UMassAmherst

Critical Design Report Presentation

Triton

Team 11
February 28, 2017

Department of Electrical and Computer Engineering

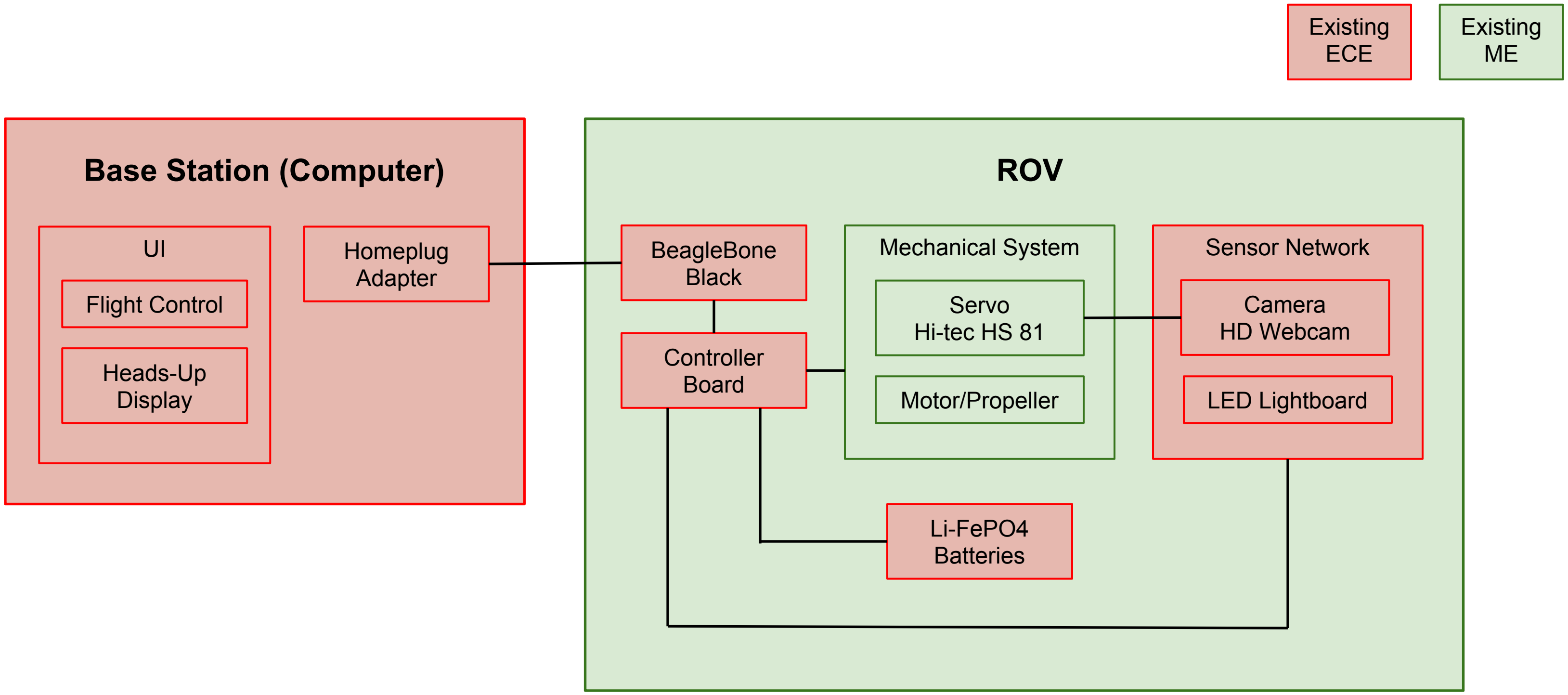
Introduction

- No economical solution for extended underwater monitoring
- Ecologists from UMass Amherst interested in studying spawning behavior river herring
- Triton will allow researchers to observe and record underwater biological phenomena

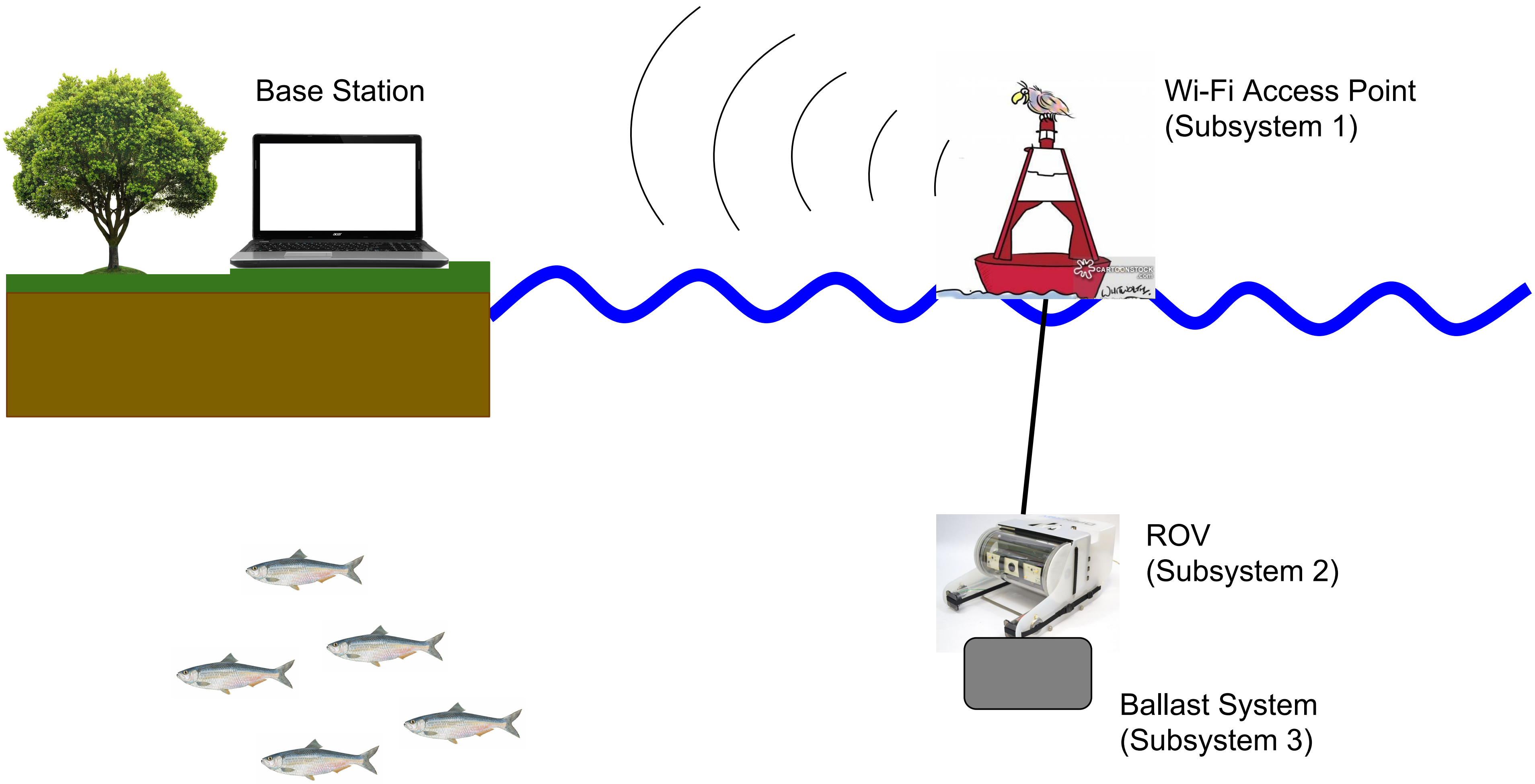
Requirements Analysis: Specifications

- Must be able to reach a depth of 20 feet underwater
- Must be able to operate up to 300 feet away from the base station
- Must be able to operate and provide HD quality video feed up to 2 hours
- Must be able to provide sufficient video quality and lighting to ease navigation underwater
- Should be able to readjust its orientation through control loop

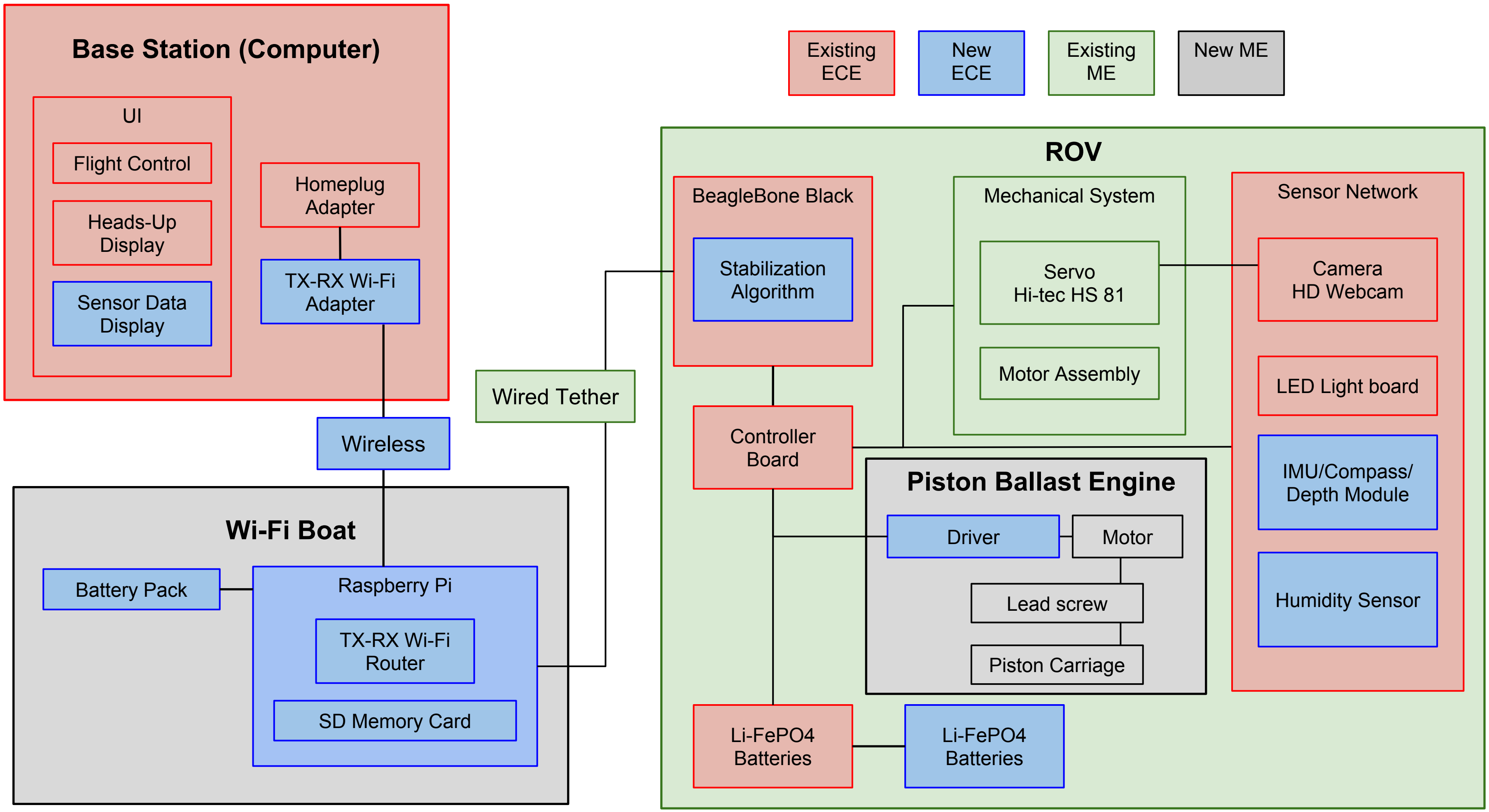
System Block Diagram of Stock ROV



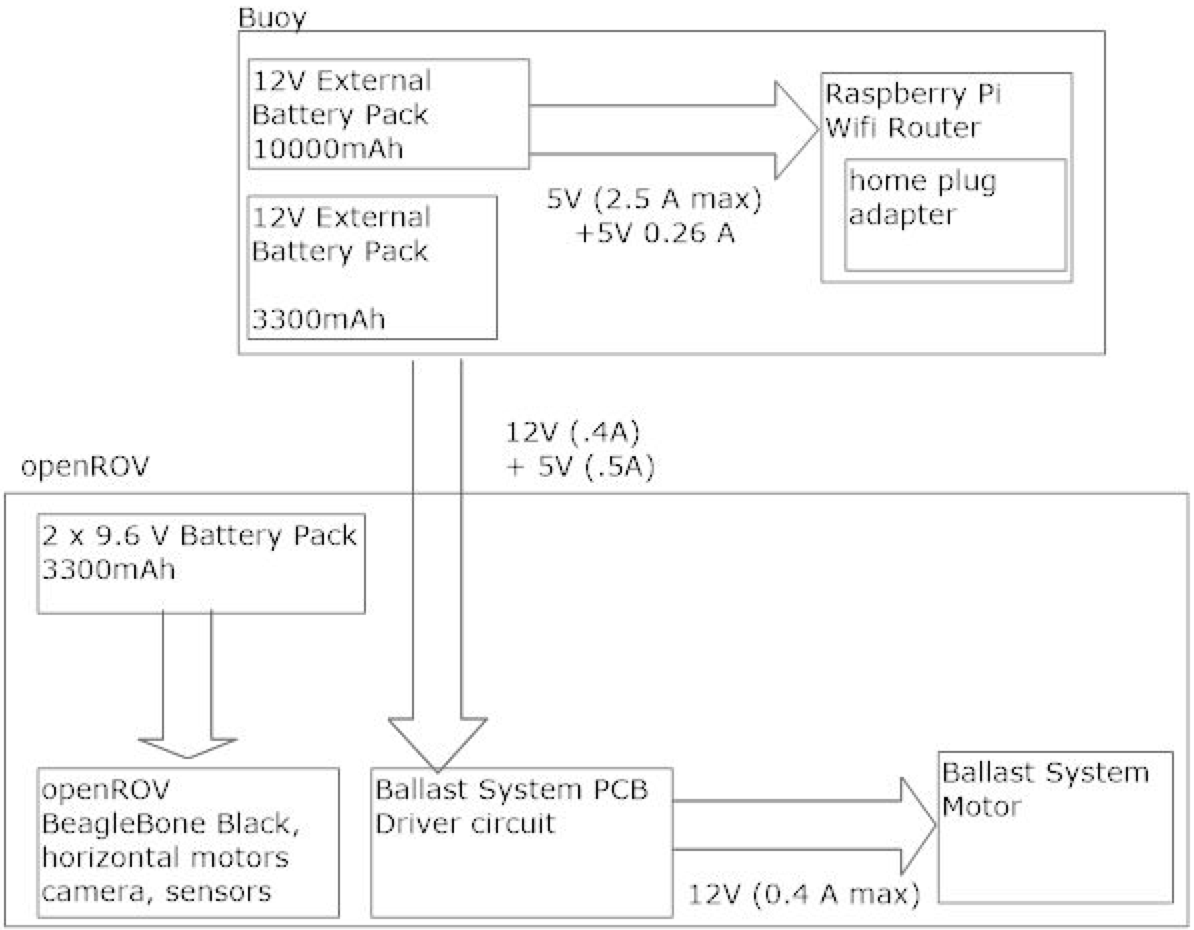
Visual Representation



System Block Diagram

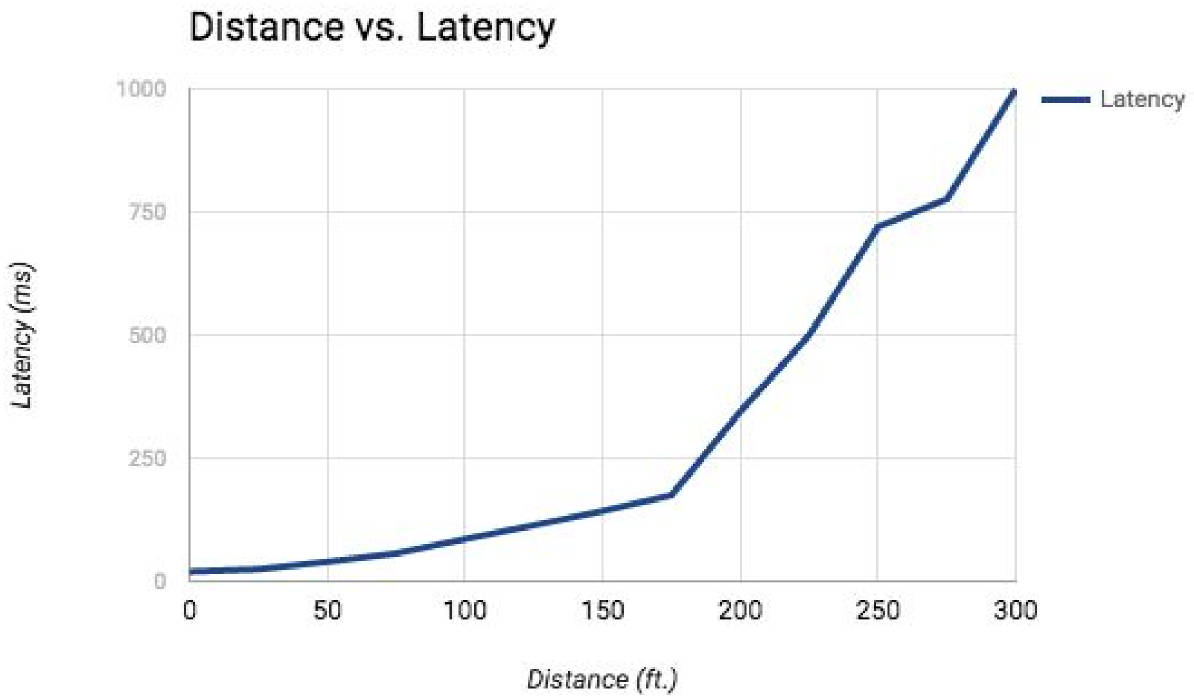


Power Flow

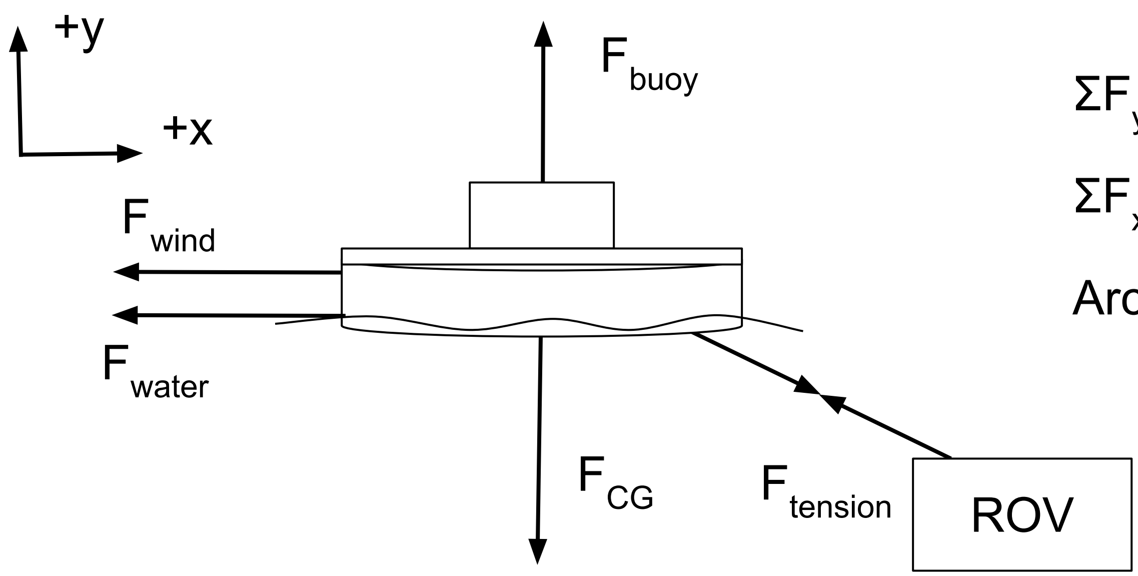

Buoy
12V External
Battery Pack
10000mAh
12V External
Battery Pack
3300mAh
5V (2.5 A max)
+5V 0.26 A
Raspberry Pi
Wifi Router
home plug
adapter
12V (.4A)
+ 5V (.5A)
openROV
2 x 9.6 V Battery Pack
3300mAh
openROV
BeagleBone Black,
horizontal motors
camera, sensors
Ballast System PCB
Driver circuit
12V (0.4 A max)
Ballast System
Motor

Subsystem 1: WiFi Setup

- Raspberry Pi and ethernet adapter
- Video saving capabilities on local drive



Subsystem 1: Housing Design

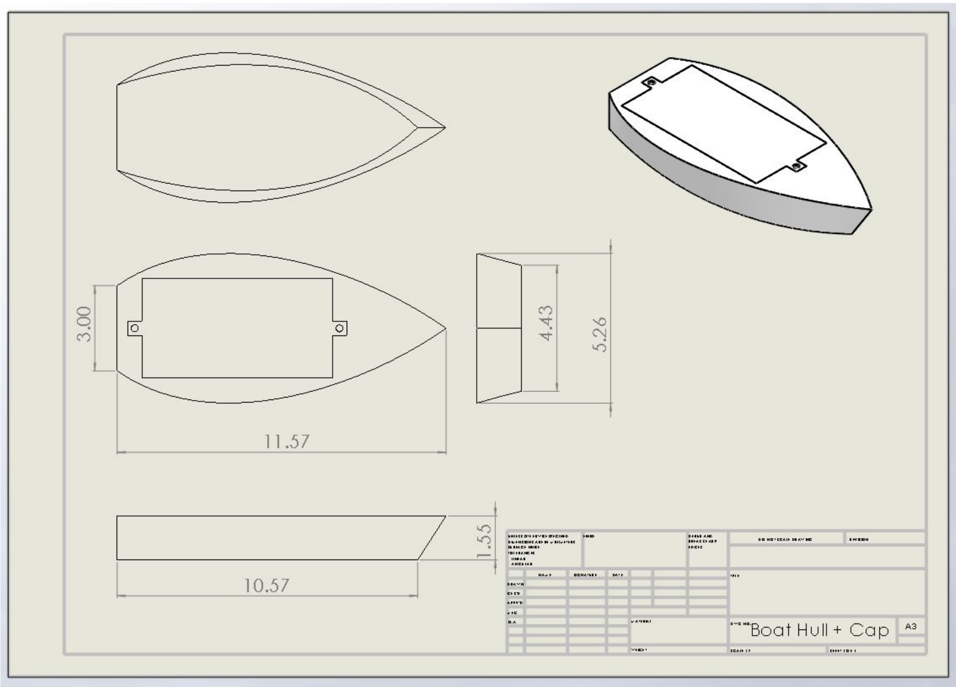


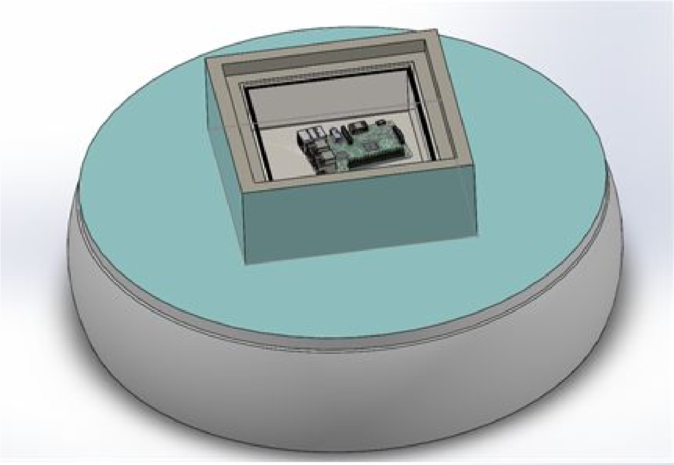
ΣF_y: $F_{CG} - F_{buoy} = 0$

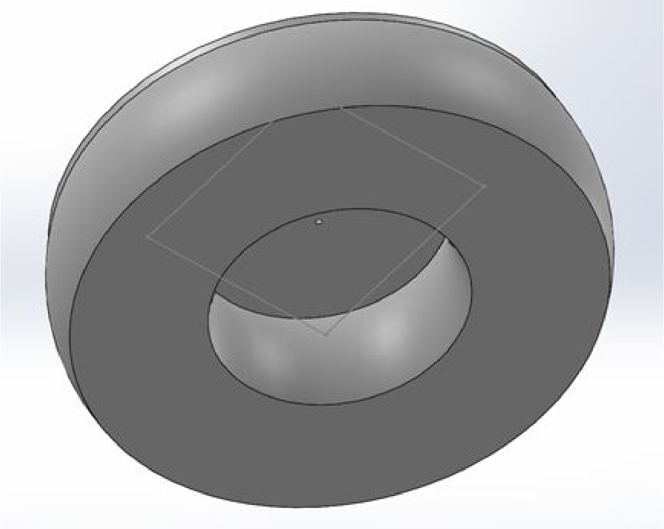
ΣF_x: $F_{tension} - F_{wind} - F_{water} = 0$

Archimedes' Principle: $F = \rho g V$

Subsystem 1: Housing Design







Subsystem 2: ROV

- Main component of project
- What was done?
  - Rewired
  - Old/damaged electrical components were replaced
  - Re-sealed electronics payload
  - water tested
- Depth/compass sensor
  - For telemetry and accurate navigation
- Humidity sensor
  - Used for detecting leaks in electronics compartment

Subsystem 3: Ballast Piston

- Preliminary piston prototype
  - Stepper motor driven by circuit and user input
  - Separate 12v power source
- Passive ballasting
  - Does not draw energy when stepper motor is not energized
  - Self-locking lead screw eliminates need for system brake to prevent rotation when de-energized

Subsystem 3: Ballast Piston

- Power calculations
  - Initial runtime = 1:21 hrs
    - Need to extend -- reduce power consumption
- Performance improvement
  - Target runtime = 3:51 hrs
  - 226.7% increase to current operable duration

ROV On-board power capacity $C_{ROV} := 6.600\ A \cdot hr \cdot 10\ V = 237.6\ 10^3 \cdot J$

Power draw of vertical motor $I_v := 7\ A$ $V := 10\ V$ $P_v := I_v \cdot V = 70\ W$

Average duty cycle for a base-level OpenROV system at depth $t_{dcv} := \frac{1}{2}$

$Draw_{electronics} := 1.4\ A \cdot hr$

$E_{electronics} := V \cdot Draw_{electronics} = 50.4\ 10^3\ J$

Current draw and energy consumption per hour from onboard electronics

$E_v := P_v \cdot t_{dcv} \cdot 1\ hr = 126\ 10^3 \cdot J$

For vertical motor depth-holding power consumption per hour:

$\frac{C_{ROV}}{E_v + E_{electronics}} = 1.347$

An anticipated 1.347 hours or ~ 1:21 hours of runtime with vertical motor

$I_m := 0.4\ A$ $V_m := 12\ V$ $t_{dcm} := \frac{1}{7}$

Power draw of ballast system based upon stepper motor piston

$P_m := I_m \cdot V_m = 48\ W$

$E_m := P_m \cdot t_{dcm} \cdot 1\ hr = 24.686\ 10^3 \cdot J$

For hypothetical ballast system energy consumption per hour

$C_m := 2.2\ A \cdot hr \cdot 12\ V = 95.04\ 10^3 \cdot J$

$.85 \cdot 60 = 51$

$\frac{C_{ROV}}{E_{electronics}} = 4.714$ $\frac{C_m}{E_m} = 3.85$

An anticipated 3.85 hours or ~ 3:51 hours of runtime with ballast system

$$\frac{\frac{C_m}{E_m} - \frac{C_{ROV}}{E_v + E_{electronics}}}{\frac{C_{ROV}}{E_v + E_{electronics}}} \cdot 100 = 185.833$$

185.8% increase to operable battery time

Subsystem 3: Ballast Piston

- Preliminary piston prototype
  - PVC and acrylic construction
  - Easily machined, constructed
- Motor selected
  - Torque requirements
  - Geometric constraints
  - Power considerations

Vehicle volume, mass, and values determined from CAD model call-out and manufacturer specifications

$V_{ROV} := 115\ in^3$ $SA_{ROV} := 1181.031\ in^2$ $m_R := 1.8\ kg$

$W_{ROV} := m_R \cdot g = 3.968\ lbf$ $\frac{m_R}{V_{ROV}} = 955.154\ \frac{kg}{m^3}$

Archimedes' Principle (for buoyant force)

$F_B = \rho_{fluid} \cdot V_{displaced} \cdot g$ $\rho_{water} := 1000\ \frac{kg}{m^3}$

$F_B := \rho_{water} \cdot V_{ROV} \cdot g = 4.155\ lbf$

Net forces acting in the vertical column

$F_B - W_{ROV} = 0.186\ lbf$

This is the force that must be reduced to zero by the piston ballast system in order to achieve neutral buoyancy

Center of Buoyancy and center of mass CAD calculations. A greater vertical distance, or metacentric height between these two will yield greater stability against overturning, as a greater righting moment is introduced to the system.

Subsystem 3: Ballast Piston

Heat Transfer and Pressure Calculations

Assumed worst case scenario - maximum temperature rise at motor stall torque

$T_{motor} := 80\ \Delta°C = 144\ \Delta°F$ Peak motor temperature rise as determined by manufacturer specification

$T_w := 35\ \Delta°F$ Film temperature of the PVC surface exposed to water

$k_{PVC} := 0.19\ \frac{W}{m \cdot K}$ Thermal conductivity of PVC

$T_{max} < 140\ °F$ PVC temperature cannot exceed 140 degF

$q = U \cdot A \cdot (T_m - T_{inf})$ $\quad L := 2\ in$ $\quad r_1 := \frac{2.067\ in}{2} = 1.034\ in$

$r_2 := \frac{2.375\ in}{2} = 1.188\ in$

$R_{tcond} := \frac{\ln\left(\frac{r_2}{r_1}\right)}{2 \cdot \pi \cdot L \cdot k_{PVC}} = 2.29\ \frac{K}{W}$ thermal resistance of PVC walled cylinder

Thermophysical properties evaluated at ambient air temperature of ~20degC (68degF)

$\nu := 15.11 \cdot 10^{-6}\ \frac{m^2}{s}$ $\quad \alpha := 3.43 \cdot 10^{-3} \cdot \frac{1}{K}$ $\quad k_f := 0.0257\ \frac{W}{m \cdot K}$

$V := 0.001\ \frac{m}{s}$ $\quad D_h := \pi \cdot 2\ in$

Prandtl number: $Pr := \frac{\nu}{\alpha} = 0.004\ \frac{m^2 \cdot K}{s}$ ratio of the momentum and thermal diffusivities

Reynolds number: $Re_L := \frac{V \cdot L}{\nu} = 3.362$ ratio of the inertia and viscous forces

Nusselt number: $Nu = \frac{h \cdot D_h}{k_f} = 4.36$ ratio of convection to pure conduction heat transfer for fully developed laminar flow

$h := 4.36 \cdot \frac{k_f}{D_h} = 0.702\ \frac{W}{m^2 \cdot K}$ $\quad A := 2 \cdot \pi \cdot r_1 \cdot L + \pi \cdot r_1^2$

$q := \frac{-(T_{motor} - T_w)}{\left(R_{tcond}^{-1} + A \cdot h\right)^{-1}} = -26.888\ W$ $\quad T_{s1} := -(q \cdot R_{tcond} + T_w) = 75.848\ \Delta°F$

Torque Calculations

$d_i := 0.1\ in, 0.11\ in .. 5\ in$ $\quad h := 5.9\ in$

$A_c(d_i) := \frac{\pi}{4} \cdot d_i^2$

$W(d_i) := 11\ psi \cdot \frac{\pi}{4} \cdot d_i^2$

Range of cross sectional areas of the carriage

Plot displaying relationship of weight applied to thrust collar and cross-sectional area

$A_c(2\ in) = 3.142\ in^2$ $\quad r_1 := \frac{2.067\ in}{2} = 1.034\ in$

$W(2\ in) = 34.558\ lbf$ $\quad r_2 := \frac{2.375\ in}{2} = 1.188\ in$

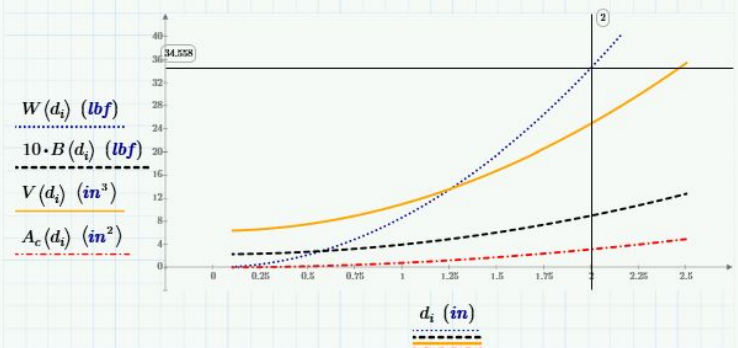
$P_s := \rho_{water} \cdot g \cdot 25\ ft = 10.838\ psi$

$V_{pvc} := \pi \cdot (r_2^2 - r_1^2) \cdot h = 6.34\ in^3$

$V(d_i) := \frac{\pi}{4} \cdot d_i^2 \cdot h + V_{pvc}$

$B(d_i) := V(d_i) \cdot \rho_{water} \cdot g$

$B(2\ in) = 0.899\ lbf$



Subsystem 3: Ballast Piston

Torque required to raise load W

$$Tra(d_i) = \frac{W(d_i)\cdot d_m}{2}\cdot\frac{f\cdot\pi\cdot d_m + L\cdot cos(\alpha_n)}{\pi\cdot d_m\cdot cos(\alpha_n) - f\cdot L}$$

Torque required to lower load W

$$Tla(d_i) = \frac{W(d_i)\cdot d_m}{2}\cdot\frac{f\cdot\pi\cdot d_m - L\cdot cos(\alpha_n)}{\pi\cdot d_m\cdot cos(\alpha_n) + f\cdot L} + \frac{W(A_c)\cdot f_c\cdot d_c}{2}$$

For the Acme thread, cos(a_n) is so nearly equal to unity that we may simplify the previous equations into the following equations for a square thread:

Torque required to raise load W

$$Tr(d_i) = \frac{W(d_i)\cdot d_m}{2}\cdot\frac{f\cdot\pi\cdot d_m + L}{\pi\cdot d_m\cdot - f\cdot L}$$

Torque required to lower load W

$$Tl(d_i) = \frac{W(d_i)\cdot d_m}{2}\cdot\frac{f\cdot\pi\cdot d_m - L}{\pi\cdot d_m + f\cdot L} + \frac{W(A_c)\cdot f_c\cdot d_c}{2}$$

Note:
- W = Weight supported by the power screw
- L = Lead
- f = Friction coefficient of the screw material
- d_m = Mean diameter of thread contact
- d_c = Thrust bearing diameter
- f_c = Friction coefficient of the collar washer/bearing

Most applications of power screws require a bearing surface or thrust collar between stationary and rotating members. As a result, additional torque required to overcome collar friction

For a given leadscrew selected from catalog (NEMA 17)

$L := 8\ mm$

$d_m := 0.25\ in$

$f := 0.2$ $\quad f_c := 0.2$

Assumed coefficient of friction from steel to cast iron interface

$d_c := L + 0.5\ in$

Hypothetical collar

$\alpha_n := 14.5\ deg$

$$SLa(L) := \frac{L\cdot cos(\alpha_n)}{\pi\cdot d_m} \qquad SL(L) := \frac{L}{\pi\cdot d_m}$$

Lead screws can be self locking at low leads. Generally, the lead of the screw should be more than 1/3 of the diameter to satisfactorily backdrive

$SL(4\ mm) = 0.201$

Torque required to raise load W

$$Tr(d_i) := \frac{W(d_i)\cdot d_m}{2}\cdot\frac{f\cdot\pi\cdot d_m + L}{\pi\cdot d_m - f\cdot L}$$

Torque required to lower load W

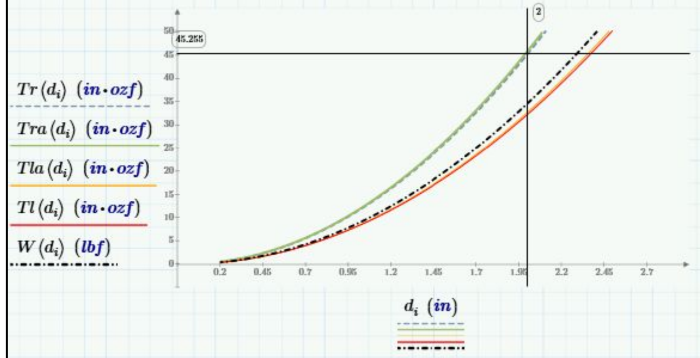
$$Tl(d_i) := \frac{W(d_i)\cdot d_m}{2}\cdot\frac{f\cdot\pi\cdot d_m - L}{\pi\cdot d_m + f\cdot L} + \frac{W(d_i)\cdot f_c\cdot d_c}{2}$$

Torque required to raise load W

$$Tra(d_i) := \frac{W(d_i)\cdot d_m}{2}\cdot\frac{f\cdot\pi\cdot d_m + L\cdot cos(\alpha_n)}{\pi\cdot d_m\cdot cos(\alpha_n) - f\cdot L}$$

Torque required to lower load W

$$Tla(d_i) := \frac{W(d_i)\cdot d_m}{2}\cdot\frac{f\cdot\pi\cdot d_m - L\cdot cos(\alpha_n)}{\pi\cdot d_m\cdot cos(\alpha_n) + f\cdot L} + \frac{W(d_i)\cdot f_c\cdot d_c}{2}$$

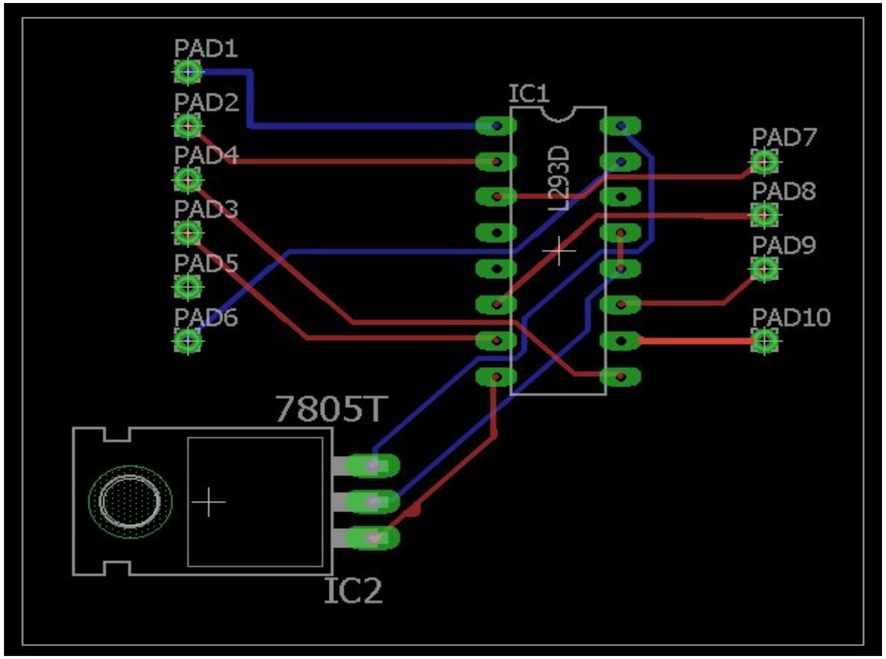


Friction Coefficient [f] for Threaded Pairs				
Screw Material	Nut Material			
	Steel	Bronze	Brass	Cast Iron
Steel, dry	0.15-0.25	0.15-0.23	0.15-0.19	0.15-0.25
Steel, machine oil	0.11-0.17	0.10-0.16	0.10-0.15	0.11-0.17
Bronze	0.08-0.12	0.04-0.06	-	0.06-0.09

Source : From Shigley's Mechanical Engineering Design [Ref 1] and Mechanical Design and Systems Handbook [Ref 2]

Subsystem 3: PCB

- Driver for stepper motor
- Voltage Regulator 12V to 5V



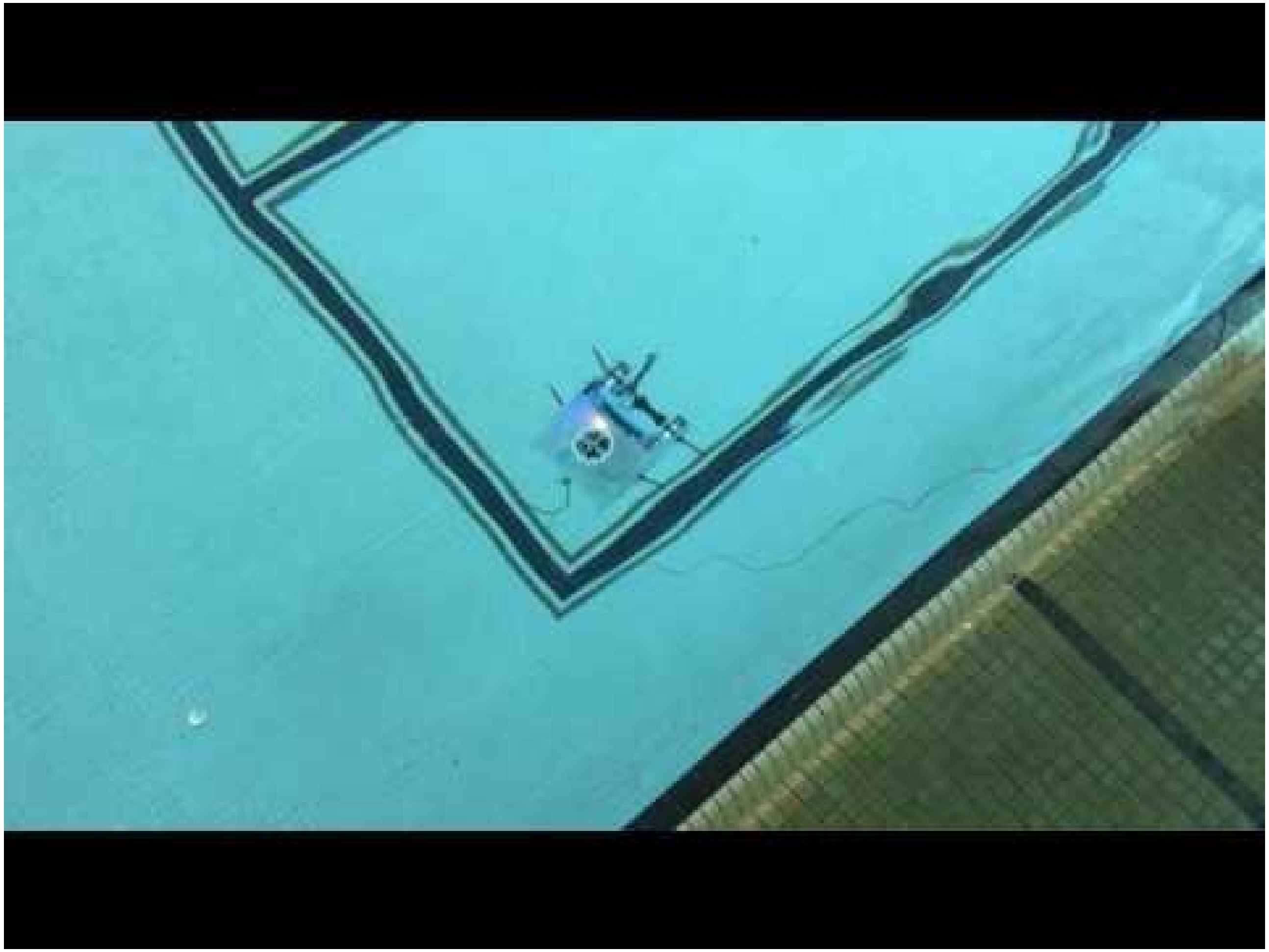
Previously Proposed CDR Deliverables

- Demonstration of ROV reaching 20 feet depth in a lake
- Final design of the boat with WiFi setup onboard
- Prototype of a working ballast system
- Prototype of PCB
- Implementation of humidity and depth/compass sensors

Boat Water Test

Fully Closed ROV Water Test 1

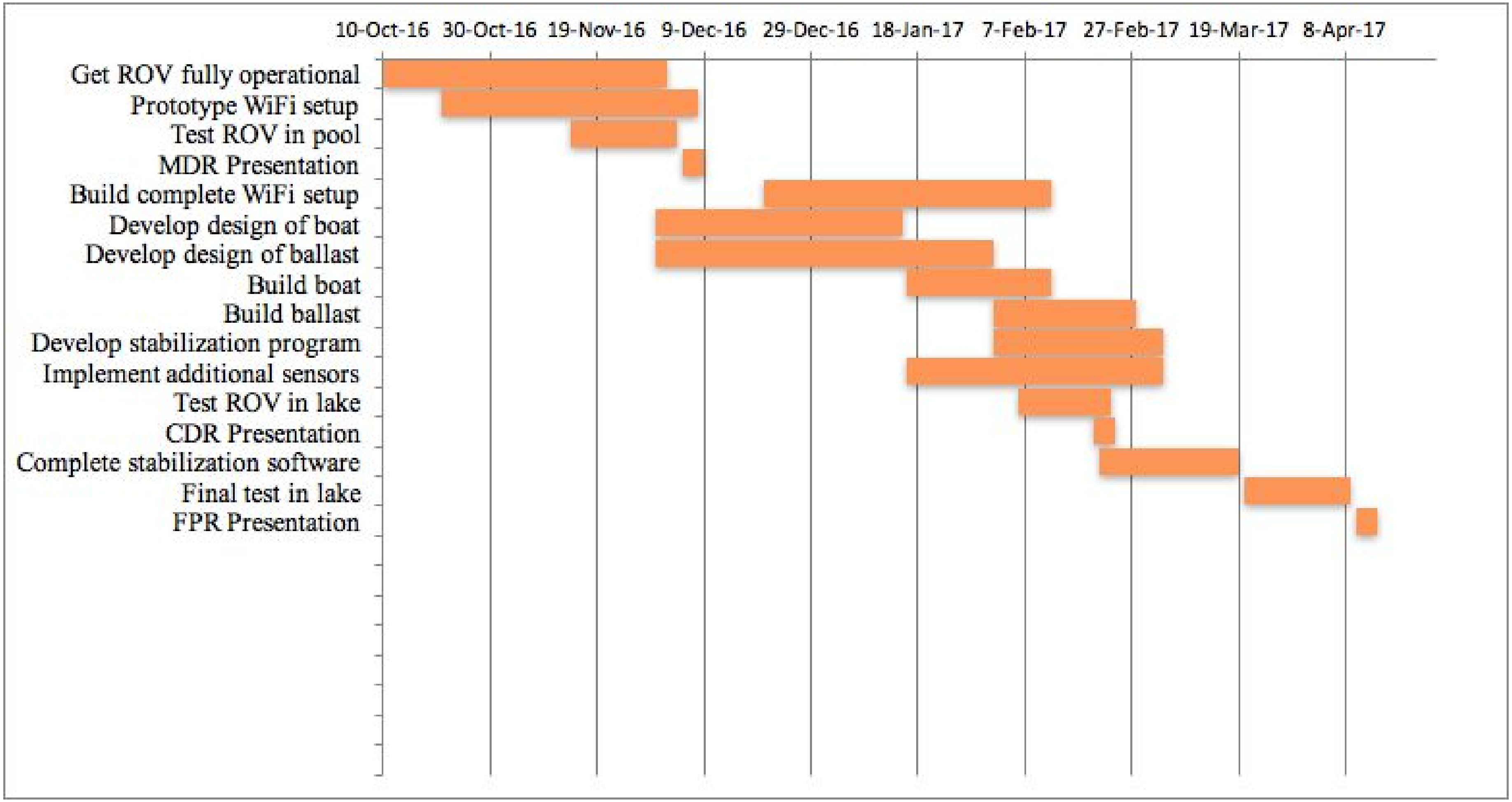
Fully Closed ROV Water Test 2



Proposed FPR Deliverables

- Successful lake test for the ROV
- Fully integrated ballast system
- Finalized WiFi setup and buoy design
- HD video capture and storage capabilities onboard the buoy and computer base station
- Implementation of humidity sensor with UI alert

Proposed Timeline



Cost of Materials

Item	Cost	Shipping Cost
BeagleBone	56.61	0
WiFi Module	19.95	8.59
Syringes (4)	2.12	10
Acrylic Cement	11.81	0
Cement Applicator	5.75	0
Styrofoam/Epoxy (2)	25	0
Humidity Sensor	13.79	13.79
Foam Ring Pool Buoy	25.13	0
L293DNE IC Chip (5)	17.70	10.00
Silicon Spray Lubricant	8.62	0
Adjustable Angle USB	5.99	0
Battery Pack	15.99	0
Rasberry Pi Model B	49.99	0
PCB	80.00	10.00
	Total Cost	390.83
	Current Budget	109.17