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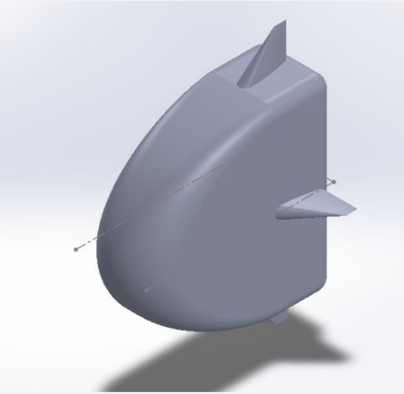
Micro Autonomous Underwater Robot



Week 1-5, Winter ‘22

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Problem Definition/Project Description

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- **Problem:** Robots are often deployed in areas that are inaccessible for humans to go. Many times, these areas are in mediums where radiocommunication is not available, like water. In those situations, autonomous vehicles operating in a self sufficient way without human input are a great solution.

- **Solution:** Create a small scale autonomous underwater vehicle capable of detecting different signals and effectively approach and connect to signal source in a 3D environment.

Jose Gilbert

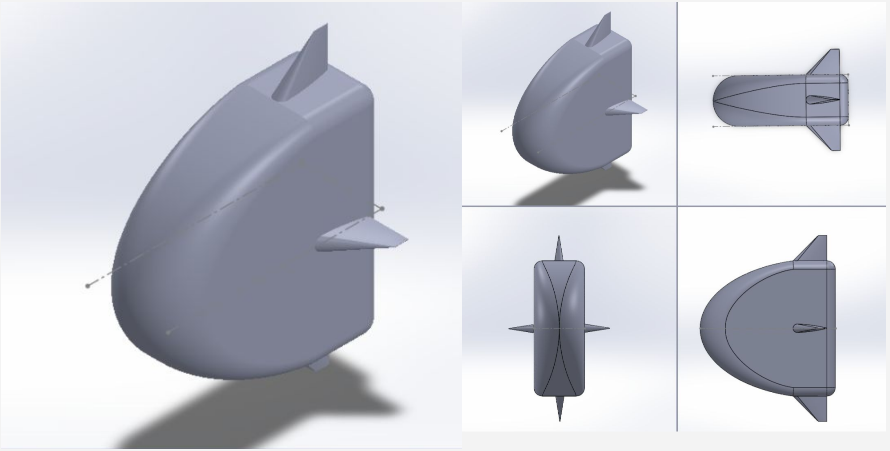
Design Requirements

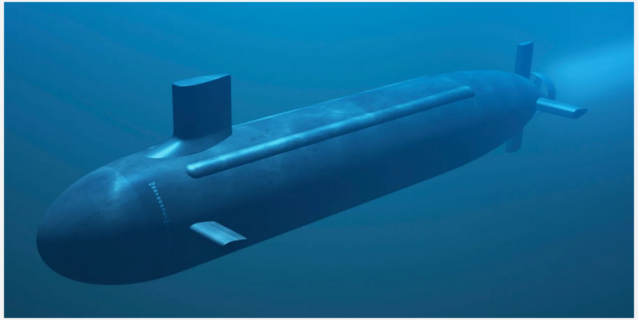
Design Attribute	Metric	Req	Const	Function/Means
Small Size	<1000 cm^3	x		
Low power	<10 W	x		Microcontroller & low complexity electronic components
Must operate at depth	100 cm		x	
Waterproof			x	3-D Printed body, PU/Epoxy Sealant
Detects magnetic field @ Distance	>5cm			LSM 3030 Magnetometer
Detects sound @ distance	>300cm			MAX9184 Microphone
Navigate underwater to target	~300 cm	x		Magnetic/Acoustic Feedback Control System
Connects to underwater target		x		Able to autonomously connect and disconnect
Completely autonomous navigation		x		Able to navigate it's medium without any exterior input

Robot Body

Motivation

- Hydrodynamic Design
- Underwater Stability
- Maneuverable Controls
- Waterproof housing





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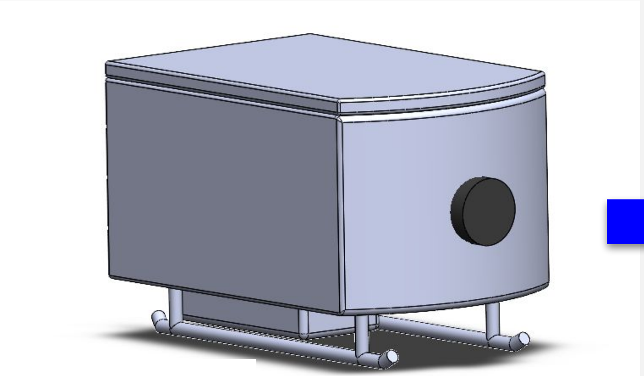
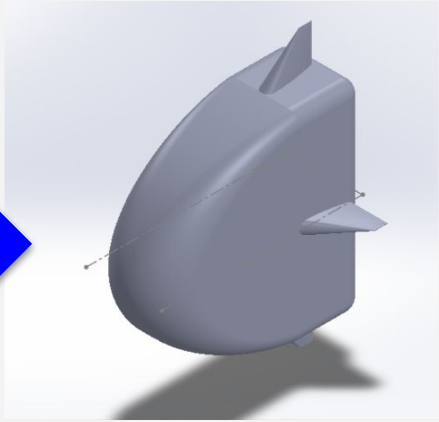
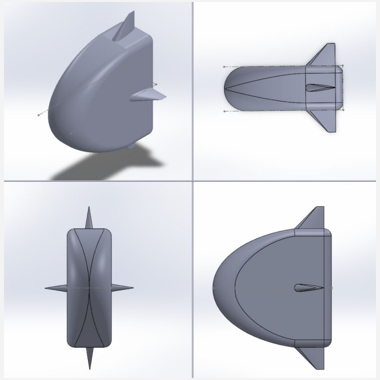
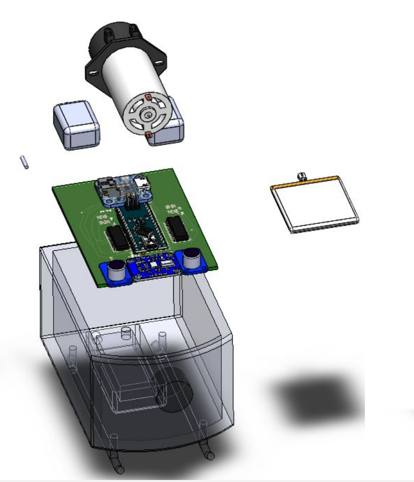
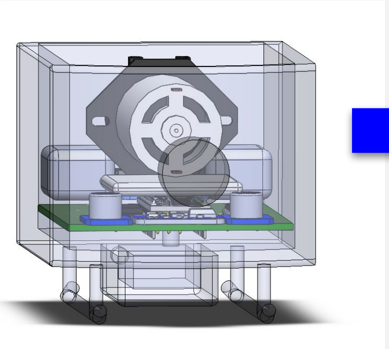
Design Improvements

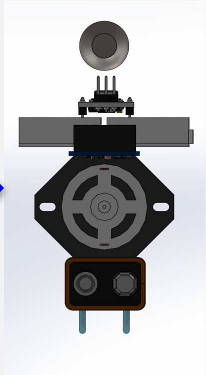


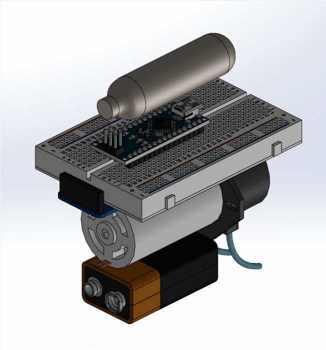


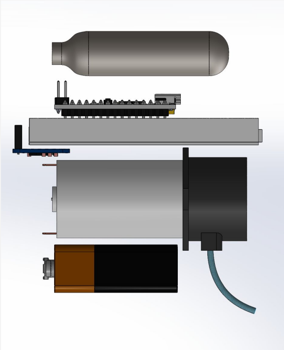












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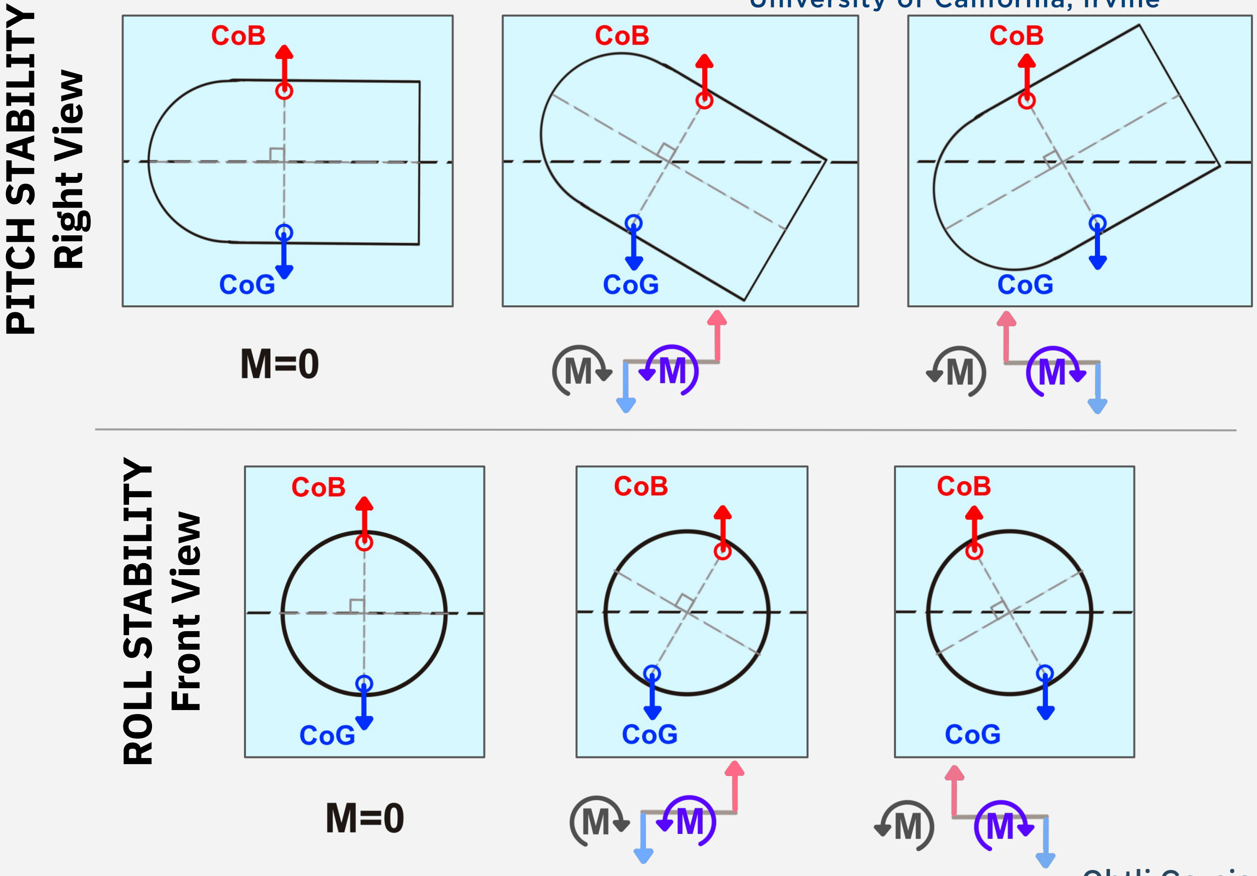
Robot Stability

Pitch and Roll Stability

- Moment Coupling
- Center of Gravity
- Center of Buoyancy

Yaw stability

- Vertical Tail
- Natural Body Shape



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Robot Controls

Propulsion

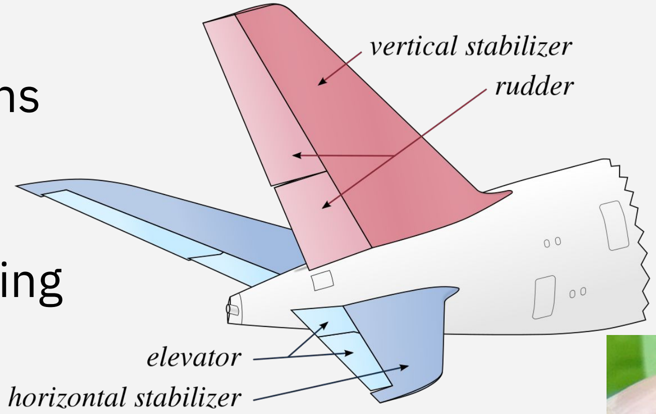
- Propellers in Opposite Directions

Propellers vs Control Surfaces

- Path planning vs Path Responding
- Rudder and Elevator Design

Actuation

- Size constraint
- Servos to Step Motors



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Acoustic Navigation System (ANS)

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Direct the robot towards some signal

Motivation

- Radio waves don’t work well underwater
- Magnetic fields have limited range
- Light waves require complex sensing

Challenges

- Don’t know where source is
- Don’t know where we are
- Have intensity only

Mike Sutherland

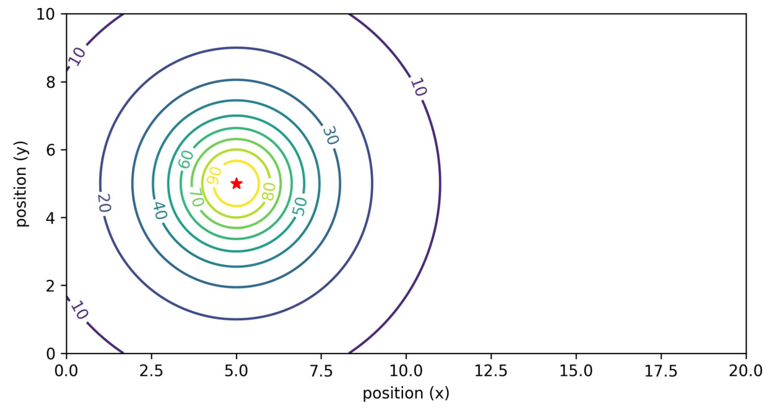
ANS - Engineering Model

Simple inverse square intensity model

$$I \propto \frac{I_{max}}{1 + r^2}$$

r: distance to target, *I:* intensity

Find coefficients empirically.



Mike Sutherland

ANS - Validating the Engineering Model

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This model probably works for some frequencies

Modeling shallow water acoustics is enormously complex

We must rely on empirical testing:

1. To verify the efficacy of the model
2. To fit model parameters

ANS - Experiment Design

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Place MAX9814 at various <x,y,z> locations in the tank, with a frequency emitter of known intensity and frequency

Measure MAX9814 intensity readings

With sufficient samples at <x,y,z> points in the tank, the model can be fit

The intensity response near walls and the surface may give us extra information about the acoustics of the system

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ANS (Experiment Design)

MAX9814 Waterproof Housing

Disposable: wires are cut/desoldered and seal cracked after use

Epoxy Seal between cover plate and body

Housing Body: 3-D Printed (~10g), 35min print time

Bottom line: quick and cheap!

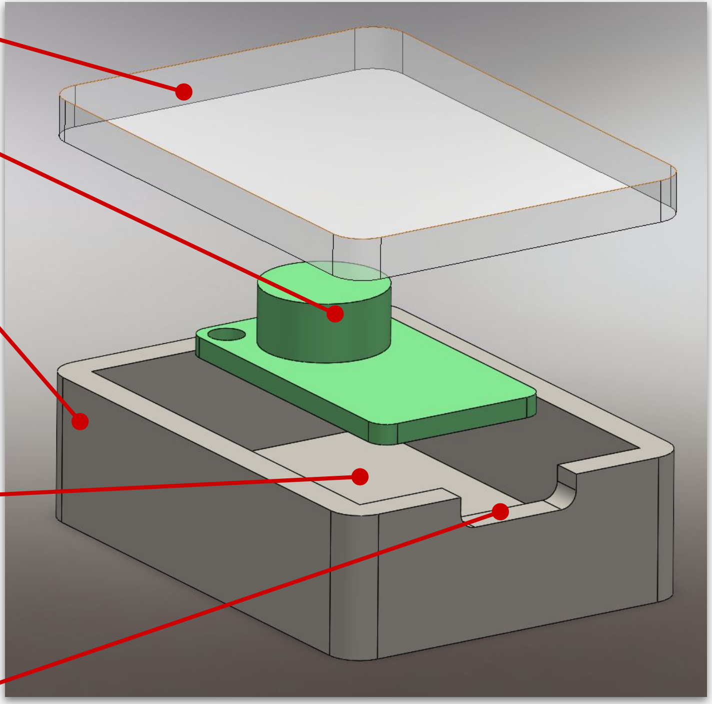
Cover Plate
(⅛ Acrylic, laser cut)

MAX 9814

Housing Body (3-D Printed)
2.5mm wall thickness
Can be latex-coated/painted for better seal

Housing can be mineral-oil filled for high-pressure and low impedance operation

2.5mm Wire Gap and plate/housing is Epoxy-sealed



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ANS (Experiment Design)

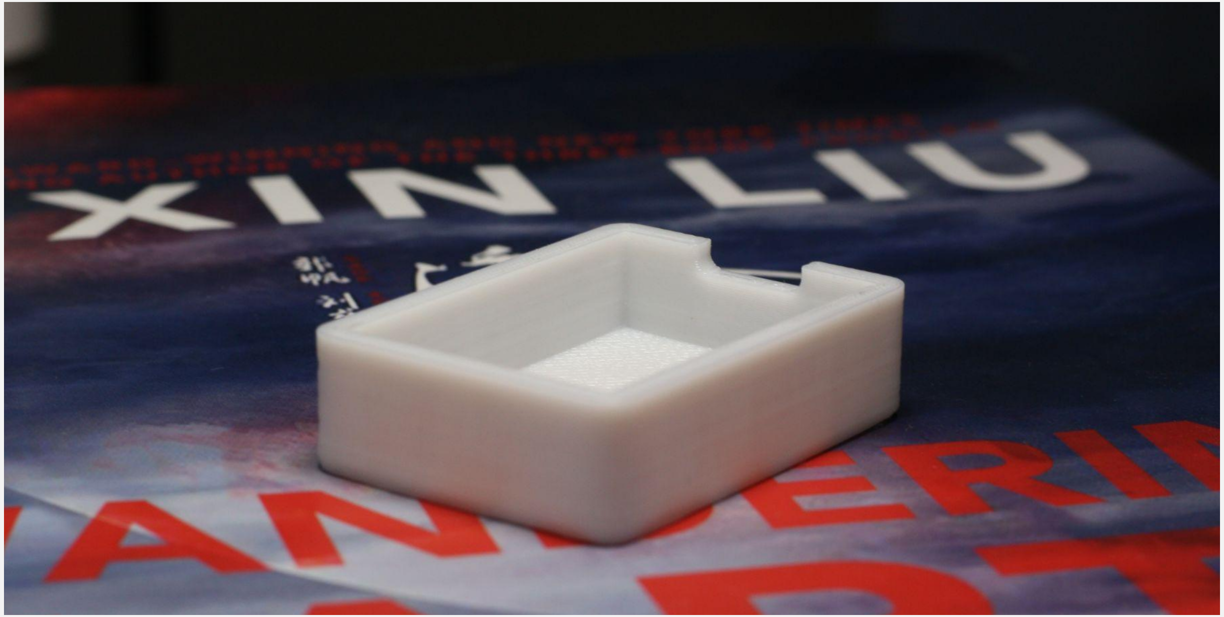

Image:
First 3-D printed prototype

ANS - Control System Design

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COVID protocols = can't be in lab

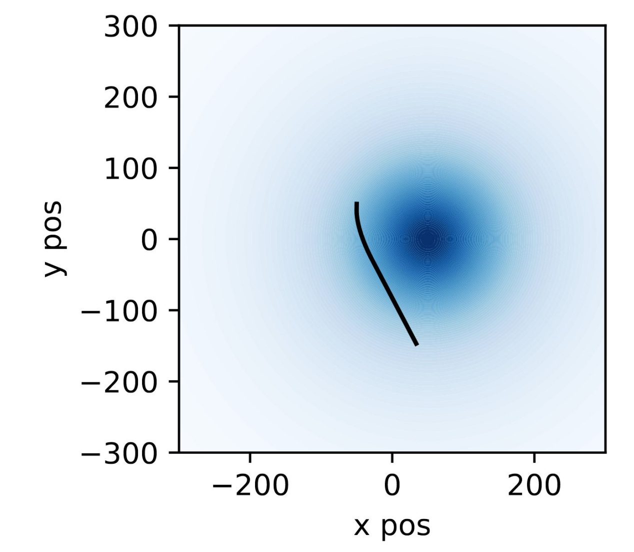
Run with engineering model assumptions, develop a controller

Simulation of point source with inverse-square dropoff

Dubins-Car model for vehicle dynamics

- Max Turn Radius
- Constant Velocity

Control System under development



Simulation results. The vehicle starts at the high position and moves in the -y direction. We successfully turn to the source, but fail to continue turning when intensity derivative values become small.

Mike Sutherland

ANS - Control System Design

Use the derivative and second derivative of intensity over time as we move through the field

We attempt to maximize $\frac{\partial^2 I}{\partial t^2}$ by actuating turn radius

Issues: derivatives become small when moving parallel to constant--intensity contours.

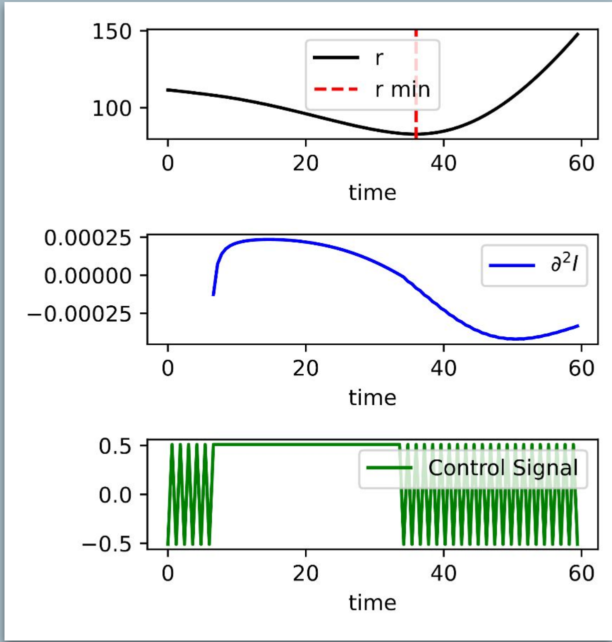


Figure: Results from the simulation

ElectroMagnet and EPM Connection

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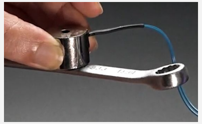
Purpose: Allow for autonomous connection and disconnection between robot and docking station

Requirements: less than 300mA of current and connection on command

Current Electro-Magnet Design

Review of Characteristics
- Function: Creates magnetic field as long as current is applied
- Current: 220mA
- Voltage: 5V
- Dimensions: Diameter: 20mm x Height: 15mm
- Underwater performance=Dry air performance

Problems/Risks Encountered:
- 220mA used while EM is on
- Consumes large amount of power
- Takes up large amount of volume in new design iteration



Electro-Permanent Magnet in Process

New Requirements:
- Function: Uses current to toggle a magnetic field on or off
- Current<110mA
  - EPM uses one pulse to indefinitely stay on and one pulse to indefinitely stay off
- Voltage at 5V
- Volume cut by at least half

Current Developments:
- Solidworks body developed
- Materials chosen
  - **Magnets**: AlNiCo, NdFeB, **Soft Metal:** Iron, **Wiring**:Copper
- Fabrication alongside testing in order to meet requirements still needed

Christian Loyola

EPM Development Cont.

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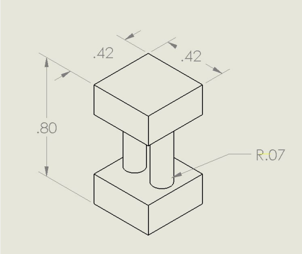
Fabrication/Testing Plan:

Solidworks/Body Design Finalized



Materials and Material Sources to be Chosen

Magnets: AlNiCo, NdFeB, **Soft Metal:** Iron, **Wiring**:Copper

Fabrication

Theory Confirmation

In order to test equations found, an adjustable DC Power Supply will be used to determine length and number of turns of wire.

Current and Magnetic field as a function of Length and N turns of wire

Requirements:

- B>.1884 T
- V= 5v
- I <110mA

B = kμnI or n = B/(kμI)

Fine Tuning Testing in order to meet requirements

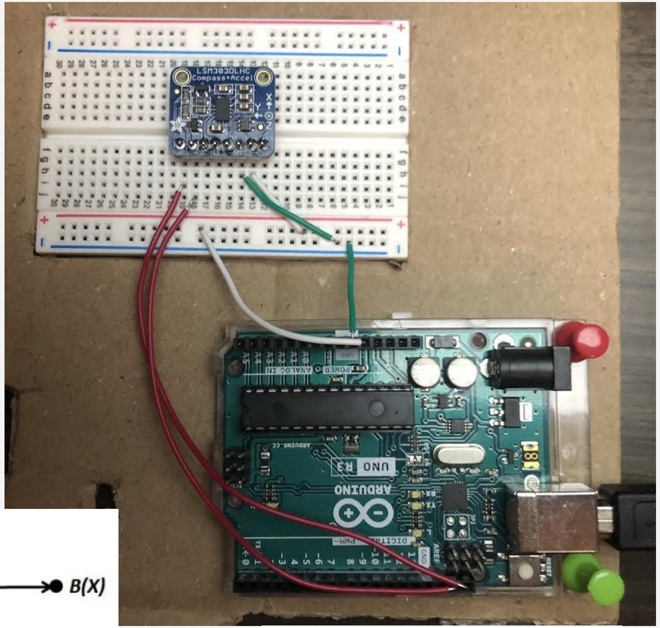
Current<110mA in 1 hour, able to create magnetic field

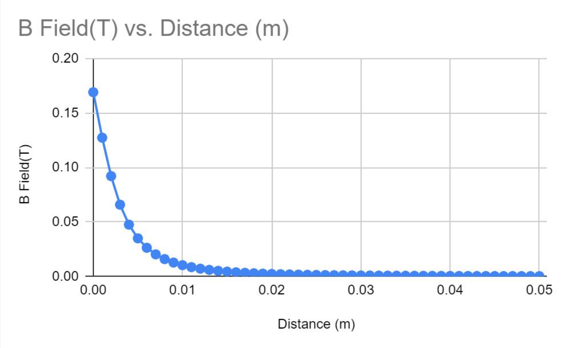
Once EPM has met requirements, it will replace Electromagnet on robot

Christian Loyola

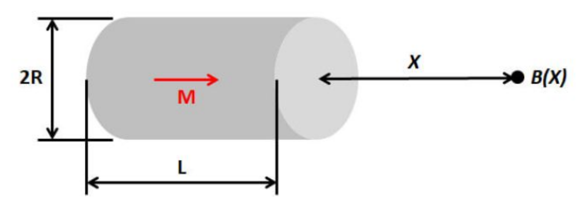
Magnetic Navigation System

- From Last Quarter:
  - Successfully measures angle of magnetic field
- This Quarter:
  - Distance measurement:
    - Characteristic equation of B field vs distance
    - Compare the measure values with actual
    - Create code using this characteristic equation





B field vs Distance curve



$$B(X) = \frac{Br}{2}\left[\frac{L+X}{\sqrt{R^2+(L+X)^2}} - \frac{X}{\sqrt{R^2+X^2}}\right]$$

B field strength with respect to distance of cylindrical magnet

$$F = \frac{\mu_0 H^2 A}{2} = \frac{B^2 A}{2\mu_0}$$

Force of magnetic pull

Jose Gilbert

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Magnetic Navigation System: Testing

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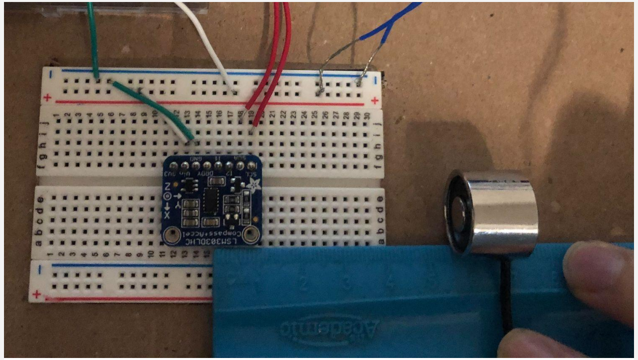
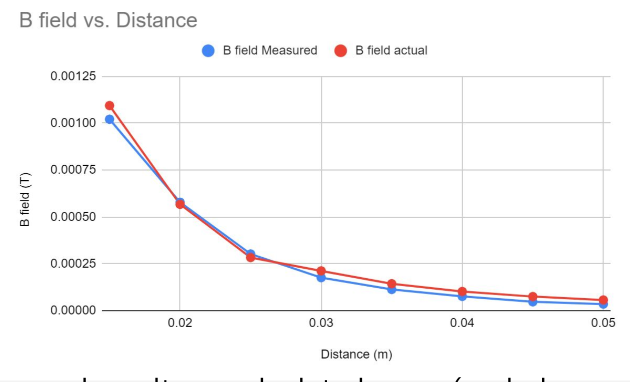
- Testing Conditions

Placed magnet away from sensor at various distances and measured the magnetic field strength at these distances:

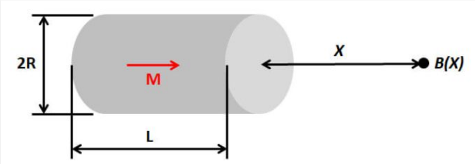
1.5 - 5 cm with magnet facing sensor’s Y axis

- Results:
  - The trend of the measured values is correct
  - At the moment only works with specific placement





Measured results vs calculated curve (scaled properly)



$$B(X) = \frac{Br}{2}\left[\frac{L+X}{\sqrt{R^2+(L+X)^2}} - \frac{X}{\sqrt{R^2+X^2}}\right]$$

B field equation for cylindrical magnet

Robot will have to align with magnet first for an accurate distance value

Jose Gilbert

Magnetic Navigation System

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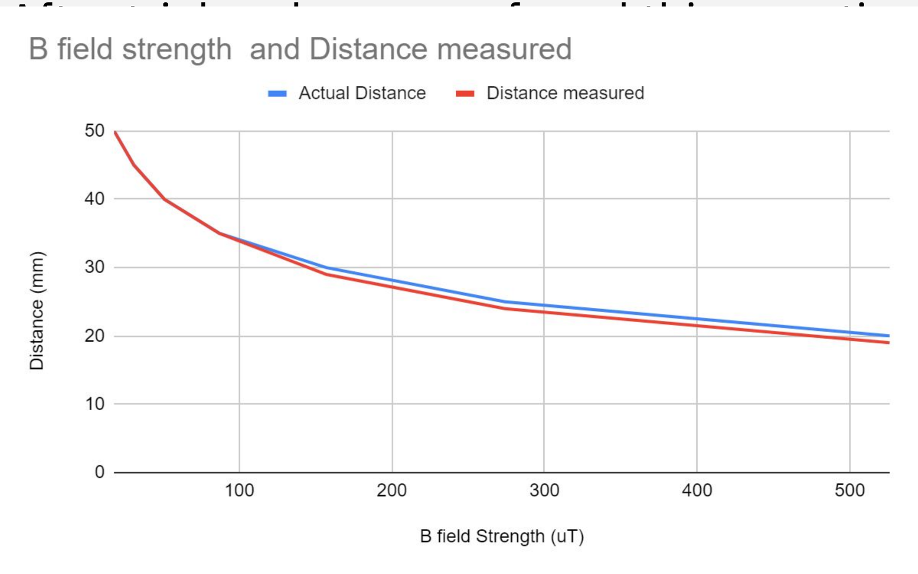
- Using 1/(x)^-1 approximation graph to implement into code
- B field roughly decays at y=1/x^2 with respect to distance, inverse would be x=(1/y)^-1



$$y = \left(500\sqrt{\frac{.94}{2(x+40)}} + 5\right)$$

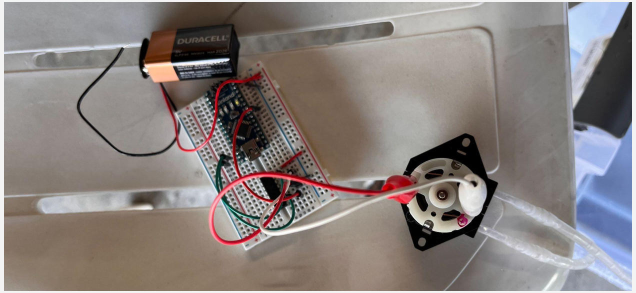
Distance vs B field Equation Approximation

Actual Distance	B field strength	Distance measured
20	526	19
25	274	24
30	157	29
35	87	35
40	51	40
45	31	45
50	18	50

Jose Gilbert

Buoyancy Control

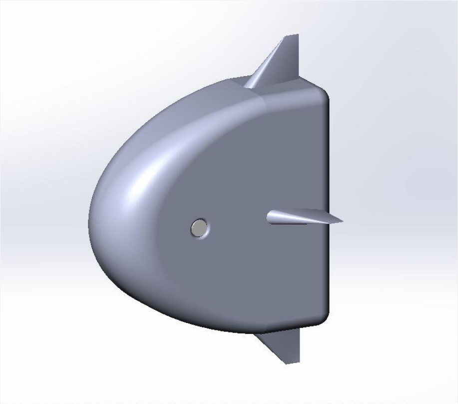
- The mason jar below represents the robot
- When the pump injects water into the robot, the robot will descend
- When the pump ejects water out of the robot, the robot will ascend
- The pump will be controlled with an h-bridge to reverse the pump's DC connection

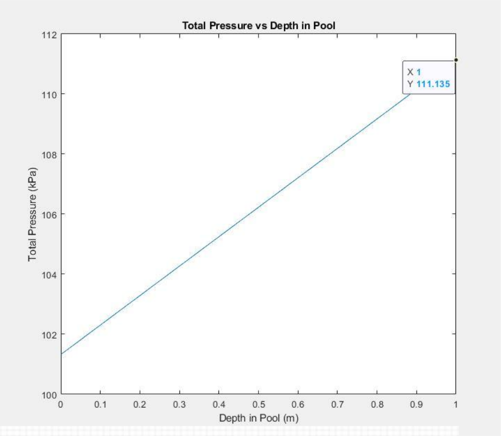


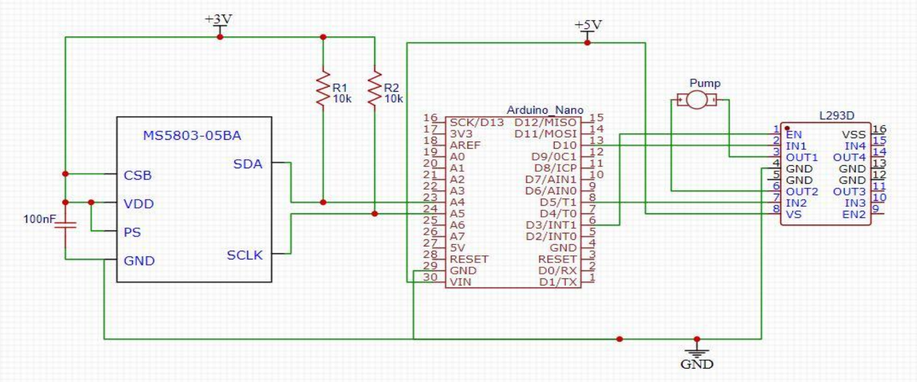
Varn Saechao

Pressure Sensor on the robot

- The pressure sensor will be located on the side of the robot to reduce dynamic pressure
  - O-ring for waterproofing
  - Can read up to 5 bar max (500 kPa)
- Max pressure at the bottom of a 1-meter pool of water = 111.14 kPa
- A schematic diagram of the pressure sensor, h-bridge, pump, and Arduino Nano







Varn Saechao

Moving Forward

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Weeks 6-7	• Combine electronic systems to test underwater and create a combined schematic that integrates all the electronic components together (e.g. combining the buoyancy control with electromagnet system) • Find a proper power supply suitable for all the electronics, such as a LiPo battery • Validate ANS engineering model with experimental sound intensity data
Weeks 8-9	• Manufacture the first prototype of the robot and combine all the components (including the full design of the AUV body) for complete underwater testing • Test actuators for control system and alter controller as needed to incorporate non-simulated vehicle dynamics
Week 10	• Complete the first prototype and realize our goal of having the robot attach autonomously to a specified item inside a 1-meter deep pool of water

Varn Saechao