University of New Hampshire

Sea Grant New Hampshire

Buoyless Lobster Trap

Tech 797 2014-2015

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Table of Contents:

I. Abstract 3

II. Introduction 4

III. Design Considerations 5

IV. Design Solution 6

V. Acoustic and Electrical Design 7

a. Acoustics 7
b. Breadboard 8
c. Arduino 10

VI. Mechanical Design 11

a. Release Mechanism 11
b. Waterproofing the Housing 13
c. Other Tasks 15
d. Final Assembly 16

VII. Tests and Results 17

VIII. Future Work 19

IX. Conclusions 20

X. Appendices 21

a. Expense Chart 21
b. Arduino Code 23
c. Filter Calculations 25

I. Abstract:

Though visitors of coastal towns enjoy the sight of colorful buoys floating offshore in the harbor, the lines that span the water column from the buoy to the seafloor can cause entanglement of marine mammals, especially whales. Equally harmful are free-floating lines, torn from buoys and traps by marine traffic and harsh storms, wrapping up marine life and leading to injury and possible death. Removing buoys and vertical lines from the water column will prevent the unnecessary endangerment of marine mammals while clearing the way for marine traffic and end the litter of lost buoys and lines.

This proof-of-concept solution drags the buoy and line down to the seafloor with the lobster traps and releases the buoy once the device receives a specific acoustic signal from a boat on the ocean surface. Though the device is housed within a lobster trap, it does not catch any lobsters. The lobster trap is used so that it can easily be attached to a trawl, or line of lobster traps. This means all the fishing equipment sits on the sea floor leaving no vertical lines or buoys free in the ocean until retrieval. This will protect most gear from being lost due to damage from storms and marine traffic and leave a clear water column for marine mammals.

II. Introduction:

In the modern day fishing industry, buoys are used for a wide array of applications including: moorings, lobster traps, and collecting ocean data. Although buoys are widely used in the fishing industry, few are aware of the hazards and harms these present to the many marine mammals that swim in the waters surrounding them. A buoy is anchored to the seafloor by a chain or rope. This helps prevent the buoys' position from being changed by factors such as the changing tides or offshore storms. In areas that are densely populated by buoys, the larger marine mammals have difficulties navigating through this dense field of ropes and chains. These ropes can ensnare the animals. In attempt to escape, marine mammals tend to tuck their fins and roll, trapping them further. Trapped marine life cannot find food effectively, so in most cases, entanglement can ultimately lead to the death of the animal due to starvation. The removal of these hazardous lines and associated buoys can help prevent the accidental death of these marine mammals.

There are more benefits to removing buoys and lines from the water. Without the constant presence of buoys on the ocean surface, gear cannot be lost due to a propeller cutting a buoy free from its gear. A harsh storm cannot tear a buoy from its gear. Reducing the loss of gear also works to prevent the litter of broken or lost traps, rope, and buoys. By removing buoys from the ocean's surface, navigation becomes easier for marine traffic. Boaters would not need to worry about catching buoys, untwisting the rope from their propellers, or cutting the gear free.

The removal of buoys and their lines can proactively save marine mammals from unnecessary deaths, prevent the loss of gear, stop a source of litter, and simplify marine traffic.

III. Design Considerations:

Given the problem at hand, several design objectives were established:

- Lines spanning the water column must be removed.

The main objective of this project is removing the lines from the water. The removal of lines opens the waters for easy travel for marine mammals and prevents entanglement.

- Gear must be able to be retrieved from the seafloor.

Though we want to remove them from the water, the need for buoys still exists. The solution must serve this one purpose of a buoy: to allow for the retrieval of gear from the sea floor.

- Design must minimize number of moving parts to prevent failure.

Since the solution operates in the water, it must account for the suspended debris, particulates, and organisms in seawater. The solution could fail due to the lodging of debris in a moving part. For example, sand could cause a rotating joint to jam and therefore no longer operate accordingly. Failure underwater could mean the loss of gear. For this reason, the solution should limit the number of moving parts exposed to the seawater.

In addition to these design objectives, this project focuses specifically on the recreational lobster fishing applications. This adds more design objectives:

- Design must focus on low cost.

If the solution is directed towards lobster fishermen, then it must not be expensive. Lobstermen tend to be on a limited budget and, since the goal is to convince them to purchase something that replaces a simple and uncomplicated system they have always used, this cannot be a large expense.

- Design should be easily integrated into lobster trawls.

Again, since the target audience is lobstermen, the solution cannot significantly change their fishing process. A lobsterman sets out a trawl, or set of lobster traps connected in series. The solution should not require a change to this method.

- Design shouldn’t significantly increase workload on fisherman.

Along the same lines of the last point, the solution cannot add significantly to the workload of the lobsterman. This solution will already likely be a tough sell to the target demographic, so it is important to minimize any negative factors of implementing the solution.

IV. Design Solution:

The solution devised to meet these criteria was to create a device that would be housed within a gutted-out lobster trap. Using the cage of a lobster trap would allow the device to be easily added on to the end of the lobsterman's trawl and to be stacked and thrown into the water the same way any normal lobster trap would be.

A buoy was attached to the top of the trap. The coils of rope that connect the buoy to the trap were contained in a burlap sack in one half of the trap. While the use of a buoy sounds as though it does not meet the main objective, this buoy would sit with the trawl on the seafloor until it is released to ascend to the surface. This means there are merely minutes in which the buoy and its line freely float in the water, opposed to many days. If this design were commonly used, the chance that a few buoys are free in the water at the same time is slim, let alone the multitude that are dangerous to marine mammals.

The buoy will be released when the device is activated using an acoustic signal sent from the lobsterman's ship. The device will listen for three signal attributes: the signal must be the correct frequency to distinguish it from ambient ocean noise, the signal must have the proper amplitude to determine that the fisherman sending the signal is within an appropriate range, and the signal must meet the previous two criteria for a certain period of time to ensure that the conditions aren't met by chance alone.

Upon meeting these conditions, the device will release the buoy, allowing it to rise under the power of its own buoyant force. The buoy will drag rope that connects the buoy and the trap to the surface. The buoy is then retrieved by the lobsterman using the traditional methods. With the buoy, the rest of the trawl is hauled up from the seafloor.

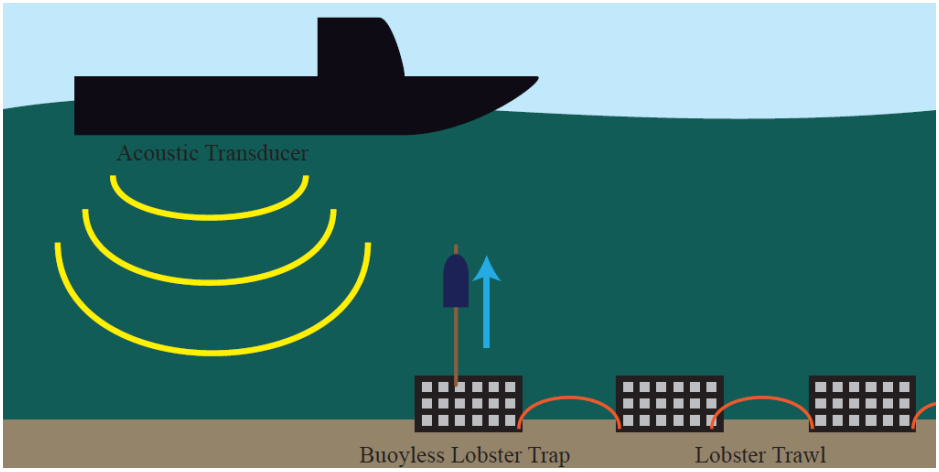

Figure 1: Buoyless Lobster Trap concept.

V. Acoustic and Electronic Design:

Acoustics

A 1 kHz signal was chosen after consulting Wentz curves of ocean ambient noise and considering the distance the signal would need to travel. The signal also has to be a frequency that is not too close to the sampling rate of the microcontroller, the Arduino Uno. Since the Arduino can only sample through its analog pin at 10 kHz without modification, this put an upper limit on the signal frequency that could be used confidently. Since this was a proof-of-concept design, the 1 kHz was chosen for its ease of use between the 5 kHz Nyquist frequency upper limit and lower frequencies where ambient noise is stronger.

Figure 2: Aquarian H1c Omnidirectional Hydrophone

The acoustic signal is received by the device using a hydrophone. A hydrophone is a piezoelectric device that converts acoustics into voltages. The hydrophone used in this design was an Aquarian H1c omnidirectional hydrophone, which work for frequencies between 1 Hz and 100 kHz and operate at a depth of up to 80 m.

Breadboard

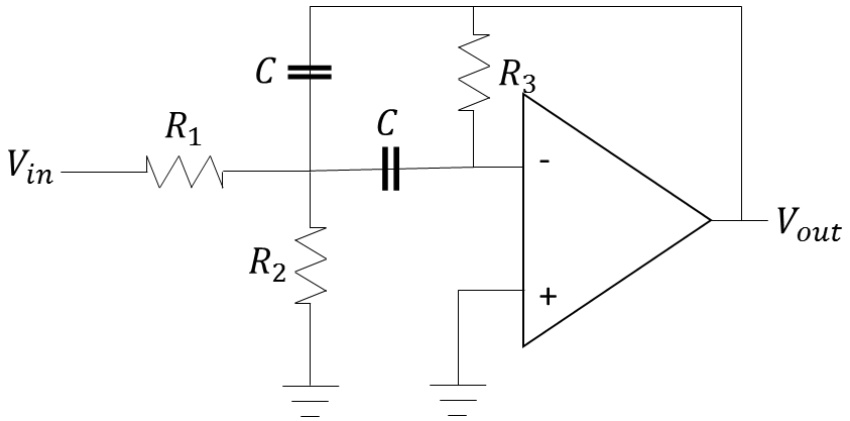

Figure 3: Schematic of Deliyannis-Friend Filter

A second order bandpass filter was created to diminish any ambient noise frequencies and to amplify 1 kHz frequency signals. A second-order bandpass filter was desired due to its narrow bandwidth. Ultimately, a Deliyannis-Friend filter was built using a μA741 operational amplifier and several resistors and capacitors. The filter was designed with three resistors (R_1 = 10 kΩ, R_2 = 250 Ω, and R_3 = 100 kΩ) and two capacitors (both with capacitance C = 0.03 μF). The op amps are powered by a battery pack of 8 AA batteries in series, giving 12 volts.

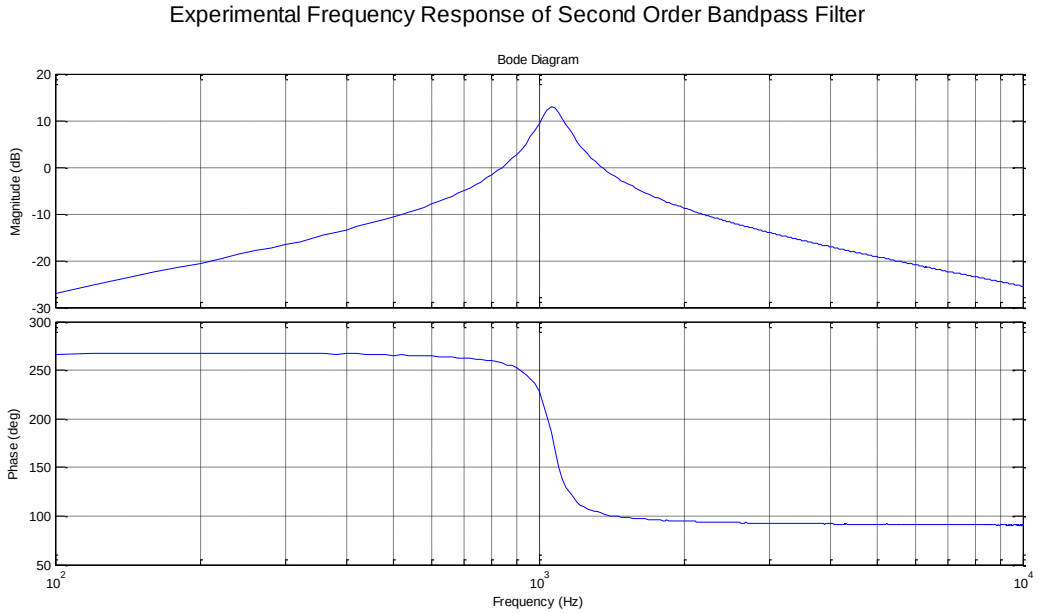

Figure 4: Experimental Frequency Response of Deliyannis-Friend Filter

The experimental frequency response, created by sending a broadband signal through the filter using LabView, of the filter gives the peak at approximately 14 dB, which converts to a gain of about 5. The band is 100 Hz centered at 1.0 kHz.

In order to read this signal using the Arduino Uno's 'Analog In' pin, which only accepts 0-5 volts, the signal cannot have negative voltages. This filtered signal is offset by 3 volts using a series of op amps. This ensures that this signal always has positive voltages.

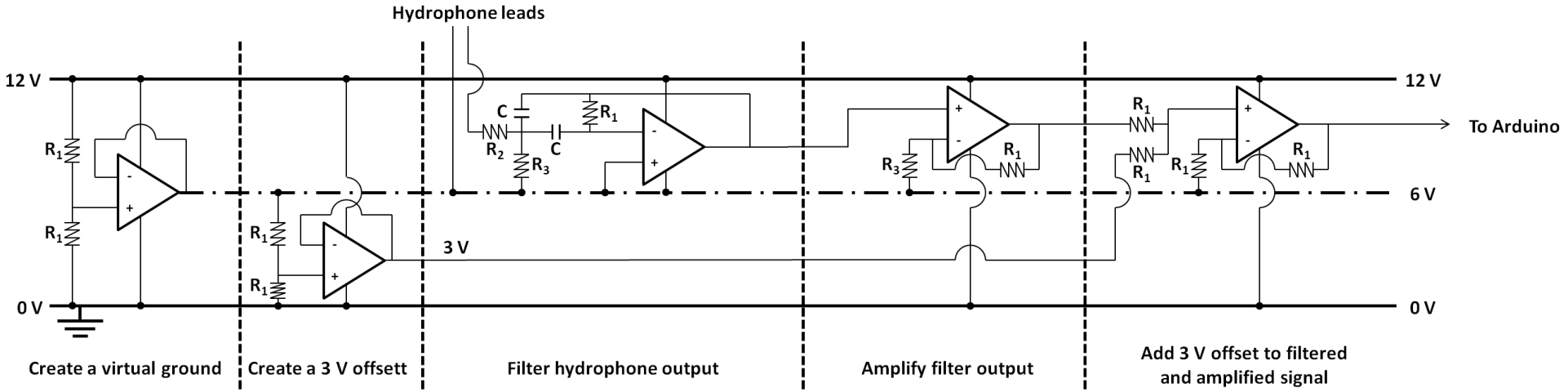

Figure 5: Schematic of breadboard circuitry and objectives (R_1 = 100 kΩ, R_2 = 10 kΩ, R_3 =250 Ω, and C = 0.03 μF).

Arduino

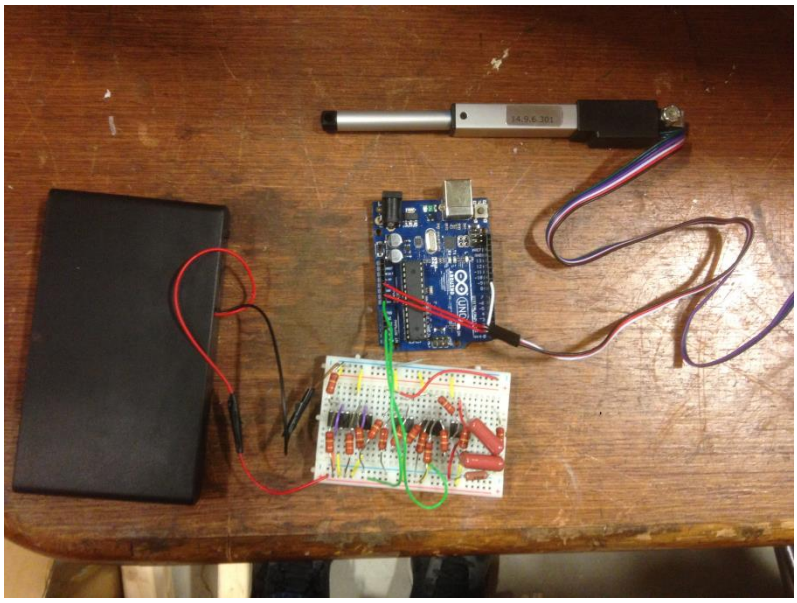

Figure 6: Battery Pack, Breadboard, Arduino Uno, and Firgelli Linear Actuator

This offset signal is read using an Arduino Uno microcontroller. Over 10 ms periods, the Arduino calculates the offset, subtracts it from the voltages it reads, and sums these voltages. After this period, the voltage sum is divided by the number of readings the Arduino took during the 10 ms period second and the square root is taken. This calculates the root-mean-squared voltage of the incoming wave.

Since the magnitude will be largest when the frequency is 1 kHz, a voltage threshold was determined experimentally for a limit of when the 1 kHz signal is present. The Arduino compares the calculated root-mean-square voltage to the threshold. If the calculated voltage is larger than the threshold, a count is started. Each consecutive instance that the calculated voltage is higher than the threshold, the count is increased by one. If the voltage is smaller, then the count is reset. Once the count reaches 50, the Arduino instructs the Firgelli Mini Linear Actuator to retract, wait, and then return to the original position. This releases the buoy and resets the count.

In simple terms, the Arduino determines if the input voltage amplitude is greater than an experimentally determined value constantly for 500 ms. If so, the Arduino retracts the actuator and thereby the pin, waits, then returns them to their original position.

VI. Mechanical Design:

Release Mechanism

The release mechanism needed to be rugged and include the fewest amount of moving part due to the fact that most of the parts are open to the harsh sea water. The retrieval buoy is an important part to the success of having this device work. It needed to be able to hook on to the device securely but also be easily released when needed. For the design of this part, the assembly included a lobster buoy, a PVC pipe and a metal anchor shackle. The lobster buoy slide onto the PVC piping and secured with a bolt and a nut to ensure that the buoy would not slide off. On the opposite side of the pipe from the buoy, a hole was drilled to allow the anchor shackle to be mounted to the pole. The shackle would be fastened to the trap with a locking pin that would allow it to be released once the correct signal was received from the fishing vessel. Mid way up the PVC pipe, a hole was drilled that allows a neutrally buoyant line to be attached which connected the buoy to the trap. This allows the fishing vessel to pull up the trap once the buoy reaches the surface.

Figure 7: Retrieval buoy with PVC pipe, anchor shackle and retrieval line to pull up trap.

The release mechanism allows the buoy to be secured to the trap for the entire soaking period of the trawl but will release the buoy once the correct signal is received. This release mechanism involves a pin that goes through the anchor shackle of the buoy pole locking it to the trap. This pin is covered with a rubber covering that is clamped to the electronics housing that ensures that no water can enter into the housing. This pin fills the space inside the rubber covering where it holds down the buoy. When the correct signal is received, the release mechanism is triggered where the pin is pulled into the housing leaving the rubber covering empty. Due to the pin leaving the rubber covering, the buoyant force of the buoy will cause the rubber covering to deform allowing the buoy to escape the release mechanism and ascend to the surface. Also incorporated into this section of the release mechanism is a metal channel that

ensures the buoy doesn't slip off the pin and rubber covering. This channel wraps around the pin allowing the rubber covering to only deform in one direction which is up allowing the buoy to ascend. Otherwise this channel covers all areas around the pin securing the shackle onto the pin.

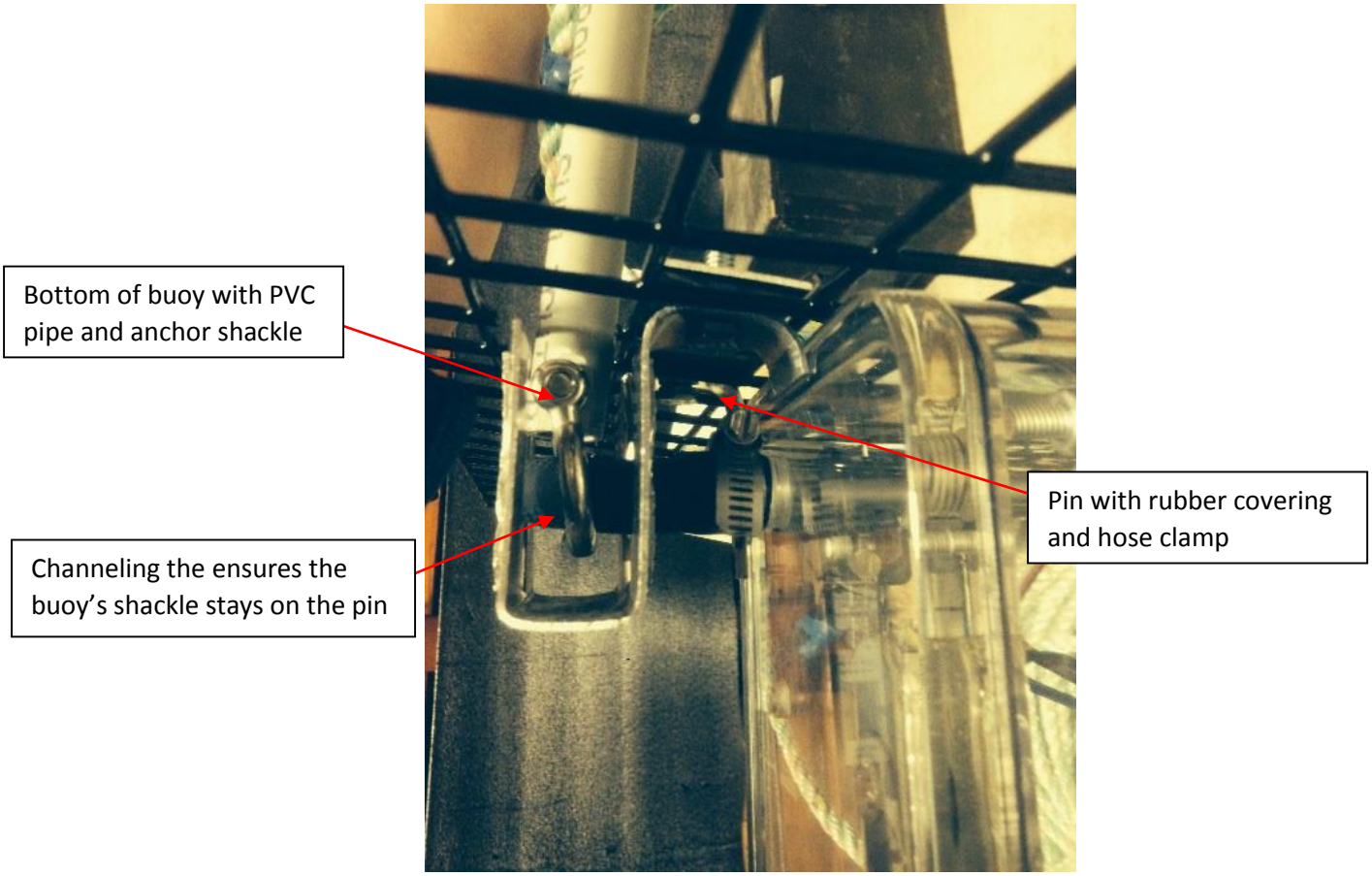

Figure 8: Picture of the release mechanism outside of the electronics' housing. It includes the bottom of buoy with shackle, pin with rubber covering, and channel.

Waterproofing the Housing

Figure 9: Hydrophone with brass fitting screwed into the lid of housing.

Since this device operates submerged in seawater, the electronics must be sealed in a waterproof container. This housing needed to be watertight at various depths so that this device could be placed anywhere without any concerns of water leaking in. The waterproof housing consisted of an Ikelite housing made of a clear acrylic. The clear acrylic was helpful for the proof-of-concept design to easily debug wires and other components inside. It also enabled for a visual inspection of the batteries and actuator. With this housing, there were two modifications needed to create the device that was desired. Two holes needed to be drilled: one to let the actuator/pin to slide through the housing's lid and one for the hydrophone port which allowed a cord to pass through the lid as well.

Figure 10: (left) pin in release position; (middle) pin in locking position; (right) pin with cover.

The hydrophone port was plugged using a brass fitting with pipe threads that had the hydrophone's cord epoxied into it. It could be tightly screwed with plumber's tape into the lid of the housing allowing for a water tight seal. The actuator/pin port was more difficult to solve due to the moving parts that needed to remain water tight. The solution involved a rubber covering (rubber finger from a glove), a brass fitting, and a hose clamp. The brass fitting was half threaded, half smooth piping. This allowed it to tightly screw into the housing with the pipe threads and the smooth end would allow the rubber cover to tightly slip over it and be clamped on with the hose clamp to ensure a water tight seal. This brass fitting also had a hole through the center allowing the pin connected to the actuator to slide in and out of the rubber covering so it could lock/release the buoy.

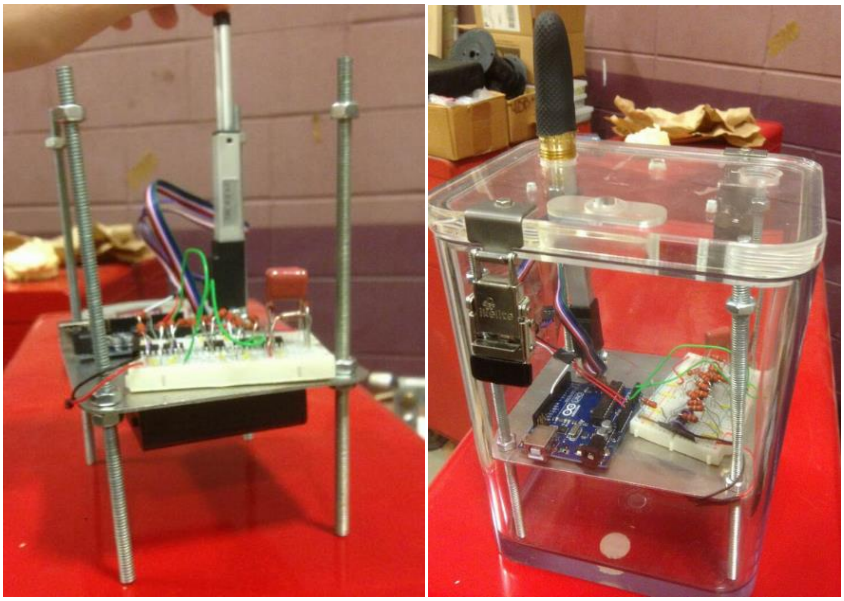

Figure 11: Skeleton with Arduino, breadboard, actuator, and battery pack outside (left) and inside the electronics housing (right).

A skeleton was designed to hold all the electronics to run the device as needed. A platform was made to hold everything which held the battery case on the bottom, and the filter, Arduino, and actuator on top. It is supported inside the housing by four threaded rods allowing it to set at the correct level for the actuator to run. This skeleton is meant for easy extraction of the insides to debug, change batteries, or recode the Arduino. This helps to clean up the device and ensure a working mechanical performance from everything. This incorporates everything of the mechanical device that is needed which deals with constraints of the lowest amount of moving parts and keeping it simple.

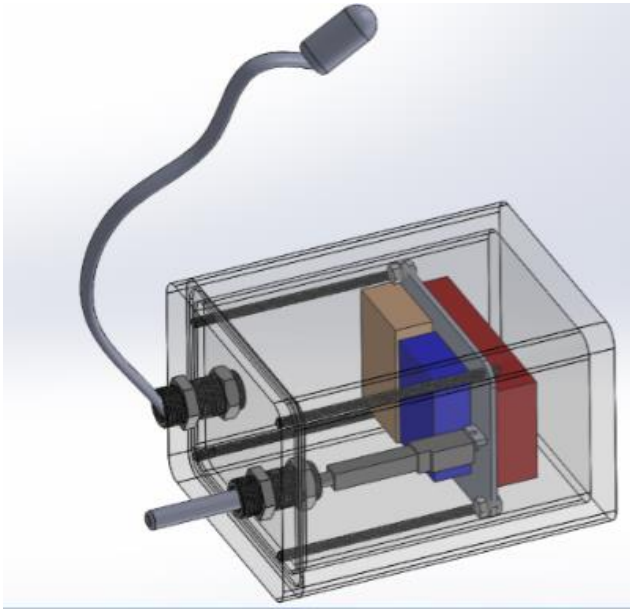

Figure 12: SolidWorks drawing for the housing. It also includes the skeleton on the inside holding electronics

Other Tasks

Once the buoy is released from the device, it drags up neutrally buoyant line that attaches the buoy to the trap. The range of line can vary for every fisherman (20ft. to 250ft.). Inside this trap, there is a burlap sack that holds all the coiled line neatly inside the trap allowing for easy release of the line as the buoy ascends. The line is left in a coiled fashion because it doesn't let the line to get tangled or snagged if it is left untouched once it is put into the trap. Also, many fishermen tend to coil their line in barrels because it is a fast method that allows them to keep moving and not have to worry about correctly reeling in the line. Though putting the coils on their own in the trap seems like the least elegant option, other ideas, such as spooling the line, simply add more resistance to the buoy and add more places for the line to catch. Therefore, the line is left in the burlap sack allowing it to be snag free with no worry of it getting caught. Also added to the cage is a PVC fitting that acts as a snag-free feeding port. It is shaped like a funnel on the inside of the trap to keep the line feeding through the center of the burlap sack for quick and easy feeding of line for the buoy. A final modification to the trap was the addition of bricks to the inside of the trap. The bricks help to overcome the buoyancy of the buoy and housing, letting the trap sink to the seafloor.

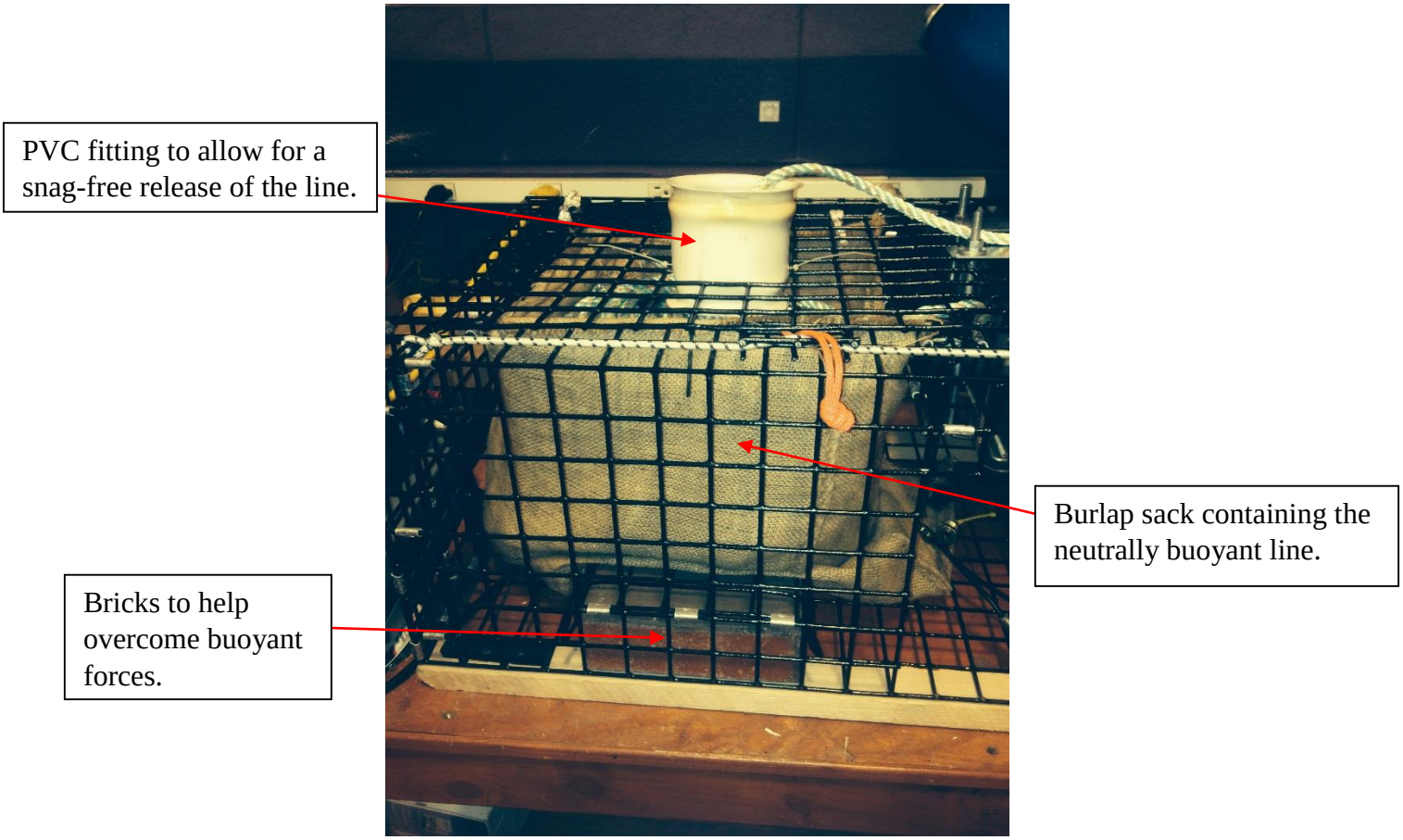

Figure 13: Half of the trap that contains the retrieval components.

Final Assembly

Figure 14: The completed trap design

After all the modifications were made and designs completed, the final assembly could be put together. Square U-bolts were used to fasten the housing onto the inside of the trap along with the channel and the hydrophone. This makes personalizing a fisherman's trap easy and useful. Not all traps are the same size and usually range from 3 ft. to 5 ft. This allows the release system to not be specific to one sized trap and can be mounted to many. Also it enables some to reuse the system if the trap becomes damaged or old. In the end, the BLT became a durable, easily accessible, and strong system that allows the buoy to be pulled to the seafloor and acoustically released while protecting animals, traps and cleaning up the ocean's surface.

VII. Test and Results

During the process of building the 'Buoyless' Lobster Trap, some tests had to be performed to ensure that everything that was being made worked correctly. All tests were performed in UNH's Chase Ocean Engineering Lab in the wave tank or in Kingsbury's J-lab room. The first test that was done was testing the design the electrical system. Here, the bandpass filter was designed and built and the Arduino was coded. They were then connected together along with the actuator. Two function generators were used to combine a signal to be sent into the electrical system. The signals sent in ranged anywhere from 10 Hz to 50 kHz. This is a big range to test a lot of frequencies to see if the filter did its job of minimizing all frequencies outside the band. In addition, a 1 kHz frequency and a random frequency were sent in to see if the filter could find the 1 kHz signal through the noise (the random signal). This was to simulate the signal sent by a fisherman and ambient noise. The filter was able to distinguish the 1 kHz signal, as observed on an oscilloscope. Arduino counted for the appropriate duration and triggered the actuator.

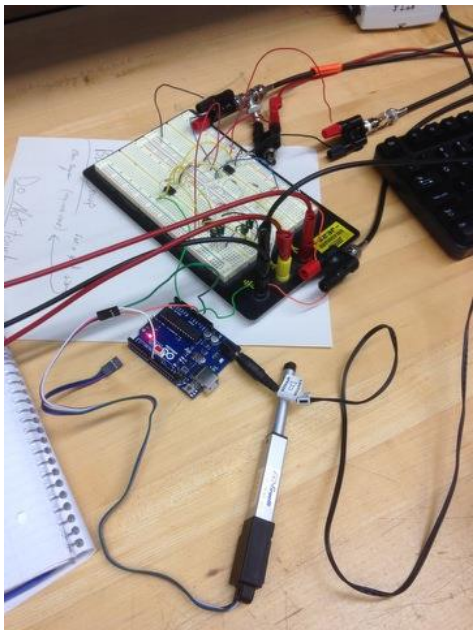

Figure 15: Electronics testing in Kingsbury.

For the next test in Chase Ocean Labs wave tank, the electronics were connected to the hydrophone. Two hydrophones were used in this test, each having a different purpose. One was attached to the electronics as the receiving hydrophone that would read the signal to be read by the electronics and trigger the actuator. The other was being driven by a function generator, sending out the acoustic signal that would be read by the receiving hydrophone. The driving hydrophone was meant to mimic the fisherman's boats sending out his signal to retrieve his traps. The hydrophones were placed at different distances that range from 1 inch to about 12 feet (the width of the wave tank). First, the 1 kHz was sent out to test if the hydrophone could see the signal and trigger. This successfully triggered the actuator, showing that the hydrophone communicated with the Arduino in the correct fashion. Next, other frequencies were tested to see if they would trigger the system. The driving frequency started at 500 Hz and slowly increased in 100 Hz increments. The system ignored the signal until the 1 kHz was sent out and

read proving that the filter ignored all outside frequencies. The system also was tested from 1.5 kHz and was decreased to show that it could work from both ways. This also proved successful.

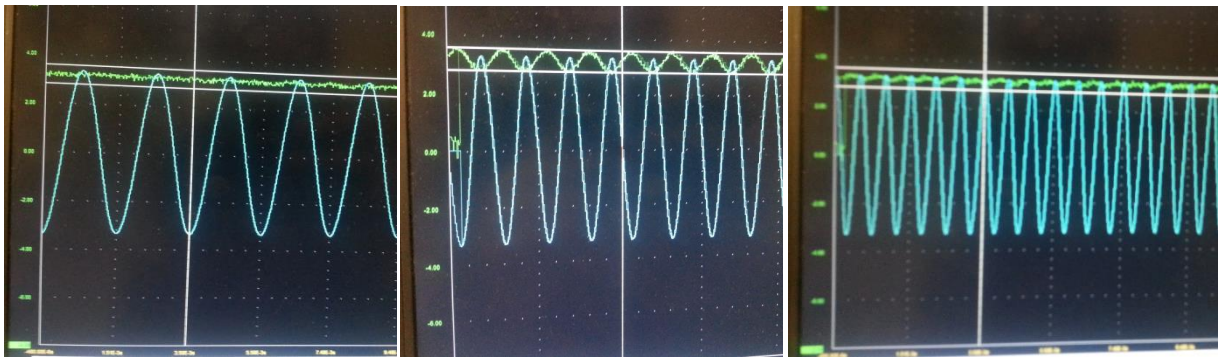

Figure 16: View of oscilloscope showing the driven signa1 (blue) and the signal sent to the Arduino (green). The smaller (left) and larger (right) frequencies result in signal amplitude much smaller than the 1 kHz signal (center) being read through the filter.

The next step was the water proofing test. This test was looking for leaks on all the modification and seals on the housing. This was significant due to the fact that the electronics could not get wet causing the system to fail and the trawl to be irretrievable by the acoustic trigger. The rubber covering was clamped on by the hose clamp and a screw was inserted into the hole where the hydrophone cord would go. The housing was emptied and filled with tissues to show where leaks originate if they occur. The housing was tied to a cinderblock where it then was dropped in the water for soaking. After a few minutes, it was brought up and there happened to be water in the housing. After some analysis, the cause of the leak was the screw that was used in place of the hydrophone cord. This screw happened to be a slightly wrong thread count and caused the leak. After consideration, the cord was epoxied into the brass fitting and screwed onto the lid of the housing for another test. It soaked for 5-10 minutes and came up dry. The test proved successful. It now can be assembled and tested as a whole.

VIII. Future Work

There are many modifications and experiments that can be used to enhance the current design. The trap would be tested at different depths so the design won't lose functionality at different depths. For instance, if the tides changed and became drastically higher than when the design was deployed, this could have adverse effects on the gear if not properly accounted for.

The electronics of the design could be modified to allow for a wider range of acoustic frequencies to be accepted by the release mechanism. This would then lead to the implementation of acoustic key codes which could allow for multiple traps to be deployed in close proximity to one another without all the buoys being released when the acoustic signal is sent by the boat retrieving the gear.

A system could be added that would use a sequence of lights in order to tell the operator how much power remains in the batteries. This would help eliminate the chances of the batteries becoming completely depleted of energy while deployed to the seafloor. However, if the batteries do lose all power while deployed, a fail-safe mechanism could be created that would release the buoy after the battery power dips below a certain threshold that would be prescribed for the design. Also, a button could be added that would override the electronics to open the pin after the trap is retrieved. This would let the lobsterman replace the buoy into the release mechanism easily.

In regards to the actual deployment of the trap into the ocean, stabilizers would need to be designed to allow the trap to remain in the correct orientation during its descent to the seafloor. This would prevent any loss of gear if the trap landed in a manner which wouldn't allow the successful release of the buoy.

A final observation is that the housing used for this proof-of-concept design is convenient for debugging and come to no additional cost to the designers, but wastes a lot of space. This housing could be specifically manufactured for the device, reducing the cost of the housing and reducing the space that the housing takes up in the cage.

IX. Conclusion:

The overall task of developing an acoustically triggered mechanical release worked out very well in regards to proving the conceptual aspect. The system was able to receive an incoming acoustic pulse mimicking the lobsterman's signal and filter out all the ambient noise that would be present in the ocean and that was present in the wave tank. The voltage is then able to be measured by the Arduino to find the RMS voltage. This is then compared to the threshold to be able to turn on the actuator or keep searching for the correct RMS voltage for a specified time.

The success of the BLT in these tests proves that this concept is ready for testing as a complete system. By testing the system entirely assembled, any design flaws could be realized. This is an important step, but a step that is ready to be taken. From this preliminary work on the BLT, it is clear that this solution provides a reliable, low-cost, solution to the buoy problem.

X. Appendices:

Expense Chart:

Name of product	Cost	Quantity	Supplied from previous projects	Component used for
BBD Wire Kit	6.99	1		Electronics
AA Battery Holder	6.81	1		Electronics
24 Duracell AA batteries	10.69	1		Electronics
Solderless Breadboard	5.36	1		Electronics
140 Jumper cable wires	5.02	1		Electronics
10xUA741 op amps	7.39	1		Electronics
0.03 uF capacitors	0.86	4		Electronics
Arduino Uno	14.46	1		Electronics
100kOhm resistors	0.10	21		Electronics
10kOhm resistors	0.10	2		Electronics
250kOhm resistors	0.46	2		Electronics
Aquarian H1c Hydrophone	(129.00)	2	Previous Project	Electronics
Trossen Robotics L12 50mm 210:1 Linear Actuator	90.00 +7.99(shipping)	1		Release Mechanism
Linear Solenoid	29.43	2		Release Mechanism
Hose clamp	0.98	1		Release Mechanism
¼ “ rod	Donated	1		Release Mechanism
1’x1’ aluminum sheet metal	Donated	1		Release Mechanism/ housing
¼”x 20 x 1” bolts	Donated	2		Release Mechanism

Pex plastic plug	1.29	4		Housing
¼” hex nut	0.06	16		Housing/Release Mechanism
Grease Monkey Long Cuff Neoprene gloves	3.07	1		Housing
Loctite Plastic Epoxy	5.47	1		Housing
½ x 1” Brass Pipe Nipple	4.47	1		Housing
36” ¼ x20 threaded Rod	1.97	1		Housing
½ x2” Brass Pipe Nipple	5.52	1		Housing
½ x 1/8 Brass Hex Bushing	3.64	1		Housing
U-bolts	Donated	2		Housing
U-bolt nuts	Donated	4		Housing

Buoy	Donated	1		Buoy
5/16” SS Anchor Shackle	4.70	1		Buoy
Blue Paint	3.48	1		Buoy
Neutrally Buoy Line	(14.13)	1	Previous Project	Buoy
PVC piping	Donated	1		Buoy

Burlap Sack		1	Previous Project	Trap
Lobster Trap	(38.95)	1	Previous Project	Trap
Bricks		2	Previous Project	Trap

Total expense (2014-2015)	259.65			
Total cost for project	570.73			

Arduino Code:

```
int analogPin = 3;     // potentiometer wiper (middle terminal) connected to analog pin 3
                       // outside leads to ground and +5V
double val = 0;           // variable to store the value read
int led = 13;

double thresh = 0.11;
int count = 0;

#include <Servo.h>
#define LINEAR210PIN 9        //Linear Actuator Digital Pin
#define LINEAR210_MIN      1050  //
#define LINEAR210_MAX      2000 //

Servo LINEAR210;  // create servo objects to control the linear actuators
int linear210Value = 1500;   //current positional value being sent to the linear actuator.

int speed = 10;

void setup()
{
 Serial.begin(9600);
 //initialize servos
  LINEAR210.attach(LINEAR210PIN, LINEAR210_MIN, LINEAR210_MAX);      // attaches/activates the linear actuator as a
servo object

//use the writeMicroseconds to set the linear actuators to their default positions
  LINEAR210.writeMicroseconds(linear210Value);

     linear210Value = map(0, 0, 1023, LINEAR210_MAX, LINEAR210_MIN); //Map analog value from the sensor to the linear
actuator
   //use the writeMicroseconds to set the servos to their new positions
 LINEAR210.writeMicroseconds(linear210Value);
   delay(10000);

   // initialize the digital pin as an output.
   pinMode(led, OUTPUT);
}

// the loop routine runs over and over again forever:
void loop() {

// find offset
int i = 0;
double voltsum = 0;
int t=millis();
int f=millis();
while (abs(t - f) < 1)
  {
    voltsum = voltsum + analogRead(analogPin)*5.00/1023.00;    // read the input pin
    i = i+1;
    t=millis();
  }
  double voltoff = voltsum/i;

  // calc rms voltage
  i = 0;
  double voltsq = 0;
  t=millis();
  f=millis();
  while (abs(t - f) < 10)
```

```
 {
   voltsq = voltsq + sq(analogRead(analogPin)*5.00/1023.00-voltoff);    // read the input pin and subtract offset
   i = i+1;
   t=millis();
 }

double Vrms = sqrt(voltsq/i);


 if (Vrms >= thresh){
  count = count + 1 ;
 }
 else{
 count = 0;
 }

 if(count >= 50){
  digitalWrite(led, HIGH);   // turn the LED on (HIGH is the voltage level)
  delay(1500);               // wait for a second
  digitalWrite(led, LOW);    // turn the LED off by making the voltage LOW

     linear210Value = map(1023, 0, 1023, LINEAR210_MAX, LINEAR210_MIN); //Map analog value from the sensor to the
linear actuator
   //use the writeMicroseconds to set the servos to their new positions
 LINEAR210.writeMicroseconds(linear210Value);
  delay(10000);
  linear210Value = map(0, 0, 1023, LINEAR210_MAX, LINEAR210_MIN); //Map analog value from the sensor to the linear
actuator
   //use the writeMicroseconds to set the servos to their new positions
 LINEAR210.writeMicroseconds(linear210Value);
  delay(20000);
  count = 0;
 }

 Serial.println(Vrms);
 //Serial.println(analogRead(analogPin)*5.00/1023.00-2.52);
 delay(10);

}
```

Calculations/Derivations:

Filter Analysis:

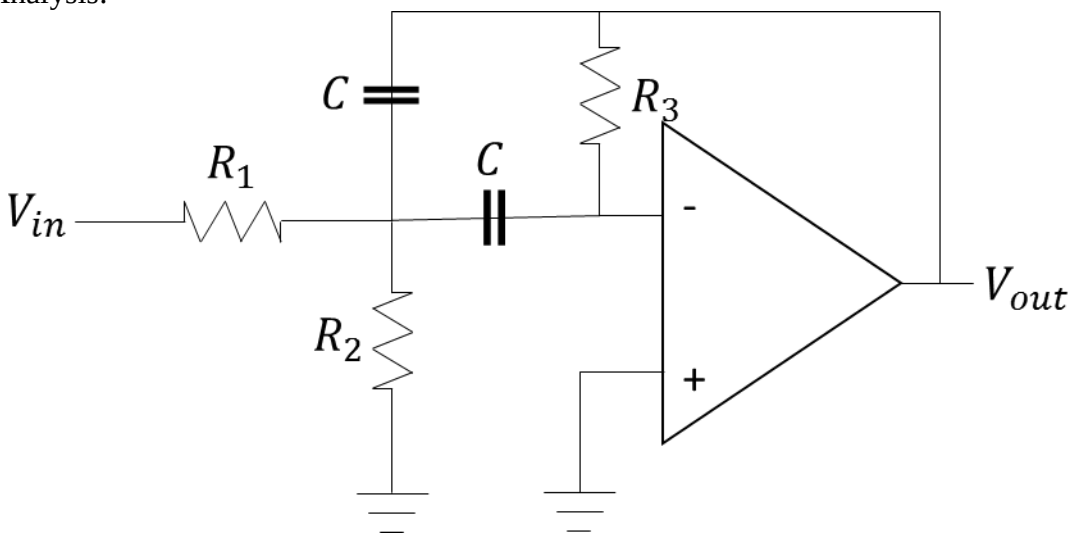

Figure 17: Schematic of Deliyannis-Friend Filter

Node law is performed at Nodes *A* and V_N:

Node A $$C\frac{d}{dt}(V_N - 0) + \frac{V_{out}-0}{R_3} = 0 \quad [1]$$

Node V_N $$\frac{V_N - V_{in}}{R_1} + C\frac{d}{dt}(V_N - V_{out}) + \frac{V_N - 0}{R_2} + C\frac{d}{dt}(V_N - 0) = 0 \quad [2]$$

Solving for V_N in each of the above equations gives:

$$V_N = -\frac{1}{R_3 Cs}V_{out}$$

$$V_N = \frac{CsV_{out} + \frac{1}{R_1}V_{in}}{\frac{1}{R_1} + \frac{1}{R_2} + 2Cs}$$

Combining these gives:

$$-\left(CsV_{out} + \frac{1}{R_1}V_{in}\right)\left(\frac{R_1R_2R_3C^2s^2}{R_1 + R_2 + 2R_1R_2Cs}\right) = V_{out}$$

Separating V_{in} and V_{out}:

$$-\frac{R_2R_3Cs}{R_1 + R_2 + 2R_1R_2Cs}V_{in} = \left(1 + \frac{R_1R_2R_3C^2s^2}{R_1 + R_2 + 2R_1R_2Cs}\right)V_{out}$$

Solving for the transfer function:

$$\frac{V_{out}}{V_{in}} = -\frac{R_2R_3Cs}{R_1+R_2+2R_1R_2Cs+R_1R_2R_3C^2s^2} = -\frac{\frac{1}{R_1C}s}{s^2+\frac{2}{R_3C}s+\frac{R_1+R_2}{R_1R_2R_3C^2}} \quad [3]$$

From the transfer function, the break frequency and damping ratio can be obtained:

$$\omega_b = \sqrt{\frac{R_1+R_2}{R_1R_2R_3C^2}} * \frac{1}{2\pi} \quad (in\ Hz) \quad [4]$$

$$\zeta = \sqrt{\frac{R_1R_2}{(R_1+R_2)R_3}} \quad [5]$$

Using the transfer function, its properties, a set of equations could be obtained to determine resistance and capacitor values. The *Q* factor is a term that describes the slope of the filter and *B* is the bandwidth of the filter:

$$H_o = \frac{K}{2\omega_b\zeta} = \frac{\frac{1}{R_1C}}{\frac{2}{R_3C}} = \frac{R_3}{2R_1} \quad [6]$$

$$Q = \frac{1}{2\zeta} = \frac{\omega_b}{B} = \frac{1}{2}\sqrt{\frac{R_3(R_1+R_2)}{R_1R_2}} \quad [7]$$

$$B = \frac{\omega_b}{Q} = \frac{\frac{1}{2\pi C}\sqrt{\frac{(R_1+R_2)}{R_1R_2R_3}}}{\frac{1}{2}\sqrt{\frac{R_3(R_1+R_2)}{R_1R_2}}} = \frac{1}{\pi CR_3} \quad [8]$$

An equation for the second resistor is found by solving the *Q* equation for R_2.

$$4Q^2 = \frac{R_3(R_1+R_2)}{R_1R_2} = \frac{2H_o}{R_2}(R_1+R_2) = 2H_o\frac{R_1}{R_2} + 2H_o$$

$$4Q^2 - 2H_o = \frac{R_3}{R_2}$$

$$R_2 = \frac{R_3}{4Q^2-2H_o} \quad [9]$$

By setting the gain to 5, the bandwidth to 100 Hz, the break frequency to 1 kHz, and the first resistor value R_1 to 10 kΩ, the remaining resistor and capacitor values can be found:

$$H_o = 5, B = 100, \omega_b = 1000\ Hz, R_1 = 10\ k\Omega$$

$$Q = \frac{\omega_b}{B} = \frac{1000\ Hz}{100\ Hz} = 10 \quad [10]$$

$$R_3 = 2H_oR_1 = 2(5)(10\ k\Omega) = 100\ k\Omega \quad [11]$$

$$R_2 = \frac{R_3}{4Q^2-2H_o} = \frac{100\ k\Omega}{4(10)^2-2(5)} = 256.4\ \Omega \approx 250\ \Omega \quad [12]$$

$$C = \frac{1}{\pi BR_3} = \frac{1}{\pi(100)(100000)} = 3.183 * 10^{-8} \approx 0.03\ \mu F \quad [13]$$