Autonomous Underwater Robots Final Presentation

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Outline

- Problem statement
- Objective and metrics
- Functional requirements
- Background information
- System block diagram
- Division of labor
- Subsystems
- Results
- Conclusions

Problem Statement

- Map underwater terrain using multiple autonomous robots
- Avoid collisions
- Generate a final image of the terrain

Objectives and Metrics

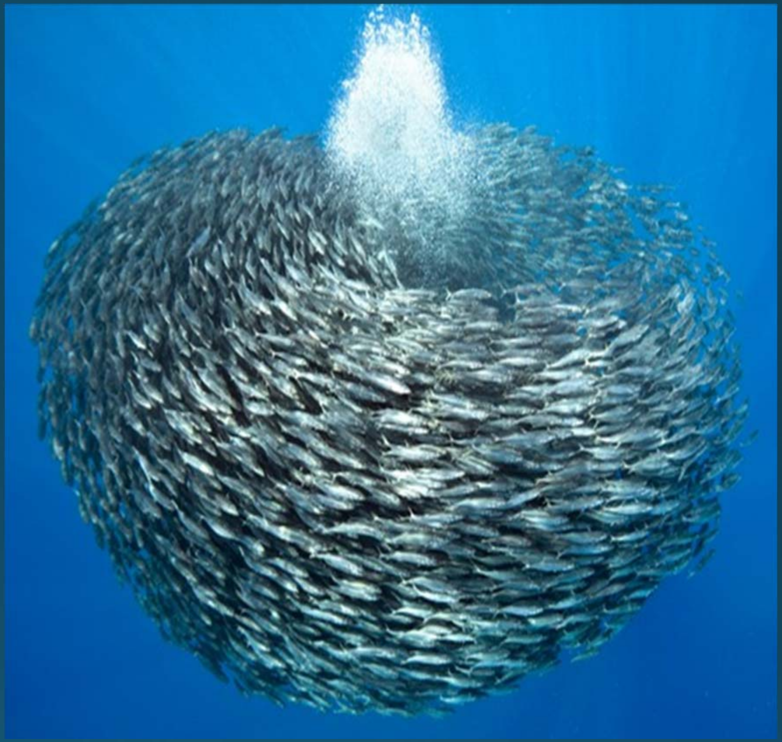
Objective	Metric
Minimize Cost	Determined by the production cost of one member of the swarm.
Autonomous	The amount of human interaction needed for the swarm to function.
Mobile Underwater	The turn radius of each swarm member and how close the swarm member is to neutrally buoyant.
Durable	The amount of places that fail per swarm member.
Portability	The perceived size and weight of each swarm member.

Functional Requirements

Functional Requirements
The submarines shall have a battery life of at least 15 minutes.
The swarm shall maneuver through a body of water.
Each submarine shall detect other submarines.
The swarm members shall operate as a swarm when near each other.
The swarm shall take images of underwater terrain.
Each submarine shall surface upon its battery level dropping below 5%.
Software shall create an image that is collected from the individual submarine images.

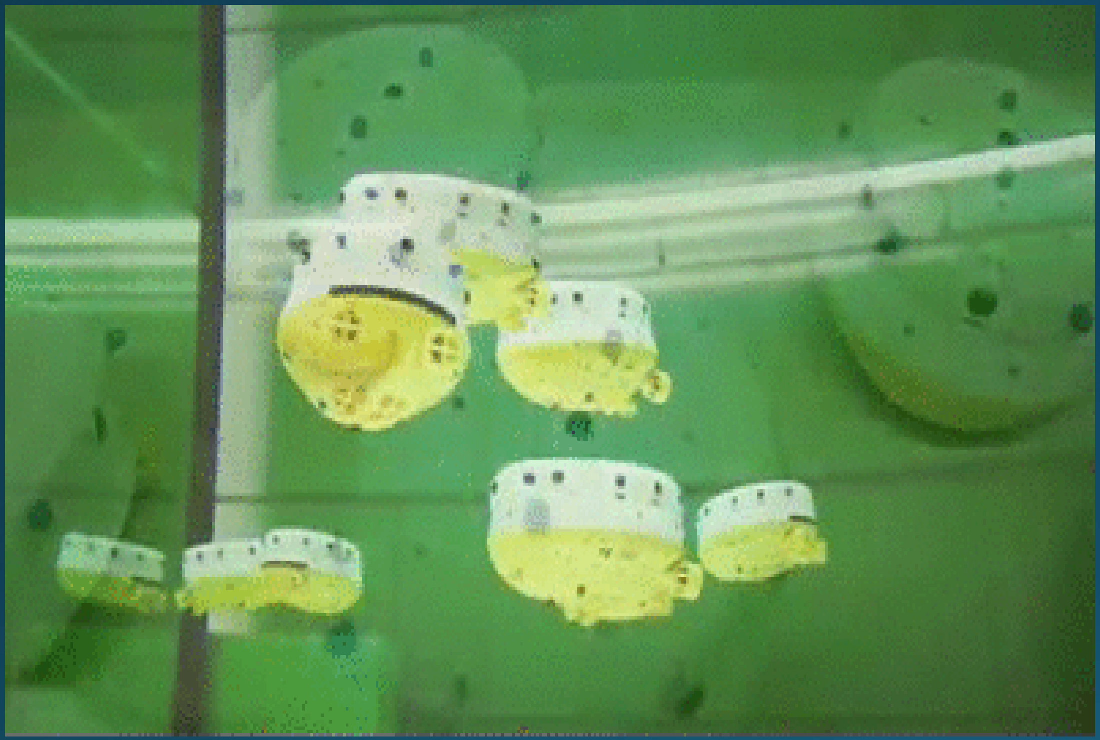
Literature Review

- AUV history
- AUV swarm research
  - Cocoro



Swarm of Fish [1]

Cocoro



Cocoro normal operation [2]

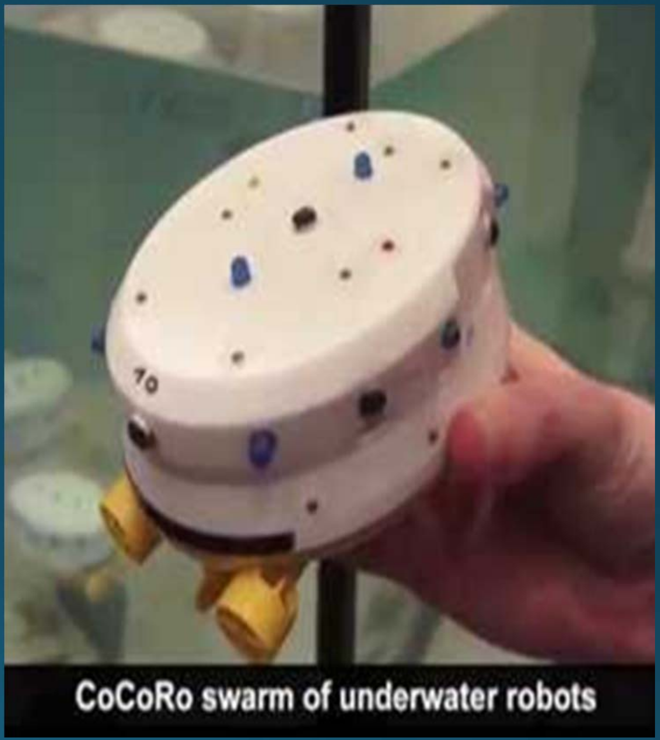
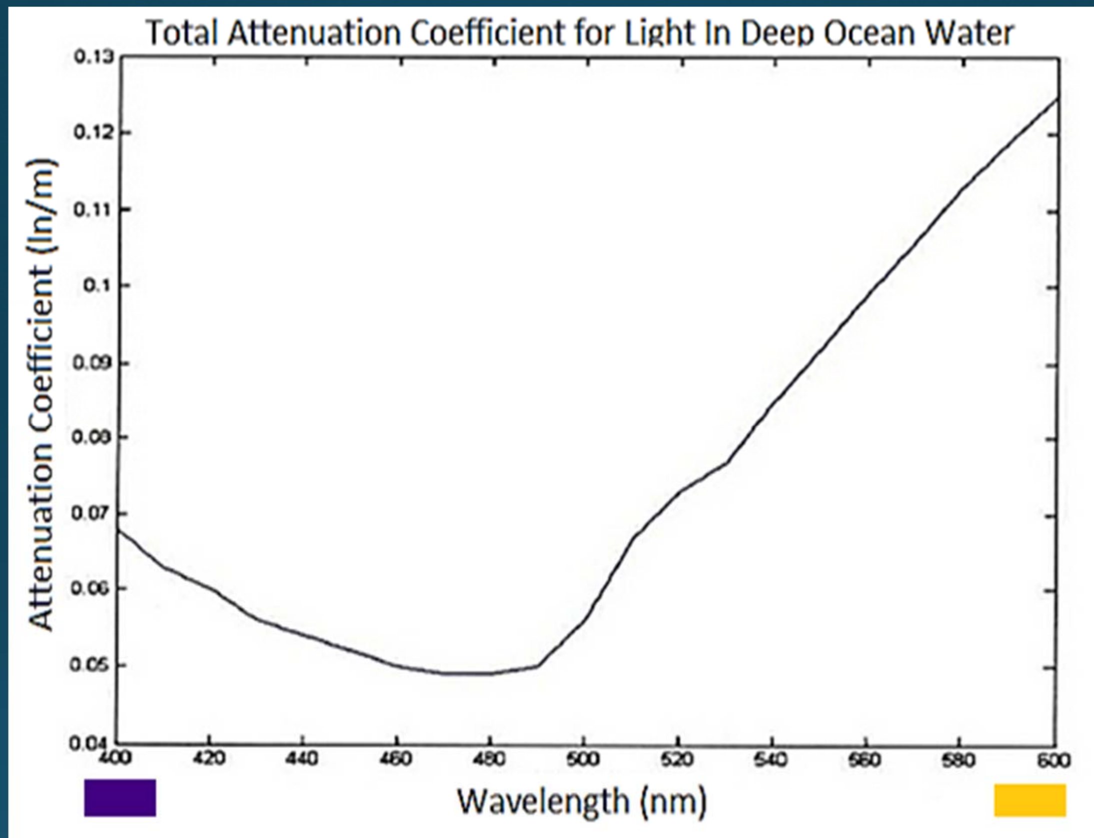


Image of Cocoro [3]

Blue LEDs - Visibility



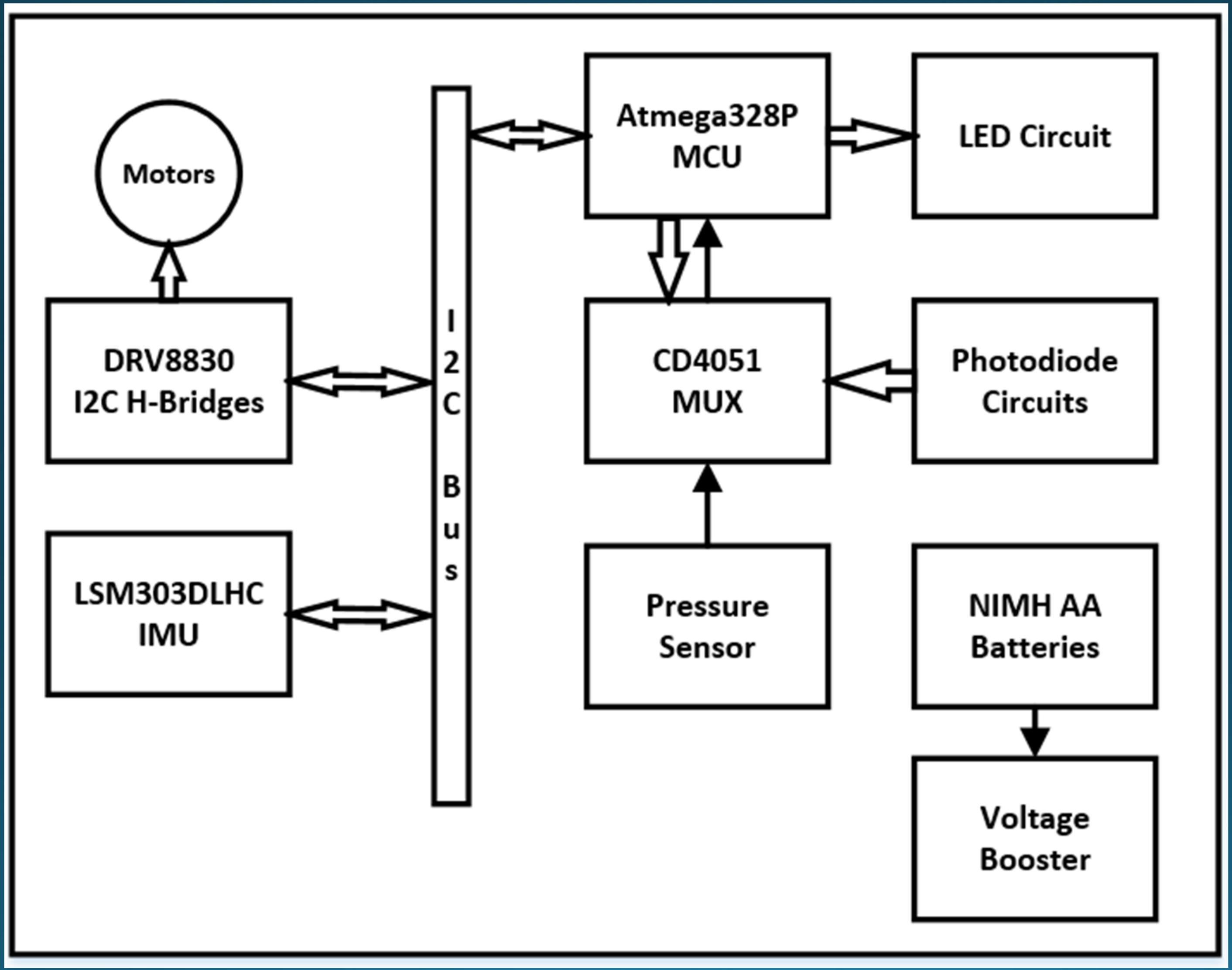
Attenuation of ligh in ocean water [4]

Blue LEDs - Detection

	Photoresistors	Phototransistors	*p-n* Photodiodes
Speed	Slow *<1 Hz*	Moderate *<250KHz*	Fast *Tens of MHz to tens of GHz*
Size	Small	Small	Small
Gain	Little	100-1500	Unity
Linearity	Over small regions	Good	Excellent
Ambient Noise Performance	Very good	Excellent	Very Good

Characteristics of detection methods [4]

System Block Diagram



Division of Labor

Cameron – hardware

- Camera system
- Detection array
- Power system

Ryan – hardware and software

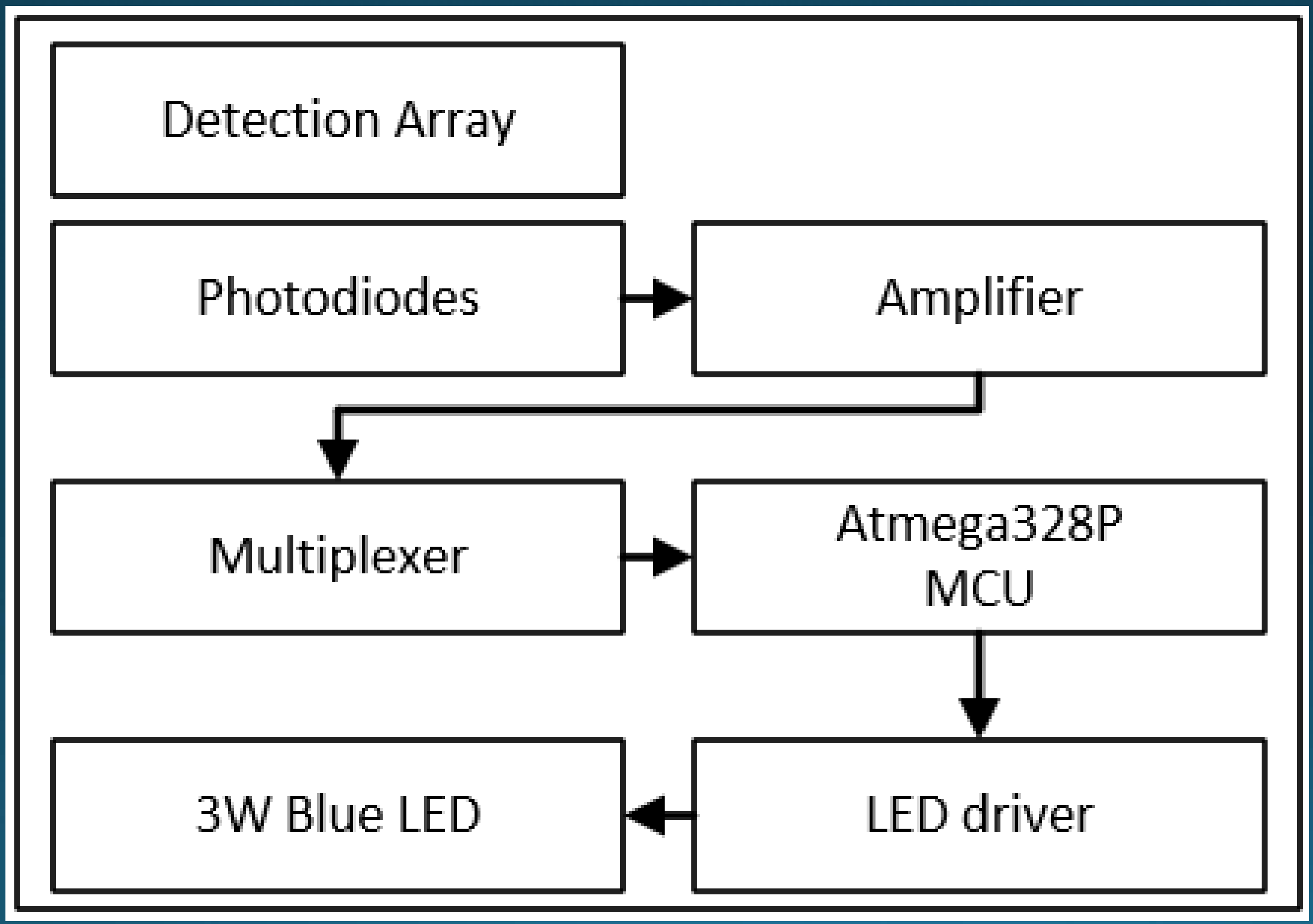
- Detection array
- Motor control
- Power system

Nick – software

- Camera system
- Motor control
- Power system

Detection Array

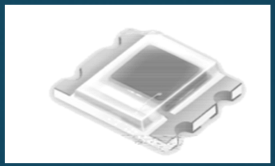
Block Diagram



Detection Array

Results

Osram photodiode [5]



Everlight photodiode [6]

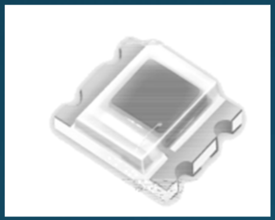
Saturation	36 inches – 4.9 Volts	4 inches – 4.89 Volts
Max Distance	180 inches – 0.6 Volts	132 Inches -- 0.120 Volts
Linearity	Linear	Non-Linear
Ambient Light	100% Saturation	29% Saturation
Price	$8.85	$0.59

Photodiode comparison

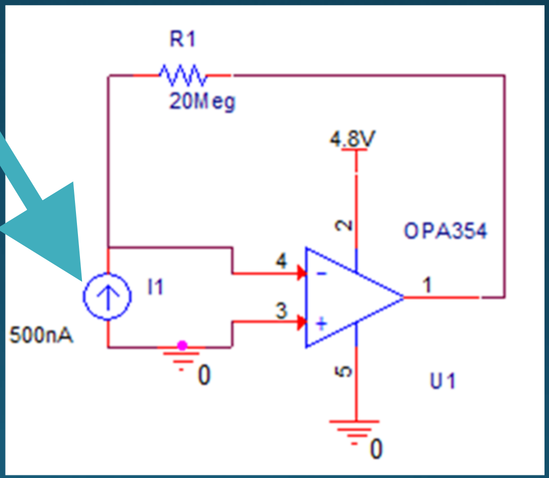
Detection Array

Design

Model of
photodiode



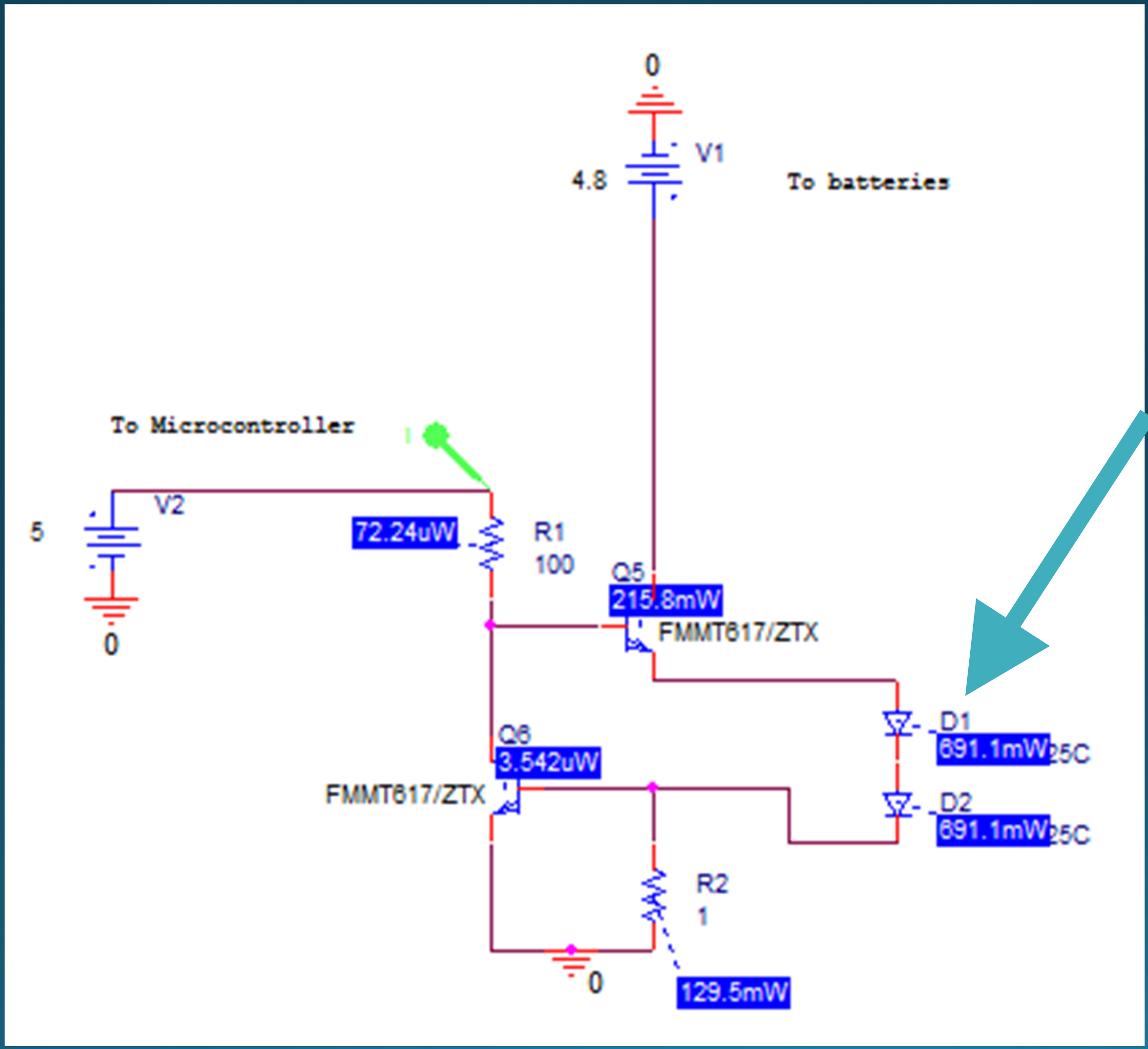
Everlight photodiode [6]



Transimpedance amplifier

Current Source design

Simulation



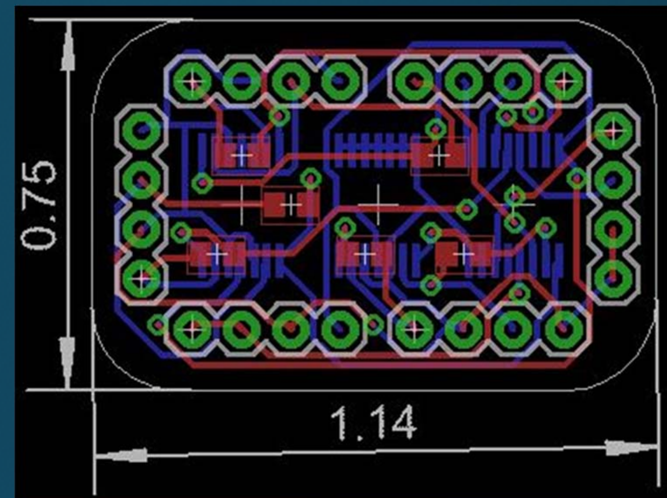
Model of 3 W LED

Circuit Layout

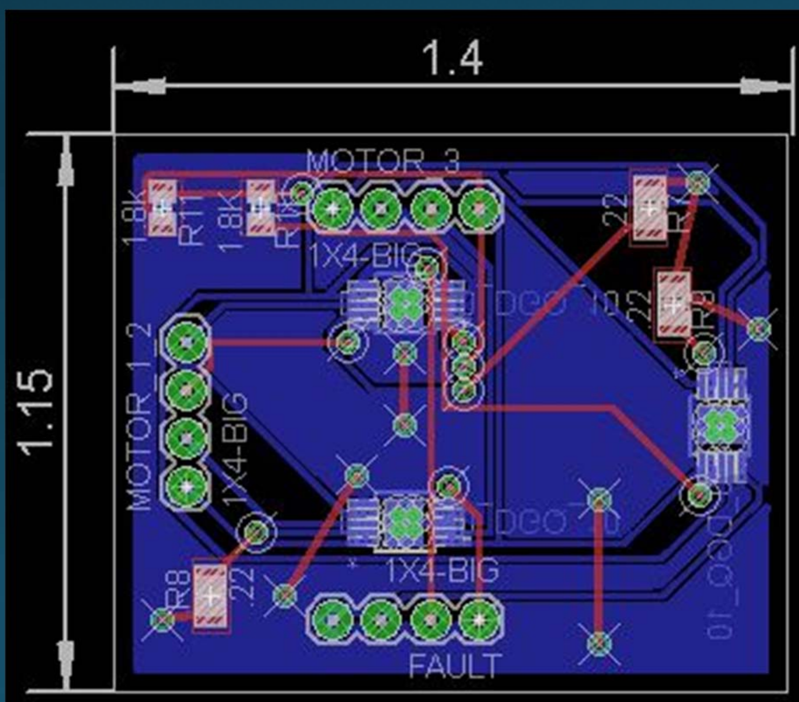
Design

Eagle 7.1.0

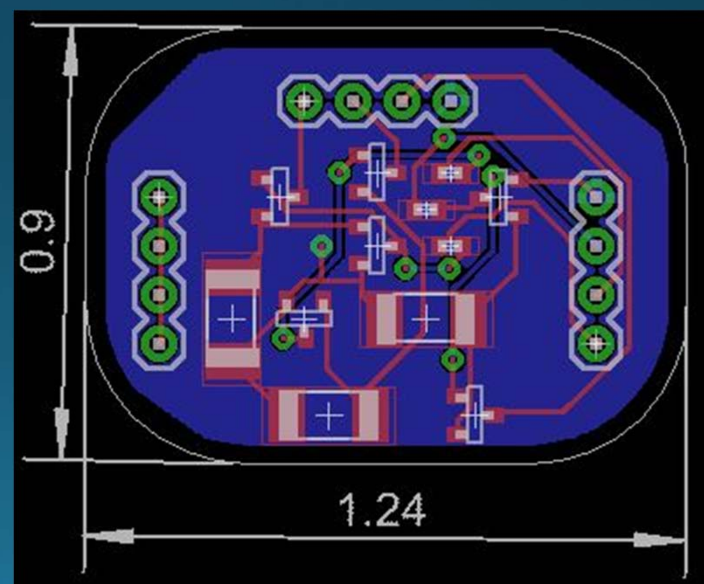
- Boards sent to OSH Park



Photodiode interface board



H-bridge board

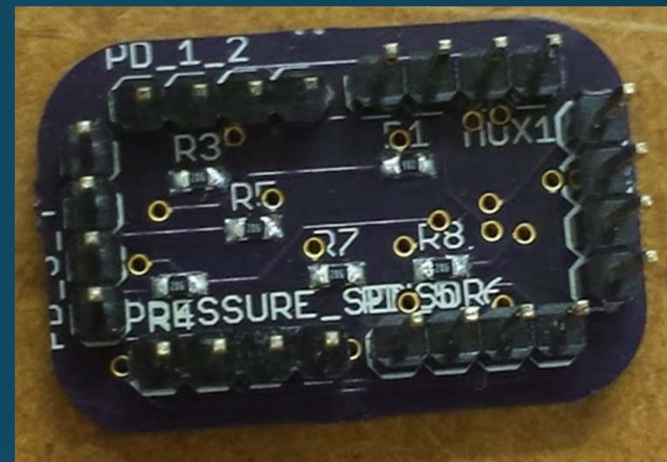


LED driver board

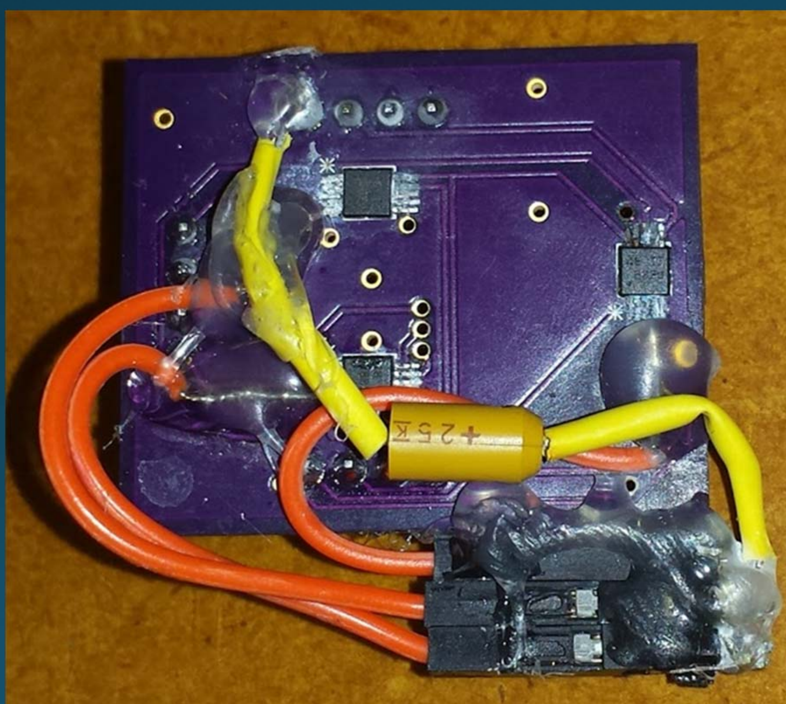
Circuit Layout

Results

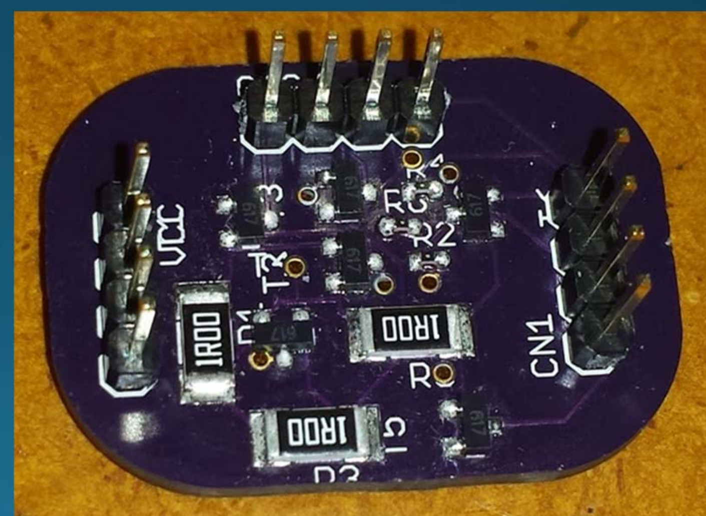
Finalized OSH Park boards



Photodiode interface board



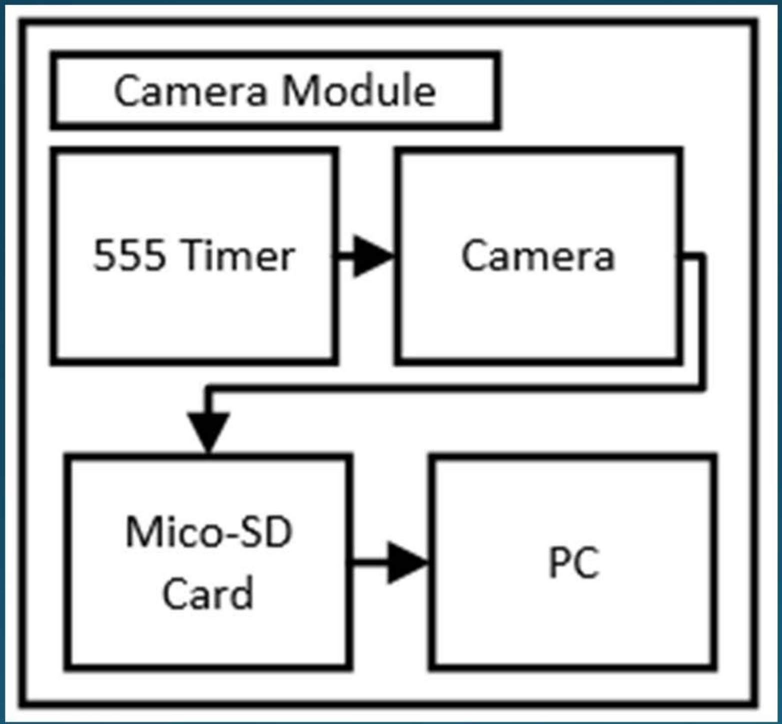
H-bridge board



LED driver board

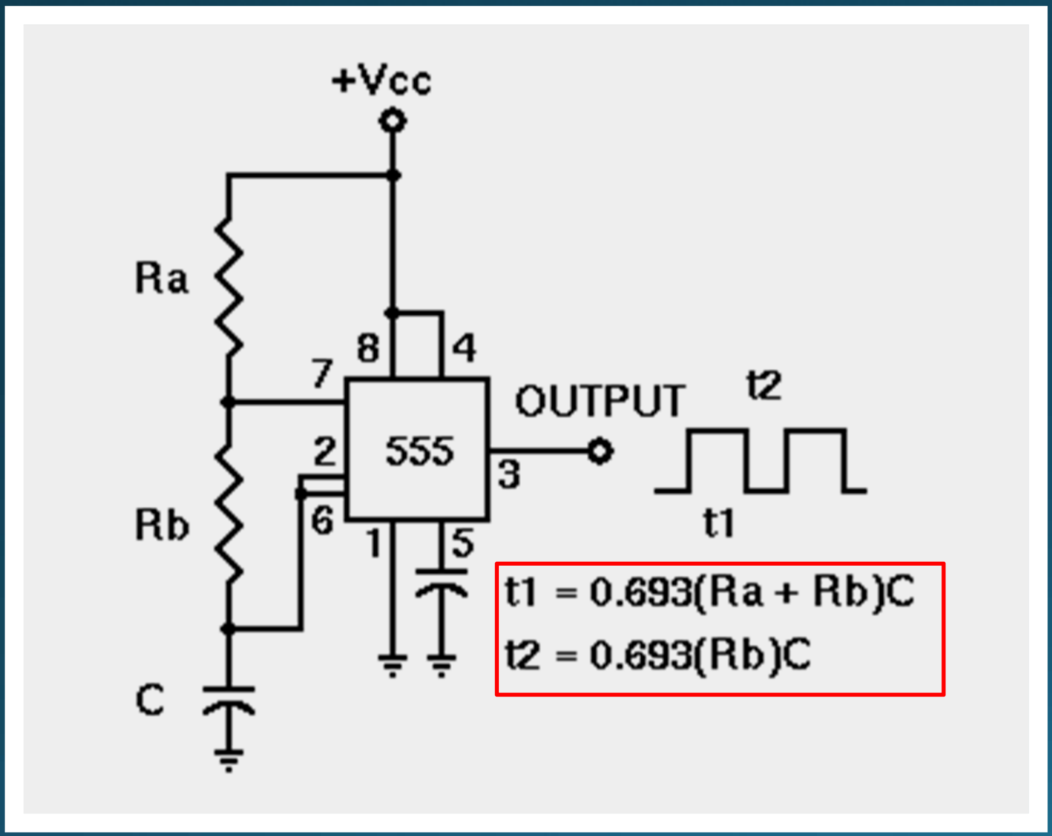
Camera System

Block Diagram

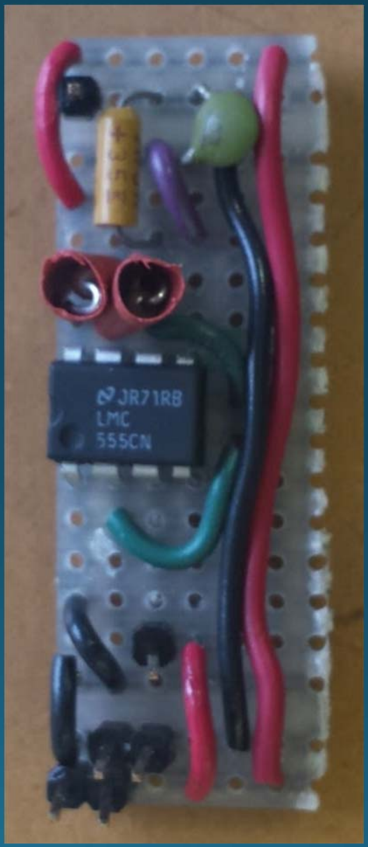


Camera System

Results



555 timer [7]

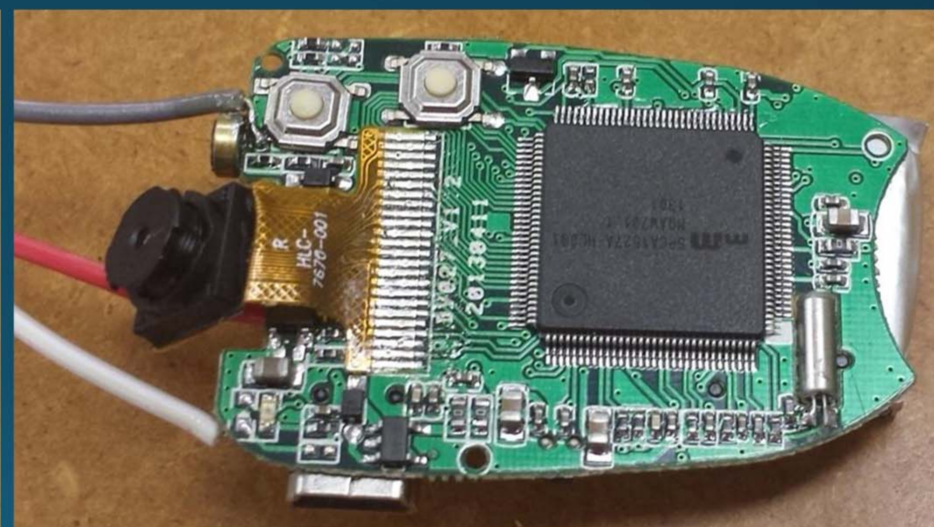


555 timer on perfboard

Camera System

Method

Camera key fob



Camera interface board

Camera

Method

With timestamp

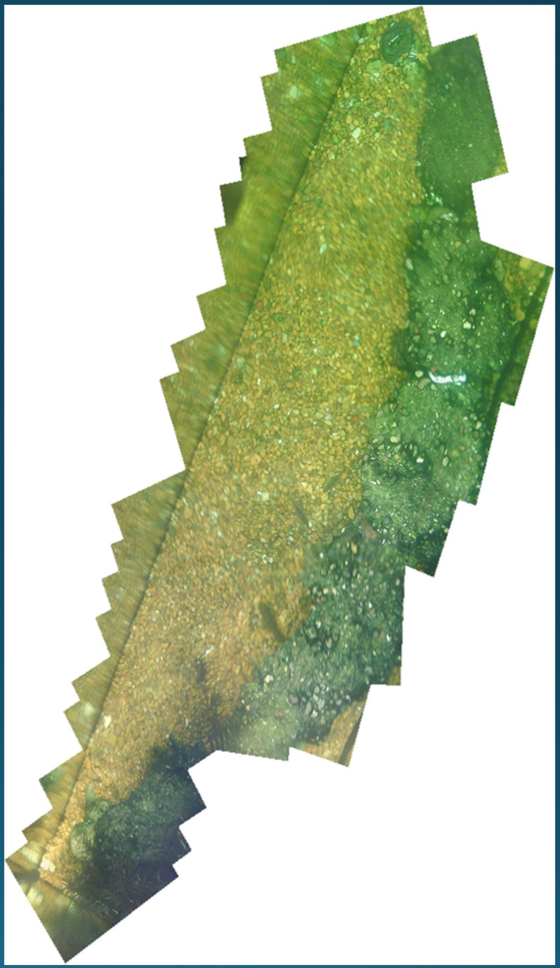
Without timestamp

Camera

Results

Meets spec for 10% gap in final image

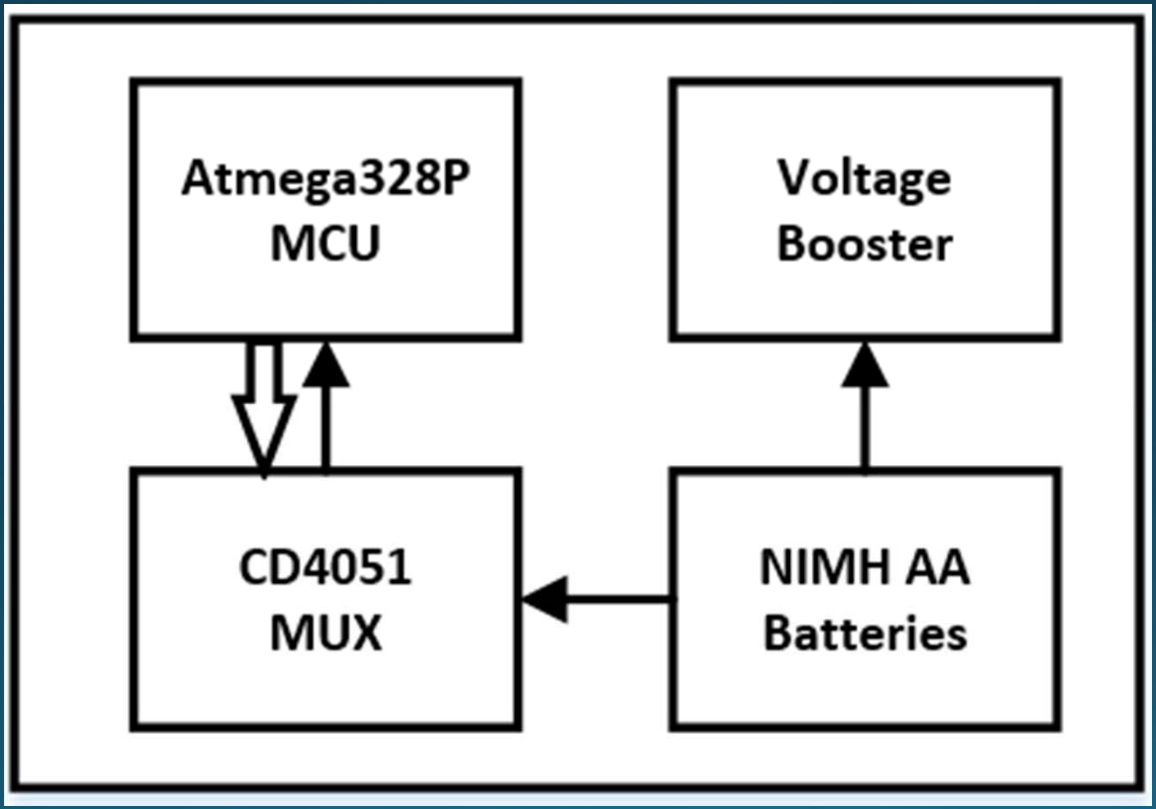
Picture of fish tank



Final image

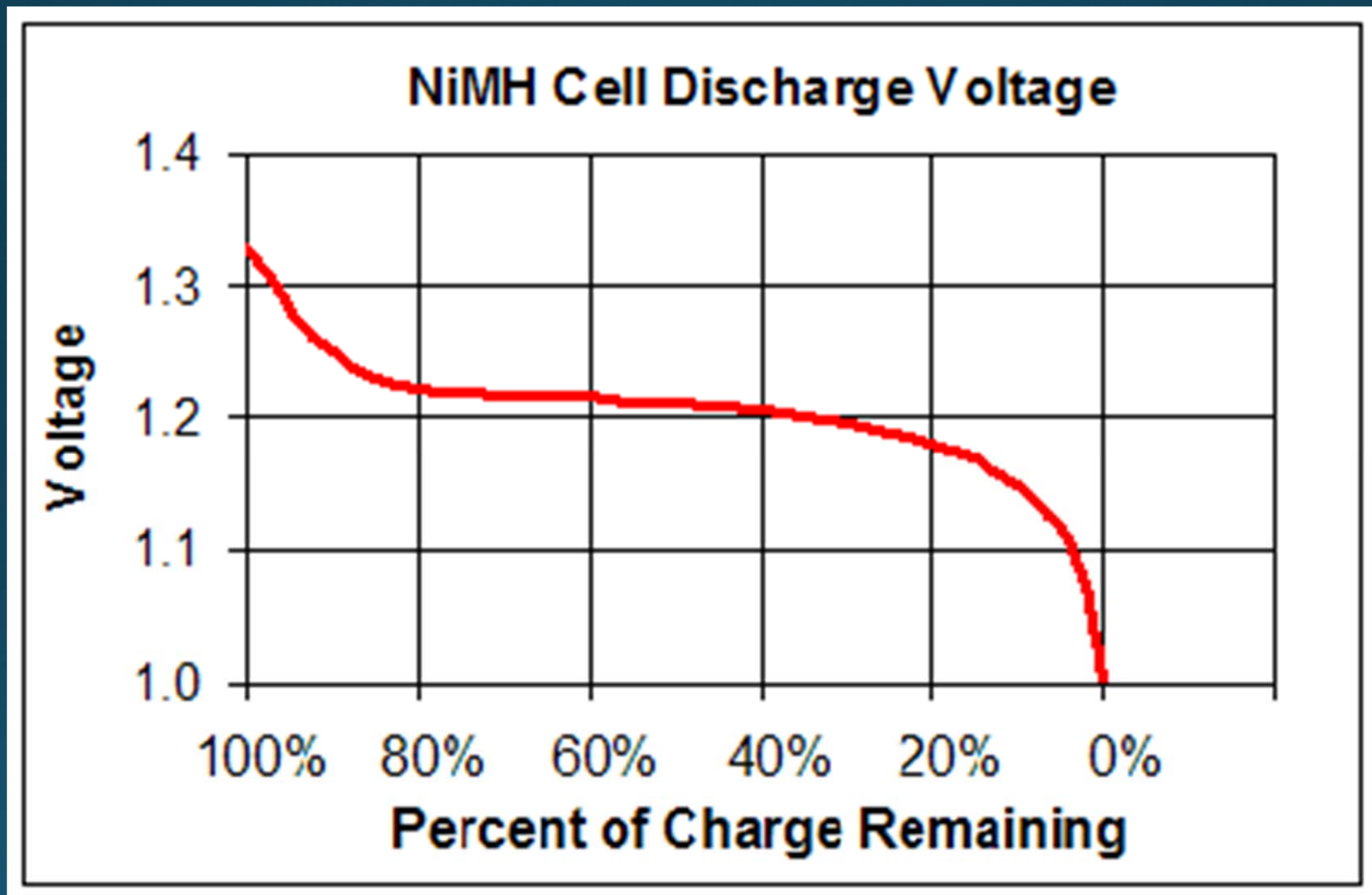
Power System

Block Diagram



Power System

Research



Discharge of NiMH batteries [8]

Power System

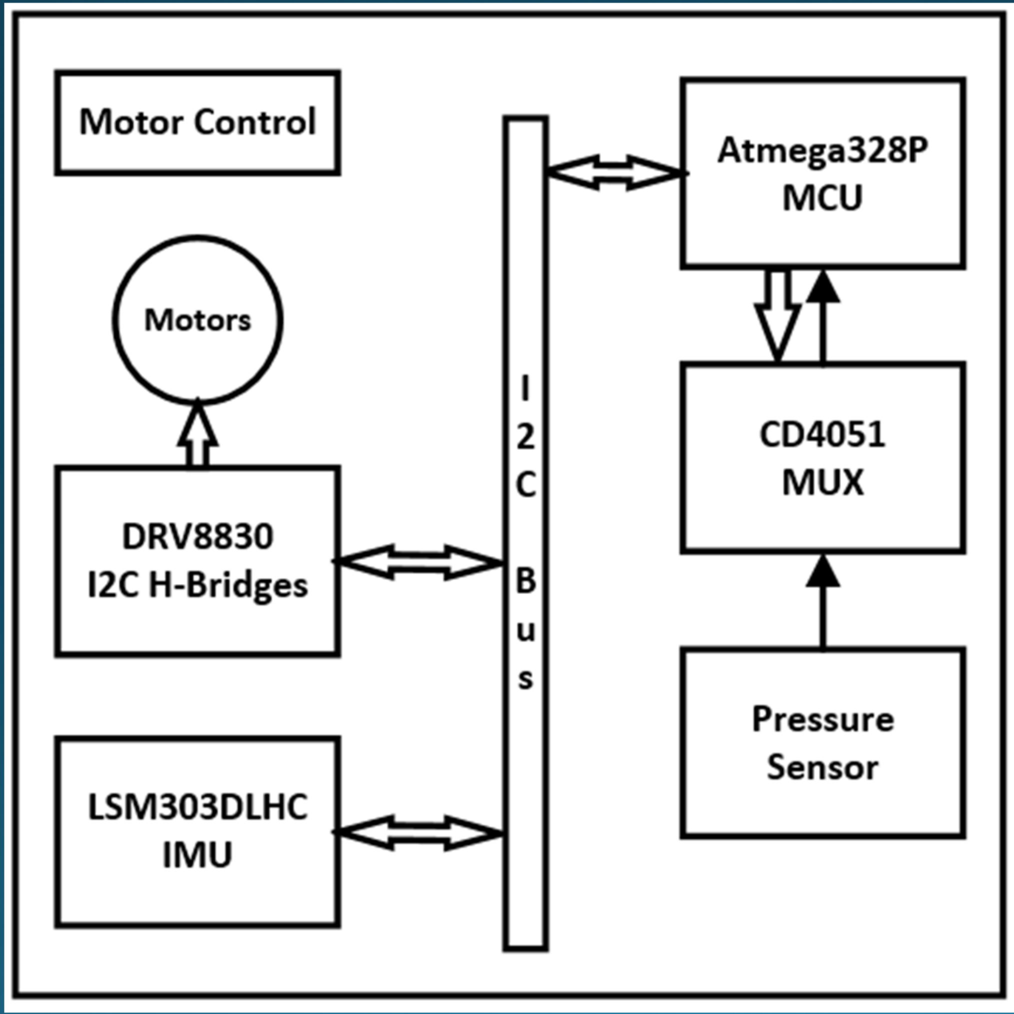
Method

- Step-up regulator
  - Input minimum 2.5 volts
  - Output 5 volts
- Reference voltage
- Noise isolation
- Diode
- Meets spec for surfacing at 10%

Pololu U3V12F5 [9]

Motor Control

Block Diagram



Motor Control

Design

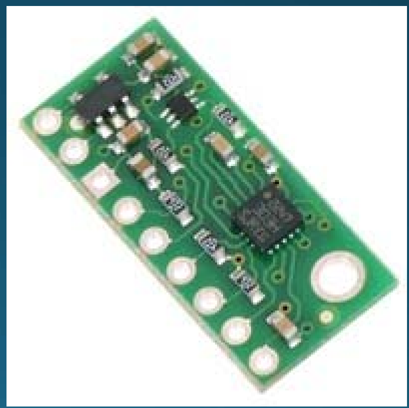
- I2C h-bridge (DRV8830)
- Single channel, PWM controlled h-bridge
- Heatsinking through PowerPAD™
- 1 A, 2.75 - 6.8 V
- Cost: $2.44

DRV8830 [10]

Motor Control

Design

- I2C IMU (LSM303D)
- Use the accelerometer
- Meets spec for velocity control and using I2C

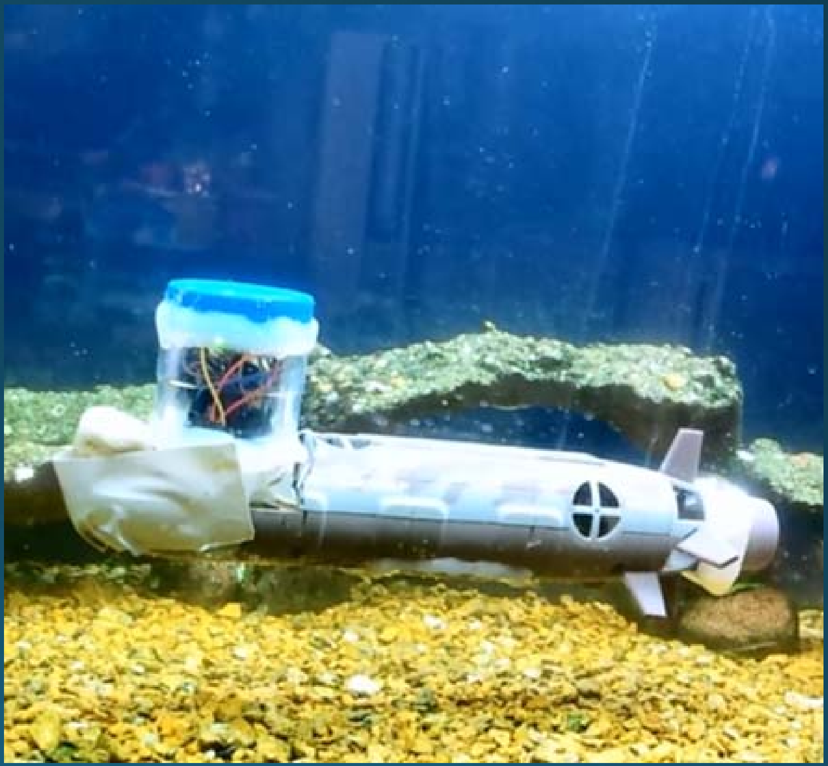


LSM303D [11]

Motor Control

Design

- Depth tracking
  - 6 cm dead band
  - Testing at 52 cm deep
  - PID control

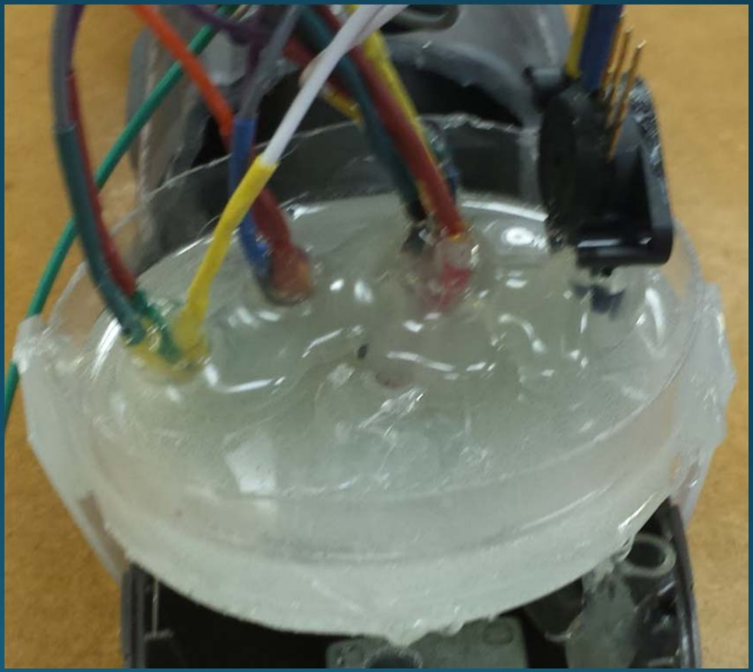


Testing setup in aquarium

Motor Control

Design

- Waterproofing
  - Plastic cylinder
  - Hot glue
  - Epoxy

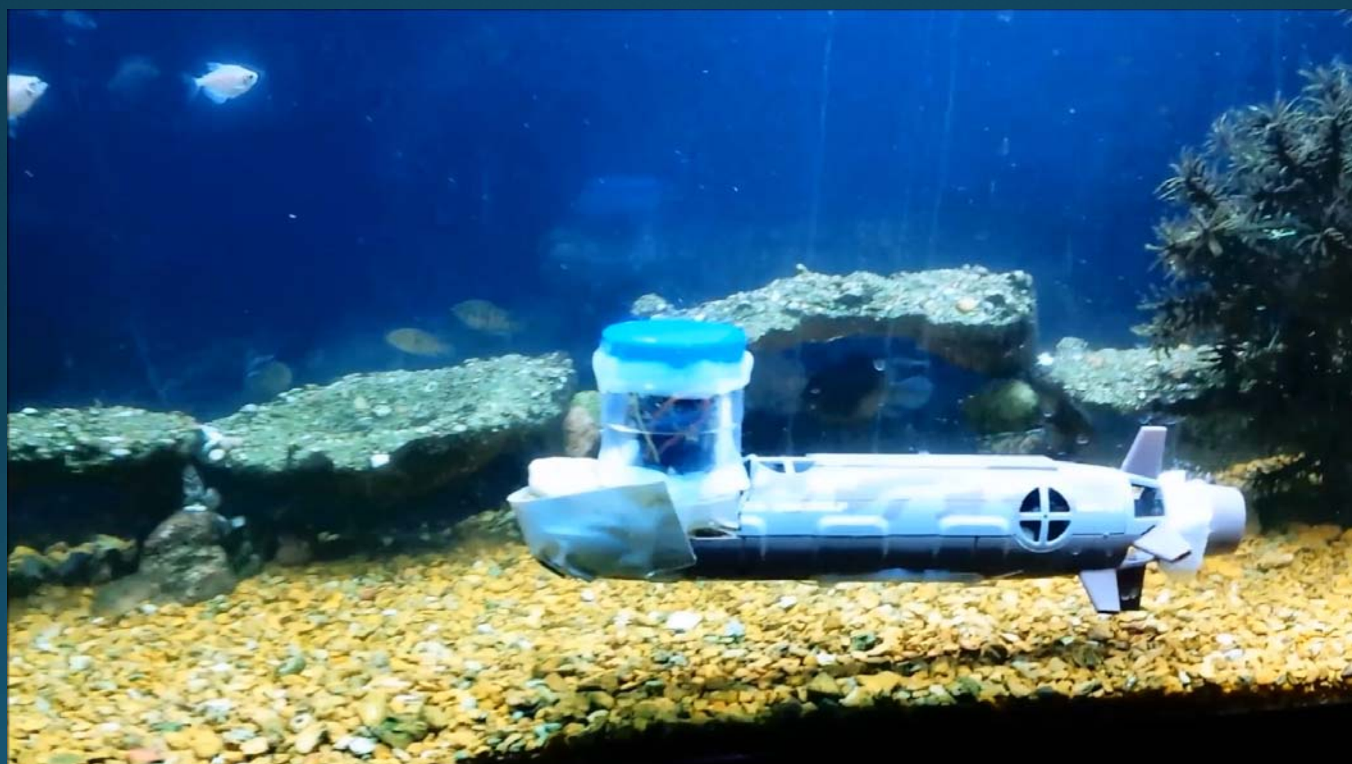


Waterproofed bottom of sail

Motor Control

Results

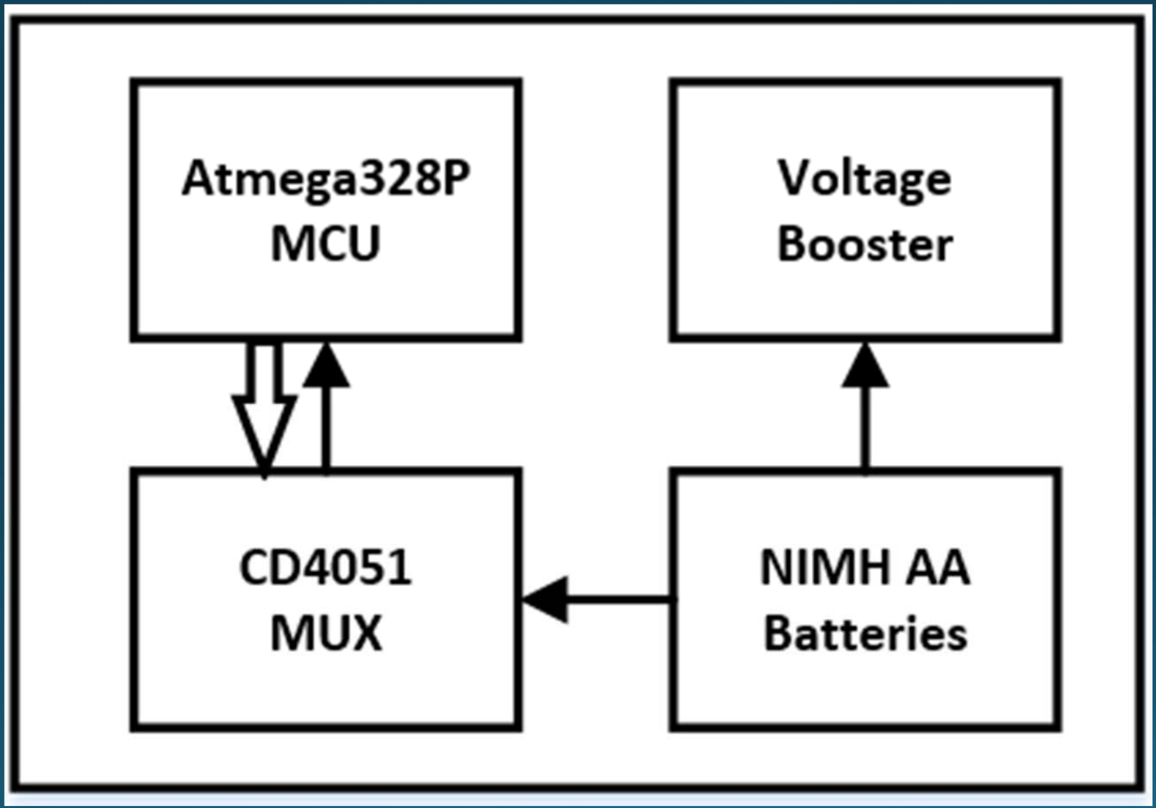
- Depth tracking



https://www.youtube.com/watch?v=KP_CVridH08
https://www.youtube.com/watch?v=-tTprnzq--I
https://www.youtube.com/watch?v=9dOgWr1T1QA

Power System

Block Diagram



Power System

Design

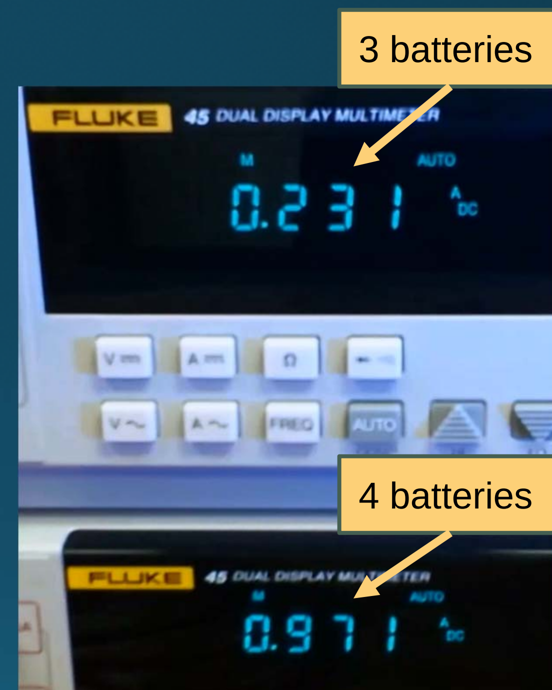
- Battery supply
  - 4 NIMH AA batteries
    - 1.34 V per cell
    - 2500 mAh
  - 5.36 V: h-bridges, LED drivers and pressure sensor
  - 4 V: voltage booster → all other hardware

Tenergy AA battery [12]

Power System

Results

- Battery life calculation
  - Bench-top test
    - Average current draw: 1202 mA
    - Estimated run time: 124 minutes
  - Battery life spec is 25 minutes



Bench-top current draw

Power System

Result

- Worst case battery life calculation
  - All three motors at max duty cycle
    - Peak current draw: 1202 + 2550 - 450 = 3302 mA
    - Estimated run time: 45 minutes
  - Still meets 25 minute spec

System Test Results

Objective	Metric
Minimize Cost	Determined by the production cost of one member of the swarm.
Autonomous	The amount of human interaction needed for the swarm to function
Mobile Underwater	The turn radius of each swarm member and how close the swarm member is to neutrally buoyant.
Durable	The amount of places that fail per swarm member.
Portability	The perceived size and weight of each swarm member

System Test Results

- Minimize cost

Quantity	Description	Price
21	Resistors	$5.72
6	Transistor	$3.14
1	IMU	$9.95
1	4 pack AA Batteries	$5.99
3	I2C H-bridge	$7.32
1	Camera Module	$11.99
1	Pressure Sensor	$16.09
1	Motorworks Submarine	$61.99
3	Blue LED	$7.86
1	Step-Up Voltage Regulator	$3.95
1	Adafruit Pro Trinket	$9.95
1	Multiplexer	$0.44
2	Op-amp	$7.20
5	Photodiode	$1.90
1	PCB's	$6.13
1	Other	$12.89
	Total	**$172.51**

System Test Results

- Autonomous & mobile underwater

https://www.youtube.com/watch?v=wOSrQxpOtXE

System Test Results

- Autonomous & mobile underwater

https://www.youtube.com/watch?v=wOSrQxpOtXE

System Test Results

- Durable

System Test Results

- Portability
  - 35 cm long
  - 12.5 cm tall at the sail

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[2] *CoCoRo Largest AUV swarm 2013 (2013, May 29)* [Online]. Available: https://www.youtube.com/watch?v=Hjkmm13Scm4

[3] *CoCoRo swarm of underwater Robots (n.d.)* [Online]. Available: i.ytimg.com/vi/XUk-qLfiwlc/0.jpg

[4] H. Brundage. "Designing a Wireless Underwater Optical Communication System" unpublished.

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[10] *DRV8830* (n.d.) [Online]. Available: http://www.ti.com/product/drv8830

[11] *Pololu LSM303D 3D Compass and Accelerometer Carrier with Voltage Regulator* (n.d.) [Online]. Available: https://www.pololu.com/product/2127

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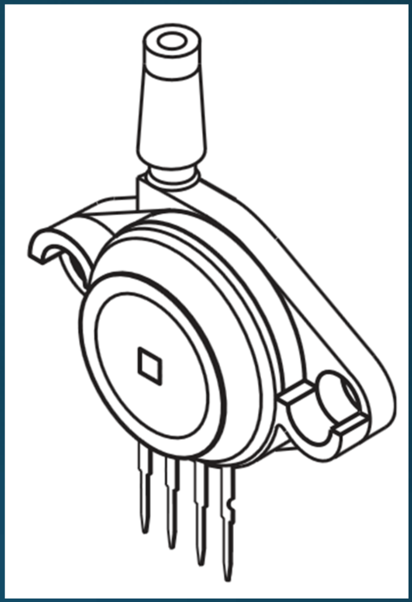
Research Parts

Reasearch

- Pressure sensor
  - Package
  - Gauge vs absolute

MPAK package [13]



Unibody package [13]

Collision Detection

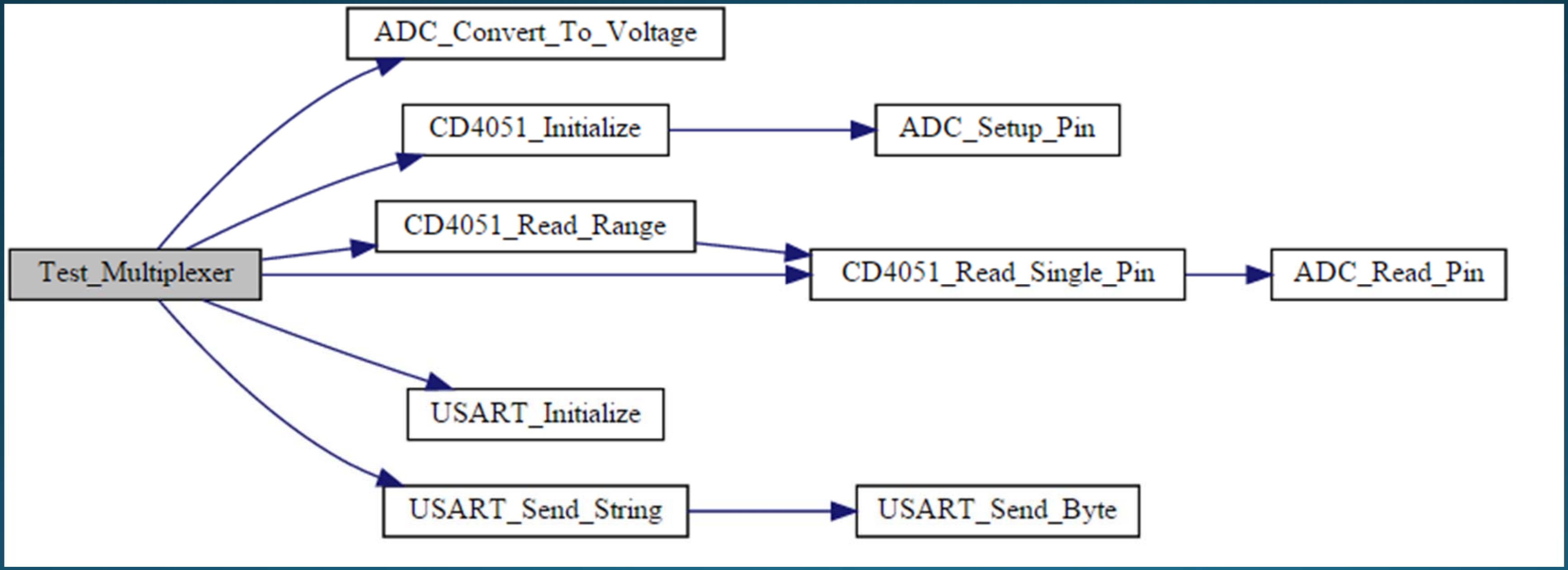
```
Collision: 0 Acc: -1744, 2272, -18000 Tilt_Acc: -1, 1, -10
Collision: 0 Acc: -1216, 304, -16640 Tilt_Acc: 0, 0, -9
Collision: 1 Acc: -3552, 864, -16752 Tilt_Acc: -2, 0, -9
Collision: 0 Acc: -736, -368, -16592 Tilt_Acc: 0, 0, -9
Collision: 0 Acc: 1984, -336, -16320 Tilt_Acc: 1, 0, -9
Collision: 3 Acc: 7664, 160, -14208 Tilt_Acc: 4, 0, -7
Collision: 3 Acc: 7040, 464, -16448 Tilt_Acc: 3, 0, -9
Collision: 0 Acc: -2304, -160, -13616 Tilt_Acc: -1, 0, -8
Collision: 0 Acc: -1360, 288, -16768 Tilt_Acc: 0, 0, -10
Collision: 1 Acc: -7760, 2384, -7024 Tilt_Acc: -3, 1, -2
Collision: 1 Acc: -3904, -1392, -16944 Tilt_Acc: -2, 0, -9
Collision: 4 Acc: 4176, -3296, -21360 Tilt_Acc: 2, -1, -12
Collision: 0 Acc: -800, 304, -16656 Tilt_Acc: 0, 0, -9
Collision: 0 Acc: -1568, 112, -16768 Tilt_Acc: 0, 0, -9
Collision: 0 Acc: 1408, -32, -16608 Tilt_Acc: 0, 0, -9
Collision: 0 Acc: -2464, -2160, -20992 Tilt_Acc: -1, -1, -12
Collision: 0 Acc: -1456, -4368, -14160 Tilt_Acc: 0, -1, -8
Collision: 0 Acc: -1440, -3600, -15216 Tilt_Acc: 0, -1, -8
Collision: 0 Acc: -1088, -1584, -16864 Tilt_Acc: 0, 0, -10
Collision: 0 Acc: -1424, -448, -16752 Tilt_Acc: 0, 0, -9
Collision: 0 Acc: -944, 448, -16992 Tilt_Acc: 0, 0, -10
```

Collision detection and tilt compensation

Software Integration

Design

- Combining code for subsystems
  - Optimization
  - Functional programming style

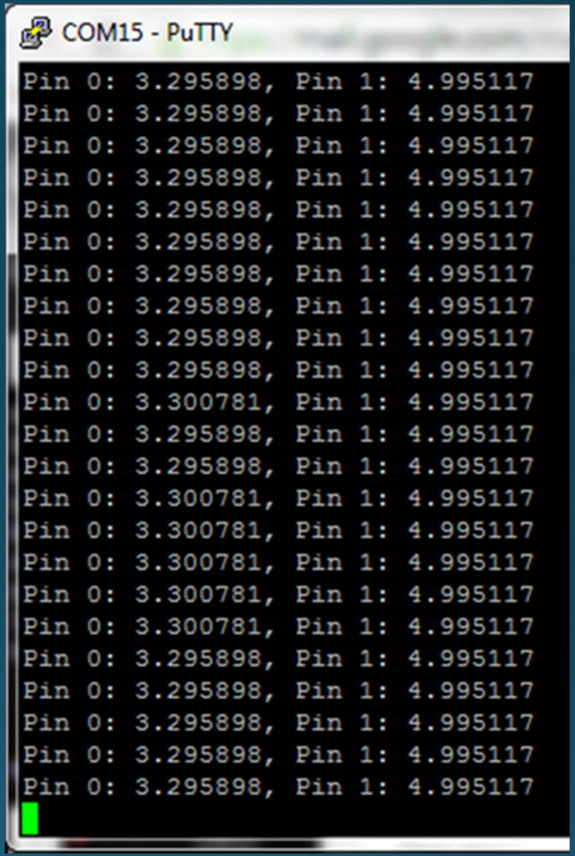


Doxygen output for the multiplexer

Regulator Output

Result

- Step-up regulator
  - Input minimum 2.5 volts
  - Output 5 volts
- Reference voltage
- Noise isolation

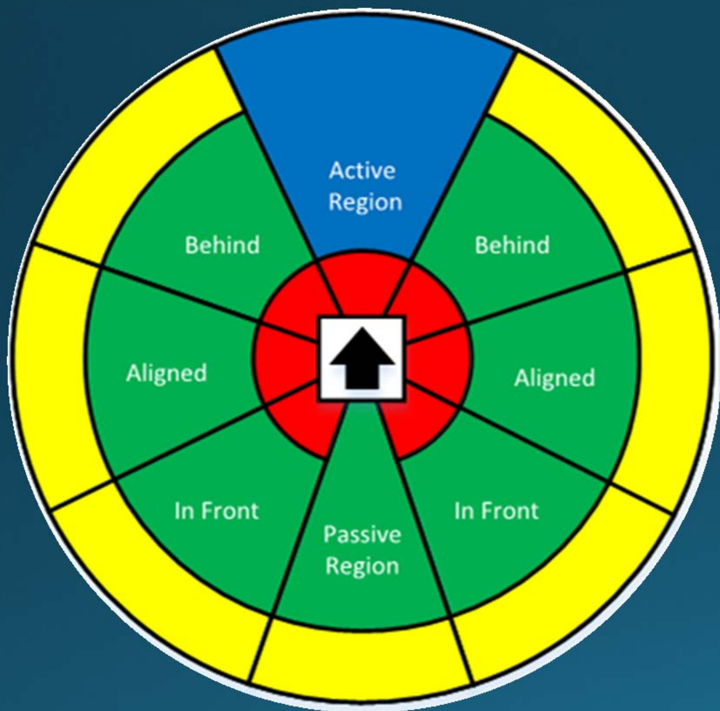


Console Output for Regulator and Multiplexer

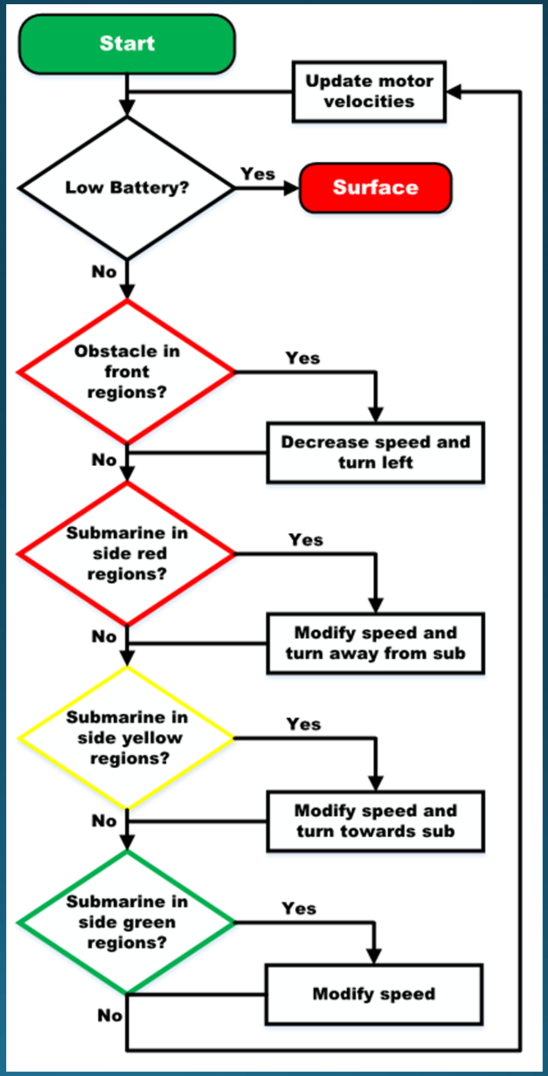
Swarming Algorithm

Design

- Flowcharts were first design step



Detection zones

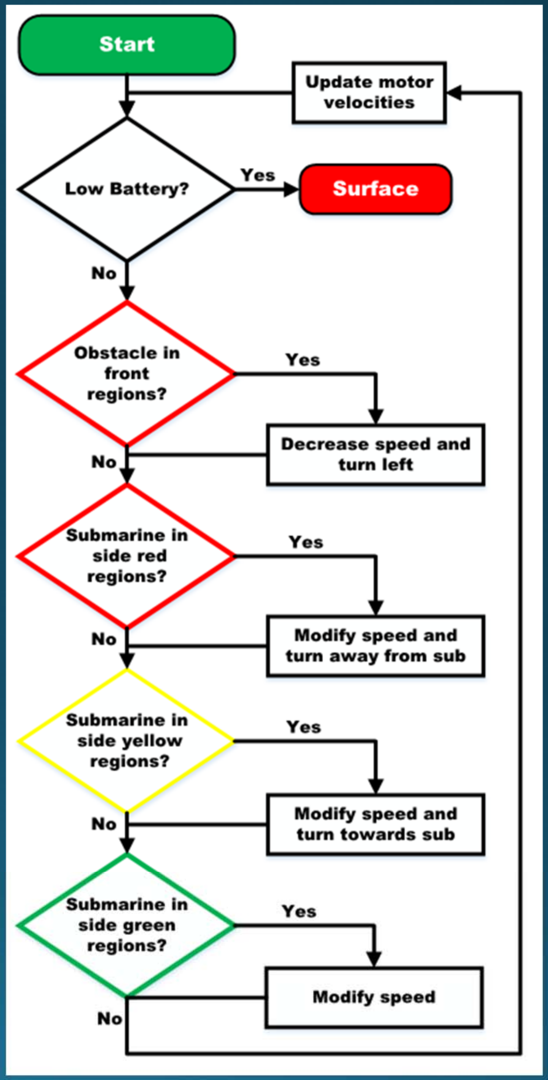


Simplified swarming flowchart

Swarming Algorithm

Design

- Multiple iterations before coding
  - Zone checking priority
  - Integrating with rest of code
- Zone checks alter variables that factor into the motor control
  - Only applies to X and Y motors
- Motors updated after all zones checked
- Code runs until low battery voltage is detected

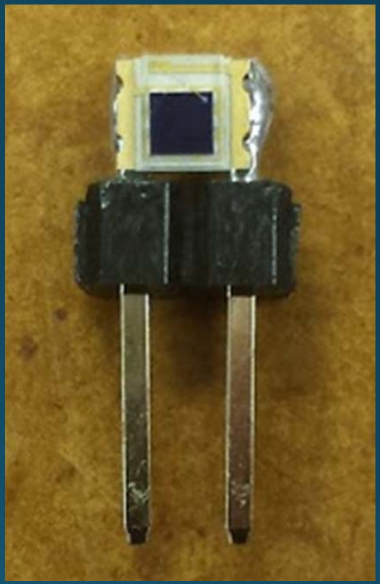


Simplified swarming flowchart

Circuit and System Layout

Design

- Everlight photodiodes
  - Planned to solder strands wires to each side
    - Difficult to solder without bridging the leads
    - 2.1 mm between the leads
  - Solution: Use small section of straight header pins to extend leads
    - Reduces soldering difficulty
    - Much more rigid connection
    - Plastic section of header pins doubles as a mounting point



Everlight photodiode soldered to section of header pins

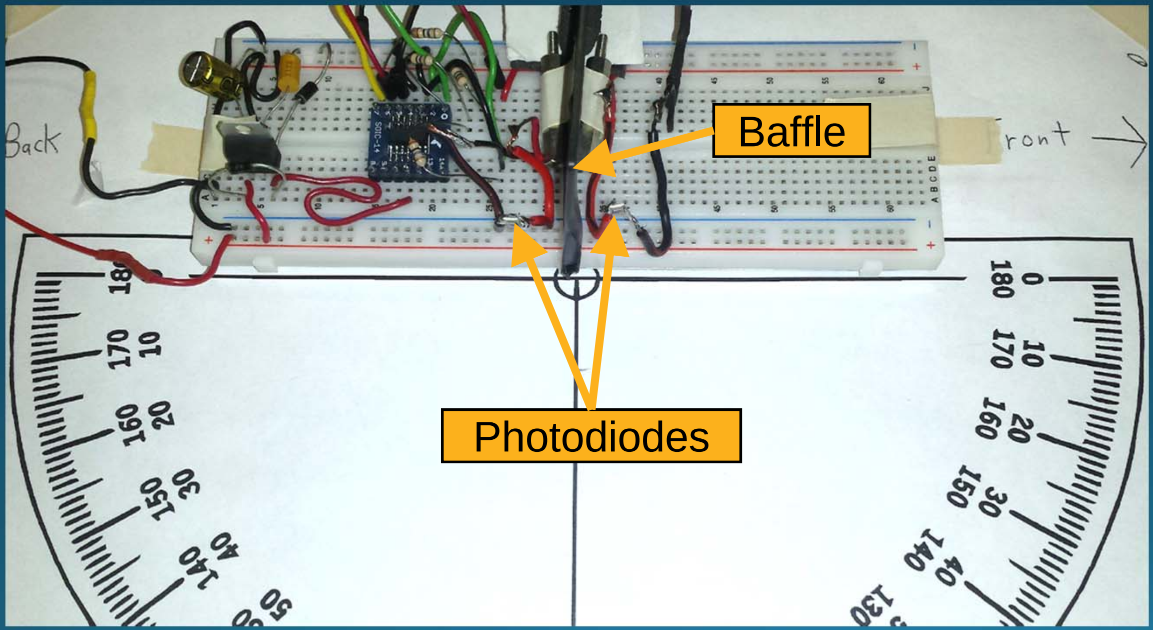
Motor Control and Power

- 3 DC brushed motors (x, y, z configuration)
  - Y motor highest current draw: 860 mA peak draw
    - Recorded with only rear propeller submerged
  - X and y motor feedback: IMU
  - Z motor feedback: pressure sensor

Detection Array

Experiment

- Bench top detection array
  - Baffle configuration testing
    - Baffle protrusion distance and LED distance experimented with
    - LED swept from 0 to 180° while recording light intensity

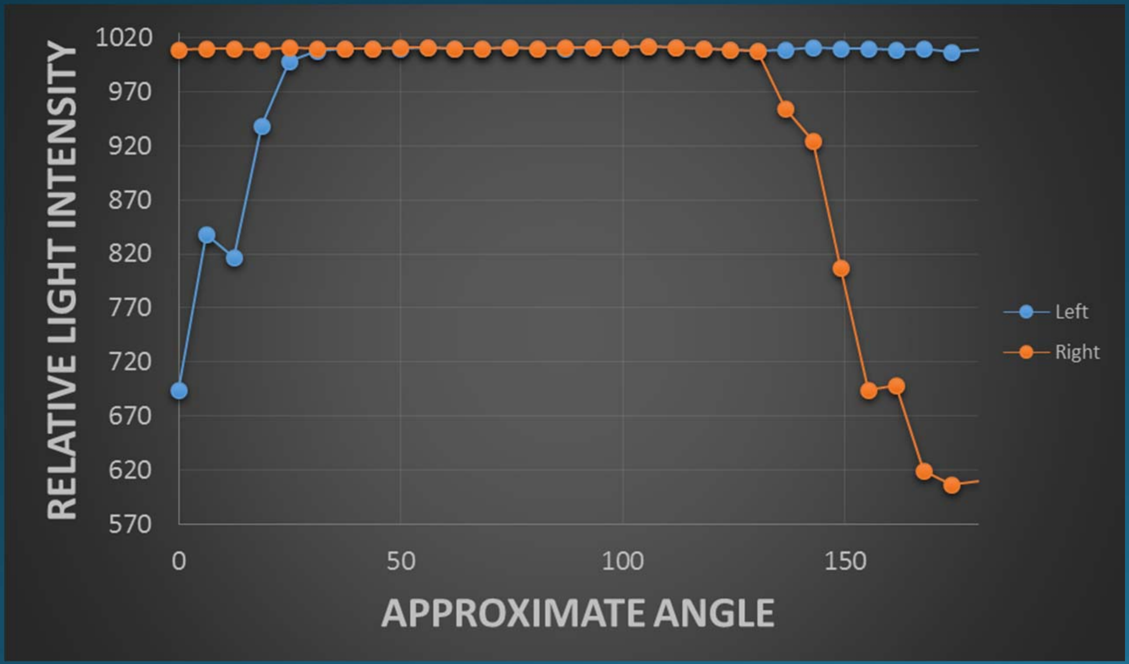


Baffle test setup

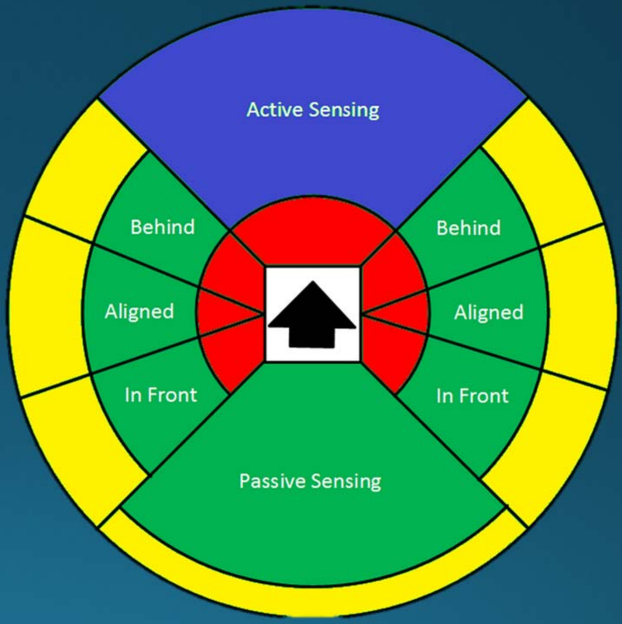
Detection Array

Result

- Bench top detection array
  - Baffle configuration testing
    - 12cm LED distance

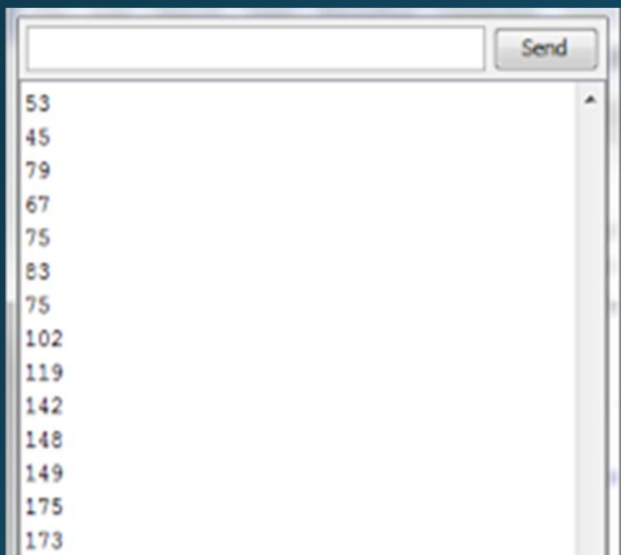


Left vs right photodiode (5 mm baffle)

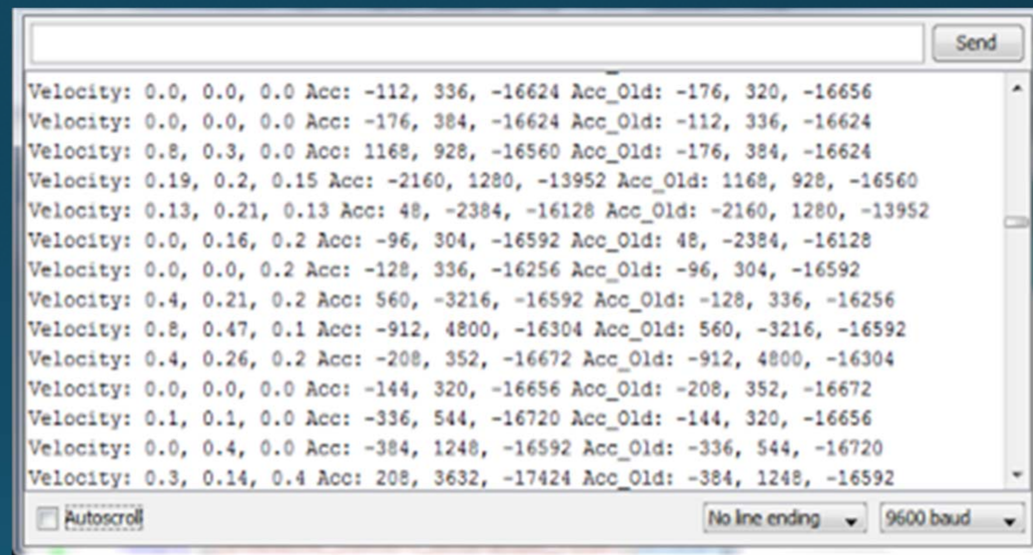


Detection zones

Compass and Accelerometer

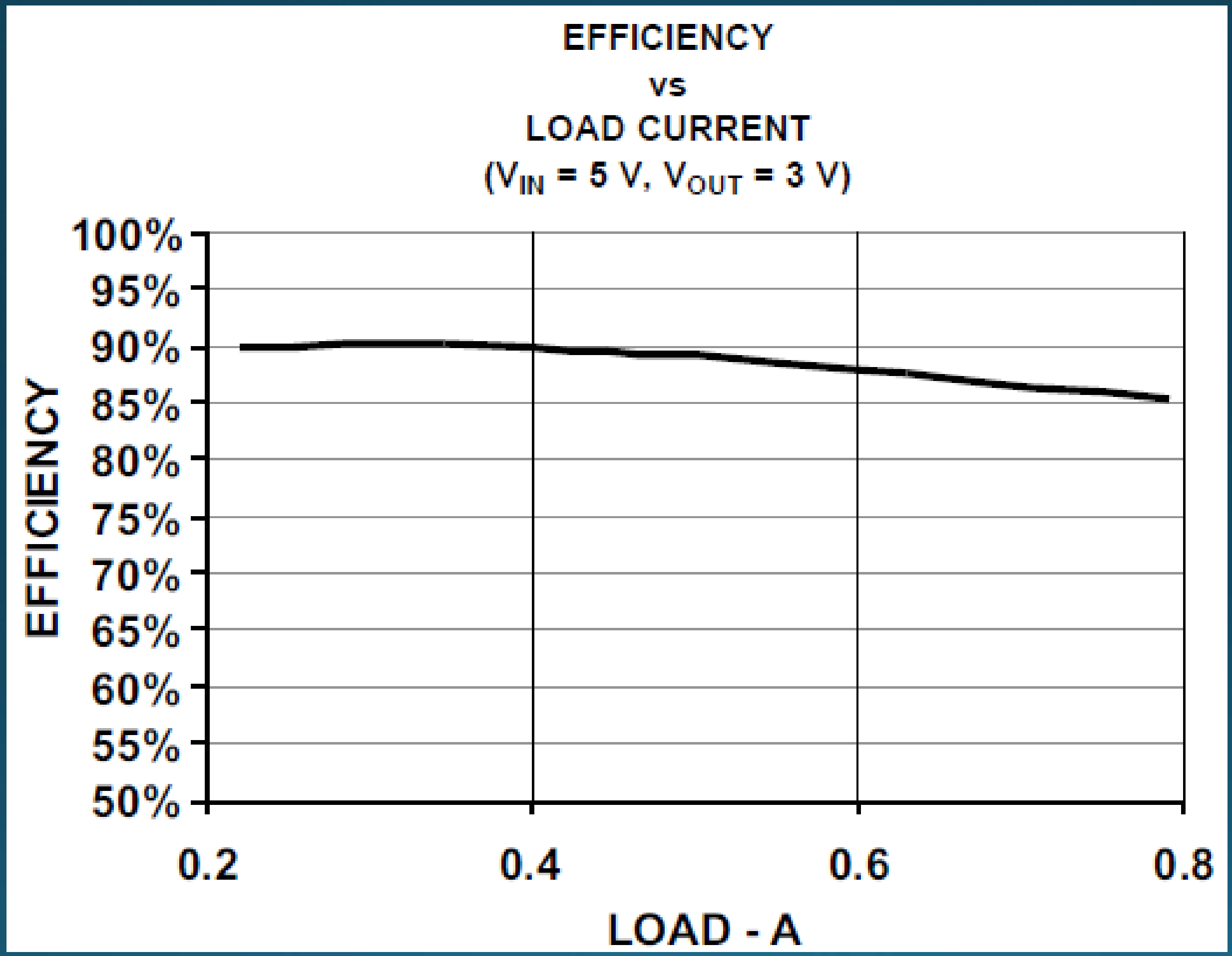


Heading test output

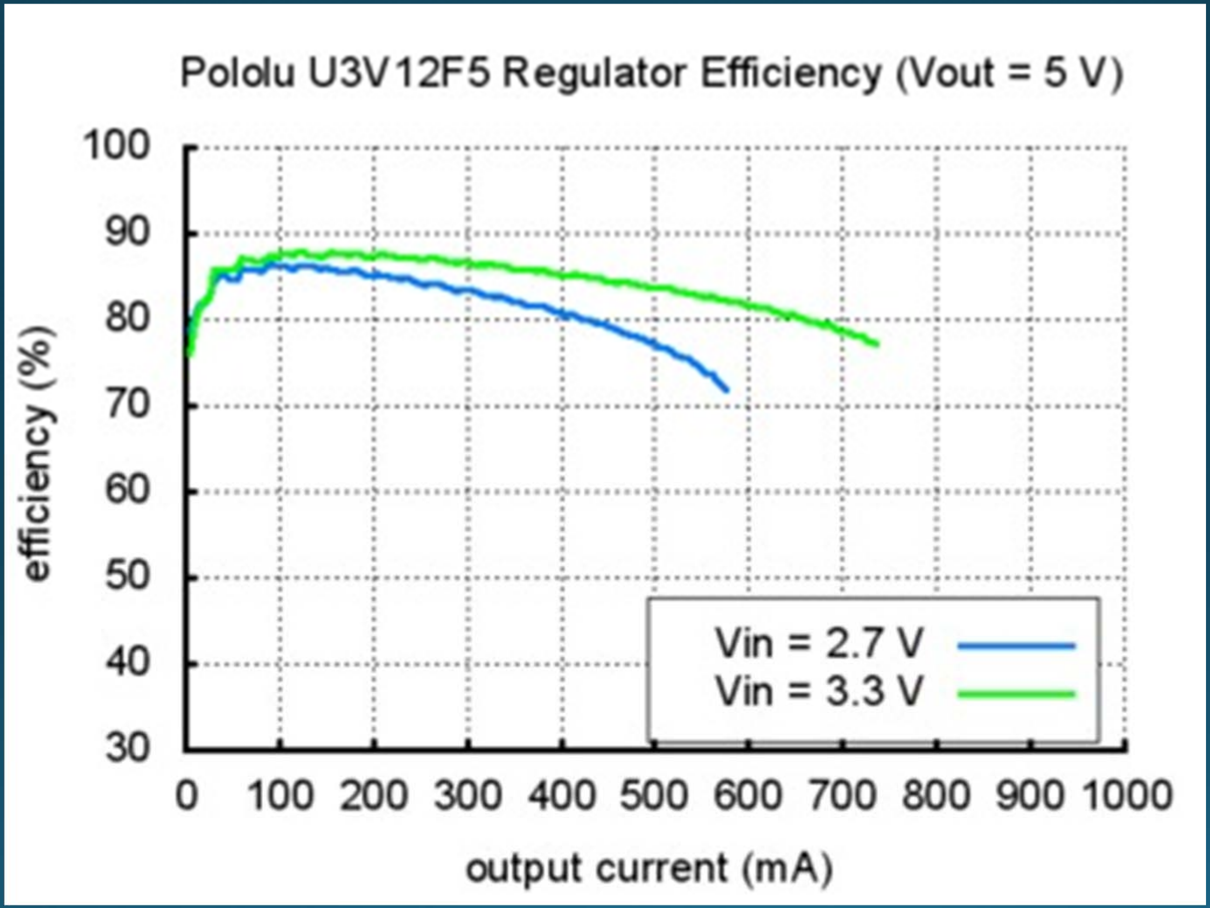


Velocity test output

Efficiency of Motor [14]



Step-Up Regulator Efficiency [9]



Pressure Sensor Output MPX5010 [13]

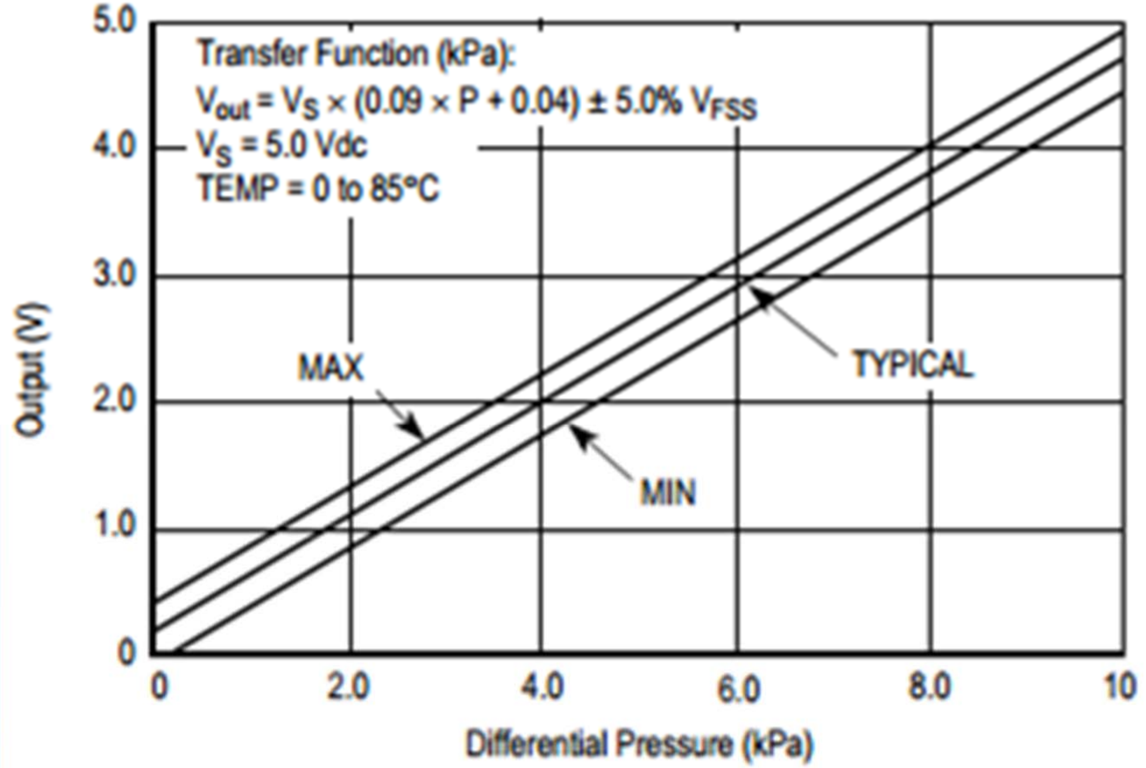


Figure 4. Output vs. Pressure Differential

Pressure Sensor Circuit Diagram MPX5010 [13]

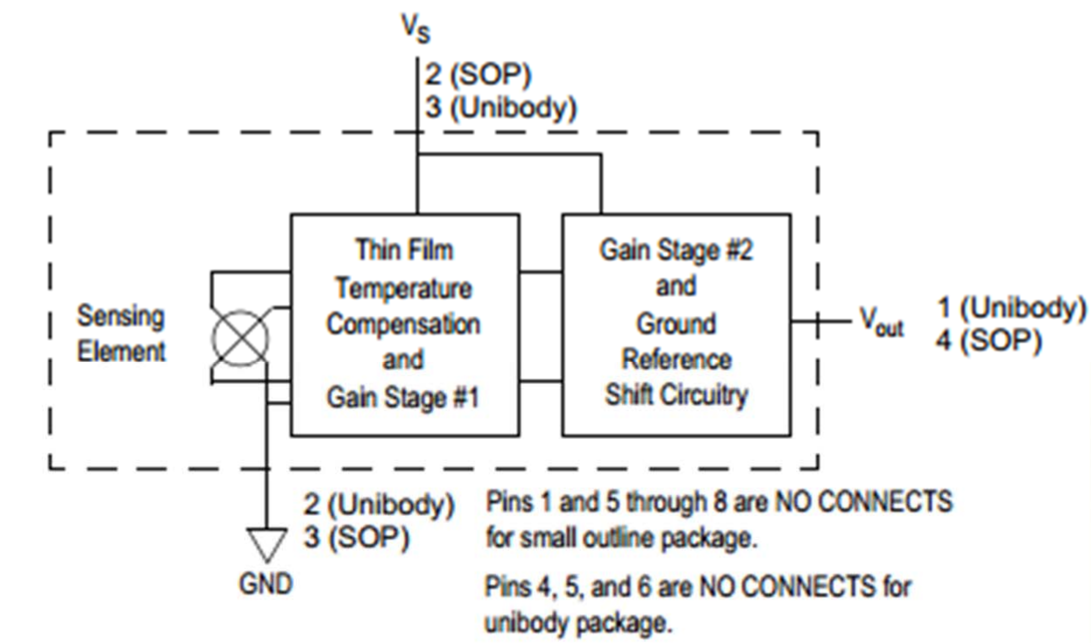
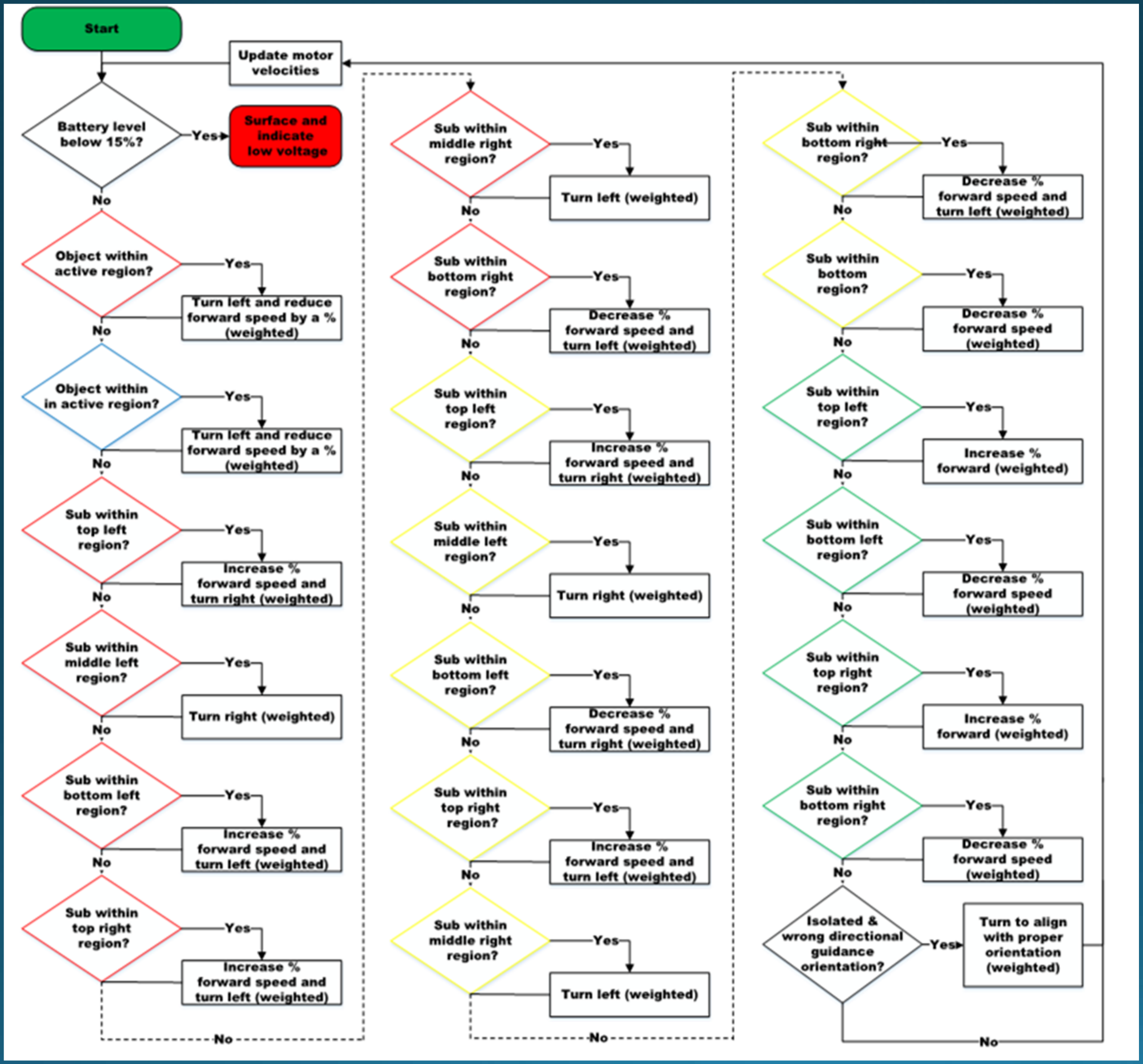


Figure 1. Fully Integrated Pressure Sensor Schematic

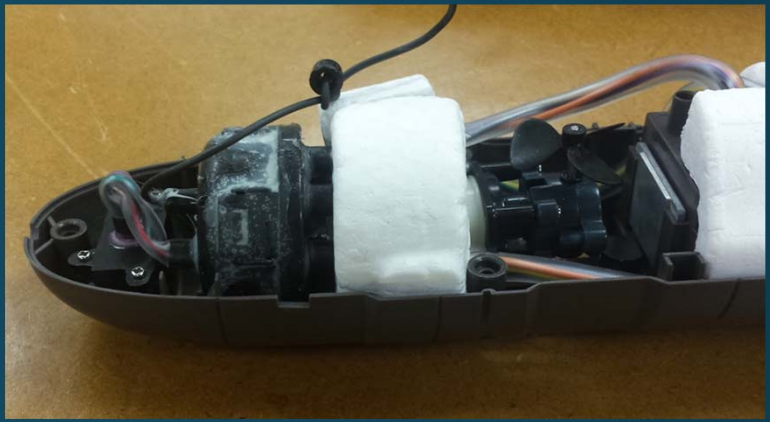
Complete Swarming Flowchart



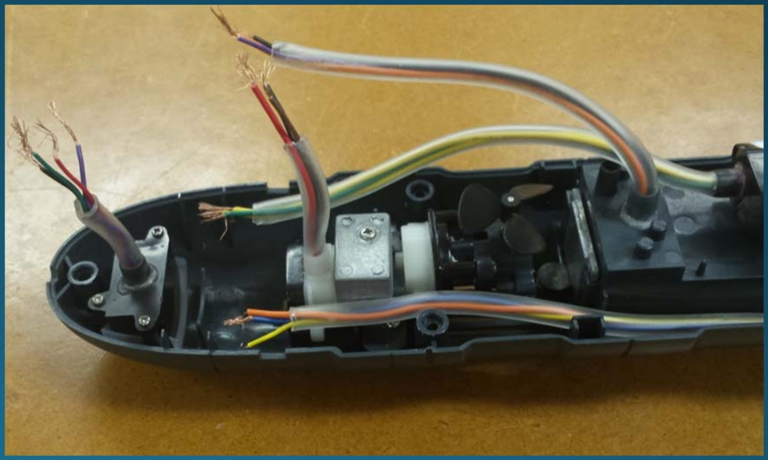
Circuit and System Layout

Analysis

- Submarine dissection
  - Each motor has 2 leads along with a third wire
    - Determined to be a ground wire
  - Battery compartment has a
  - 4.8 V, 3.6 V and ground lead
  - Switch has 4 leads
    - Identified each lead
  - First submarine is now prepped for assembly



Original submarine



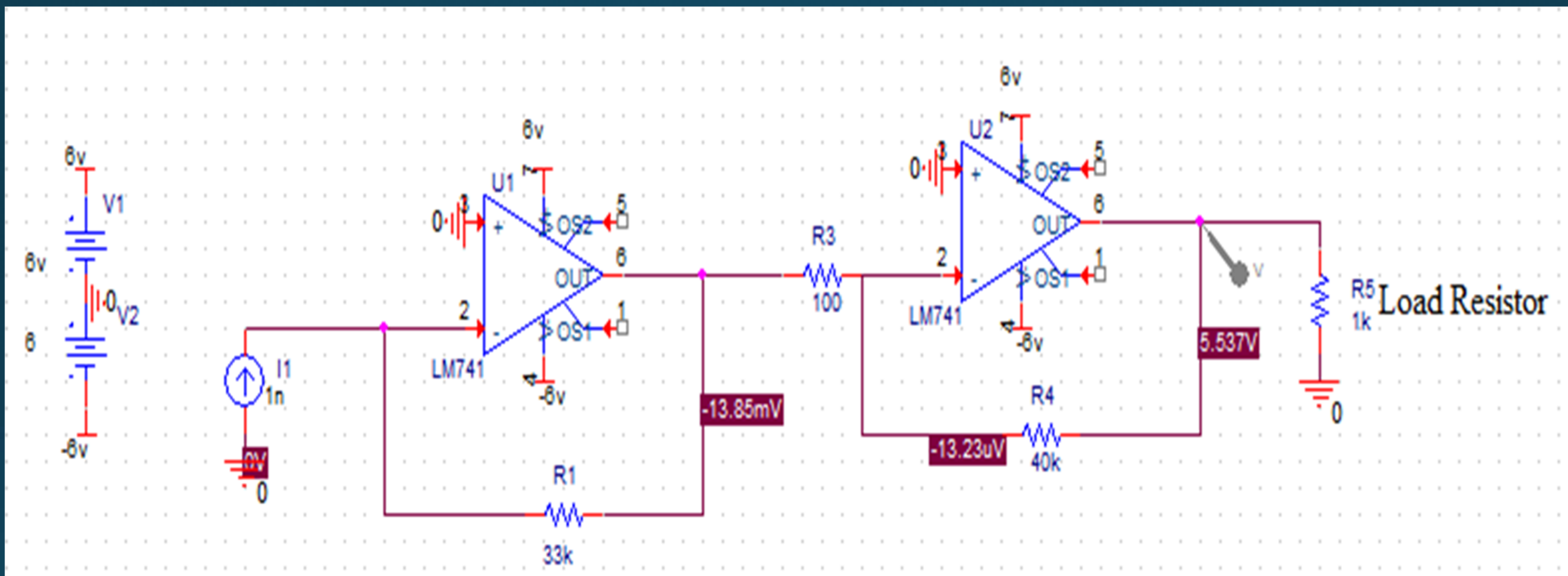
Disassembled submarine

Swarming Algorithm

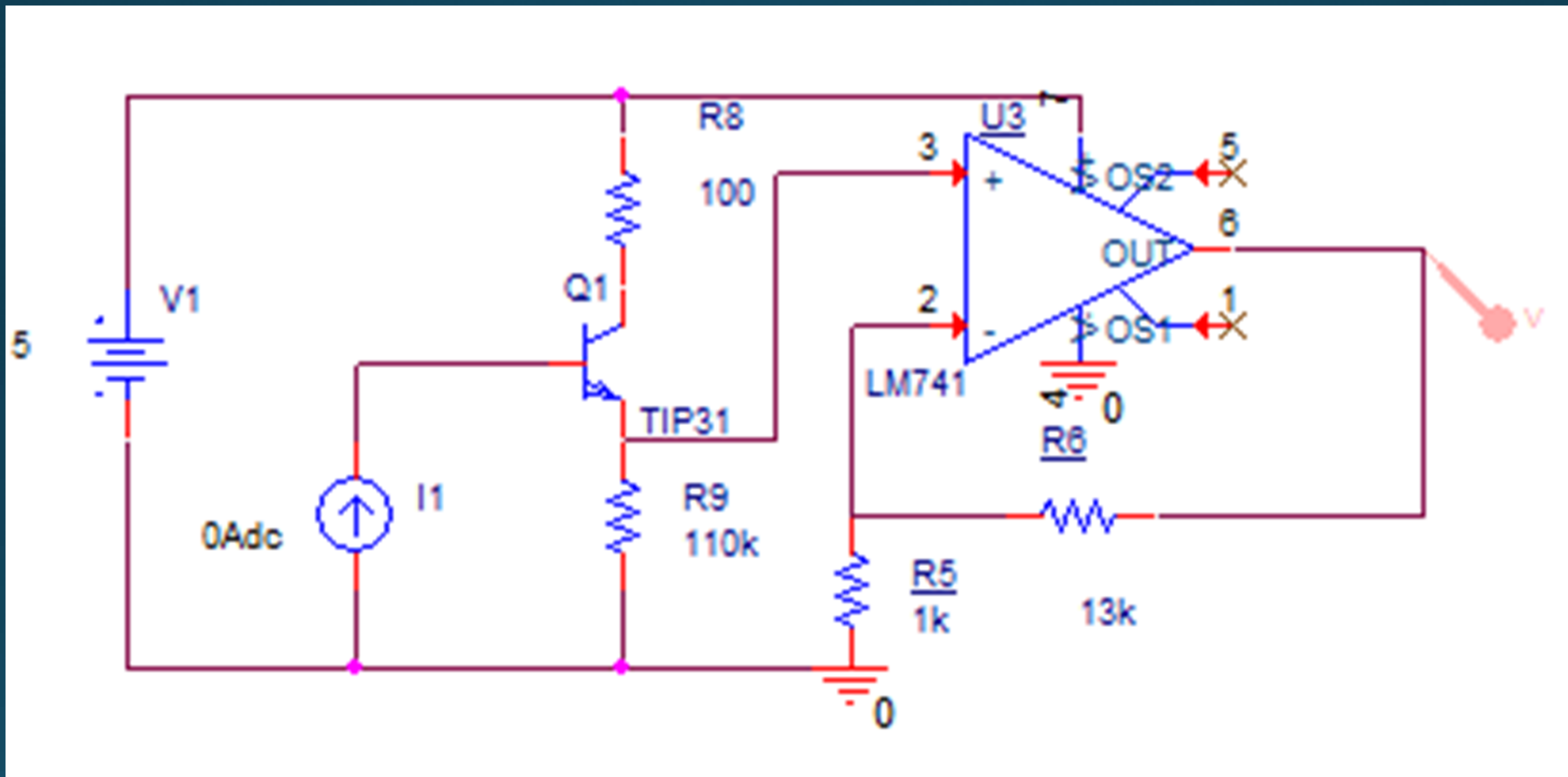
Design

- Design of this algorithm is complete
- Algorithm can be partially tested on a bench top
- Full testing will be possible only when the swarm is constructed
- May need to alter weighting of variables or radii of the different zones

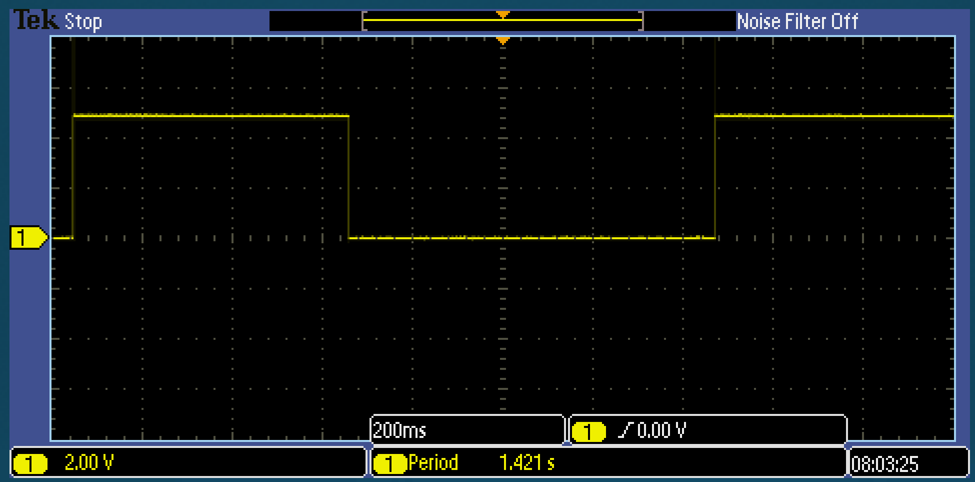
First amplifier design

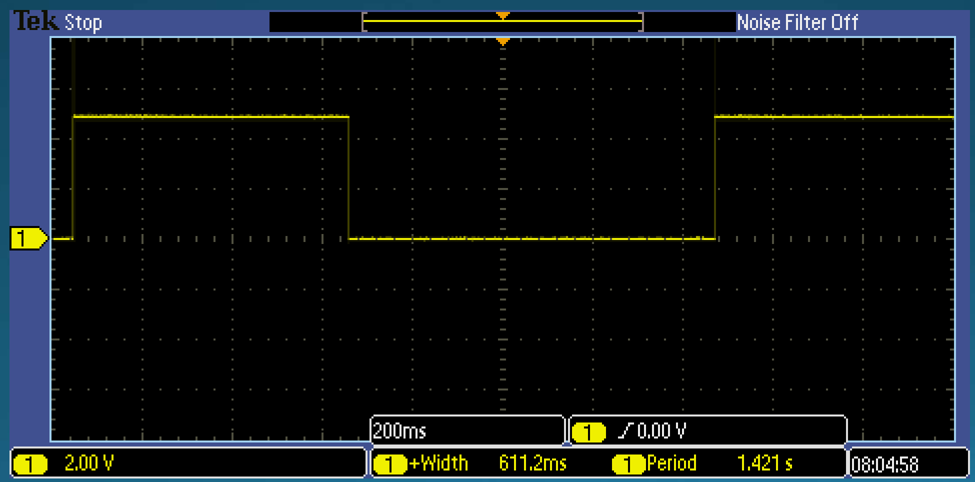


Second photodiode design

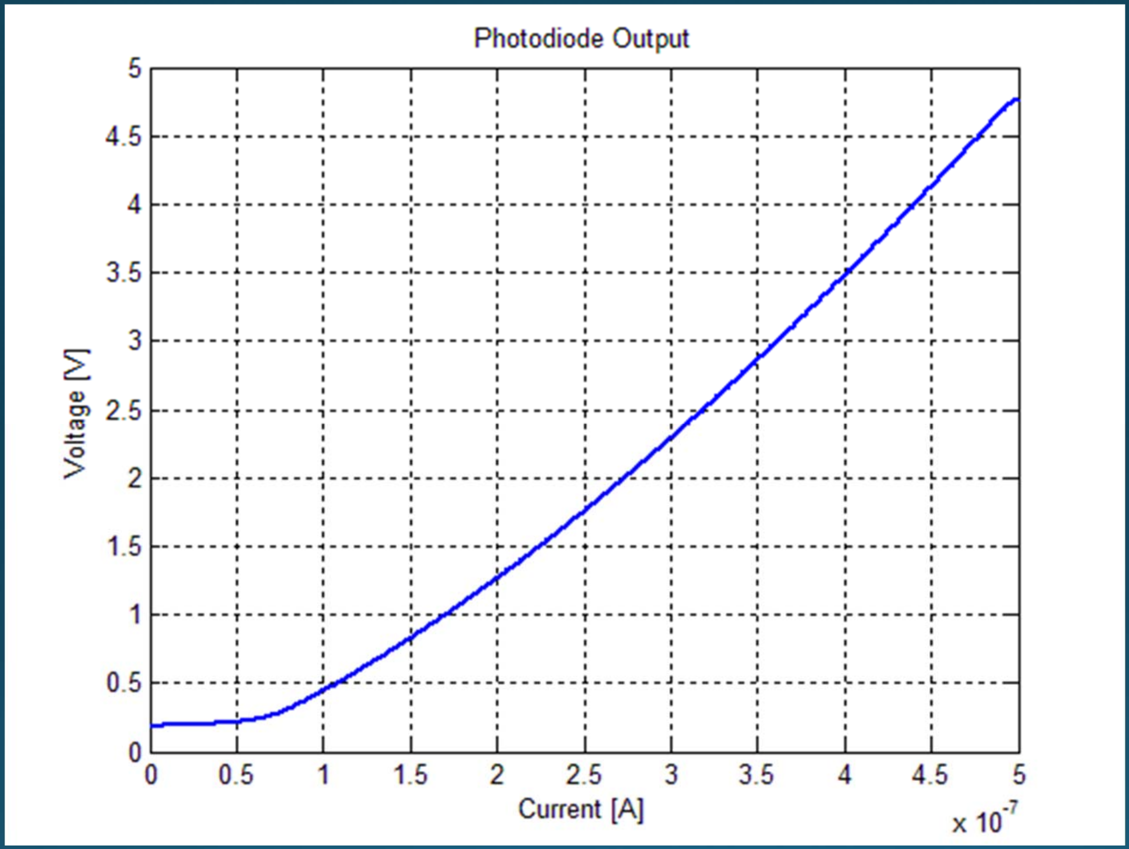


555 Timer Output

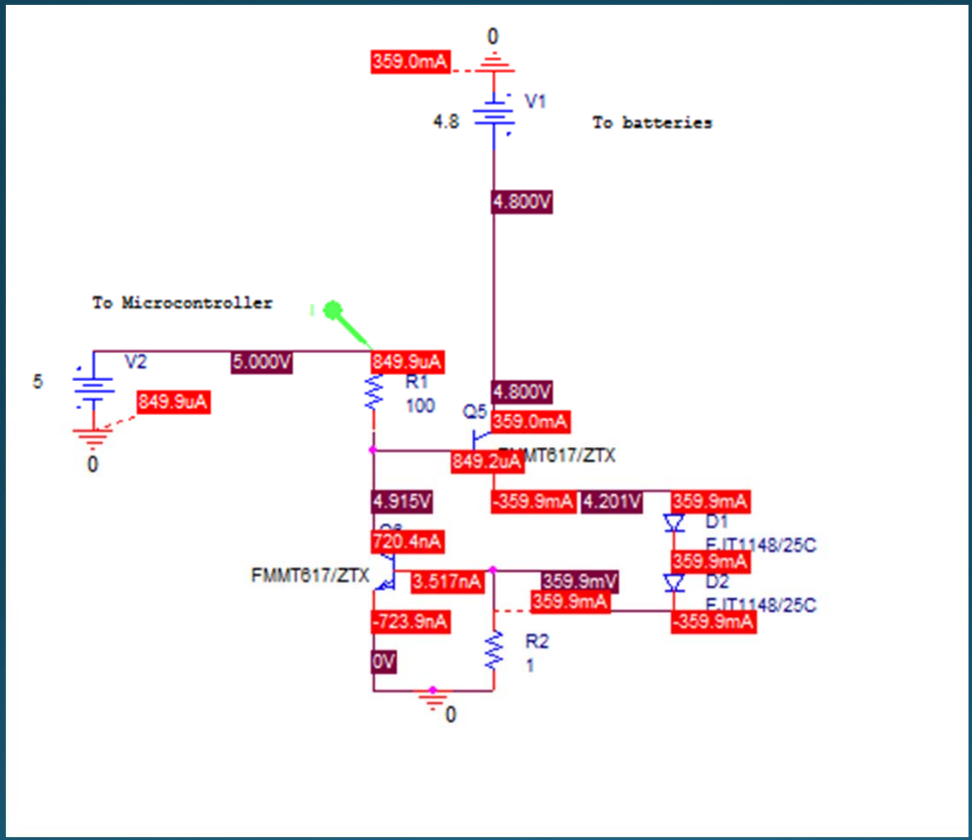




Second design iteration output

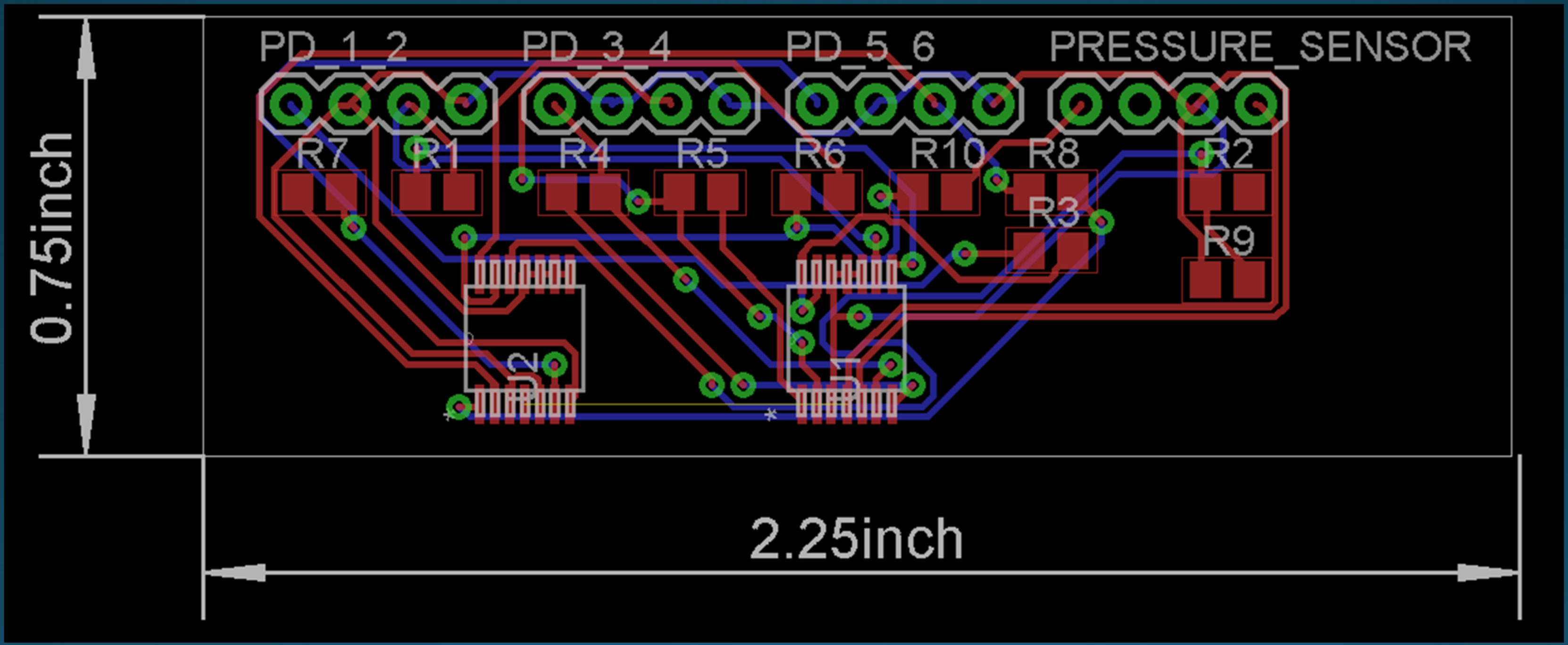


Current Source design



Circuit Layout

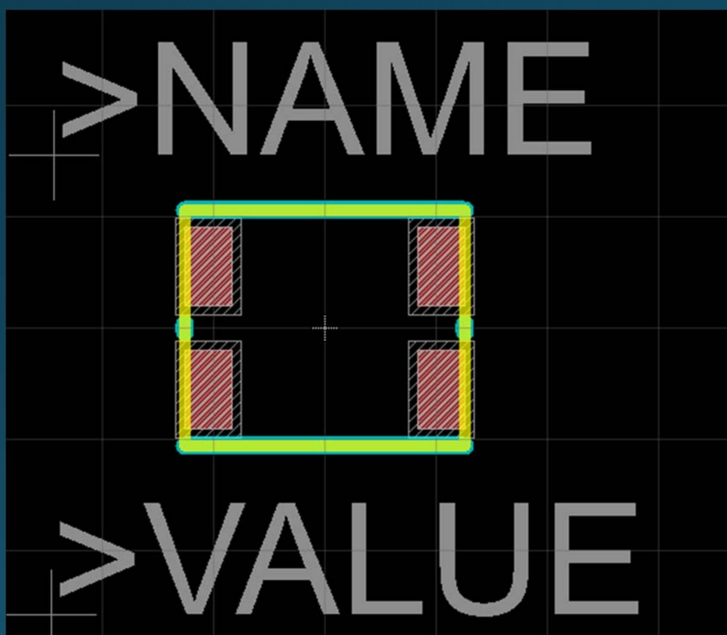
Eagle 7.1.0



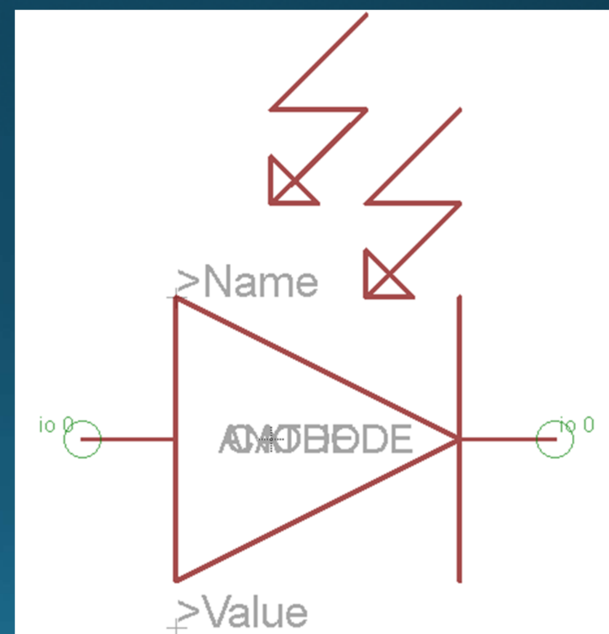
First iteration of the detection array surface mount board

Circuit Layout

Eagle 7.1.0



First library package Everlight photodiode

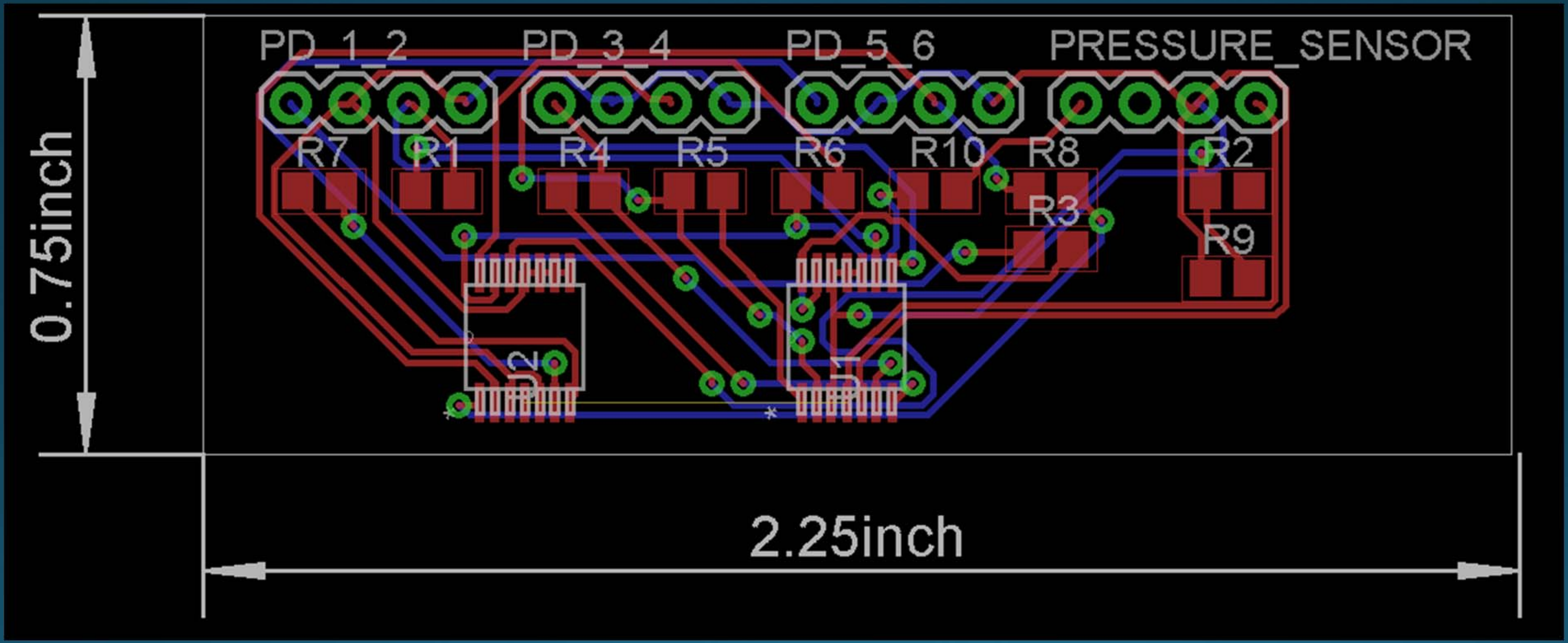


First library symbol Everlight photodiode

Circuit Layout

Eagle 7.1.0

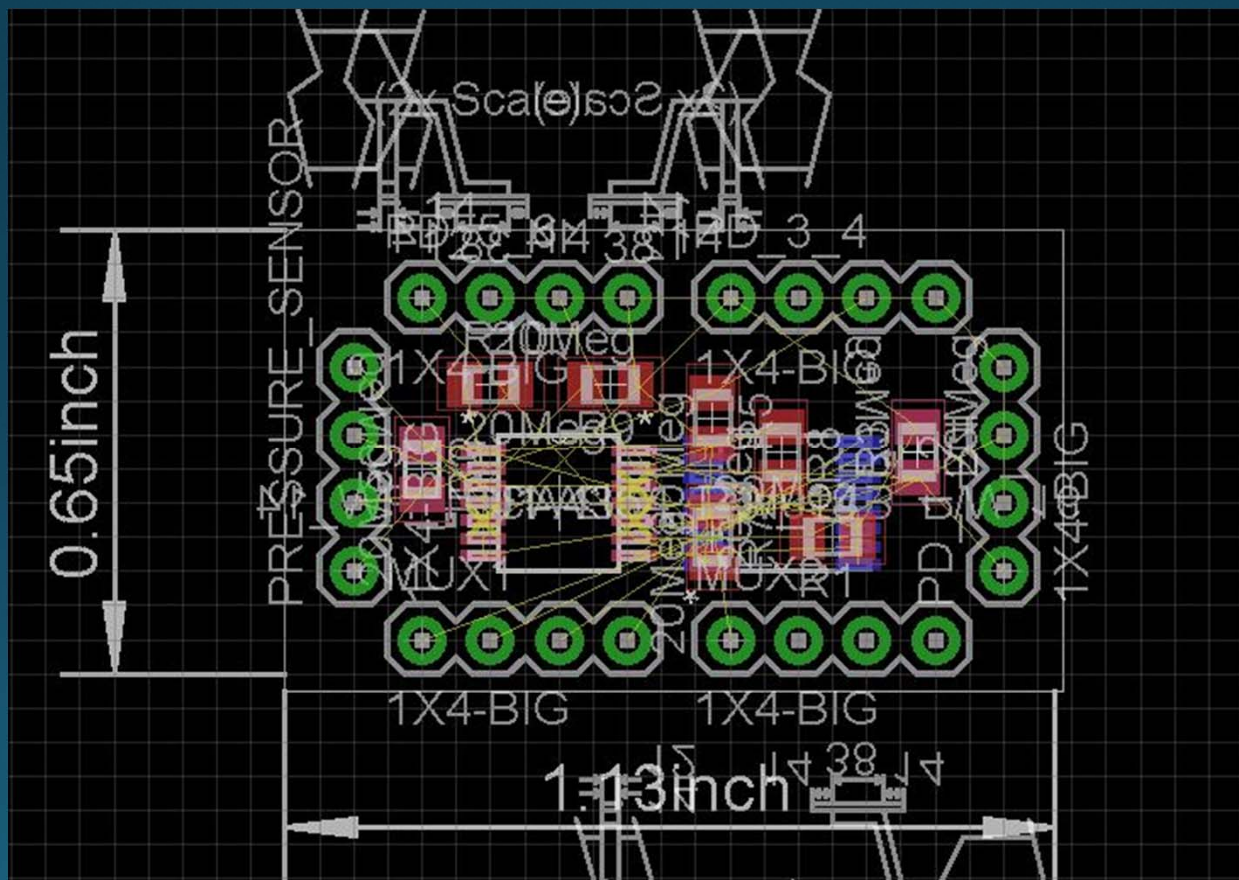
- Photodiode board rev. 1



Circuit Layout

Eagle 7.1.0

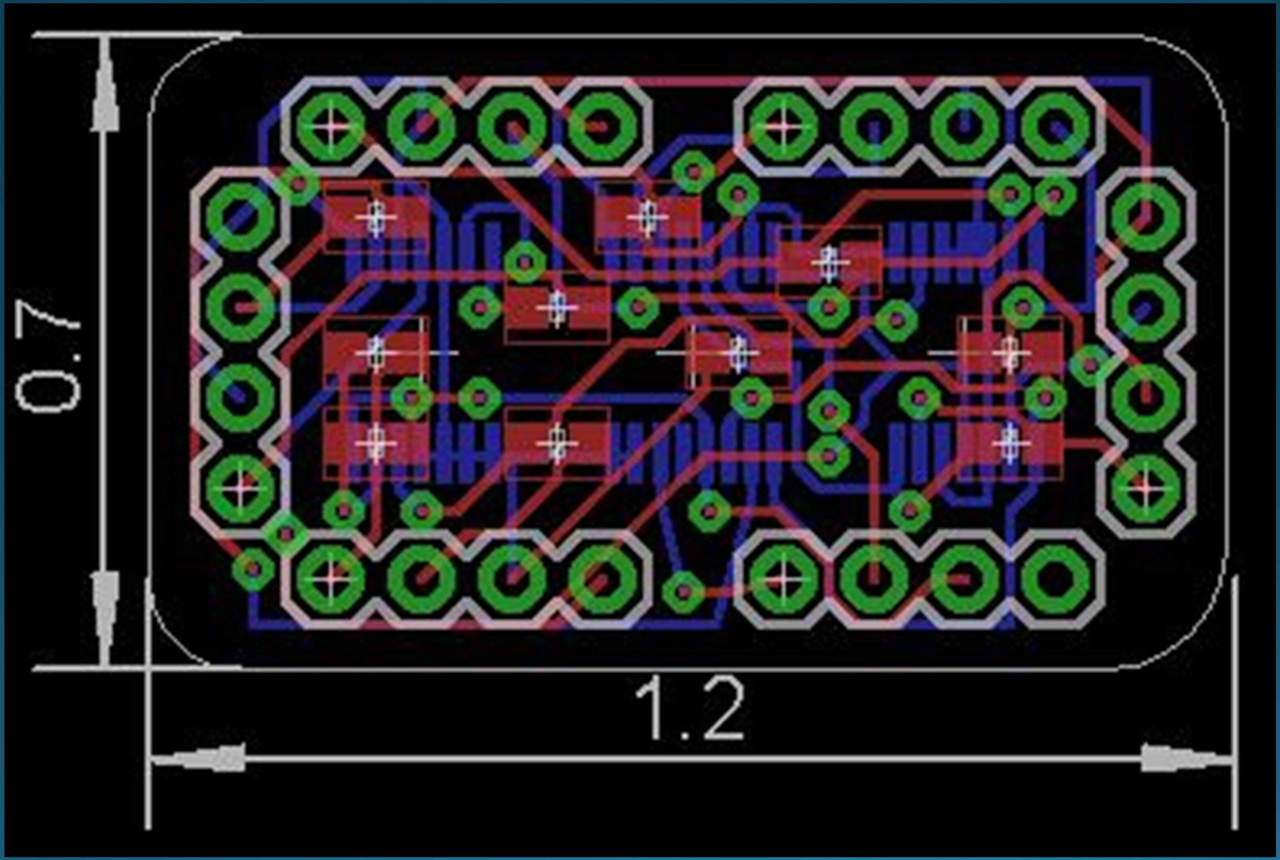
- Photodiode board rev. 2



Circuit Layout

Eagle 7.1.0

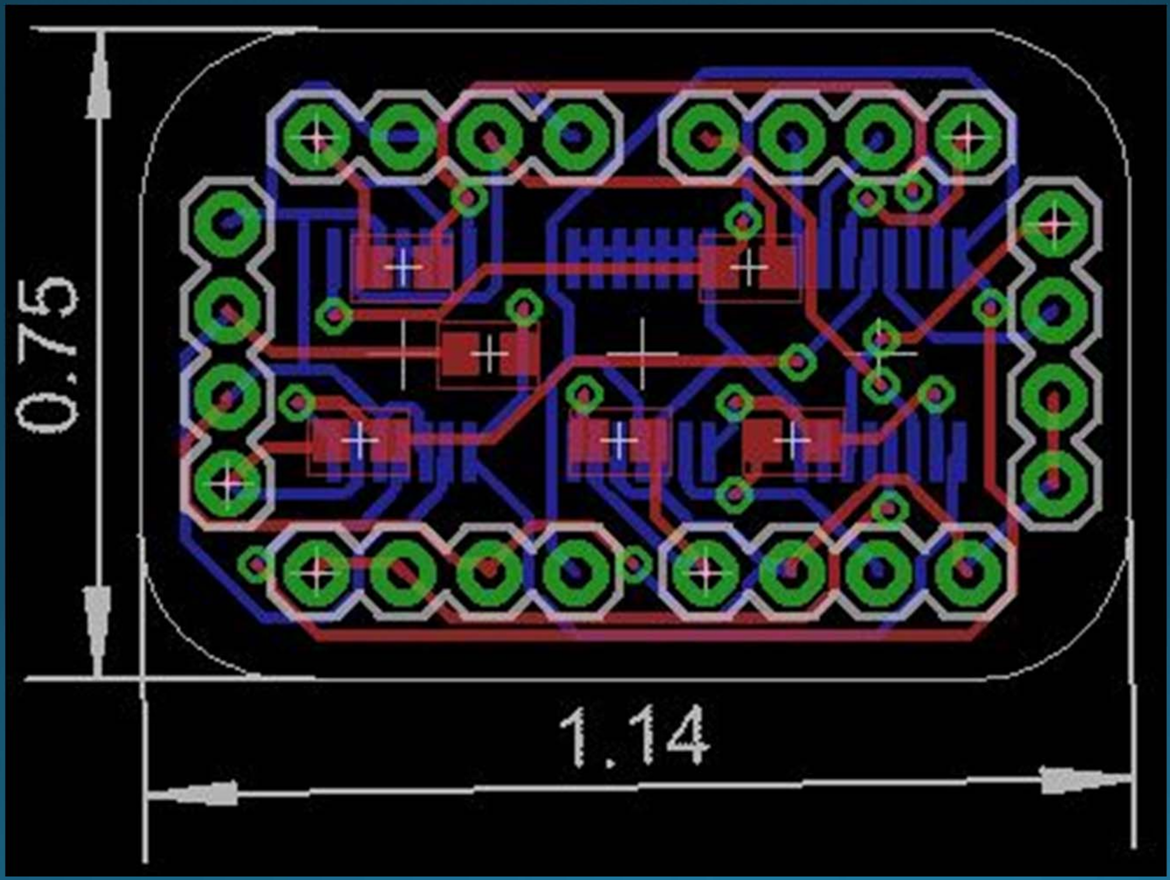
- Photodiode board rev.3



Circuit Layout

Eagle 7.1.0

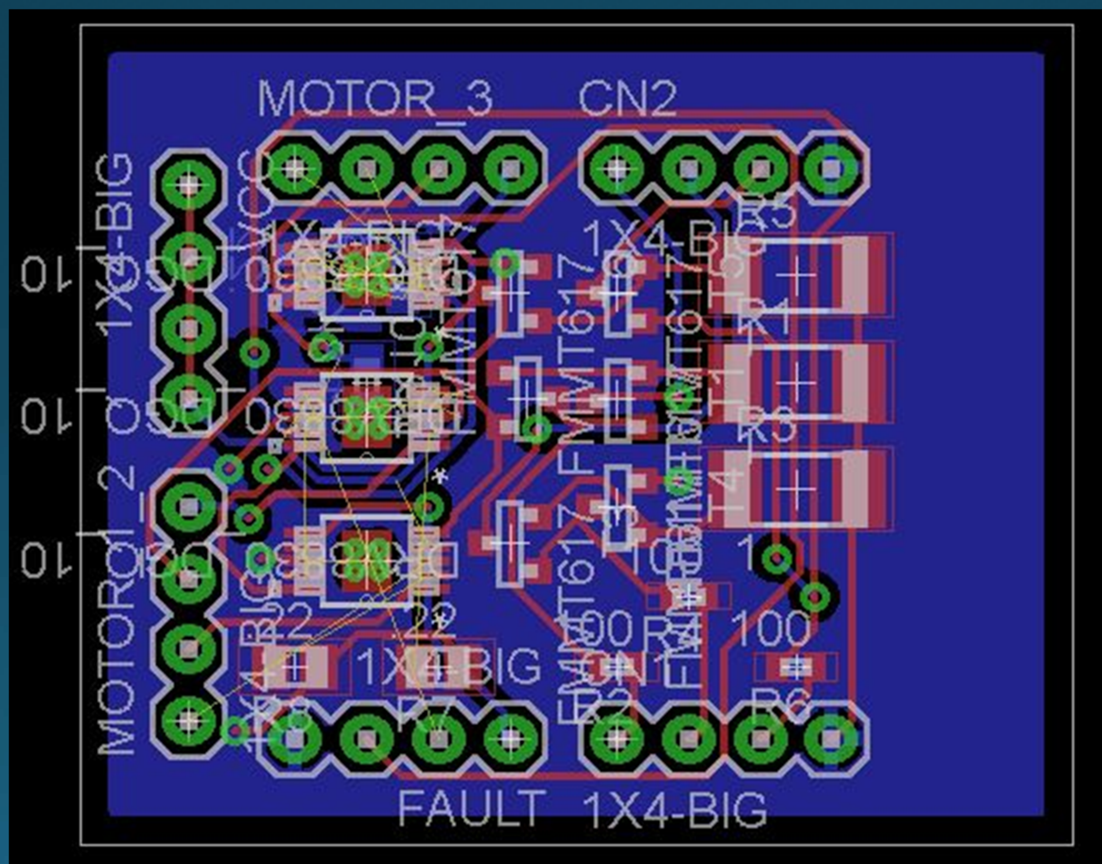
- Photodiode board rev.4



Circuit Layout

Eagle 7.1.0

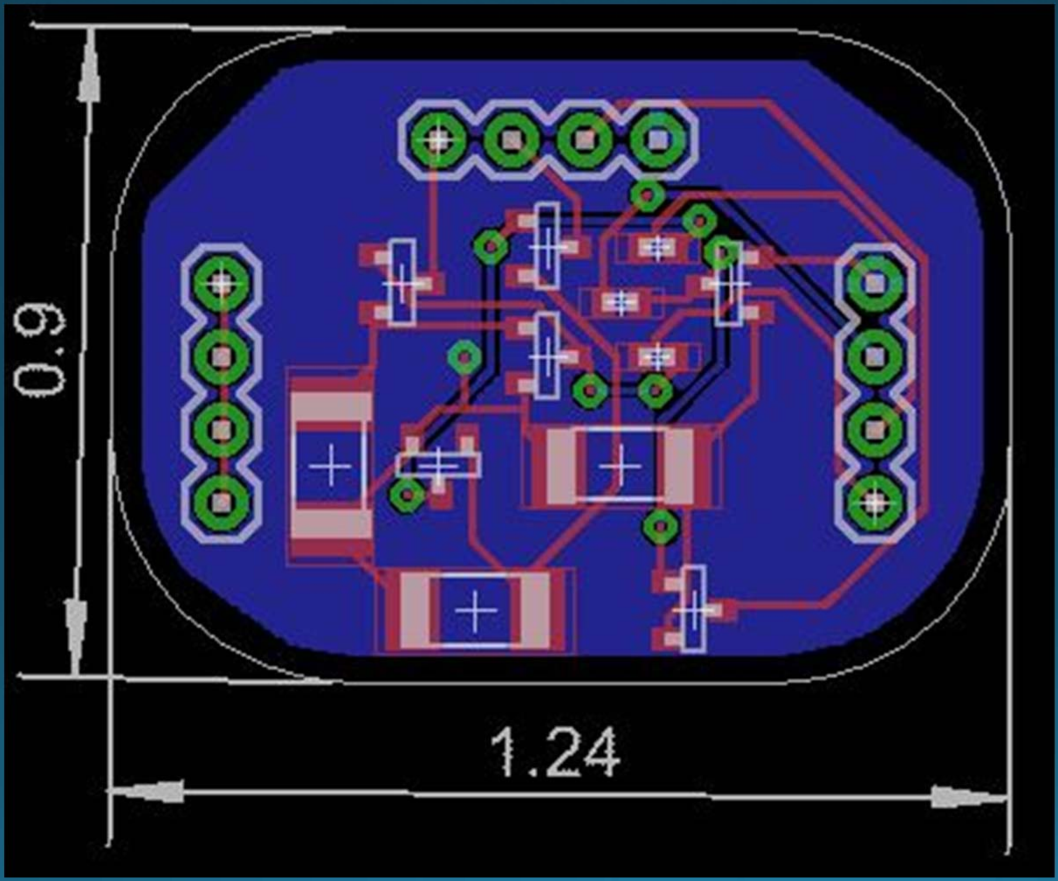
- High current board rev. 1



Circuit Layout

Eagle 7.1.0

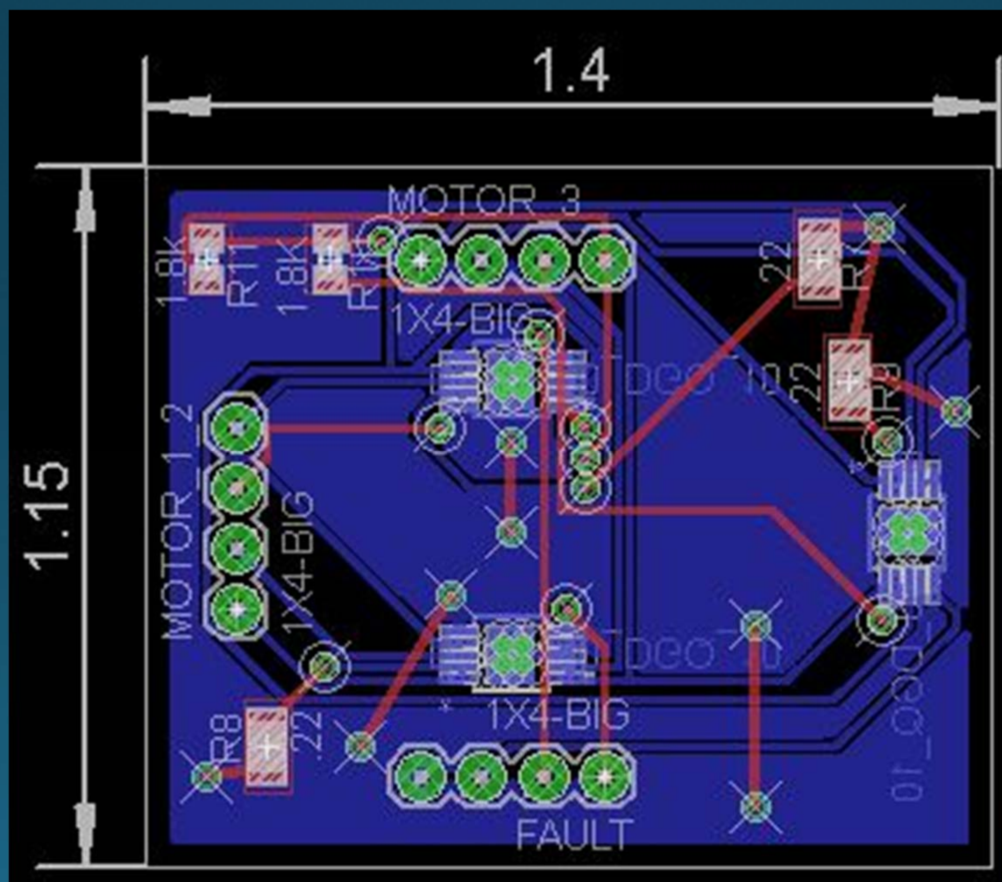
- LED driver board rev. 1



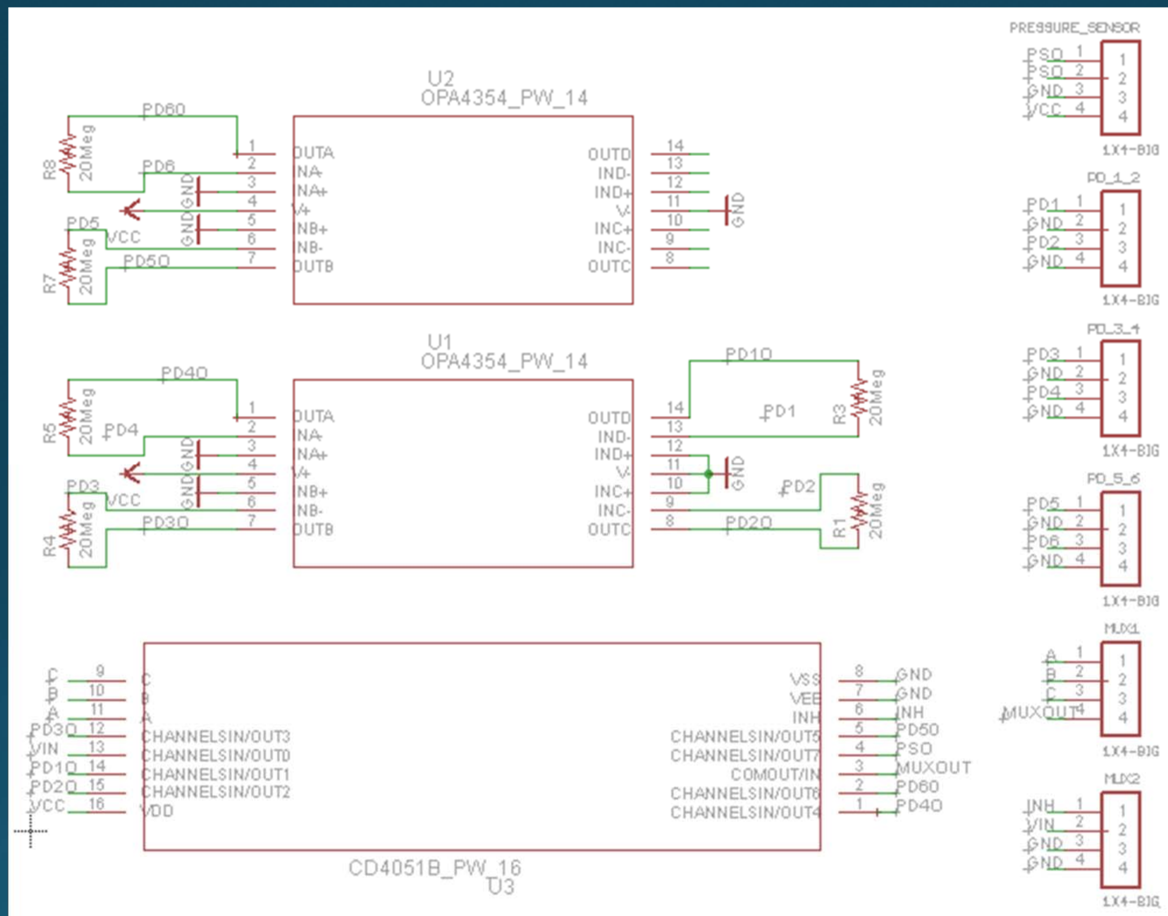
Circuit Layout

Eagle 7.1.0

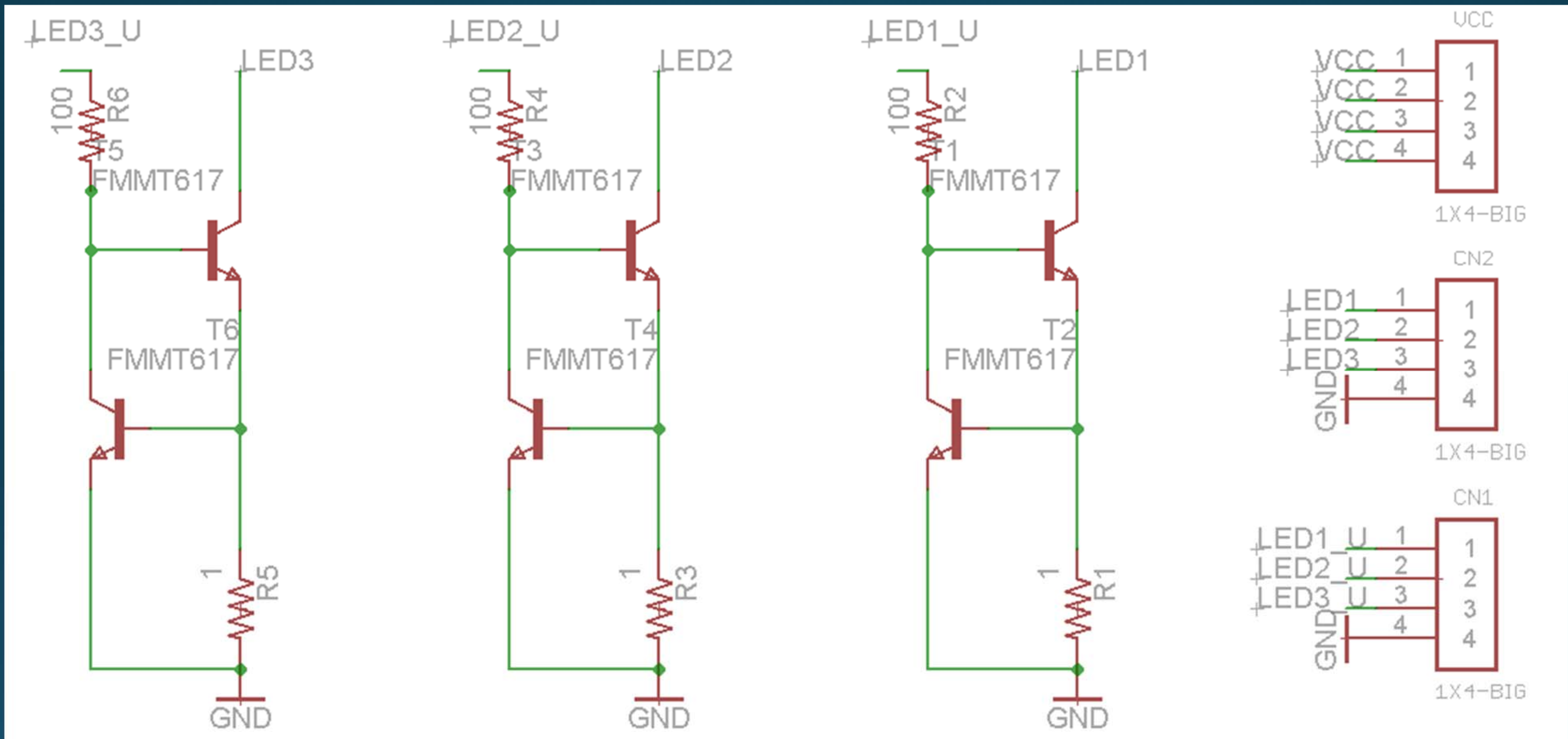
- Motor driver board rev. 1



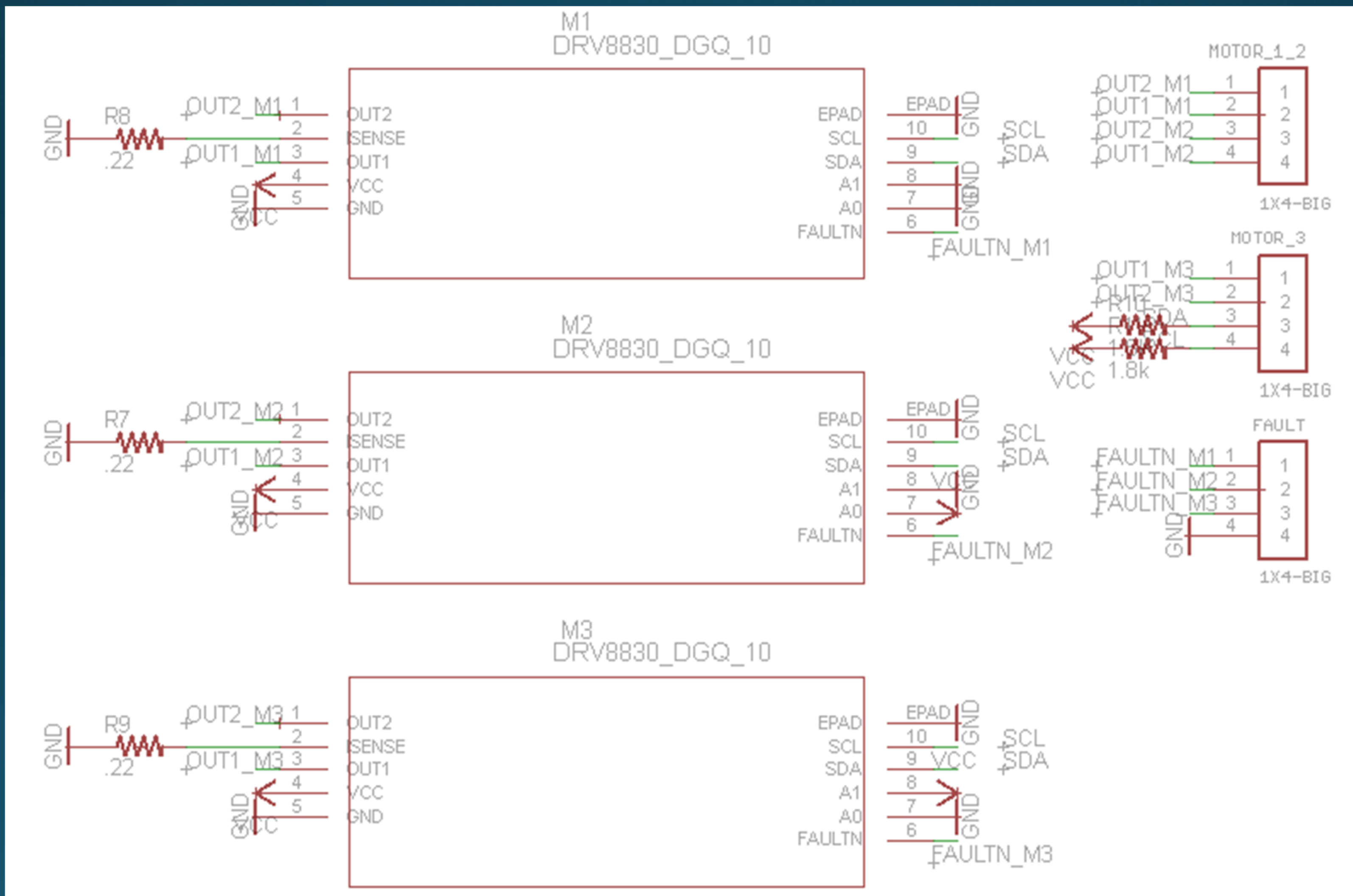
Eagle Schematic



Eagle Schematic



Eagle Schematic



Constraints

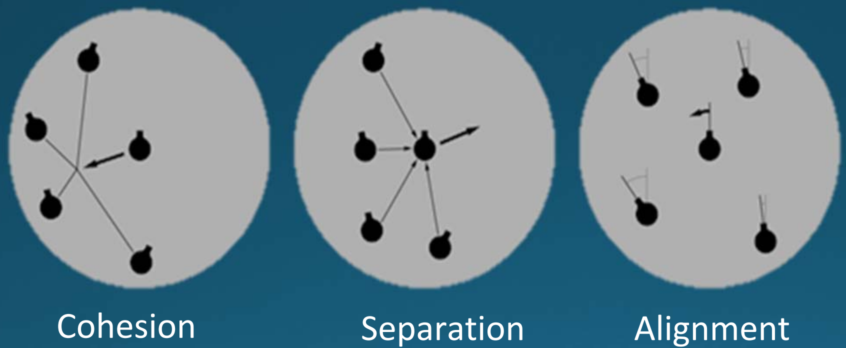
- Avoid harming underwater organisms
- Battery life
- Functional up to two feet of water
- Robots must be reasonably sized

Detection Methods

- Acoustic
- Electromagnetic
- Optical
  - Image processing
  - LEDs

Swarming Techniques

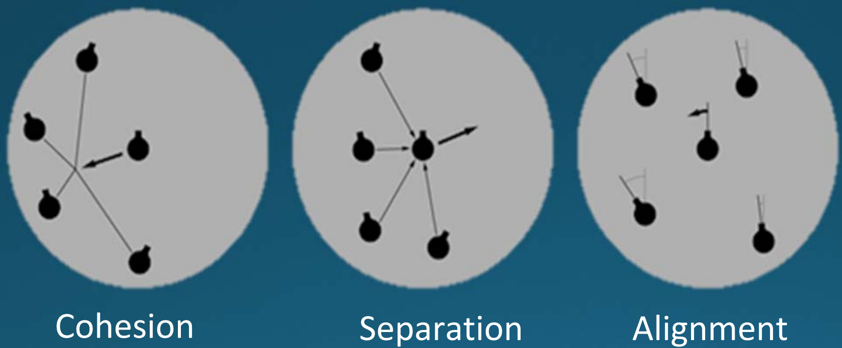
- Boids
  - Simulates the flocking of birds
  - Criteria include cohesion, separation and alignment



Principles of swarming [15]

Swarming Techniques

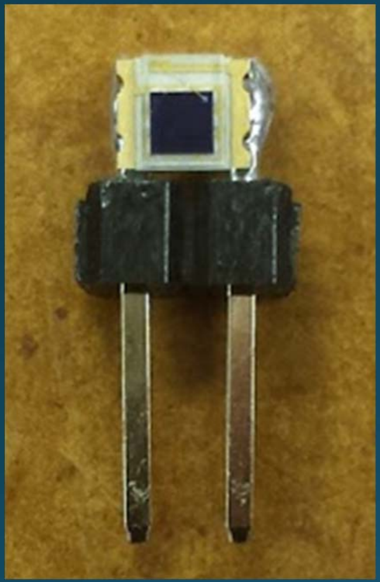
- Minimalistic
  - Based upon Boids
  - Criteria include cohesion, separation and pseudo-alignment



Principles of swarming [15]

Assembly/Soldering

Result



Everlight photodiode soldered to section of header pins

LED soldered to section of header pins

Functional Requirements

Functional Requirement	Specification/Method
Each submarine shall detect other submarines.	1.22 meters, on PCB's
The swarm shall take images of underwater terrain.	640x480, compiled image
The swarm shall maneuver through a body of water.	Depth: ± 10 cm, up to 60cm, constant speed ± 5%, I2C controlled
The submarines shall have a battery life of at least 15 minutes.	Battery life: 25 min
The swarm members shall operate as a swarm when near each other.	Passive sensing while close
Software shall create an image that is collected from the individual submarine images.	10% image gaps or less
Each submarine shall surface upon its battery level dropping below 5%.	Surface at 10% battery life

Societal Impact

- Development is ethical
- Aquatic industries/research will be affected
- Originally marketed as a toy RC submarine
- Submarines will navigate at relatively slow speeds
- Boats could collide with the swarm

Environmental Impact

- Low natural resources costs
- Lost submarines could pollute the water
- Plant life could be disturbed
- Large obstacles will be detected and avoided

Related Patents

- CN 102916744 A - Underwater LED visible light communication system
- US 20140212142 A1 - Underwater optical communication system
- US 20050232638 A1 - Methods and apparatus for underwater wireless optical communication