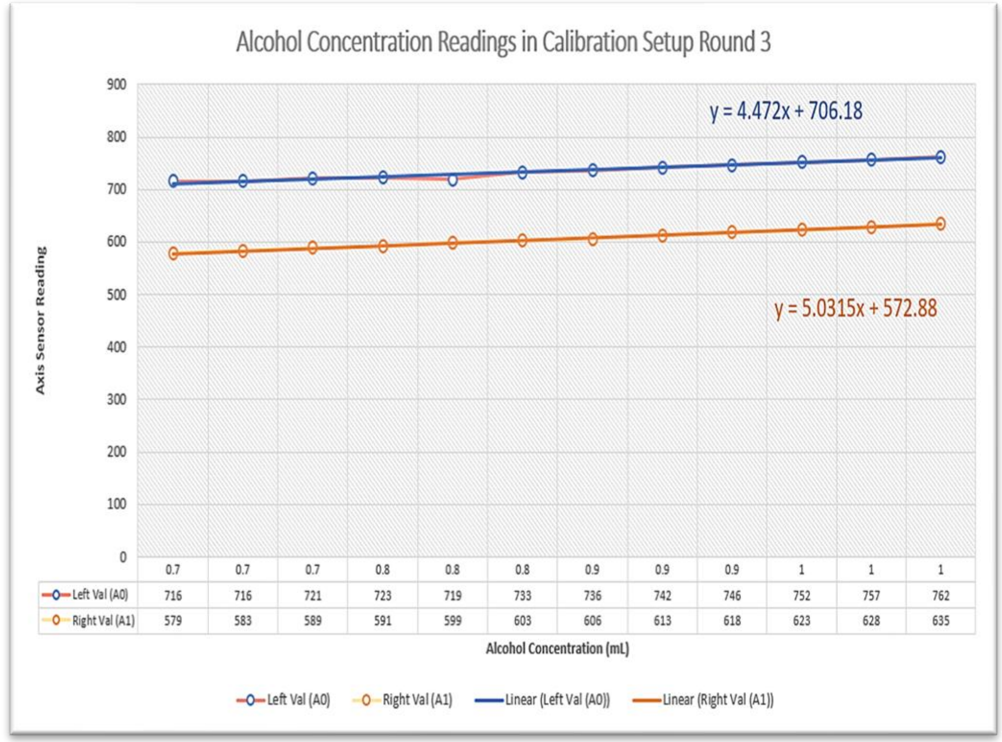
CALIBRATION OF MQ SENSORS

Because of their manufacturing, a pair of MQ Arduino sensors will never produce the same raw concentration readings unless calibrated. To ensure ALV+IN utilizes each sensor to their full potential accuracy, a set of MQ-135 and MQ-2 sensors were calibrated. This process involved reverse-engineering the output reading “curves” that each sensor produced, then inverting them to implement in the localization algorithms.



CALIBRATING MQ-135 SENSORS (ALCOHOL)

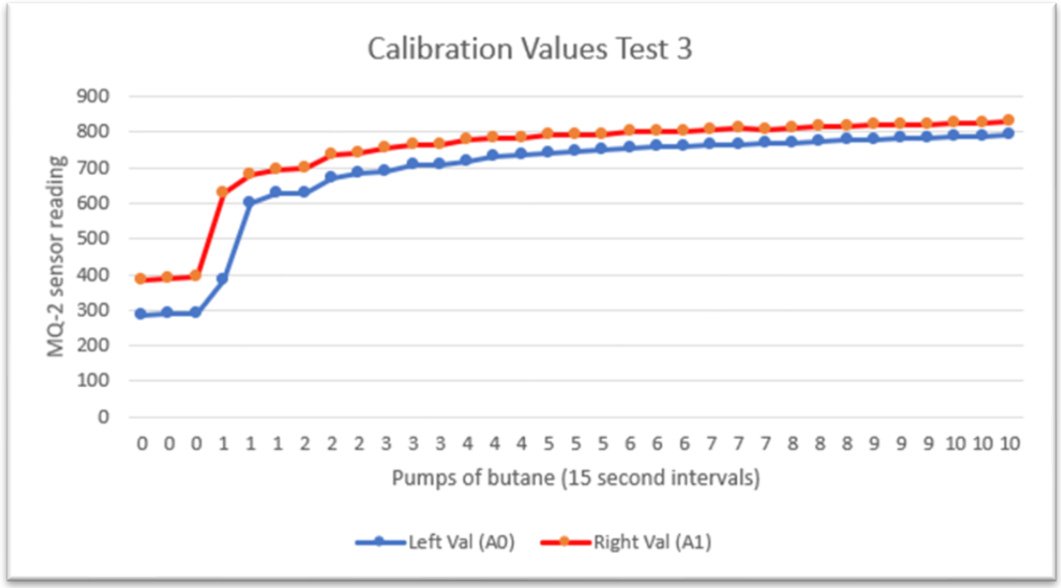


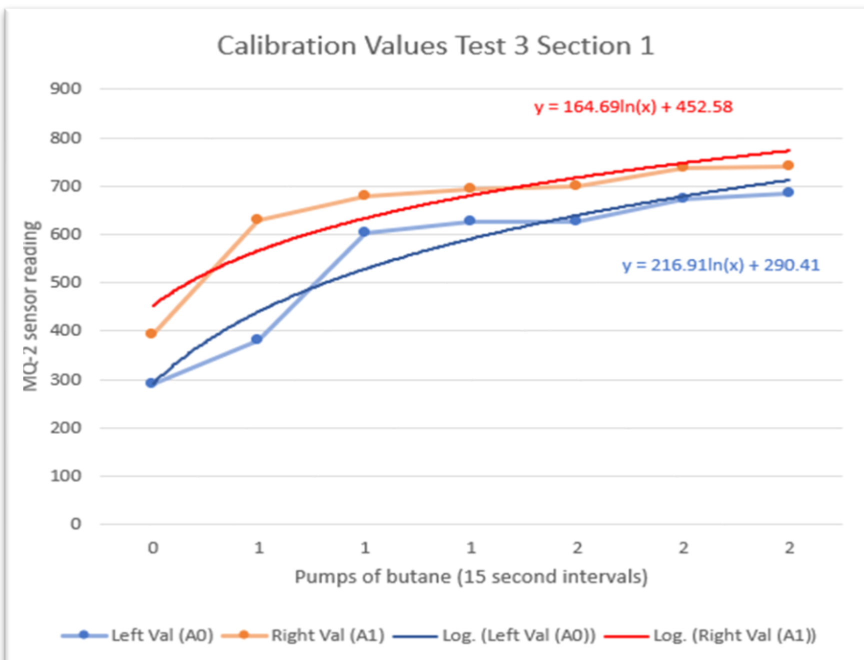


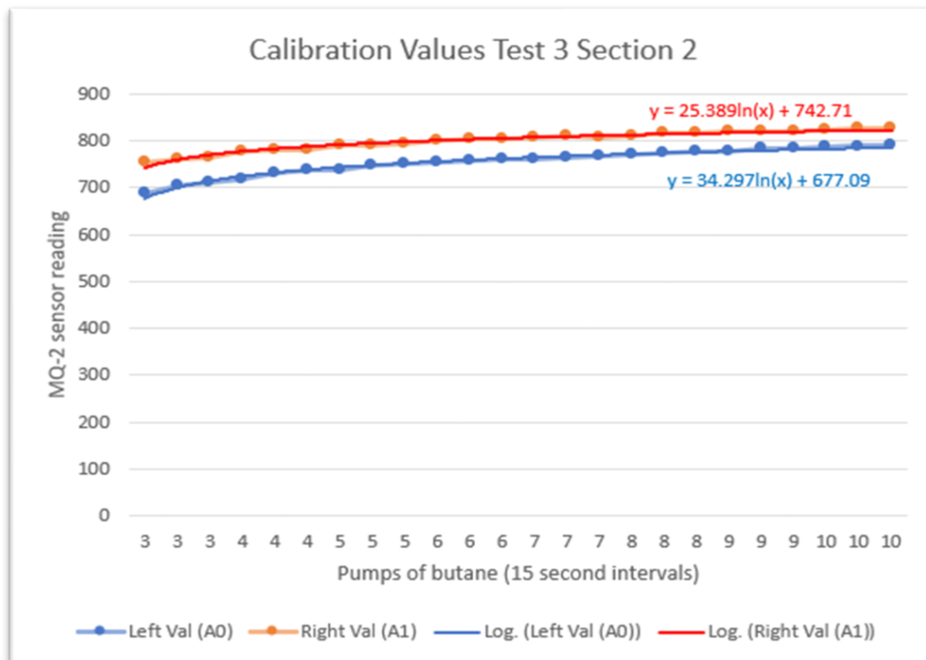
Segment Name	Equation
Segment 1 left	$f(x) = 416.81\ln(x) + 93.662$
Segment 2 left	$f(x) = 4.472x + 706.18$
Segment 1 right	$f(x) = 312.98\ln(x) + 96.965$
Segment 2 right	$f(x) = 5.0315x + 572.88$

Segment Name	Inverse Equation
Segment 1 left	$f^{-1}(x) = 0.798747e^{0.00239917x}$
Segment 2 left	$f^{-1}(x) = -0.223614\,(706.18 - x)$
Segment 1 right	$f^{-1}(x) = 0.733585e^{0.00319509x}$
Segment 2 right	$f^{-1}(x) = -0.198748\,(572.88 - x)$

CALIBRATING MQ-2 SENSORS (BUTANE)







Segment Name	Equation
Segment 1 left	$f(x) = 216.91\ln(x) + 290.41$
Segment 2 left	$f(x) = 34.297\ln(x) + 677.09$
Segment 1 right	$f(x) = 164.69\ln(x) + 452.58$
Segment 2 right	$f(x) = 25.389\ln(x) + 742.71$

Segment Name	Inverse Equation
Segment 1 left	$f^{-1}(x) = 0.262147e^{0.00461021x}$
Segment 2 left	$f^{-1}(x) = (2.66794)(10^{-9})(e^{0.0291571x})$
Segment 1 right	$f^{-1}(x) = 0.0640512e^{0.00607201x}$
Segment 2 right	$f^{-1}(x) = (1.97464)(10^{-13})(e^{0.0393871x})$

```
#define MULTIPLIERLEFT 100
#define MULTIPLIERRIGHT 625

double invertLeft (double x) {
    if(x < 750){
      return constrain(0.262147 * exp(0.00461021 * x) * MULTIPLIERLEFT, 0, 1024);
    }
    return constrain(0.000000001 * 2.66794 * exp(0.0291571 * x) * MULTIPLIERLEFT, 0, 1024);
}

double invertRight (double x) {
    if(x < 796){
      return constrain(0.0640512 * exp(0.00607201 * x) * MULTIPLIERRIGHT, 0, 1024);
    }
    return constrain(0.0000000000001 * 1.97464 * exp(0.0393871 * x) * MULTIPLIERRIGHT, 0, 1024);

}
```

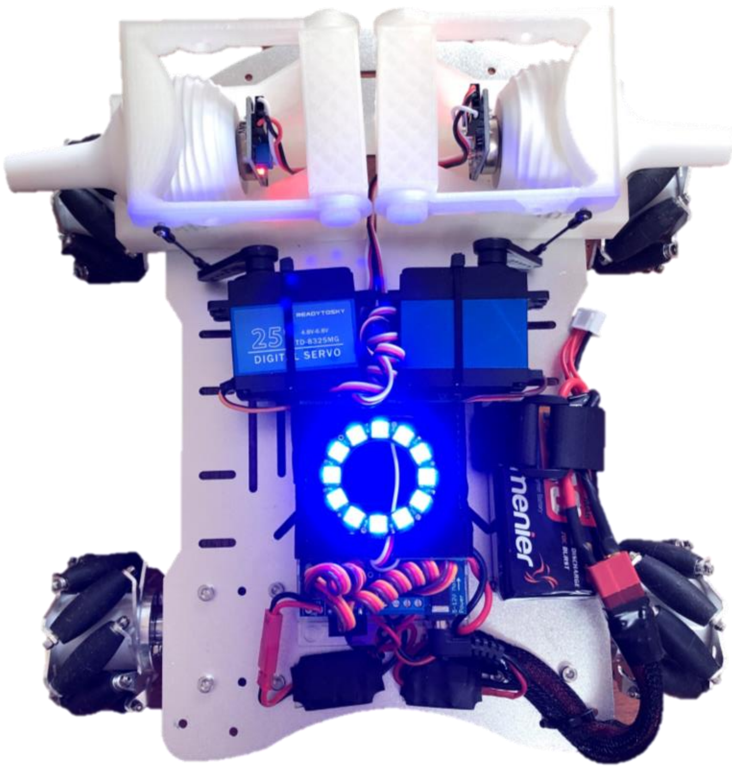
TESTING AND RESULTS

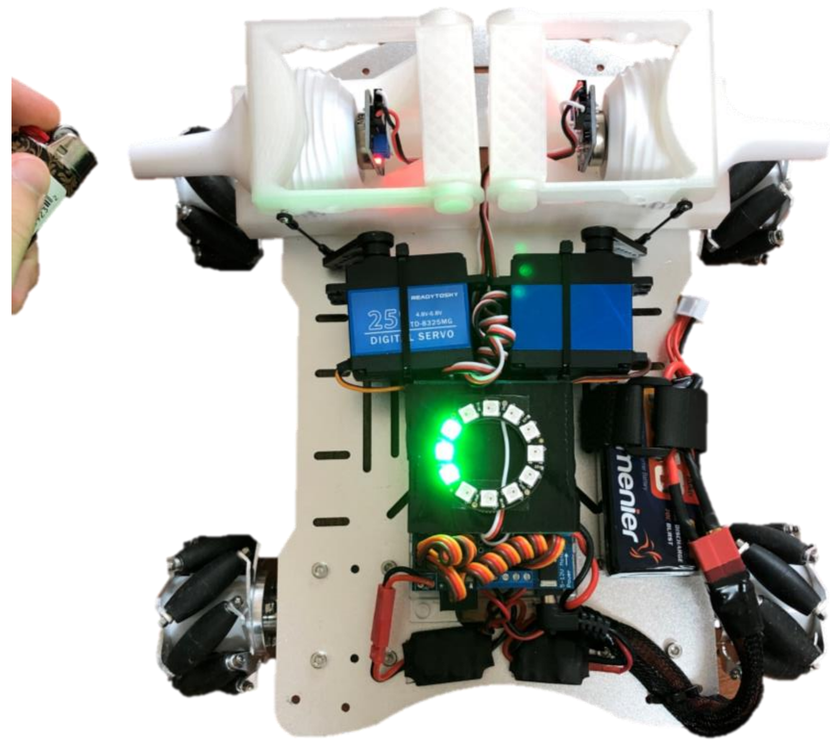
```
Left: 187 (62.08), Right: 114 (79.99)
Left: 183 (60.95), Right: 99 (73.03)
Left: 185 (61.51), Right: 86 (67.48)
Left: 181 (60.39), Right: 85 (67.07)
Left: 182 (60.67), Right: 77 (63.89)
Left: 179 (59.83), Right: 75 (63.12)
Left: 183 (60.95), Right: 70 (61.24)
Left: 178 (59.56), Right: 68 (60.50)
Left: 180 (60.11), Right: 66 (59.77)
Left: 181 (60.39), Right: 67 (60.13)
Left: 179 (59.83), Right: 65 (59.40)
Left: 178 (59.56), Right: 62 (58.33)
Left: 177 (59.28), Right: 62 (58.33)
Left: 176 (59.01), Right: 63 (58.69)
Left: 176 (59.01), Right: 61 (57.98)
```

Even though the raw sensor readings show contrasting values,
The normalized values are very similar.
This is an indication that the inverse functions used accurately calibrate the sensors.

```
Last reading: 54.81,54.90; 1 total.
Angle: 10 degrees, Step: 10 inches
Sniffing...
Last reading: 55.07,53.58; 2 total.
Angle: 2 degrees, Step: 10 inches
Sniffing...
Last reading: 55.07,240.07; 3 total.
Angle: 45 degrees, Step: 8 inches
Sniffing...
Last reading: 55.32,78.55; 4 total.
Angle: 31 degrees, Step: 9 inches
Sniffing...
Last reading: 54.56,1024.00; 5 total.
Angle: 71 degrees, Step: 4 inches
Sniffing...
```

If the normalized value is very large, the value is capped at 1024. This will mean that the sensor is completely saturated.





AVL+IN begins the movement process by taking a reading, or "sniffing", using the olfactory pump systems. To indicate this process, the LED ring displays a full blue circle.

When a difference in butane concentration is detected, ALV+IN will display the robot interpretation of the location of the odor source. This is based off a buffer of 3 readings.

When the robot reaches the odor source (defined as both sensors reading a value of over 400, the robot will stop, and the LED ring will display a full white circle.

CONCLUSIONS

SUCCESS

ALV+IN can successfully determine the next path of travel based on sensor readings from each olfactory pump system. Calibration of MQ sensors produced successfully normalized sensor readings used in the localization algorithms.

SENSOR ERROR

Due to imprecisions of the MQ-135, MQ-6, and MQ-2 sensors for Arduino, even with calibration, the sensors will not show equal readings when exposed to equal amounts of butane, methane, alcohol, etc. This will constantly make it difficult for a robot to follow an odor reliably.

TESTING RESTRICTIONS

Using an odor source such as a piece of paper soaked in rubbing alcohol or a butane lighter does not supply a sufficient concentration of the odor for the robot to detect from far away. In order to properly test ALV+IN's real efficiency, a large-scale butane plume will need to be devised. This will also include finding a safe, well-ventilated area in which to test the robot. Currently, due to safety and space constraints, such a test cannot be run in my workspace. The feasibility and execution of this test will have to be looked into and carefully calculated before implementing due to the risks involved.

NEXT STEPS

TESTING

1) Research methods for simulating butane plumes
2) Find a safe space to produce plumes and test

ADJUSTING

1) Experiment with weight values for previous readings to gain the most accurate next angle/path of travel
2) Find a more accurate way to calibrate sensors using more precise functions or replace sensors with more sensitive ones

ADDITIONS TO ROBOT

1) Utilize mecanum capabilities of robot to strafe sideways rather than turn (this will change the algorithms used)
2) Replace current servos with faster ones (to increase speed of "sniffing", therefore increasing concentration reaching each sensor)

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For research paper and more information regarding ALV+IN's design process, test results, and algorithm specifics: