Triton

Team 11
February 28, 2017
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

Base Station (Computer)
- UI
- Flight Control
- Heads-Up Display
- Homeplug Adapter

ROV
- BeagleBone Black
- Controller Board
- Mechanical System
  - Servo
  - Hi-tec HS 81
  - Motor/Propeller
- Sensor Network
  - Camera
  - HD Webcam
  - LED Lightboard
- Li-FePO4 Batteries

Existing ECE
Existing ME
Visual Representation

Base Station

Wi-Fi Access Point (Subsystem 1)

ROV (Subsystem 2)

Ballast System (Subsystem 3)
Subsystem 1: WiFi Setup

- Raspberry Pi and ethernet adapter
- Video saving capabilities on local drive
Subsystem 1: Housing Design

\[ \Sigma F_y : F_{CG} - F_{buoy} = 0 \]

\[ \Sigma F_x : F_{tension} - F_{wind} - F_{water} = 0 \]

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

\[
\begin{align*}
C_{\text{ROV}} &= 6.600 \ A \cdot \text{hr} \cdot 10 \ V = 237.6 \ 10^3 \ J \\
I_m &= 7 \ A \\
V_m &= 10 \ V \\
P_m &= I_m \cdot V_m = 70 \ W \\
E_{\text{electronics}} &= V_m \cdot \text{Draw}_{\text{electronics}} = 50.4 \ 10^3 \ J \\
E_v &= P_m \cdot t_{\text{dem}} \cdot 1 \ hr = 126 \ 10^3 \ J \\
\text{Draw}_{\text{electronics}} &= 1.4 \ A \cdot \text{hr} \\
\text{Energy consumption per hour from onboard electronics} &= 50.4 \ 10^3 \ J \\
E_v &= P_m \cdot t_{\text{dem}} = 24.686 \ 10^3 \ J \\
C_m &= 2.2 \ A \cdot \text{hr} \cdot 12 \ V = 95.04 \ 10^3 \ J \\
\text{Power draw of ballast system based upon stepper motor piston} &= 48 \ W \\
C_{\text{ROV}} &= 1.347 \quad \text{An anticipated 1.347 hours or } \approx 1:21 \text{ hours of runtime with vertical motor}
\end{align*}
\]

\[
\begin{align*}
I_m &= 0.4 \ A \\
V_m &= 12 \ V \\
t_{\text{dem}} &= \frac{1}{7} \\
P_m &= I_m \cdot V_m = 48 \ W \\
E_m &= P_m \cdot t_{\text{dem}} \cdot 1 \ hr = 24.686 \ 10^3 \ J \\
C_m &= 2.2 \ A \cdot \text{hr} \cdot 12 \ V = 95.04 \ 10^3 \ J \\
E_v &= P_m \cdot t_{\text{dem}} = 24.686 \ 10^3 \ J \\
C_{\text{ROV}} &= 4.714 \quad \text{An anticipated 3.85 hours or } \approx 3:51 \text{ hours of runtime with ballast system}
\end{align*}
\]

\[
\begin{align*}
\frac{C_{\text{ROV}}}{E_v + E_{\text{electronics}}} &= 1.00 - 185.833 \\
\frac{C_m}{E_v + E_{\text{electronics}}} &= 1.85.8\% \text{ increase to operable battery time}
\end{align*}
\]
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:

\[ V_{ROW} = 115 \text{ in}^3 \quad SA_{ROW} = 1181.031 \text{ in}^2 \quad m_R = 1.8 \text{ kg} \]
\[ W_{ROW} = m_R \cdot g = 3.968 \text{ lbf} \quad \frac{m_R}{V_{ROW}} = 955.154 \text{ kg/m}^3 \]

Archimedes’ Principle (for buoyant force):

\[ F_B = \rho_{\text{fluid}} \cdot V_{\text{displaced}} \cdot g \quad \rho_{\text{water}} = 1000 \text{ kg/m}^3 \]
\[ F_B = \rho_{\text{water}} \cdot V_{ROW} \cdot g = 4.155 \text{ lbf} \]

Net forces acting in the vertical column:

\[ F_B - W_{ROW} = 0.186 \text{ lbf} \]

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 metacenter 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

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

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

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

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

$q = U \cdot A \cdot (T_m - T_w)$

$L = 2 \text{ in}$

$r_1 = \frac{2.067 \text{ in}}{2} = 1.034 \text{ in}$

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

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

Thermophysical properties evaluated at ambient air temperature of $\sim 20\text{degC (68degF)}$

$\nu = 15.11 \cdot 10^{-6} \frac{m^2}{s}$

$\alpha = 3.43 \cdot 10^{-3} \frac{1}{K}$

$V = 0.001 \frac{m}{s}$

$D_h = \pi \cdot 2 \text{ in}$

$k_j = 0.0257 \frac{W}{m \cdot K}$

Prandtl number: $Pr = \frac{\nu}{\alpha} = 0.004 \frac{m^3 \cdot K}{s}$
ratio of the momentum and thermal diffusivities

Reynolds number: $Re_L = \frac{V \cdot L}{\nu} = 3.302$

ratio of the inertia and viscous forces

Nusselt number:

$Nu = \frac{h \cdot D_h}{k_j} = 4.36$

ratio of convection to pure conduction heat transfer for fully developed laminar flow

$h = 4.36 \cdot \frac{W}{m \cdot K}$

$\frac{k_j}{D_h} = 0.702$

$A = 2 \pi \cdot r_1 \cdot L + \pi \cdot r_2 \cdot L$

$q = \left( \frac{T_{\text{water}} - T_w}{R_{\text{cond}} + A \cdot h} \right) = -26.888 \frac{W}{in}$

$T_m = \frac{-q \cdot R_{\text{cond}} + T_w}{A} = 75.848 \frac{\Delta F}{C}$

Torque Calculations

$d_i = 0.1 \text{ in}, 0.11 \text{ in}, \ldots, 5 \text{ in}$

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

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

Range of cross sectional areas of the carriage

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

$A_i(2 \text{ in}) = 3.142 \text{ in}^2$

$r_1 = \frac{2.067 \text{ in}}{2} = 1.034 \text{ in}$

$W(2 \text{ in}) = 31.558 \text{ lbf}$

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

$P_i = \rho \cdot \text{water} \cdot g \cdot 25 \text{ ft} = 10.838 \text{ psi}$

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

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

$B(d_i) = V(d_i) \cdot \rho \cdot \text{water} \cdot g$

$B(2 \text{ in}) = 0.899 \text{ lbf}$

Department of Electrical and Computer Engineering
Subsystem 3: Ballast Piston

Torque required to raise load W

\[ T_{ra}(d_i) = \frac{W(d_i) \cdot d_m}{2} \frac{f \cdot \pi \cdot d_m + L \cdot \cos(\alpha_n)}{\pi \cdot d_m \cdot \cos(\alpha_n) - f \cdot L} \]

Torque required to lower load W

\[ T_{la}(d_i) = \frac{W(d_i) \cdot d_m}{2} \frac{f \cdot \pi \cdot d_m - L \cdot \cos(\alpha_n)}{\pi \cdot d_m \cdot \cos(\alpha_n) + f \cdot L} + \frac{W(A)}{2} \cdot f_s \cdot d_c \]

For the Acme thread, \( \cos(\alpha_n) \) 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

\[ T_{ra}(d_i) = \frac{W(d_i) \cdot d_m}{2} \frac{f \cdot \pi \cdot d_m + L}{\pi \cdot d_m - f \cdot L} \]

Torque required to lower load W

\[ T_{la}(d_i) = \frac{W(d_i) \cdot d_m}{2} \frac{f \cdot \pi \cdot d_m - L}{\pi \cdot d_m + f \cdot L} + \frac{W(A)}{2} \cdot f_s \cdot d_c \]

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
- \( f_s \) = 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 lead screw selected from catalog (NEMA 17)

\[ L = 8 \text{ mm} \]
\[ d_m = 0.25 \text{ in} \]
\[ f = 0.2 \]
\[ f_s = 0.2 \]
\[ d_c = L + 0.5 \text{ in} \]
\[ \alpha_n = 14.5 \text{ deg} \]

Assumed coefficient of friction from steel to cast iron interface

Hypothetical collar

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

\[ SL(4 \text{ mm}) = 0.301 \]

Friction Coefficient [t] for Threaded Pairs

<table>
<thead>
<tr>
<th>Screw Material</th>
<th>Nut Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>Steel</td>
</tr>
<tr>
<td>Steel, dry</td>
<td>Steel</td>
</tr>
<tr>
<td>Steel machine oil</td>
<td>Steel</td>
</tr>
<tr>
<td>Bronze</td>
<td>Bronze</td>
</tr>
<tr>
<td>Brass</td>
<td>Brass</td>
</tr>
<tr>
<td>Cast Iron</td>
<td>Cast Iron</td>
</tr>
</tbody>
</table>

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

- Get ROV fully operational
- Prototype WiFi setup
- Test ROV in pool
- MDR Presentation
- Build complete WiFi setup
- Develop design of boat
- Develop design of ballast
- Build boat
- Build ballast
- Develop stabilization program
- Implement additional sensors
- Test ROV in lake
- CDR Presentation
- Complete stabilization software
- Final test in lake
- FPR Presentation
## Cost of Materials

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
<th>Shipping Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>BeagleBone</td>
<td>56.61</td>
<td>0</td>
</tr>
<tr>
<td>WiFi Module</td>
<td>19.95</td>
<td>8.59</td>
</tr>
<tr>
<td>Syringes (4)</td>
<td>2.12</td>
<td>10</td>
</tr>
<tr>
<td>Acrylic Cement</td>
<td>11.81</td>
<td>0</td>
</tr>
<tr>
<td>Cement Applicator</td>
<td>5.75</td>
<td>0</td>
</tr>
<tr>
<td>Styrofoam/Epoxy (2)</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>Humidity Sensor</td>
<td>13.79</td>
<td>13.79</td>
</tr>
<tr>
<td>Foam Ring Pool Buoy</td>
<td>25.13</td>
<td>0</td>
</tr>
<tr>
<td>L293DNE IC Chip (5)</td>
<td>17.70</td>
<td>10.00</td>
</tr>
<tr>
<td>Silicon Spray Lubricant</td>
<td>8.62</td>
<td>0</td>
</tr>
<tr>
<td>Adjustable Angle USB</td>
<td>5.99</td>
<td>0</td>
</tr>
<tr>
<td>Battery Pack</td>
<td>15.99</td>
<td>0</td>
</tr>
<tr>
<td>Raspberry Pi Model B</td>
<td>49.99</td>
<td>0</td>
</tr>
<tr>
<td>PCB</td>
<td>80.00</td>
<td>10.00</td>
</tr>
</tbody>
</table>

| Total Cost                    | 390.83|
| Current Budget                | 109.17|