Lobster Resurfacing Oceanic Locator

A Major Qualifying Project
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Abstract

In recent years, the North Atlantic Right Whale population has been decreasing dramatically. This decrease in population is in part due to whale entanglement from static buoy lines from lobster traps. In response to this, many fishermen and environmentalists are calling for the removal of vertical lines in the water column. This threatens the lobster fishing industry due to the methods in which they fish. This project aimed to create a system that would eliminate the need for a static buoy line while preserving traditional lobster fishing methods. This was accomplished using a magnetic release mechanism paired with a programmable timed release system. This would allow for lobstermen to preserve the use of their current equipment while drastically reducing the time that static buoy lines are present in the water column. Deliverables included the physical device and a mobile app for ease of use.

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1. Introduction

The New England lobster fishing industry is steeped in tradition and a top economic contributor along the east coast. In 2021 alone, the lobster industry caught and sold $725 million worth of fresh lobsters [1]. Lobstermen typically make use of wire traps that are connected to long ropes attached to marker buoys that float along the surface of the ocean. While this method is effective, and has been working for over a century, these lobster traps pose a significant threat to oceanic wildlife. The main problem lies with the use of long buoy lines, as they remain static for three to seven days at a time while the traps sit collecting lobsters [2]. North Atlantic Right Whales can easily get entangled in these lines, causing deep injuries and forcing the whales to drag heavy fishing gear. These whales are nearing extinction, and entanglement is the leading cause of their death [3]. Over 85% of North Atlantic Right Whales have become entangled at some point, and with around 100 breeding female whales left [4], the need for a solution is more dire than ever.

Regulations have attempted to reduce Right Whale mortality by restricting where and when lobstermen can operate, and forcing them to use breakable components in their buoy lines [5]. These restrictions put a major financial strain on lobstermen as these breakable components typically do not come cheap. They are also not a total solution to the problem: whales can still get entangled during the seasons where lobster fishing is permitted, and can still be seriously injured even with breakable links.

Thus, there is a need for a system which allows lobstermen to legally fish in areas with North Atlantic Right Whale activity without posing a threat to the whales. The system needs to be affordable to lobstermen, and it is critical that it be reliable and robust to prevent lost gear.

The goal of this project is to produce marketable ropeless lobster trap technology that significantly decreases the amount of time a static buoy line is in place. This piece of technology will include a self-contained mechanism that releases the buoy line after a certain period of time that can be determined by the lobstermen. The buoy line at other times will remain coiled in a bag near the trap with a timer that is connected to the lobster trap, making it so the buoy line is only engaged when the traps are ready to be pulled. This mechanism will meet the specifications later detailed in this report.

2. Background

In this chapter, we begin with an overview of current lobster fishing techniques and the threats they pose to marine life. The ropes connecting lobster traps to their buoys are especially dangerous for the North Atlantic Right Whale, which are especially susceptible to entanglement and are critically endangered. We investigated how fishing gear entanglement has impacted whale mortality, and regulations that are currently in place to protect these whales. A number of companies are working to develop “ropeless” systems which would reduce risk of entanglement. Organizations such as the Ropeless Consortium are leading the charge on the effort to change regulations to allow these ropeless systems. Even as regulations change, nearly all existing ropeless systems remain too expensive to be viable for the typical lobsterman.

2.1. Issues with Traditional Lobster Traps

Traditional lobster traps, where a trap is set with a buoy line connecting the trap to a buoy resting on the water’s surface, have been used for lobster fishing since the mid 19th century [6]. These types of traps were invented around 1808 by Ebenezer Thorndike, and have since become the popular method for lobster fishing [7]. Typically lobster traps are laid out in chains called trawls; these trawls can span over half a mile and contain anywhere from 2 to 40 traps. Trawls are generally placed in depths of anywhere between 15 and 1000ft, and are marked by buoys tied to the lead and tail traps [2].

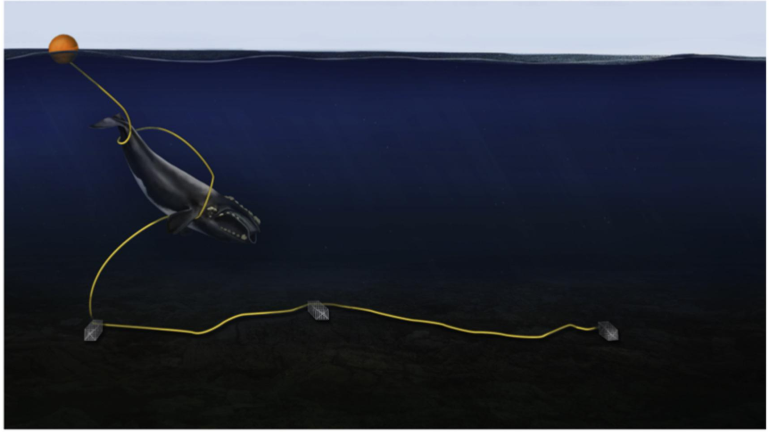
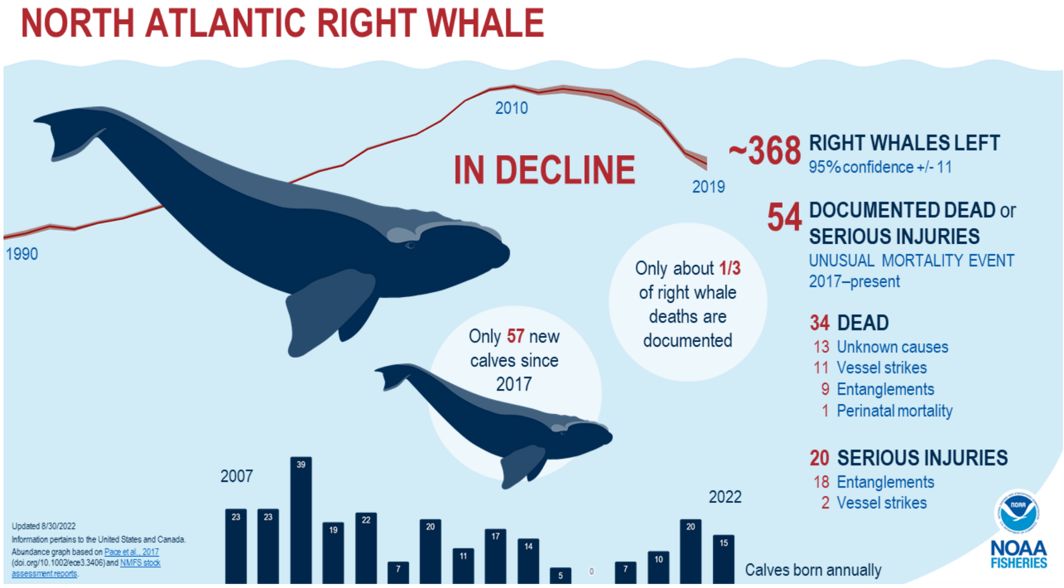


Figure 1: Whale entangled in lobster trap trawl with a buoy at the lead trap [8].

As lobster fishing has become more popular, a need for a safer way to harvest lobster has become essential. With these long ropes remaining stationary for long periods of time, the risk of entanglement for marine life is extensive. In particular, the North Atlantic Right Whale is facing possible extinction, largely in part due to these lobster traps. Because of this, many conservation groups are calling for a solution. Legislation and regulations have been put into place to try and remedy this, but without ropeless technology these regulations are placing severe stress on the lobster fishing industry and causing many businesses to suffer greatly.

2.1.1. Whale Mortality Rates

Since 2017, the North Atlantic Whale population has been decreasing drastically. During this time period, there were 34 documented deaths with an additional 20 being seriously injured [3]. Scientists now estimate that around 368 North Atlantic Right Whales are still alive [4]. Entanglements with ropes, such as lobster trap ropes, have become especially dangerous, as over 85% of these whales have become entangled at some point [4] and 58% of North Atlantic Right Whale deaths since 2009 have been because of entanglement issues [9]. The mortality rate for these whales has been drastically increasing as the population has been drastically decreasing. These whales have been on the endangered list since 1970, but there are now less than 100 breeding females left, leading many scientists to believe that their extinction is not too far away [4].



Updated 8/30/2022
Information pertains to the United States and Canada.
Abundance graph based on Pace et al., 2017 (doi.org/10.1002/ece3.3406) and NMFS stock assessment reports.

Figure 2: North Atlantic Right Whale population status [4].

2.1.2. Entanglement Case Studies

When a whale becomes entangled, the conditions that an entanglement causes can severely impact marine life. The ropes physically injure the whales and can cause infection, and they also significantly impair their ability to swim or feed. Based on how badly entangled the whale may be, they may have to expend more energy to swim than usual due to how much rope or gear they have to drag. A study by researchers at the Woods Hole Oceanographic Institute investigated drag caused by towing lines and lobster fishing gear that was removed from entangled whales. They found that on average, entanglement increased fluidic drag by 147% compared to an unencumbered whale. In extreme scenarios with a lobster trap also in tow, the drag factor was more than doubled [10]. This makes it significantly more difficult for them to feed as they need to feed more to compensate for the extra energy they expend, and dying from starvation becomes more of a threat. If a whale cannot become disentangled on their own or by rescuers, they have an average of 5 months to live [11].

2.1.2.1. Ruffian

Entangled whales, such as Ruffian, pay an extreme physiological price. In 2017, Ruffian traveled from off the coast of Canada all the way down to Florida after becoming entangled in a snow crab trap. By the time he was disentangled by rescuers, he was noticeably unhealthy. As he traveled, due to his state of entanglement, his drag was increased by an estimated 160% due to the ropes and the trap, causing him to burn an estimated 27,000 calories extra each day [9]. By the time he reached Florida and was disentangled by rescuers, he had become noticeably thinner due to how many more calories he had to burn each day. As pictured below, he had many wounds and lesions following his travels from Canada to Florida and had he not had been disentangled by rescuers, his chance of survival would have been severely low.

Figure 3: Ruffian’s wounds after an entanglement in 2009 [12].

2.1.2.2. Snow Cone

Snow Cone is one of the few remaining North Atlantic Right Whales that has the ability to bear offspring. She has been entangled more than five times and has given birth while entangled before, but her most recent entanglement will ultimately end her life [13]. In the fall of 2022, scientists reported that she is covered in orange cyamids, or whale lice, which is a clear indication that her swimming speeds have slowed and she can no longer swim effectively [13]. Her skin was also covered in marks and lesions, showing that she has sustained severe injury due to her entanglement, as seen in the picture below.

Figure 4: Snow Cone entangled in fishing gear [13].

While disentanglement efforts would greatly increase her chance at survival, due to the weather and ocean conditions in the New England area, there would be no way to safely disentangle her and scientists have stated that there is no longer hope for her survival [13]. As of February 2023, researchers have stated that Snow Cone has most likely succumbed to her injuries and do not have any hope of seeing her resurface again, along with her calf Cottontail [14].

2.2. Legislation

2.2.1. Regulations

Lobster fishing is highly regulated, as the act of lobster fishing is highly dangerous for both fishermen and marine life alike. Lobstermen are only allowed to fish in specific areas as the waters are regulated to decrease the threat to whales in those areas, especially North Atlantic Right Whales. Additionally, fishing is only allowed at certain points during the year, most commonly during May 1st to January 31st of the following year. Gear must also be labeled in a specific way, signifying where the traps are from and what their purpose is. Regulations have been increasing as North Atlantic Right Whales are nearing extinction, but regulatory support for so-called “ropeless” technology has lagged behind. Regulations have not allowed for many ropeless systems to be deployed, as current systems cannot be easily located if something goes wrong or cannot be located by other fishermen trying to place their own traps. This is partly due to the lack of inexpensive and effective systems that can be used to locate gear on the ocean floor [15].

The reasoning behind legislators being so reluctant to allow for ropeless systems that don’t have ways to easily locate lost gear lies within the fact that gear becoming lost also becomes dangerous to ocean life, while also causing fishermen great expense. Ghost traps can become especially hazardous to lobsters, as ghost traps are essentially traps that are lost to fishermen and have an unknown location. These traps continue to catch lobsters, but because they are lost to the fishermen, the traps are not retrieved and since the lobsters cannot escape, they unfortunately perish. It is estimated that over 640,000 lobsters die from these ghost traps every year [16]. While it is required in at least Florida that a part of the trap is made out of wood so it degrades over time and the trap does not continue to ghost fish, but most traps are pressure treated so they take longer to degrade. On average, a new trap with this wooden component takes 16 months to no longer ghost fish while all metal ones take 2 years [16].

With the drastic increase in North Atlantic Right Whale deaths in the past couple years and their status as an endangered species, more regulations and legislation has been implemented. Recently, a nonprofit organization called the Monterey Bay Aquarium Seafood Watch placed lobsters on the “red list” recommending consumers avoid them due to their environmental impact [17]. Many food service organizations such as Whole Foods, HelloFresh and Blue Apron partner with Seafood Watch and some have even promised to stop selling lobster entirely [18].

Environmentalists and legislators alike are urging that lobstermen stop fishing or greatly reduce the amount they fish to reduce the number of buoy lines that are stagnant in the water. This measure has been in line with NOAA, or the National Oceanic and Atmospheric Administration, who has recently banned persistent buoy lines [19].

Buoy lines are the root cause of the issue involving whales becoming entangled, so they have additional legislation and regulations tied to them. Buoy lines must not exceed a strength of 1,700 lbs and must have weak link points in them [5]. These weak link points must be chosen from a list of preapproved weak links and must not have a higher breaking strength than 1,100 lbs [5].

The use of these buoy lines is a part of the main problem, as these lines typically remain stationary in water for 3-7 days at a time until lobstermen are ready to reel back in the traps [2], and these lines remaining for such a significant amount of time is what allows for marine life, especially the North Atlantic Right Whales to become entangled. There aren't regulations currently allowing for traps without these vertical lines, as not having them poses other risks, but with the correct technology, legislation could be made to allow these types of traps.

2.2.2. What defines a ropeless system?

There are many different terms that have been used to label ropeless systems, such as "buoyless" and "on-demand" or "on-call" fishing. The general consensus is that these systems remove static vertical buoy lines from the water column while fishermen continue fishing with their current gear [20]. Most ropeless systems involve some sort of release mechanism and the most promising methods currently available involve acoustic signaling devices. Other methods involve airbag technology, where compressed air is pushed into an airbag to allow the trap to float to the surface [19]. In a recent memorandum, the director of the Division of Marine Fisheries for the Commonwealth of Massachusetts detailed six critical questions that help determine the efficacy of a ropeless system and if certain ropeless systems are viable. These six questions are listed below:

1. Can on-demand systems meet the efficiency of current fishing operations?
2. Can electronic gear marking be used to avoid gear conflicts within and between fisheries?
3. Can on-demand systems meet and/or exceed safety of current practices?
4. Can scalability result in affordability?
5. Can on-demand systems reduce gear loss?
6. Can through hull transducers improve the time of retrieval? [19]

These questions are critical in the development of ropeless technology, as if the technology does not answer them sufficiently, the technology will not receive the proper approval for testing, at least in the state of Massachusetts.

Currently, California can act as a model for ropeless legislation as the state has many standards involving detectability and retrievability. In order for a ropeless trap to be used in California, it must meet strict guidelines that allow for the traps to be detectable by individuals other than the fisherman who set it. Additionally, the gear loss rate must be under 10% with backup release capabilities so that the trap may be released to the surface in the event of gear failure. The traps must be able to be identified both underwater and at the surface, and law enforcement must be able to retrieve and redeploy the gear if necessary [15].

2.2.3. Ropeless Consortium

The Ropeless Consortium is an organization affiliated with the Woods Hole Oceanographic Institute which aims to come to a solution for the whale entanglement issue. Led by Dr. Mark Baumgartner, the consortium works towards a goal of implementing ropeless technology, spreading awareness about the dangers that roped systems have, and pushing for more regulation to support ropeless technology [21]. The consortium has held annual meetings since 2018, where researchers and companies can collaborate and demonstrate progress with ropeless system design. This year's meeting is October 24th at the New Bedford Whaling Museum in Massachusetts.

2.3. Competitors

There are a number of existing products that aim to eliminate entanglements with lobster fishing gear. The approaches vary substantially, but one major issue is cost: nearly all systems will cost lobstermen thousands to tens of thousands of dollars to adopt [22].

The first differentiating aspect between products is their retrieval signaling system. The vast majority of existing solutions use an acoustic signaling system to retrieve a lobster trap. These systems are "on-demand"; the lobster trap or buoy remains deep underwater until the lobsterman comes in close proximity and requests it, using an acoustic transmitting device on the boat. This has the advantage of reducing the time that a buoy endline is present to the absolute minimum, but it means the lobsterman has to wait for the release to actuate which can take a long time.

Sound is an effective way of transmitting wirelessly underwater, because at low frequencies it can easily travel many kilometers [23]. The speed of sound in water is also over four times faster than in air. Sonic communication in water is a widely explored field, but acoustic listening and transmitting systems suitable for marine environments are expensive.

One company called EdgeTech has an acoustically signaled ropeless system which has been extensively proven. Called the EdgeTech 5112, it occupies the entirety of the lead trap; the main chamber stores the rope, which is simply coiled without a spool. A number of small, air filled buoys are attached to the top. When a release is signaled, the entire top of the trap is detached and floats to the surface, pulling the rope with it [24]. Each trap assembly costs around \$3750, and up to two may be needed per chain of traps [22]. In addition, a dedicated deck box and transducer is required; while the price for this is not readily available from EdgeTech, similar systems from other companies cost over $2500. This is a huge price for a commercial lobsterman to bear.

Figure 5: EdgeTech 5112 system installed on a lobster trap cage [24].

There are some commercially available acoustic release systems that are somewhat more reasonably priced. The company SubSea Sonics produces some affordable systems: their AR50 Acoustic Release has a discount price of $595 per unit, although like with EdgeTech, a deck box is required and costs $1900 [25]. The AR50 system utilizes an erodible link to release a buoy to the surface. Upon receiving a release signal, the electrolytic erosion process begins and can take up to 15 minutes. The link must be replaced every time the system is deployed, and each link costs $15. The AR50 does not have a way to stow the rope while it is underwater, nor a convenient way to mount it to a lobster trap [26].

Figure 6: SubSea Sonics AR50 Acoustic Release system [26].

Another innovative acoustically signaled system is called LobsterLift. It is still actively being developed by a team of students, and no pricing data is currently available. Instead of releasing a buoy, LobsterLift utilizes a compressed air tank which inflates a buoy capable of lifting the entire lead trap to the surface. The system has been demonstrated in 150 feet of water [27].

In addition to acoustically triggered systems, there are also a couple designs on the market that use a timer. This has a few advantages: it is inexpensive, energy efficient, reliable, and the lobsterman does not have to wait for it to reach the surface after triggering it. The main disadvantage is that it is not on-demand: the lobsterman must program a release time and they cannot retrieve it earlier. If they arrive much later, then the rope will have been present and posing a threat to whales, although this risk would be far less than an ordinary lobster trap.

SubSea Sonics produces an inexpensive timer-based system called the TR4RT. The TR4RT costs around $300 per unit and is designed for single traps [28]. It is not intended for commercial lobster fisherman, but rather is targeted at smaller operations. The release mechanism utilizes a small rotary cam to secure a short line, which wraps around a coil of rope on top of the trap. In order to program the release time, the fisherman must rotate the cam through a complicated and unintuitive series of movements.

Figure 7: SubSea Sonics TR4RT attached to a single trap with rope and buoy stowed on top [28].

There are also systems that can support both a timer and acoustic triggering system. The company FioMarine has two established ropeless systems in their FioBuoy line: the TDxx series, and ACxx series. Both ranges combine a buoy and spool to form a pop up system; the electronics are housed inside the spool, and a release mechanism with a motor and pin allows the spool to unwind. The TDxx series utilize a preprogrammed time and date, while the ACxx series uses an acoustic trigger. Both series come in 100 meter and 200 meter configurations, with 10mm diameter line [29]. The FioBuoy systems are not specifically targeted to lobstermen. Pricing data is not readily available, but the cheapest systems certainly cost over $1000. FioMarine has been producing FioBuoys for over 25 years and they are thoroughly proven.

Figure 8: Fiobuoy AC100 acoustically triggered system with deck box [29].

While there are many competing systems on the market, none of them fully meet the needs of lobstermen. Systems like the EdgeTech 5112 and FioBuoy are simply too expensive and not enough incentives exist for them to be adopted by commercial lobstermen. The AR50 Acoustic Release is less expensive, but still requires a costly deck box and replaceable links. It has also not been thoroughly proven. The TR4RT is a promising design, but it is primarily for single traps and has a clunky interface. The LobsterLift meets many of the needs of lobstermen, but it is still under development and will likely be expensive due to using an acoustic release and complicated lift bag mechanism. All of the acoustic systems take time to reach the surface, and the designs that use an erodible link are especially slow. This wasted time costs lobstermen money.

Clearly there is room in the market for a system that is inexpensive, rugged and reliable; one that has an efficient interface; can attach to existing gear, and integrates closely with the workflow of lobstermen which has remained largely unchanged for decades.

3. Customer Profile

3.1. Customer

Before creating a product one must first establish a customer. In our case, the customers are lobster fishermen. We will be primarily targeting the lobstermen fishing in the North Atlantic Ocean off the coasts of New England, as these fishermen share their fishing grounds with the North Atlantic Right Whale. In 2010, 17,933 lobster fishing licenses were issued [2]. Each of these licenses represents a business of 1 to 3 individuals, and many of these lobstermen are multigenerational. These businesses are now being challenged to adapt to continuously changing regulations to protect the North Atlantic Right Whale. Legislature has already required lobstermen to lose access to fishing territory. In November of 2021, 120 to 150 lobster boats were given two weeks to remove all of their equipment from a 967 square mile section of the Gulf of Maine for a new conservation area scheduled from October to January every year [30]. The encroaching limits on the New England lobster industry are predicted to create a loss of 2 to 4 million dollars in revenue and create competition in the limited waters for fall and winter catching [30].

For the Lobster Resurfacing Oceanic Locator to be a successful product it must be designed with the needs of these lobstermen in mind. The Lobster R.O.L. must be able to be used in the different fisheries of New England. While each of these fisheries has different standard gear configurations, there is a lot of overlap that can be used as baseline requirements for our device:

- The depth of these fisheries ranges from 5 to 120 fathoms (30-720ft).
- Soak times (days between deployment and collection) ranges from 1 to 14 days
- The average weight of a single trap is 40-65lbs

- In each trawl (length of traps connected to 1 or 2 endlines) there are between 1-60 traps, must fisheries seem to use between 5-15 traps per trawl
- The largest diameter line used is ½” [22].

3.2. Interviews

To gain a better understanding of the lobster fishing industry, and lobstermen’s thoughts on ropeless fishing, we interviewed 30 people, including lobstermen, competitors, regulators, and others in the lobster industry.

3.2.1. Customer Interviews

In order to fully understand the requirements of what would be needed and how a lobstermen’s workflow operates, we interviewed 13 lobstermen. These individuals gave valuable insight on what aspects of the design would be feasible and what aspects would not work. When talking with these lobstermen, they noted a number of issues with our original design. This design involved using a spool and many of the lobstermen pointed out that a spool would have to be massive in order to handle the amount of rope needed, making it very difficult to use by the lobstermen. Additionally, the reload process for a spool would be lengthy, and the lobstermen made it clear that they value turnaround time when retrieving traps. They also indicated that using a timer would not work as well as we had originally thought. Lobstermen can have regular schedules, but when they are able to retrieve their traps is highly dependent on the weather conditions. Due to this, they indicated that they would prefer systems that would allow them to release the buoy on demand. Currently, acoustic systems are the best option for this, hence why in the future we would look to integrate an acoustic system into our product. One more major issue that the lobstermen brought to our attention was the feasibility of using this technology for inshore fisheries. We originally thought that inshore fisheries would be best to design our product around. However, from our interviews we learned that in many inshore fisheries, trawls are packed very densely and the buoys are critical to preventing traps from being laid across each other. Any electronic gear marking system would have to be very precise to support this environment. Additionally, these fisheries tend to run shorter trawls of 3-5 traps, so the per-trawl cost of using our device would be high. This contrasts with offshore fisheries where trawls can be 10-20 traps, are more spread out, and are subject to whale-related closures more often.

3.2.2. Additional Interviews

In order to find lobstermen to talk to, we talked to lobster distributors, as well as talking to competitors to learn about their devices. Many of the lobster distributors shared the sentiment that ropeless fishing would put many lobstermen out of business, which was the same concern that many of the lobstermen we interviewed had.

When talking with enforcement, responsible for checking that regulations are being met, we learned that they need to be able to pull anyone's traps to check compliance. Additionally, for a ropeless system to ever be permitted by whale protection regulations, the rope needs to be present for the minimum time possible. With a timer, the lobstermen might not be there when the buoy is released. Therefore it is unlikely a timer could be permitted.

When talking with the inventors of competing ropeless systems, we were able to gain insight on how their traps worked. They also shared with us that some of their initial designs started with using a timer system, but they would move past using a timer system once the mechanics of their release mechanism was working. Additionally, they shared with us more ideas for rope handling, and more about why a spool would not be as effective as we thought it would.

We also learned that there are many companies that produce the acoustic signaling system on its own. We will investigate using one of these systems with our release mechanism in the future.

3.3. Value Proposition

For offshore lobstermen, it’s a challenge to comply with regulations while still fishing and maintaining a business. Today, their best option is to avoid restricted areas or close down during certain periods of time which, because of current and increasing regulations, results in losing money and potentially going out of business. Thus, there is a need for a technology which allows lobstermen to fish without stagnant buoy lines. If successful at reasonable cost, this would allow lobstermen to comply with increasing regulations.

4. Design Specifications

4.1. Product Requirements

The general requirements that we derived from the different gear configurations found throughout the New England fisheries were then expanded upon into the following three sections of product requirements. Tables 1, 2, and 3 show a list of requirements for the mechanical, electrical, and human interface aspects of this product.

4.1.1. Mechanical Requirements

The mechanical requirements for this design are focused on the enclosure that will contain the electronics, and how the system will integrate with existing lobster fishing gear. The first requirement (Req. 1.01) listed in Table 1 is that the entire product must be inexpensive; while this is not solely influenced by the mechanical properties of the project, it is heavily affected by the enclosure's material choice as well as the size of the design. Requirements 1.02-1.04 describe the basic requirements of the product, that it may act as a ropeless fishing system. Requirement 1.03 is particularly important as many competitors, such as the AR50, do not offer a way to contain the line which means they are not considered ropeless systems. The survivability requirements (1.5-1.10) have to do with the enclosure protecting the unit from different conditions. 1.06 and 1.07 come from customer requirements of operating at depth and being able to withstand the longer winter soak times. Marine life such as barnacles and seals must not be able to interfere with the system; therefore, requirement 1.09 was added.

Requirements 1.10-1.14 are focused on making the product as reusable as possible. Many lobstermen take issue with the current solution to protect the North Atlantic Right whale, breakable links, as they can cause loss of equipment. We decided to mitigate these issues by focusing on durability and reusability. Finally, requirements 1.15-1.17 are related to the use of currently existing equipment such as commonly used line diameters, and standard-sized lobster traps and buoys. These requirements are to help further reduce the cost of this product and to reduce the number of new technology lobstermen would have to work with after purchasing this product.

Mechanical		
Req ID	Type	Requirement
1.01	Goal	Inexpensive
1.02	Operation	Must be able to load and reload a buoy
1.03	Operation	Must be able to store operational amount of rope
1.04	Operation	Internals must be accessible for maintenance requirements
1.05	Survivability	Must survive in seawater/be corrosion resistant
1.06	Survivability	Must withstand hydrostatic pressure at operation depth
1.07	Survivability	Must withstand multiple weeks submerged
1.08	Survivability	Must withstand cold sea floor temperatures
1.09	Survivability	Must withstand interference from marine life
1.10	Durability	Must be impact resistant
1.11	Durability	Connection to lobster trap must withstand weight of trawl
1.12	Durability	Must be able to withstand buoyancy force of buoy
1.13	Reusability	Must be reusable
1.14	Reusability	Release mechanism: must last multiple cycles
1.15	Integration	Must work with existing rope
1.16	Integration	Must work with standard lobster traps
1.17	Integration	Must work with standard lobster buoys
1.18	Ballast/ buoyancy	Must not interfere with trap sinking or lead to tangles as the trap sinks
1.19	Organization	Must provide cable management and prevent cables from tangling

Table 1. Mechanical requirements.

4.1.2. Electrical Requirements

The electrical requirements for this design concern the timing system and motor that actuates the release mechanism. Our design will utilize a timer to initiate a release, due to the cost and reliability benefits associated with a timer over an acoustic system (Req ID 2.01-2.02). The timing system must store the full time and date rather than an offset from when it is released. This will simplify the scheduling process when deploying the system. Additionally, the system must be fully reusable (Req ID 1.13); to implement this in the electronics, the battery must be rechargeable and the release must be resettable. In general, the need to open the enclosure should be minimized. It must be possible to wake the device for programming without opening the enclosure. Additionally, it must be possible to tell the state of the device externally, even in sunlight.

The device will need to operate over a range of ocean temperatures. Typically, the ocean temperature on the East Coast varies from around 0°C to 25°C [31]. The battery must be able to sit unused for a while ahead of a deployment (Req ID 2.07). Then it must last for at minimum a full deployment, which is typically 3-7 days, at any temperature in the design range. Then it must still be able to release after that time as elapsed (Req IDs 2.04-2.06). Ideally, the battery will last for a whole season of use. This would allow lobstermen to recharge all their R.O.L.s at once, and minimize resealing of the device.

The system should also include some basic failsafe systems: if water is detected in the enclosure, or if the battery gets dangerously low, it should effectuate a release (Req ID 2.08-2.09). This would drastically reduce the risk of a leak or badly attached end-cap causing a system failure, and reduce lost gear. It should not be possible to attach the buoy without programming a release time and arming the system, as it would never release the buoy (Req ID

2.11). It should also detect software errors or unintended reboots, and the time should be stored in a way that it is not lost if main power gets interrupted.

Electrical		
Req ID	Type	Requirement
2.01	Operation	Must have a configurable timer which actuates a release
2.02	Operation	Needs to store full date and time as opposed to offset
2.03	Operation	Must be rechargeable and reusable
2.04	Survivability	Must withstand typical temperatures in the Atlantic ocean without permanent damage
2.05	Survivability	Must be able to release in typical temperatures in the Atlantic ocean and provide rated torque
2.06	Battery	Must last typical deployment length and still be able to release
2.07	Battery	Must last in standby with charge remaining for one deployment
2.08	Failsafe	Must detect water in the enclosure and trigger an emergency release
2.09	Failsafe	Must detect dangerously low battery and trigger an emergency release
2.10	Failsafe	Must detect software errors or clock reset and trigger an emergency release
2.11	Failsafe	Must not be able to attach buoy unless a release time is programmed and system is activated
2.12	Timekeeping	Timer must have a backup battery that can maintain the system clock in the event of the main battery being disconnected
2.13	Timekeeping	Must store release time in non-volatile memory
2.14	Integration	Must communicate with a programming device
2.15	User Experience	Must be possible to wake and program or reprogram device without opening the enclosure

Table 2. Electrical requirements.

Finally, the electronics must be able to wirelessly communicate with an external programming device such as a smartphone (Req ID 2.14). Using a wireless method eliminates the need to open the enclosure to program the device while on an unstable boat at sea. Such a process would be risky and a hassle for the lobstermen. Additionally, using an app on the programming device allows for a more functional user interface with clearly labeled buttons.

4.1.3. Interface Requirements

The interface requirements for this design focus on creating a way to interact with the Lobster R.O.L, viewing important details about the device as well as controlling and arming it. We decided to create a complementary app in favor of using an interface built into the device. An app will be more intuitive, easier to use, and less expensive than putting a display and controls inside the device. It will also allow the device to be smaller.

Application/Interface		
Req ID	Type	Requirement
3.01	Operation	App has an opening page
3.02	Operation	Application has settings menu
3.03	Operation	App requires ability to connect to unit
3.04	Operation	Ability to control unit prior to being armed
3.05	Operation	Ability to arm unit

Table 3. Application interface requirements.

The application will feature two separate settings pages, one for the general app, and one for the connected unit (Req ID 3.01-3.02). This application will also provide the ability to connect to the unit and control the device remotely, both through manual control prior to arming, as well as setting the arm time (Req ID 3.03-3.05). The user will also be able to use the app to view important details of the unit including the current battery life of the unit.

4.2. Product Specifications

The team then used the list of requirements for the Lobster R.O.L as the basis for deriving a list of specifications. Tables 4, 5, and 6 show a list of specifications for the mechanical, electrical, and interfacing aspects of this product.

4.2.1. Mechanical Specifications

In order for this proposed design to be viable it must adhere to the mechanical specifications listed in Table 4. Item 1.01 describes the maximum rope length and rope diameter that the entire device must be able to contain. The length of rope was selected due to the average depth of the Gulf of Maine, which is about 500 ft [32]. An additional 50 ft of rope is included to compensate for swells and to provide a safety margin. A diameter of ½ inch line has been selected which is the largest diameter of line that is commonly used by lobstermen [2]. Designing around the maximum diameter allows for further compatibility with current lobstering techniques. Specification 1.02 states that the enclosure must survive at a depth of 500 ft, which as stated before is the average depth of the Gulf of Maine. 1.03 refers to protecting the internals from the temperatures both while operating at the bottom of the ocean and while dormant on the deck of the vessel. 1.04 dictates that the device must withstand 4 weeks submerged. Lobstermen usually leave their traps submerged for 3-5 days, however, during the winter season they often leave traps deployed for 1 - 2 weeks. This device should last for the maximum amount of soak time as well as additional time to ensure the product survives. Item 1.05 states that the device should be reusable for at least 243 cycles, or 2 years with traps being set every three days. During the busiest season, the average soak time of a lobster trap is three days. This means that two years would be an underestimate. The release mechanism should last a minimum of 1000 cycles. 1.06 dictates that the release mechanism must last a minimum of 1000 cycles or roughly 8 years of deployments. Lastly, the device should also withstand a tensile force of 195 lbs, or the weight of three traps being lifted from the device, in accordance with specification 1.07. Finally, in order to prioritize making an affordable solution we had set a budget of three hundred dollars per unit (Spec 1.08). The bill of materials can be seen in appendix D, but the material cost for the mechanics and the enclosure totaled to $105.74. With the electrical components, the total cost of one unit’s worth of materials was $208.53, which with decreases in pricing due to better manufacturing techniques and bulk ordering of components, the market price should not exceed $300.

Mechanical		
Spec ID	Type	Specification
1.01	Operation	Must be able to store 550 ft of 1/2" diameter line
1.02	Survivability	Must withstand a hydrostatic pressure at a depth of 500 feet
1.03	Survivability	Must withstand temperatures in the range 0C to 40C (operating), -10C to 50C (not operating)
1.04	Survivability	Must withstand 4 weeks submerged at a time
1.05	Durability	Must be reusable for at least 243 cycles
1.06	Durability	Release mechanism: minimum 1000 cycles
1.07	Reusability	Will withstand a tensile force of 195lbs
1.08	Cost	Must be under $300 per unit

Table 4. Mechanical specifications.

4.2.2. Electrical Specifications

The electrical systems are built to certain specifications derived from the requirements detailed in section 4.1.2. The system is built to be extremely power efficient. It spends almost all of its time in sleep mode, only waking up for programming and actuating a release. Components and the design of the PCB were chosen with this central principle in mind.

To provide consistent timekeeping, the DS3231SN real time clock (RTC) is used. This RTC stores the full time and date and is extremely accurate. It utilizes a temperature sensor to compensate for the quartz crystal frequency changing with environmental temperature. This allows it to retain an accuracy of ±3.5ppm between -40°C to +85°C, which equates to about two minutes per year [33]. While this level of accuracy is not critical for our application, reliability in our designated temperature range (Spec. ID. 2.03) is. Additionally, the DS3231SN has very low current draw: ~0.84uA when running on a backup battery to keep time, and 110-200uA when actively communicating with the microcontroller. The DS3231SN wakes up the microcontroller with a programmable alarm when it is time to release, maximizing the time that the microcontroller can sleep for.

The backup battery used for the RTC module is a CR1220 coin cell lithium battery. According to Energizer, this battery has a 3V nominal voltage, and can supply 35 mAh at 21°C. At 0°C, the voltage stays between 2.7V to 2.5V and the battery can supply around 33mAh [34]. Using this backup battery at 0°C with a typical draw of 0.84uA, the battery can be expected to last around 4.5 years. Ideally, the user would replace this battery every ~2 years or when charging the main battery. This is not unreasonable, as the coin cell battery costs less than $1.

The main battery for the device is a pack of four standard 18650 cell lithium ion batteries, connected in a 4x series 1x parallel configuration (4S1P). If Panasonic cells are used, then they R.O.L. have a nominal voltage of 3.6V and can supply 3300mAh [35]. Combining four batteries in series gives us a nominal voltage of 14.4V with the same capacity of 3300mAh. When operating at -10°C with a 4A draw, the battery only drops below 3V after supplying 2300mAh (Fig. 9). With four batteries, this makes the operating range of our battery pack 14.4V to 12V. Therefore, in the worst case conditions the battery can supply 2300mAh. Multiplying by the minimum voltage (12V), we get an energy capacity of 27.6 watt hours for the worst case scenario.

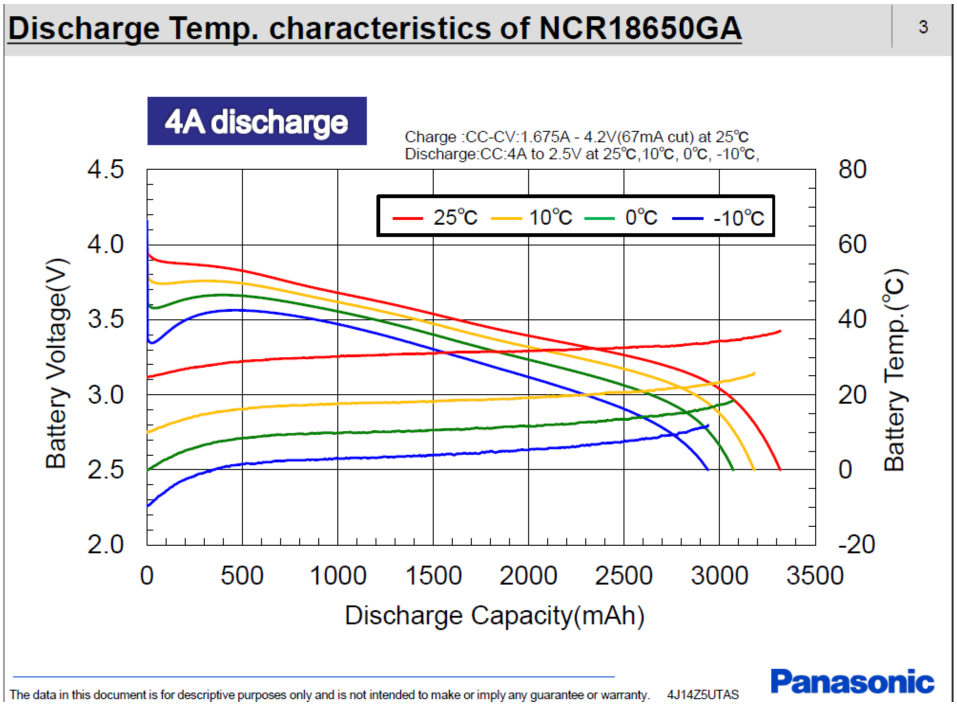


Figure 9: Panasonic 18650 cell discharge characteristics [35].

Based on our worst condition battery capacity of 27.6 watt hours, we can calculate the battery life in different use cases. With a usage frequency of one release every two days, the R.O.L.'s battery would last 13 months. It also assumes the R.O.L. will be unable to release below 12V, when in reality it could release successfully down to around 8V. Finally, a release every two days has a very high usage frequency. Typically, soak time is between 1 to 14 days. Regardless, in this worst case, the battery life still well exceeds the length of a typical lobstering season, which can reach up to about 8 months. If we go with a more realistic use case: release every 5 days, at 10°C, the typical battery life would be around 2.5 years. In a conservative use case with a release every 12 days, the battery life will be about 3.5 to 4 years. Regardless, the lobstermen are encouraged to recharge the battery every off season, as it is better for battery health.

At the heart of the electronic systems in the R.O.L. is an ESP8266 based microcontroller; specifically, the ESP-12F. This provides WiFi connectivity, allowing the R.O.L. to open a WiFi network that the programming device can connect to. The ESP-12F is capable of sleeping with a current consumption of 20 uA at 3.3V. It is inexpensive, easy to source, and well supported. The ESP-12F manages communication between all the peripherals on the board, and controls power for devices such as the real time clock, indicator LED, and motor driver, to maximize the energy efficiency of the board. However, the ESP-12F itself consumes a large amount of power when active, and if the WiFi access point is running then the power consumption is more than doubled. To minimize this, it spends almost all of its time in deep sleep mode, only waking up to certain stimuli.

If a user wants to program the device, they have to wake up the system to activate the WiFi. Opening the enclosure is not an option, due to the difficulty of resealing it. Instead, the system employs a low power accelerometer, which listens for acceleration over a given threshold for longer than a set time. When it detects this shake from the user, it provides a wake event to the wake subsystem (described in section 4.3.2.4). The microcontroller then wakes up, sees that the accelerometer was the source of the wake event, and activates the WiFi access point. If nobody connects in one minute (configurable) then the device goes back to sleep until the next wake event. If a device connects, but does not interact with the web page, then the device will sleep two minutes after the last interaction. This is important because a phone may automatically connect to the device if it wakes up, potentially draining the battery.

The real time clock can also wake up the microcontroller. When a user programs a release time, the microcontroller stores that release time and date in non-volatile memory, which is persistent through power loss. The microcontroller also sets an alarm on the real time clock, and that alarm wakes it up at the given time. The alarm is set for once every day at the release time; this is because there is a limit to the duration between alarms on the DS3231SN. It also provides an opportunity for the microcontroller to measure the battery level, and potentially perform an emergency release.

The final wake source is the water sensor. The R.O.L. always orients in the water column with the electronics at the top, and the motor core at the bottom. If there were a slow leak, it would travel down the sides of the core, and pool at the bottom. The water sensor is simply two leads of wire poking down where the water would collect. When the water reaches about 2mm deep, it shorts the two wires together, causing a wake event. The microcontroller wakes up, sees that the water sensor is the source of the wake event, and checks if it is deployed underwater with the magnet extended. If it is, it actuates an immediate release. This failsafe is hugely important, but not just for the risk of losing the release device. As discussed in section 2.2.1, lost lobster traps can become ghost traps which decimate lobster populations.

The user can see the current state of the device with an indicator light on the threaded end cap. To maintain waterproofing, this indicator light is made from a section of 4 mm diameter fiber optic light pipe. One piece of the light pipe is epoxied into the end cap, and can spin when screwing it on. This piece lines up with an internal RGB led, which is bright enough to be visible even on a sunny day. When the system wakes up, it flashes the LED green. When it is awake, standing by with the WiFi waiting for a connection, the LED will slowly breathe blue. When it receives a release time, it flashes green twice. When the release time is confirmed, it flashes green four times, and then turns off as the device goes to sleep. If the manual attach and release buttons are used, the light turns yellow as the magnet travels. When trying to set a release time, if the water sensor detects water, it will flash red and not allow the release time to be set. This indicates to the user that they need to dry the enclosure and repair the seal.

The PCB was designed with the option of future expansion. Since we may include acoustic release triggering in the future, there is a port with a serial communication interface (I^2C), GND, 3.3V and switched 3.3V (off when system is asleep). This port could also be used if the R.O.L. were to be employed in some scientific logging application; a sensor and memory card could be connected here, and the R.O.L. could wake up on a regular schedule to perform measurements.

The whole R.O.L. PCB is very inexpensive; only $30 including all components and assembly. The stepper motor and gearbox is relatively expensive at $33, and the 4S1P lithium ion battery pack is $36. In total, the full system electronics cost just over $100 for single quantity orders. This could be substantially reduced when ordering in bulk. The full schematic for the PCB can be seen in Appendix A. The specifications for the electronics can be seen in Table 5.

Electrical		
Spec ID	Type	Specification
2.01	Operation	Real time clock persistently stores the time with worst case ±3.5ppm time drift at temperature extremes
2.02	Operation	Programmable using a smartphone or computer over WiFi (802.11n)
2.03	Survivability	Temperature resistance: -10C to 40C (operating), -10C to 50C (not operating) without permanent damage
2.04	Battery	1 year battery life (absolute minimum)
2.05	Battery	2.5 year battery life (typical)
2.05	Battery	4x 18650 cell battery pack (genuine Panasonic cells), 14.4V nominal, 12V minimum
2.06	Battery	Shelf life of 8 weeks in standby with charge remaining for one deployment
2.07	Battery	Rated for 200 recharge cycles minimum
2.08	Power	Input voltage in range 12V-22V
2.08	Failsafe	Water sensor which triggers emergency release

2.09	Failsafe	Error checking which triggers emergency release
2.10	Failsafe	Battery below ~10% triggers emergency release

Table 5. Electrical specifications.

4.2.3. Interface Specifications

Upon connecting to the R.O.L.'s wireless access point and opening the app, the app displays whether the R.O.L. is armed or unarmed, the battery percentage, and the magnet position (Spec ID 3.01). If a release time is set, it will also display that. Below the device information, the app contains a datetime picker along with buttons to set the release time, arm the device, and view the settings (Spec ID 3.02/3.03). Upon setting and confirming a release time, the text in the confirm button will change to display "Unconfirm", and if clicked will disarm the R.O.L.. The settings page contains additional information for the user as well as giving the user finer control over the R.O.L. It displays the current time on both the device running the app as well as the time on the R.O.L., along with a datetime field and a button to sync the time (Spec ID 3.04). The settings page also contains buttons to attach and release the magnet, in case the user would need to override the magnet position (Spec ID 3.05). This user interface workflow is illustrated in Fig. 10 below.

Application/Interface		
Spec ID	Type	Specification
3.01	Operation	Device page features device information, including battery life and magnet position.
3.02	Operation	Release time can be set through the device control page.
3.03	Operation	Unit settings can be accessed from the device page.
3.04	Operation	Unit settings contain a button to sync device clock with phone clock.
3.05	Operation	Unit settings contain a debug menu, allowing the user to attach and release the magnet.

Table 6. Application/interface specifications.

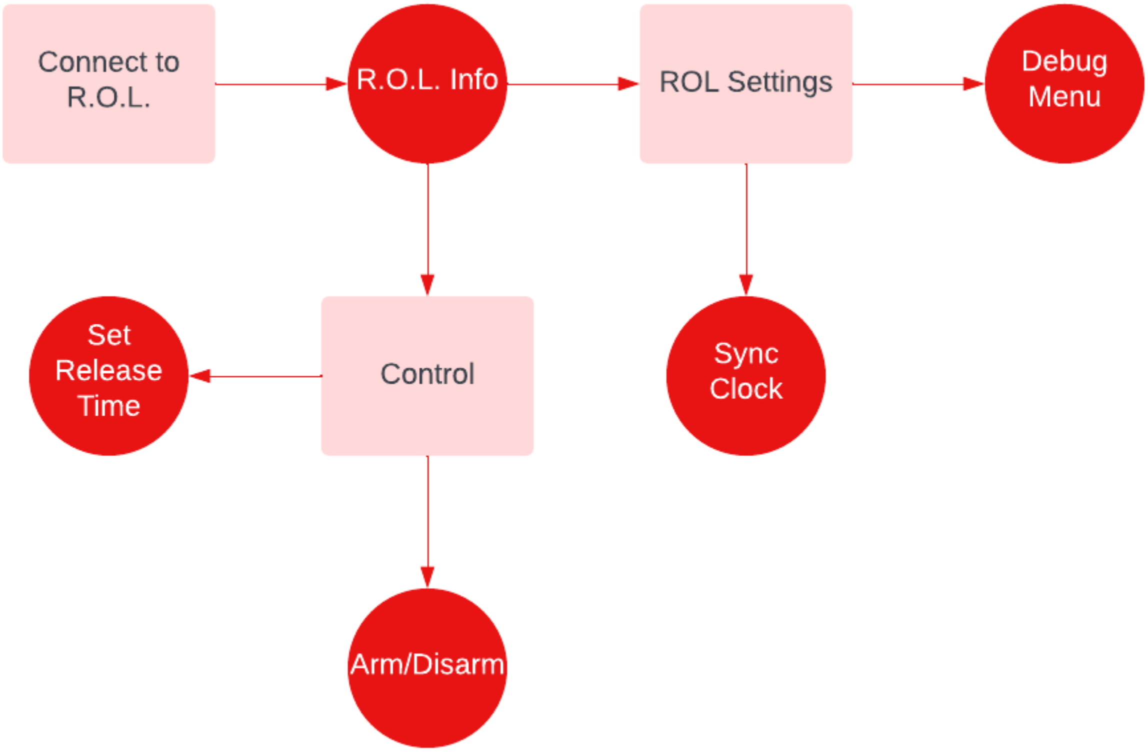


Figure 10: Application User Interface Flow.

4.3. System Design Evolution

4.3.1. Mechanical Design Evolution

At the start of this project the mechanical engineering team was presented with the final prototype created the previous year in an Electrical and Computer Engineering Design course (ECE 2799). This design acted as a proof of concept for what would become our final prototype. The enclosure for this ECE 2799 prototype consists of a box filled with wires and a release mechanism. This design lacked a method of storing the rope, instead opting to let it flow freely with the current. This design can be seen below in figure 11.

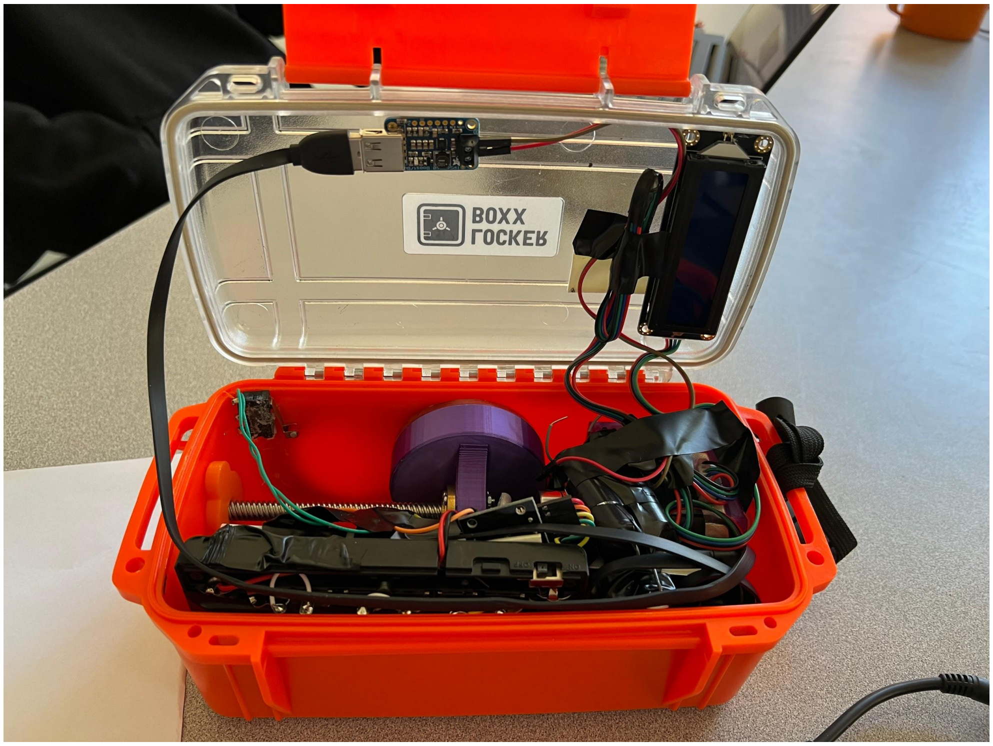


Figure 11: ECE2799 Prototype

When we began our initial designing, we planned to focus on better organizing both the electronics and the buoy line. For our first design (shown in figure 12) we planned to use a section of PVC pipe to form the pressure resistant housing. End caps enclose each end of the pipe, and have round studs which fit into machined metal brackets at the ends. The brackets mount to the edges of the lobster trap. Adapters could be built to accommodate traps of different widths. The round body of the enclosure doubles as a spool, with guides to keep the rope in position, and the spool can spin on the end brackets similar to a paper towel roll. The buoy is tied to both the long rope that is wrapped around the spool, and a short rope that attaches to a magnet in a ring outside the enclosure (figure 12).

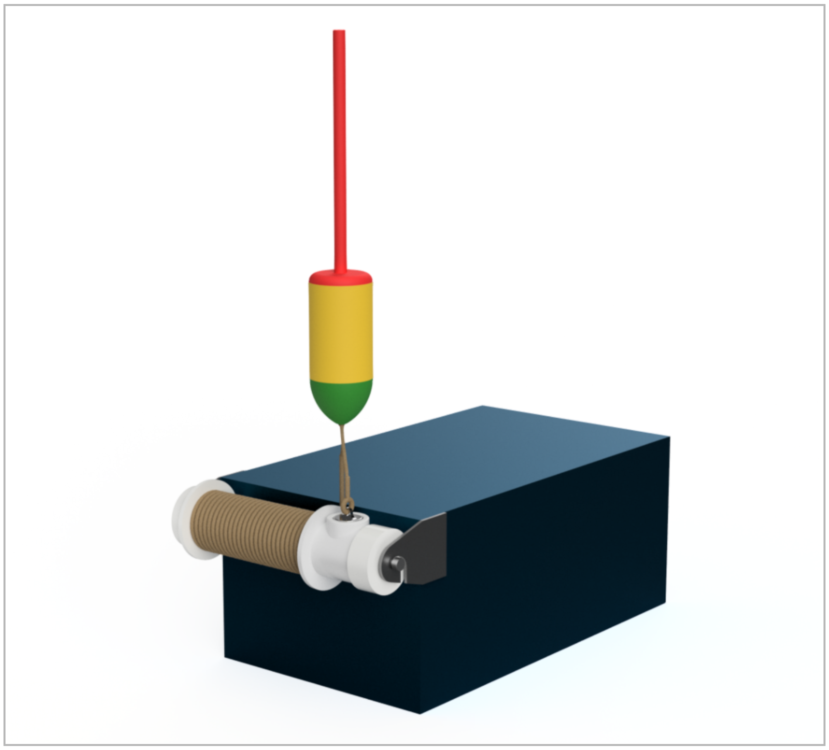


Figure 12: Lobster R.O.L. mockup render attached to a lobster trap

In order to detach the buoy, the Lobster R.O.L uses a magnetic coupling system. This system was first proven by the ECE2799 iteration of the project. In this proof of concept, the outer magnet is tied to the buoy, which sits on the top surface of the enclosure. The secondary magnet is located within the enclosure, pressed against the top surface. The two magnets generate a hold strong enough to keep the buoy attached to the system. The inner magnet is attached to a lead screw which is connected to a stepper motor. By rotating the lead screw, the stepper motor can displace the inner magnet horizontally. The outer magnet is constrained laterally with a ring that surrounds it and is fastened to the outside of the tube. The outer magnet can still be pulled vertically upwards. By laterally shifting the inner magnet while keeping the outer magnet in place, the magnetic attraction force can be broken. This leaves the buoy free to rise to the surface.

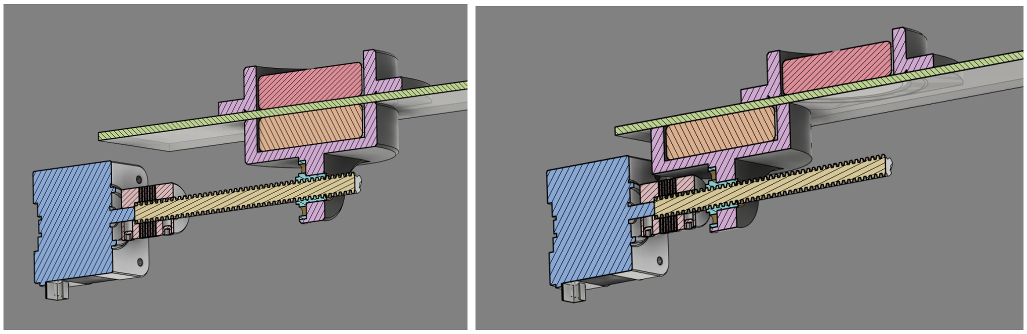


Figure 13: Magnetic release proof-of-concept.

We originally felt that our initial concept was effective, as it would work as a solution to both aspects of our problem. This design would act as both the release device and rope management system. Despite the elegance of this design, it came with many drawbacks. Firstly, it was very complex, as it relied on the bracket system, the ability to freely spin, and the magnetic release working properly. Each of these aspects created points of failure. Secondly, incorporating the magnetic release into a cylinder was a challenge, as it meant the magnets could not be brought very close together (especially as magnet diameter increases). This meant we would need to use bigger magnets and therefore a bigger PVC pipe for the enclosure. This problem is illustrated in figure 14 below, where the pipe diameter is nearly twice the magnet diameter and yet the magnets are still quite far apart.

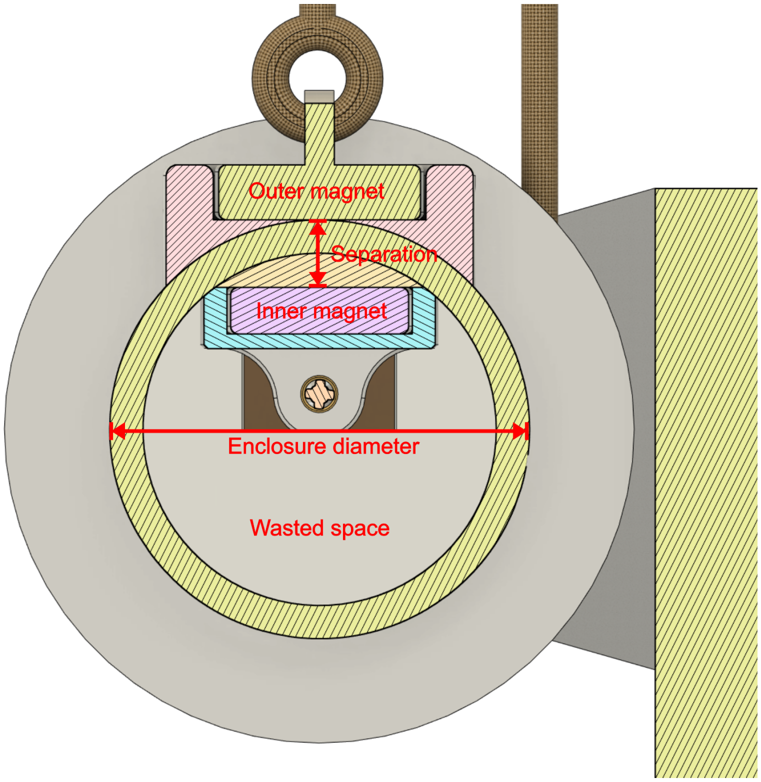


Figure 14: Magnetic release magnet separation issues.

Additionally, from our interviews with other manufacturers we found that a spool based system was impractical for scaling to increased depths, as the spool would become incredibly large. This would also interfere with the lobstermen’s workflow as they would need to respool after each haul. . Going forward, we decided to split the rope storage and the release device into two separate systems.

Returning to the drawing board, we created the design featured in figures 15 and 16 below.

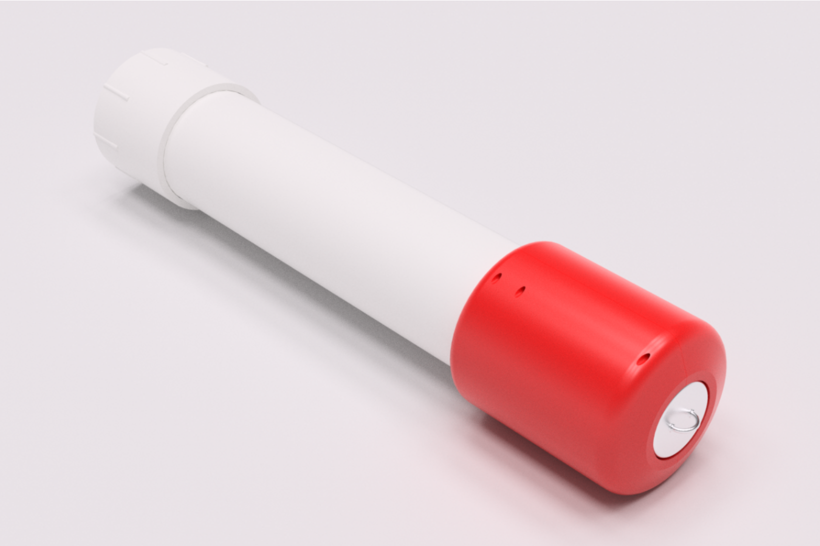


Figure 15: PVC pipe enclosure.

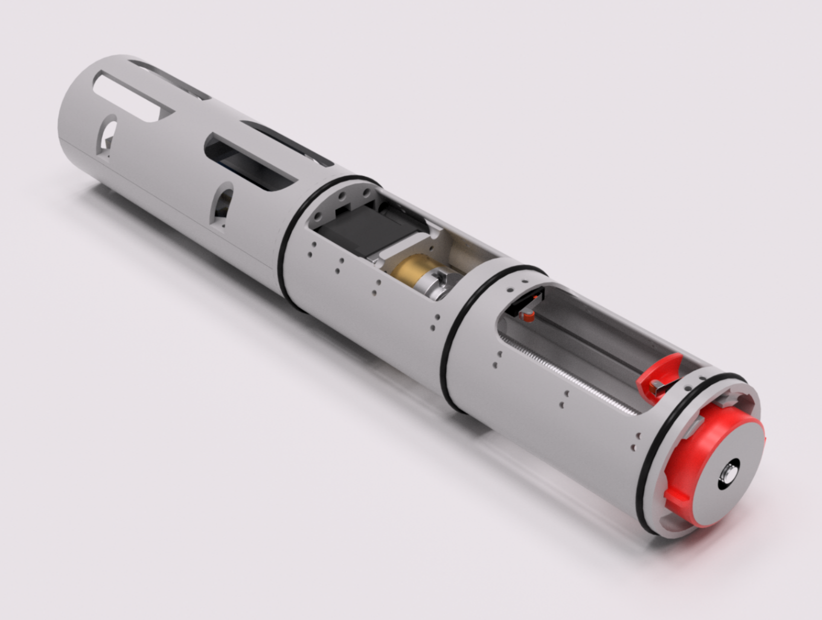


Figure 16: Electronics core design.

This concept focused mainly on simplifying the release mechanism. The release mechanism would be once again housed in a PVC pipe to provide an affordable, waterproof and pressure resistant enclosure (figure 15). Within this PVC pipe is a 3D printed core that mounts all electronics and the release mechanism. The internal release mechanism remained largely the same, but in order to better fit inside a cylindrical enclosure, we rotated the magnet 90 degrees so it separates inline with the lead screw. This has the advantage of allowing the magnet to get much closer to the end cap, which allows for a magnet diameter very close to the diameter of the enclosure. This is best shown in figure 17 below.

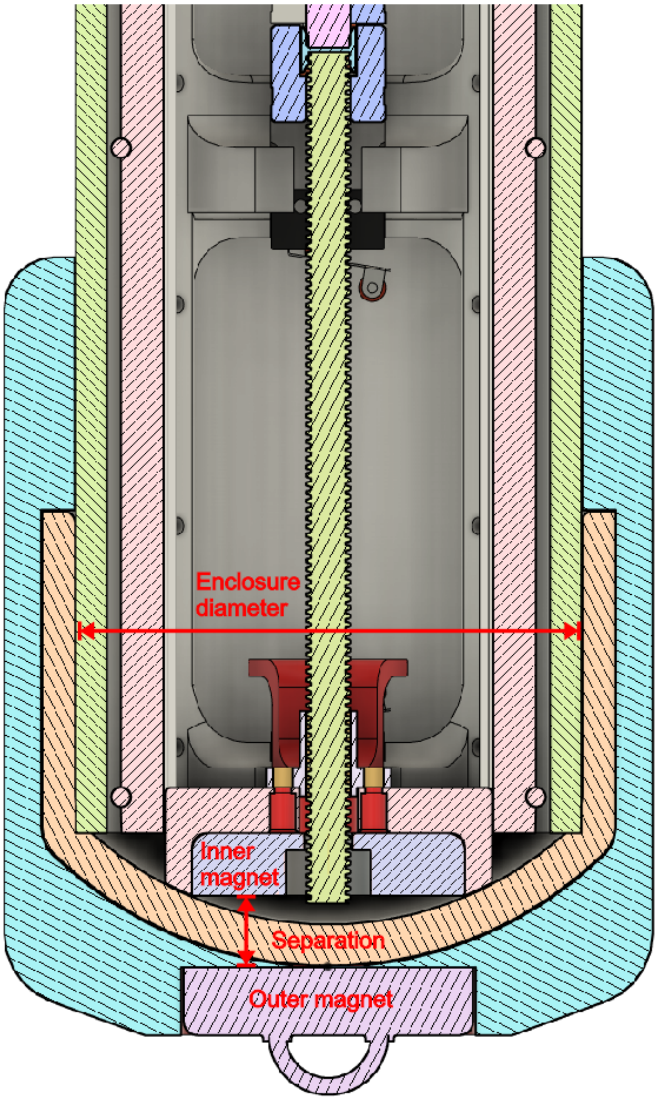


Figure 17: New inline magnetic release design.

A disadvantage of this new design is that the motor would need more torque to release the magnet. The release mechanism, with the motor, is housed in a section of the internal core.

This core provides a sturdy base and makes the device easy to service, as everything can be accessed by sliding the core out. O-Rings around the core allow it to fit snugly while providing a degree of shock absorption in the event the unit gets dropped (figure 16).

The core mounts the motor, couplers, lead screw, and a magnet holder, which rides on rails to keep it aligned. Limit switches at each end meant that the system will always know when the magnet is fully attached or released. Dedicated wire channels were added to ensure the wires would never get caught in any moving parts and would remain securely organized. The second half of the core would house the microcontroller, PCB, and battery.

Instead of being mounted to the lead trap, the system would instead be attached via line. This simplified the mounting design would allow lobstermen to preserve some of the methods they already use. Additionally, the release device will never be under substantial load, as it would already be on a lobsterman's deck as the traps are hoisted back to the surface. These fixes removed the need for specification 1.07 in the design of the release device. The rope handling is detailed out in section 4.3.1.2., but would consist of a cinched rope bag.

The next major changes to the R.O.L. came when making the jump from conceptual design to prototype. This first prototype took the concepts put forth from our second major redesign and changes were necessary for fabrication.

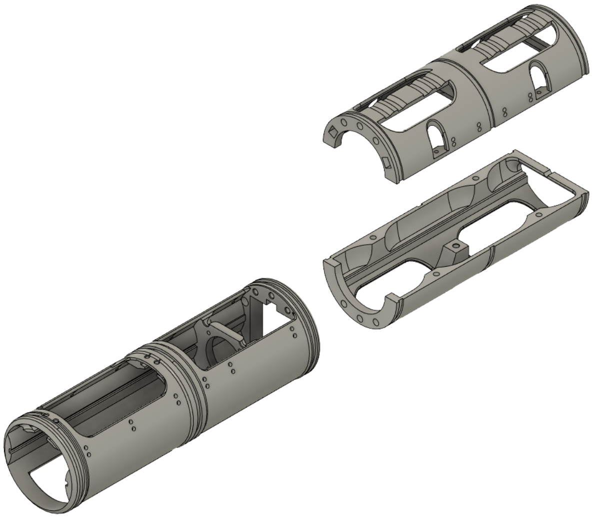


Figure 18: Core Assembly

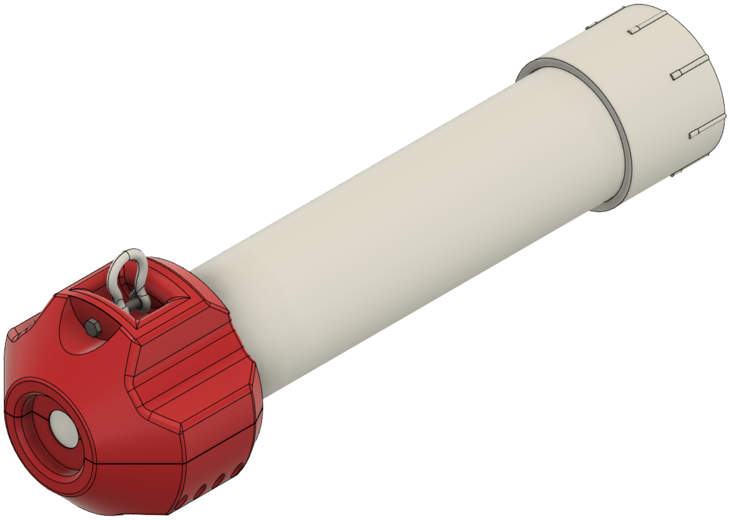


Figure 19: PVC enclosure and end cap.

Figure 20: Updated electronics and motor core.

The first of these adjustments was physically splitting the core into a motor core and an electronics core to enable them to be created through additive manufacturing. With this split came the need for fasteners between the two halves. During the process of designing the electronics core, we found that it would be difficult to access the breadboard. This core was then bisected to provide better access. The core assembly is shown in figure 20 above. The next major change from conceptual to prototype was the end cap that provided a rope mounting point. Firstly, it was split into two halves and made much thicker. This assisted with printing and allowed us to attach the end cap to the PVC end cap without compromising the PVC. The thicker end cap also provided a way to mount an anchor shackle. This shackle would provide a location to attach the retrieval line contained in the rope bag so that the Lobster R.O.L. could act as a buoy itself. We found that the R.O.L. acting as a buoy simplified the release process and could allow the device to be used for other applications, such as water quality logging, in addition to lobster fishing. The main addition over the conceptual design was that of the LED indicator on the outside of the enclosure. In order to facilitate this, an acrylic lightpipe was inserted and sealed with epoxy into the center of the screw on the end cap of the device. This light pipe would line up with an LED mounted in the electronics core.

This first prototype had multiple faults. Firstly the motor core had no way of preventing the lead screw and coupler from falling out. This mistake could have caused a catastrophic failure of the device, causing it to be locked in the attached position. This is shown in figure 21.

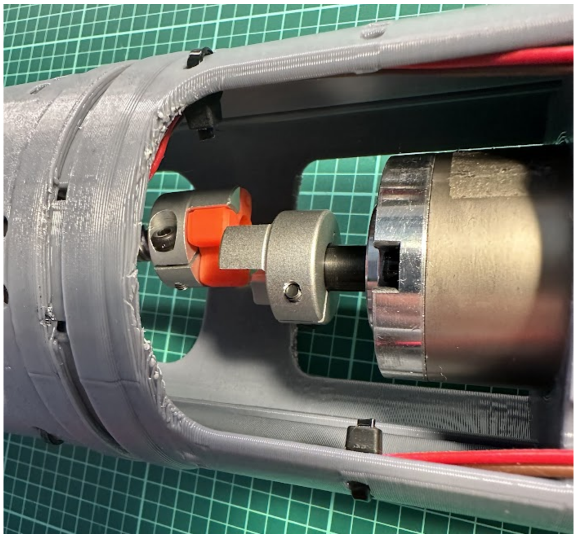


Figure 21: Coupler failure

Additionally, the light pipe was difficult to align and wouldn't function due to any small misalignment. Minor adjustments in the organization of cables internally was also required. Due to the increased thickness of the end caps, they required a significant amount of material and time to create. The most alarming issue with this prototype was that the chosen configuration of magnets was not strong enough to hold the buoyancy of both the R.O.L. and a traditional lobster buoy during testing, which was roughly 30 Newtons (buoyancy calculations can be seen in Appendix B). To begin addressing this problem, a new PVC enclosure was created with a much flatter end cap. This increased the magnetic holding strength, but not significantly enough to impact the R.O.L.'s performance with the lobster buoy.

The second and final prototype of this project was created in order to address the problems discussed above. First, the core was changed to integrate with the newly designed printed circuit board instead of a breadboard. Additionally, a wall was introduced in the motor core to prevent the coupler from sliding apart once in place. The major mechanical change affecting this design was the addition of a third class lever arm into the end cap assembly. This lever arm, shown in figure 22, was created to both simplify the arming of the R.O.L. and to add additional force to the magnet when the device is armed, preventing accidental releases and increasing the buoyancy force that could be applied.

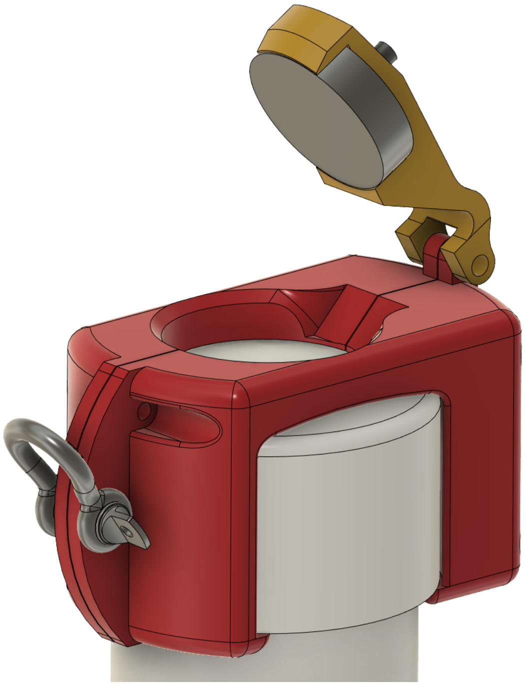


Figure 22: Lever arm in final end cap.

The calculation for the additional holding force of the lever arm is shown in Appendix C. This lever arm meant that the outer magnet could be permanently fitted to the R.O.L., meaning the device would need to hold on to the trap in a different manner. Through our conversations with lobstermen, we identified a traditional way of rigging lobster traps, known as a bridle, shown in figure 23. The bridle is placed into a notch in the lever arm to facilitate the increase in force. The material used in the end cap was also significantly reduced to save cost and production time.

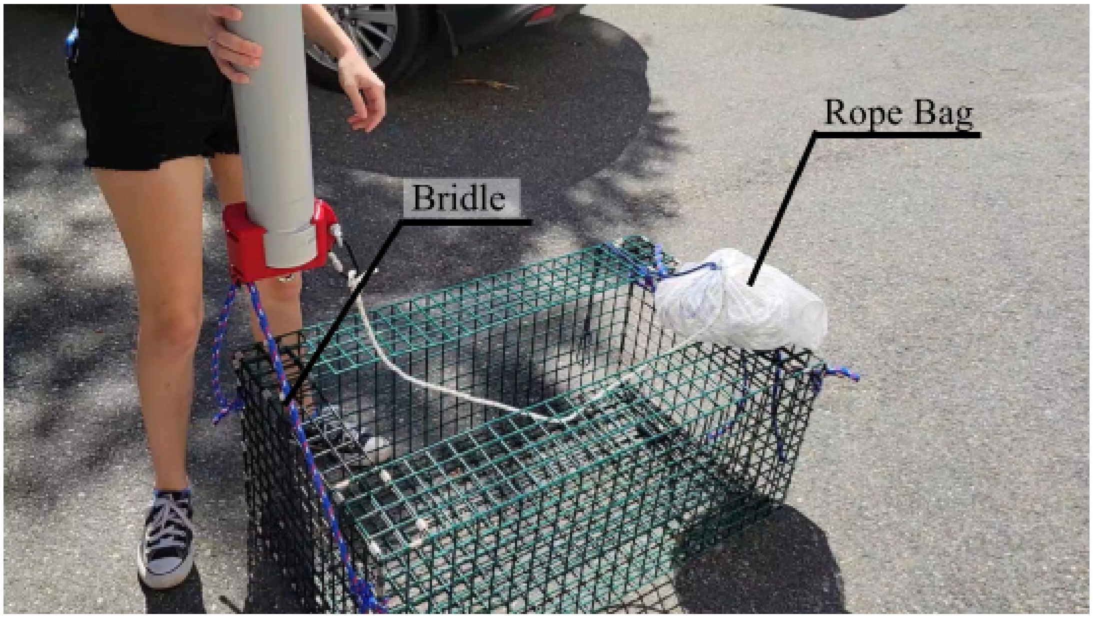


Figure 23: Bridle configuration on the trap

4.3.1.1 Rope Management: Adjustable Rope Bag

Over the course of this project the ideas for rope management changed drastically. Originally, the planned design was a spool, where all of the hardware was kept in a PVC pipe that the rope was coiled around and would uncoil after the release as the buoy rose to the surface. After speaking with lobstermen and others involved in the creation and testing of ropeless lobster systems, we learned that a spool was impractical and would never work in the deeper depths we were aiming for. Our plans then shifted, and we decided to move away from one all encompassing device that held the release mechanism and rope. After continuous brainstorming, we decided we needed some form of adjustable bag that could stretch with a larger amount of rope added and looked into using a mesh bag. We bought a mesh laundry bag, cut off the handle and shortened the cinch pull, and rolled up the bottom of the bag to accommodate a smaller amount of rope. Once this was done, two holes were cut in the bag towards the bottom near where the extra material was rolled up. One end of the rope was tied to a carabiner, and that carabiner clipped around the mesh material left between the two holes, then attached to the trap. During a pool test we learned that this was a point of failure, and after that pool test we pivoted to have the rope tied to the carabiner being completely free of attachment to the bag, going through a larger hole and clipping directly to the trap. This ensured that there would be no force on the rope bag, and the rope bag purely served as a mechanism to contain the rope and keep it from moving around when underwater.

Figure 24: Rope bag during a release

The mesh bag was attached to the trap using a bridle, similar to the way the rope holding the R.O.L. was attached. This bridle was tied to the rope used to decrease the capacity of the bag, limiting the amount of line and allowing for a one step action to increase the size of the bag.

The matter of coiling the rope in a way where it would not tangle was crucial, as the rope bag would only work if the rope could feed easily out of the bag. While lobstermen have their own method of coiling rope in a way to ensure it doesn’t tangle, we wanted to have a simple but effective way for anyone to coil the rope to ensure this device could be used on smaller fishing vessels where they might not have the automatic rope coiling machines, or for other applications. The first attempt to coil the rope worked, but was time consuming. The method is similar to using one’s hand to create a figure 8 pattern with the rope, but was adjusted for our larger diameter rope. This method involved wrapping the rope in the figure-8 pattern, but the individual would use their legs to assist in making the figure 8 pattern. This was impractical, as it required the user to sit on the ground, coil the rope around their legs (a multiple minute process), then place the rope in the bag to deploy. After determining that this method was not practical, a different way was investigated. Instead of the user using their legs, they would wrap the rope around one arm, using the hand and the elbow to create the figure-8 pattern. The user would start with one end in their fist, pull it to behind their fist and wrap it around the elbow on the opposite side that the rope came from, and cross it over the first line back to the first, creating an X on the back of their forearm. This method proved to be much easier, much more reliable, and much more practical for a user.

Once the rope was coiled into the bag, the user could simply grab the free end of the rope, attached to a second carabiner, and attach this to the R.O.L. to allow for release.

4.3.2. Electrical Design Concept

4.3.2.1. Initial Prototype

The electrical systems in the Lobster R.O.L. have evolved significantly since the proof of concept constructed in ECE2799. An initial design to test the system concept was constructed on a solderable breadboard in order to improve the reliability of connections, as the original prototype used a solderless breadboard. This initial design (figures 25 and 27) was intended to test the real time clock, WiFi for programming, and motor control systems. There was no way to make it power efficient, as the ESP8266 based development board used a Linear Drop-Out regulator (LDO) to turn 5V into 3.3V. This type of regulator is cheap, but effectively turns 1/3rd of the power consumed into waste heat. Additionally, the regulator, USB serial communication chips, LEDs, and pull resistors on the board burned a substantial amount of power when the system was sleeping. Even when powered at 3.3V, bypassing the LDO, the system would still draw 4 mA while sleeping. This is drastically more than the datasheet sleep figure of 20 uA of current draw. Despite these drawbacks, this early prototype allowed us to do early pool tests, and identify areas for improvement in the interface, release, and rope handling systems.

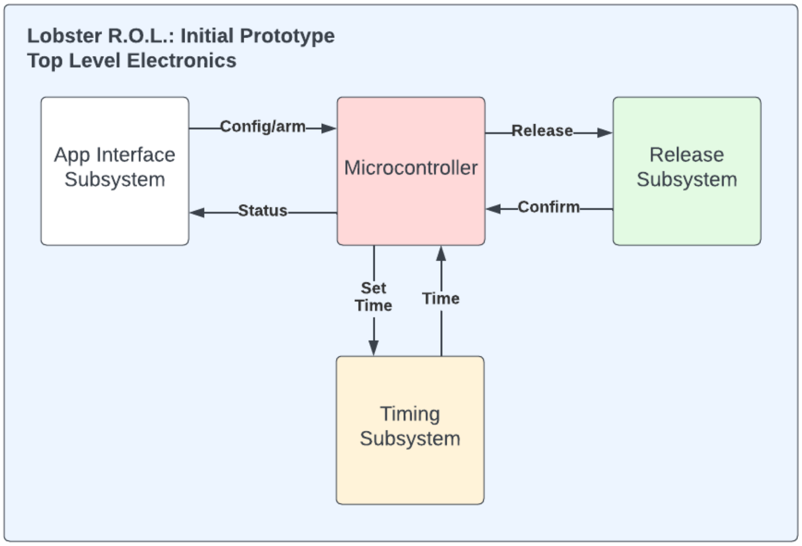


Figure 25: Top level block diagram for early solderable breadboard version.

4.3.2.2. Custom Printed Circuit Board

In order to meet our user requirements and the specifications laid out, we would need to build a custom printed circuit board (PCB). This would substantially reduce cost and assembly time, but most importantly, we could build a system that would operate for long periods without needing to open the device. There were a couple hurdles to tackle here: number one, power draw. The device had to operate without the need for a physical power switch inside the enclosure. This meant that it had to sleep at a very low power consumption. Secondly, the device needed a way to wake up from sleep when the user wanted to configure it. The PCB also needed to be compact, inexpensive, and use components that could be easily sourced. A top level block diagram of the final PCB can be seen below in figure 26. The full schematic for the PCB can be found in Appendix A.

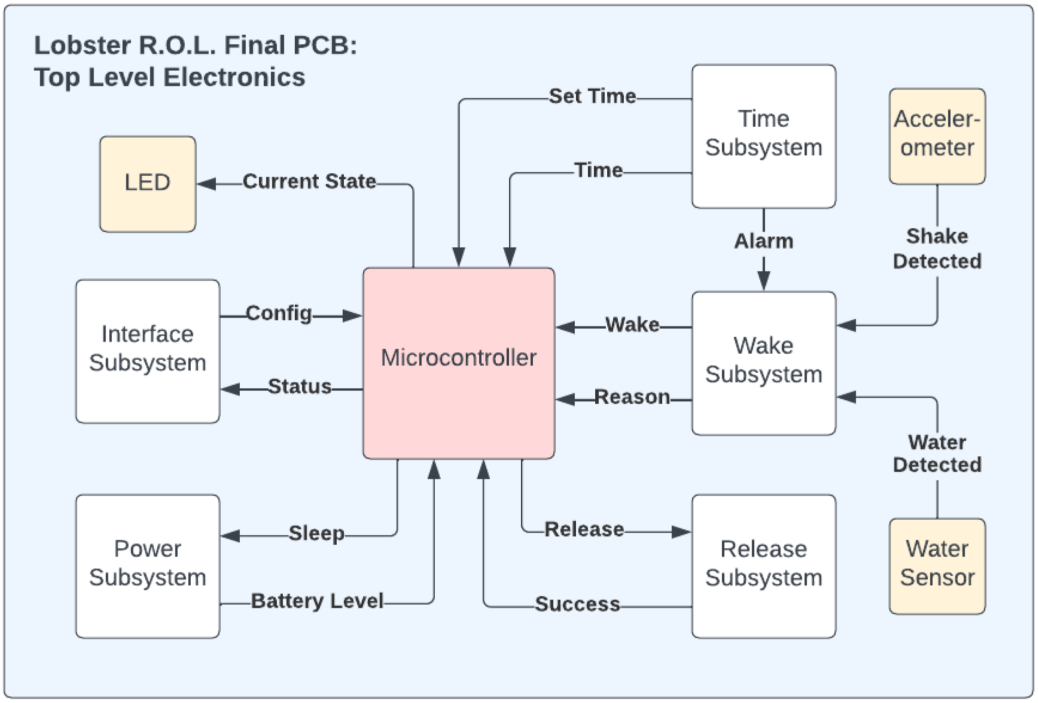


Figure 26: Top level block diagram for the final iteration of the electronics.

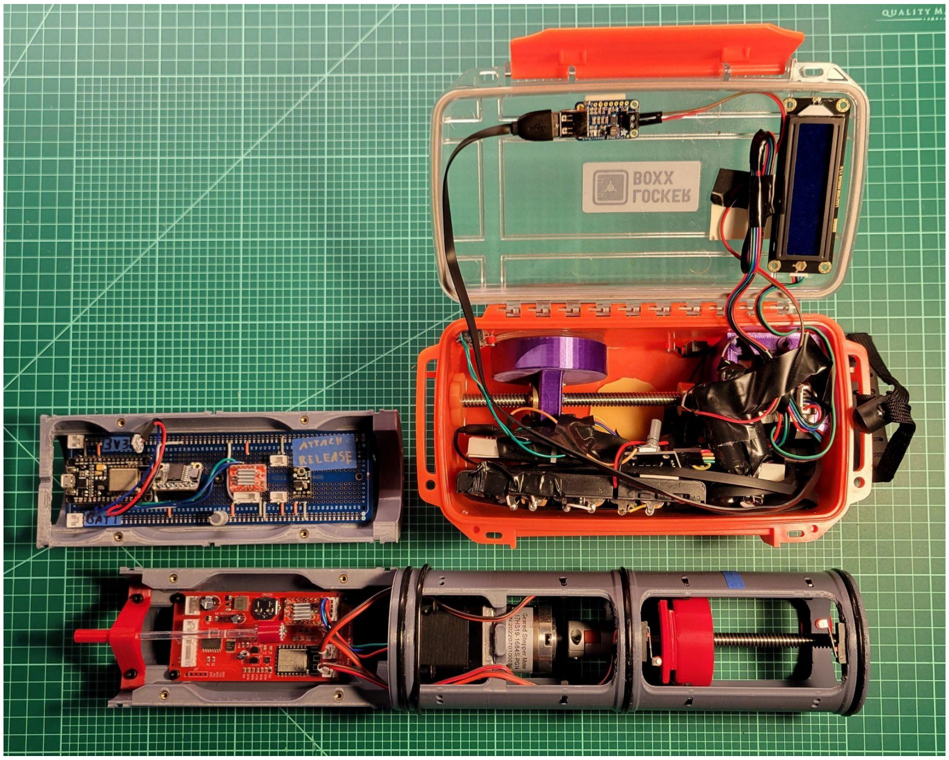


Figure 27: Three generations of electronics and release systems. Top right: ECE2799 proof of concept. Top left: solderable breadboard version. Bottom: PCB and full core.

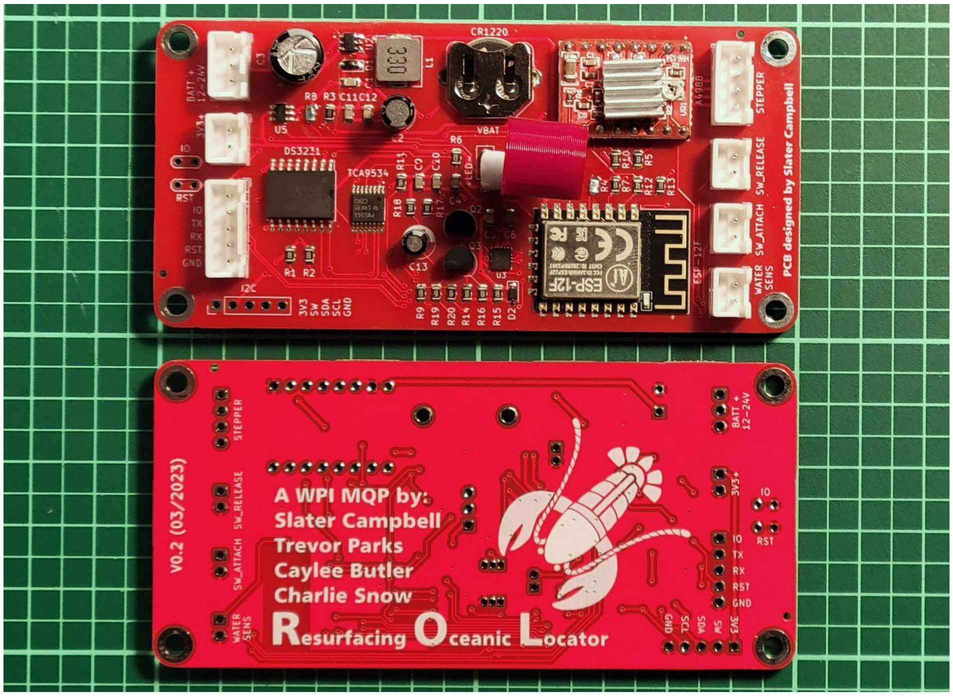


Figure 28: Front and back side of the final PCB iteration.

4.3.2.3. Real Time Clock

In order to accurately store the time and wake the device at the configured date, a DS3231 real time clock is used as described in section 4.2.2. The DS3231 is capable of generating an alarm interrupt to wake the microcontroller. This alarm cannot be set for an interval longer than 1 month, so directly entering the release time as the alarm time is not possible. Instead, the R.O.L. configures the DS3231 to alarm once every day, when the time matches the hours, minutes, and seconds of the programmed release time. On wake, the R.O.L. checks if the current day matches the stored release time, and determines whether it should release or program the alarm for the next day. According to the DS3231 data sheet, in order to generate an alarm, the RTC has to be powered from its main power (VCC) pin. This entirely bypasses the coin cell battery, and activates power hungry logic inside the RTC. This causes it to draw around 82 uA of current. Luckily, there appears to be a mistake in the datasheet; when powered from the coin cell battery (VBAT), the DS3231 will generate the requested interrupt and wake up the main processor. This cuts the current consumption of the RTC by nearly 100x, to 0.84uA. However, cutting power to just the VCC and leaving the I^2C interface powered results in the chip pulling its normal current over I^2C. To achieve our desired low current draw, the PCB implements a load switch which disconnects 3V3 power from both VCC of the RTC and the 10kΩ pull up resistors on SDA and SCL (the two I^2C communication lines). This circuit can be seen below in figure 29.

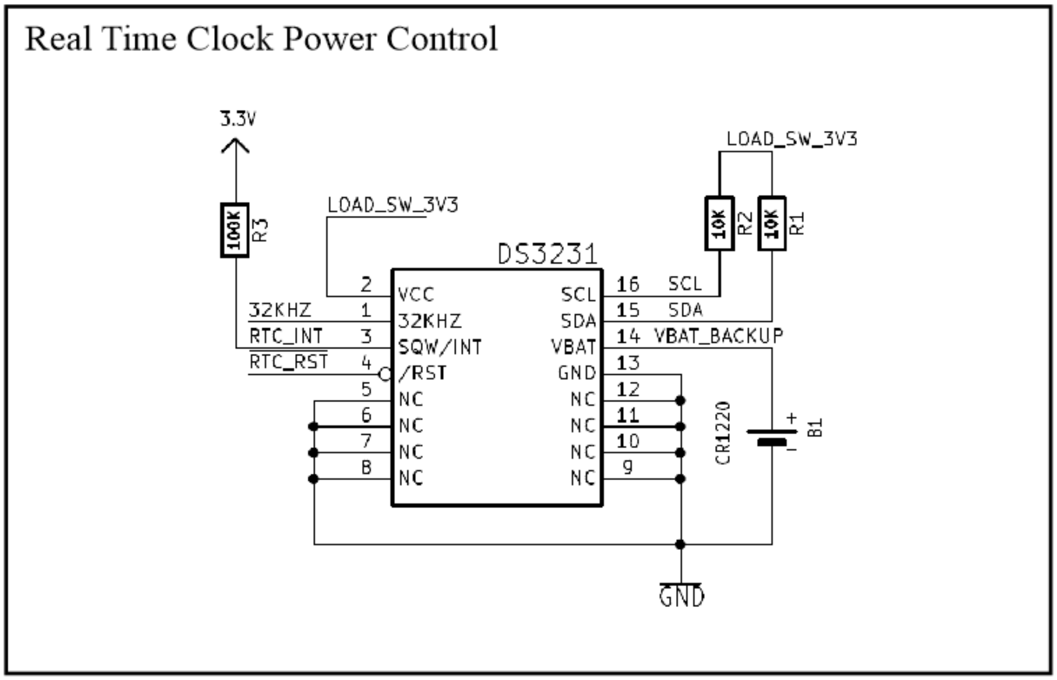


Figure 29: DS3231 real time clock with load switch for power savings.

4.3.2.4. Sleeping and Waking

Figuring out how to wake the device from sleep, without opening the enclosure required some brainstorming. An early idea was to use a magnetic reed switch. The user could wave the external magnet near the reed switch to wake up the device. This had the advantage of being a cheap and simple solution, but there were a few disadvantages. One, the magnet strength required to wake it up would not be configurable, and the orientation of the core inside would affect where the magnet had to be held to activate the switch. Also, if a few Lobster R.O.L.s were stored near each other, their powerful internal magnets could potentially activate the reed switch and drain their batteries. This last issue pushed us to consider alternatives. We investigated the use of two or more rolling ball switches, where a metal ball inside can bridge contacts in certain orientations. With two at different angles, a shake could activate both switches at the same time, which could be connected through an AND gate. When both are activated, it would wake the device. Unfortunately, rolling ball switches can be nearly $2 each, and the logic to monitor them and wake the microcontroller could be inconsistent.

Our final solution was to use an ultra low power accelerometer. The ADXL362 was chosen, as it supports a configurable wakeup mode that consumes only 0.27uA. Additionally, it only costs $2.40 per unit. The acceleration threshold, and how long that threshold needs to be maintained, can be precisely configured, reducing accidental wake events and improving consistency for the user. When the ADXL362 detects a lasting over-threshold event, it pulls an interrupt pin low until the microcontroller responds to it. This should work great in theory, but there is a major issue with how the ESP8266 handles waking from deep sleep.

When an ESP8266 based microcontroller is put into deep sleep, the CPU is fully off. The only hardware that remains on is a very inaccurate internal clock. Unlike many microcontrollers, the ESP cannot be woken through a General Purpose IO pin (GPIO). Instead, it has to be woken by pulsing the RESET pin low, and then allowing it to go high again. As long as RESET is held low, the ESP will not boot. The intended solution is to connect a specific pin, GPIO16, to RESET, and the aforementioned internal clock will generate the necessary pulse and wake the ESP at a preconfigured time. However, the internal clock can only be set for a maximum of ~200 minutes, and may drift as much as 10 minutes in that time. This would be unacceptable for our application where precise timing is needed, and it would waste power waking up so frequently. Additionally, we would be unable to connect other interrupt sources such as the accelerometer, water sensor, and real time clock.

In order to solve this, we employ a monostable multivibrator circuit. The purpose of this circuit is to take a long lasting transition from high to low (such as when the accelerometer generates an interrupt) and turn it into a short pulse low which then returns high. The output of the monostable circuit can be seen in figure 30 below. The yellow trace is connected to the interrupt output, and transitions from high to low when the interrupt arrives. It stays low until the interrupt is cleared. The green trace shows the output at the RESET pin on the microcontroller. The voltage remains below the high threshold for 22.8 milliseconds. This is more than enough time for the microcontroller to successfully wake up.

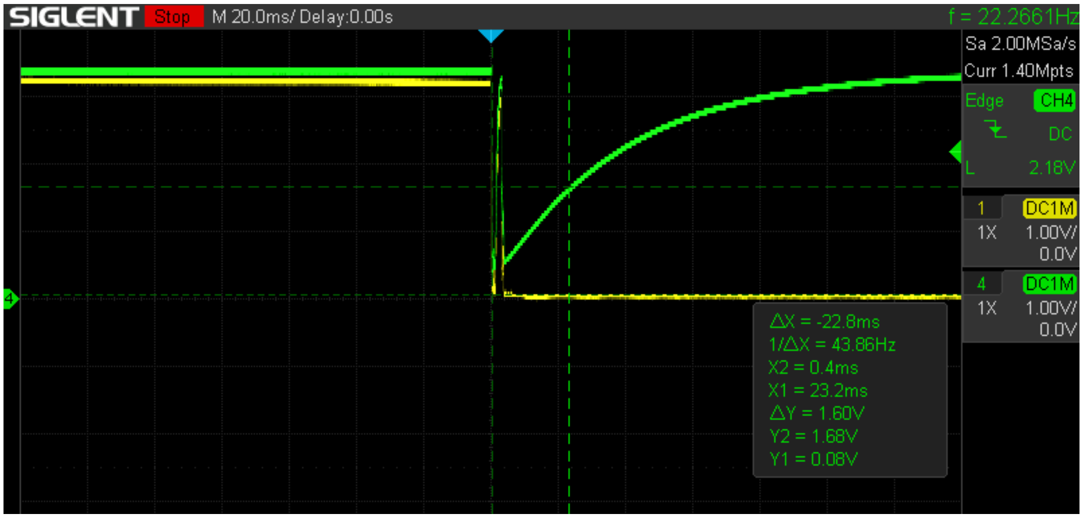


Figure 30: Monostable input (yellow trace) and output (green trace).

To handle having multiple wake events at once, we use a TCA9534 GPIO expander. When an input pin on the expander changes state, it pulls a dedicated interrupt pin low, and when that input returns to its original state, the expander releases the interrupt pin high again. This combines all interrupt sources into a single interrupt pin which can be connected to the monostable circuit. It also provides more General Purpose IO pins, to supplement the very limited number on the ESP-12F.

The diagram for the reset circuit can be seen below in figure 31. In addition to allowing the microcontroller to boot, we want it to be able to block these interrupt events when it is already running. Otherwise, shaking the device while it is awake could corrupt data or interrupt important functions. The PNP transistor Q2 shown in the bottom half of figure 31 allows the microcontroller to disconnect the wake circuit from the reset pin.

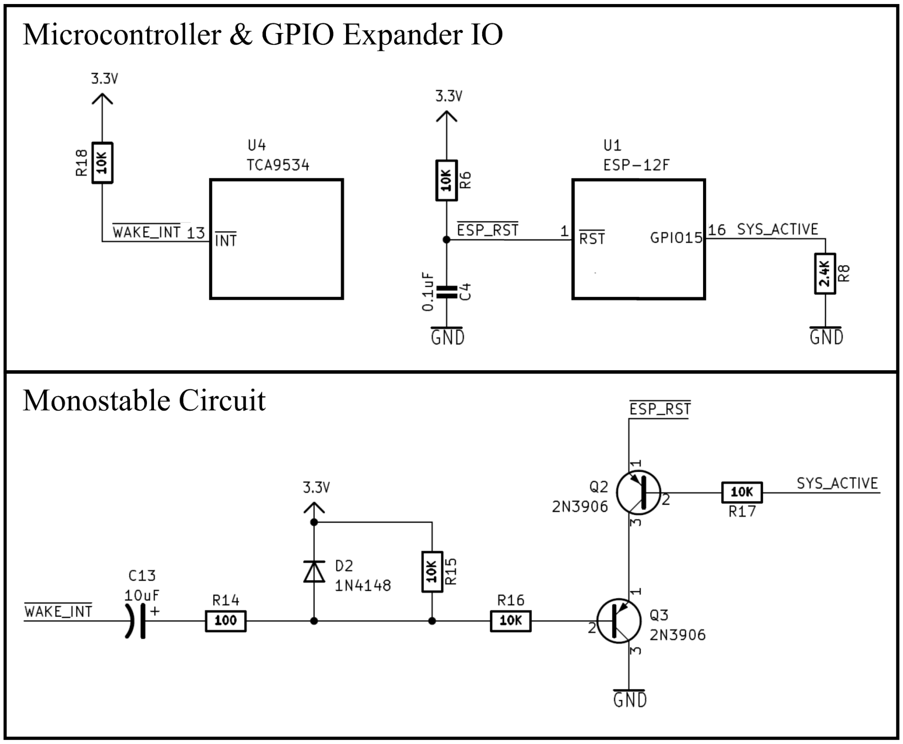


Figure 31: Monostable circuit and relevant connections to the microcontroller and GPIO expander.

4.3.2.5. Power Management

The device uses an RGB (red, green, blue) LED for indicating the current device state, as described in section 4.2.2. An addressable LED was chosen, specifically the SK6812. This is because an addressable LED requires only one pin from the microcontroller, which takes serial data packets to set its color. While the software complexity for controlling this type of LED is higher, it means we do not need separate analog channels for red, green, and blue. One downside of addressable LEDs is that the serial communication hardware inside consumes power passively, even when the LED is off. According to the datasheet, the SK6812 can consume as much as 1 mA at 5 volts. This is called quiescent current. Minimizing quiescent current on the various components of the PCB is critical. Since the LED doesn’t need to be on when the system is sleeping, we can simply disconnect it from power. For this, a low side NMOS switch is used. In other cases, a high side load switch is needed. In the case of the RTC, the load switch prevents a floating ground level. On the first iteration of the PCB, this floating ground would reset the stored time when the system booted. In the case of the motor driver, the load switch is used to disconnect the power for the logic on the driver board, which would otherwise sink about 70uA of current. The battery voltage remains connected, because the leakage there is measurably negligible when the board is powered down.

The stepper motor driver used by the R.O.L. is an A4988 based system, with a breakout board designed by Polulu. This driver was selected because it is widely used in cheap 3D printers, so it is extremely easy to source. It is far more power efficient than an H-bridge motor driver such as the L298N. The current can be tuned with a built-in trim-potentiometer, and it is capable of driving a NEMA-17 stepper motor with up to 2A per coil (with good cooling). In order to actuate a release, the Lobster R.O.L. only needs about 120mA at 14.4V through the motor. One disadvantage of this stepper driver is that in order to step at full speed, the microcontroller needs to spend almost all of its time in the motor loop. The software could potentially be optimized to utilize a dedicated PWM controller and allow the microcontroller to service other tasks such as the app interface, but it is fully functional in its current state.

In order to tell what position the inner magnet is in, two limit switches are used. If we only had one limit switch and power were lost, the device would have to home itself by bringing the magnet back to that limit switch. Then, to know when it reaches the opposite end, it would need to count steps. If the motor were to get temporarily stuck and miss a few steps, the system would have no way of knowing. A closed loop stepper or some sort of encoder system could be used, but simply having a limit switch at each end is simpler, more reliable, and cheaper.

The Lobster R.O.L. is powered by a 14.4V lithium ion battery pack, as described in detail in section 4.1.2. However, the voltage range it can support would allow many battery configurations. The stepper motor driver should receive at least 12V to ensure it has enough torque to release, and to limit excessive current draw. The voltage regulator which supplies the logic to the board supports a wide input range of 4.5V to 24V. Therefore, batteries that operate in the range of 12V - 22V should be perfectly acceptable. The power connectors for the board are keyed so they can only be inserted with the correct polarity. The battery connector uses a wider connector with three pins, so it cannot accidentally be connected to the 3.3V input which would destroy the board.

The microcontroller can read and monitor the battery voltage through a voltage divider, where the node between the two resistors is connected to the Analog to Digital Converter (ADC). The voltage divider uses a 2.2MΩ and 100kΩ resistor, so any input voltage up to 23V stays within the 0-1V range of the ADC. The function in the embedded firmware which processes the battery level will have to be calibrated if a different battery type is to be used. The battery level is relayed to the user through the app, and in the future, the R.O.L. could check the battery when it wakes every day before deciding whether it has enough battery to continue sleeping or whether it should release early.

The aforementioned 3.3V voltage regulator was chosen carefully to maximize efficiency of the board. There were a few important specs: the input voltage range, maximum supplied current, efficiency, minimum active current, and quiescent current. The maximum current needed to be around 140 mA, while the minimum current before auto-shutoff was ideally around 20uA.

The quiescent current should be as low as possible, since it is essentially wasted. The efficiency should be high over the operating voltage range. For this, the MAX1837 switching step-down converter was chosen. A switching converter is far better than the Linear Drop-Out regulator used on the development board in our prototype, because the switching converter can have an efficiency greater than 90%. The MAX1837 in particular can supply up to 250mA, with a 3uA shutdown current, 12uA quiescent current, and an efficiency of around 80% under load, 70% while the system is sleeping. While the theoretical efficiency is not excellent for our 14.4V input, it is good enough given the ultra low current consumption of the board. In actual testing, the PCB consumes 200uA asleep when powered by 3.3V. At 14.4V, the current draw is 53uA while asleep. This translates to 0.66mW at 3.3V vs 0.76mW from the battery, or about 87% efficient. The circuit diagram for the power section of the board is shown in figure 32.

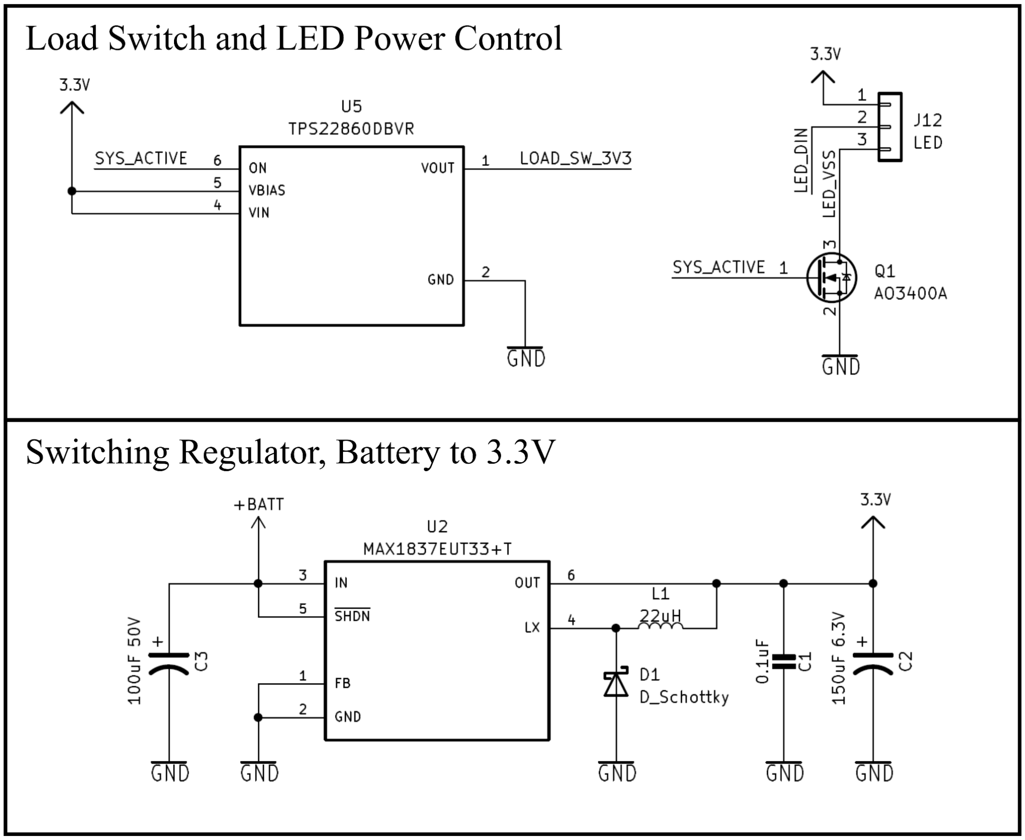


Figure 32: PCB power supply and control.

4.3.2.6. Programming and Interface

To further reduce power consumption, the Lobster R.O.L. PCB does not have any hardware for a USB/Serial interface for programming on the board. Instead, a dedicated programming port features RX and TX pins for UART communication, as well as RST and IO connections which must be pulled low at the right time to set the boot loader mode. This can be done automatically, or with buttons. The programming port could support many interfaces, but we have used it with a USB to UART board that uses an FT232RL chip. These boards are very inexpensive on Amazon, and also support Serial monitor debugging.

In order to configure the release time, set the time on the real time clock, view the battery, and access other settings, an app is used. The app connects to the R.O.L. PCB using a WiFi access point created by the ESP8266. The operation of the WiFi access point is discussed further in section 4.3.3, and the app interface in section 4.3.4.

4.3.3. Embedded Firmware

The firmware that runs on the ESP8266 microcontroller is written in C++, but nearly all of it is C style. It uses the Arduino framework, because the WiFi libraries for the ESP8266 are much more reliable and better documented than those provided directly by Espressif (the designer of the ESP8266). The code was written to be compiled and uploaded by PlatformIO, which replaces the Arduino IDE and provides far more flexibility than the sketch-based system Arduino uses. Of course, a central goal of the firmware is to ensure the system spends as much time as possible in its low power sleep mode, while staying responsive to user inputs and wake events. The sequence diagram in figure 33 shows the general operation of the firmware when the ESP8266 is booted fresh or awoken from sleep.

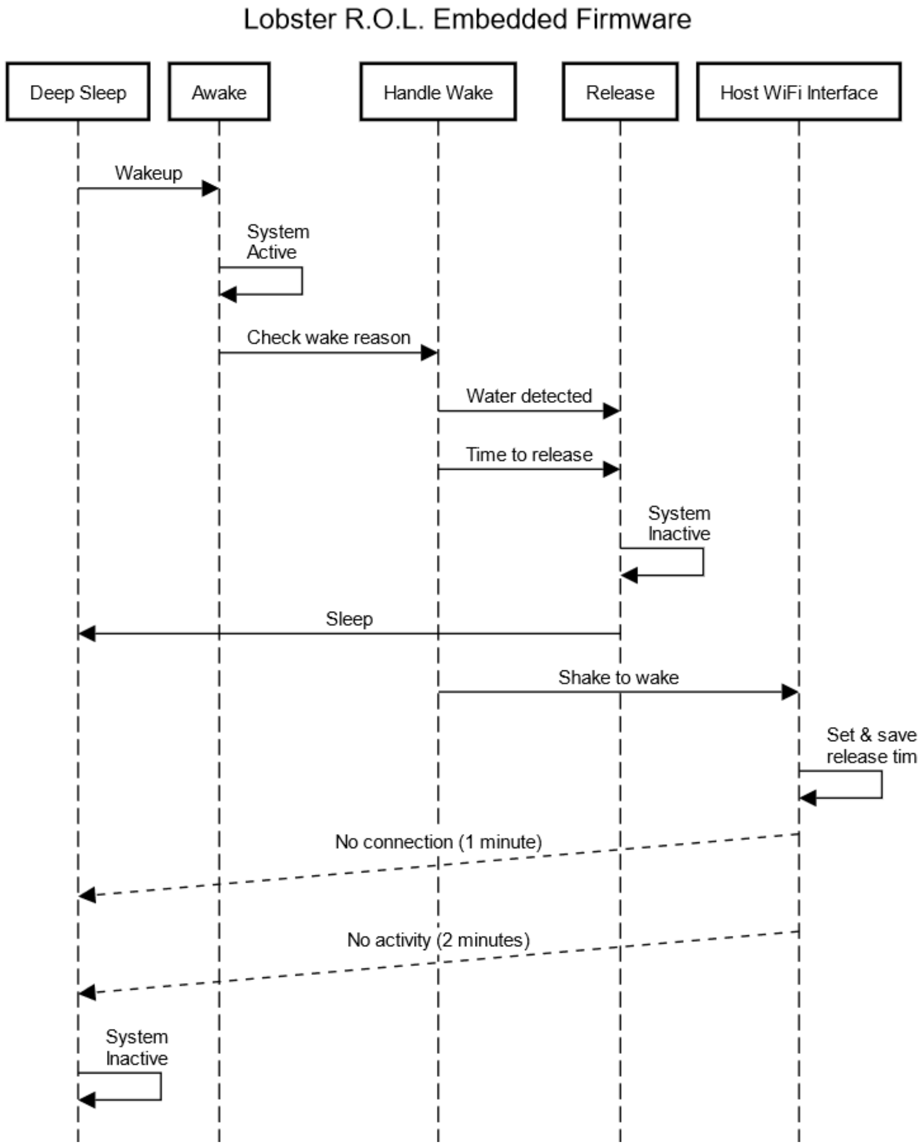
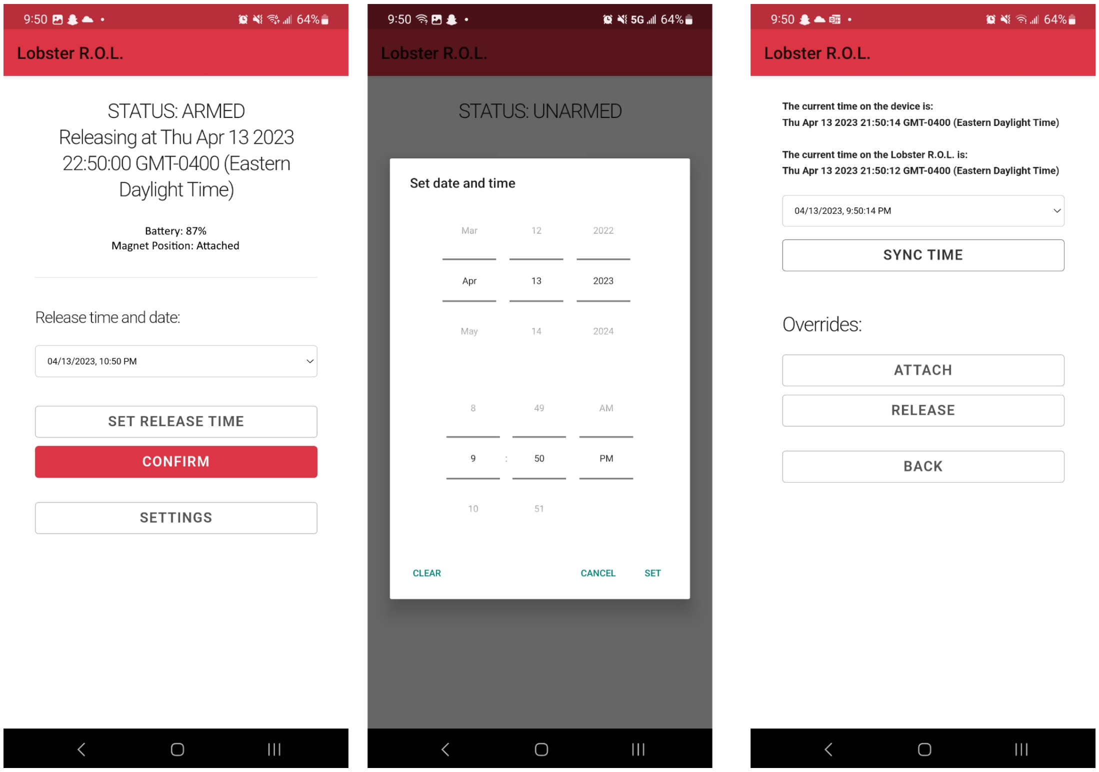


Figure 33: Very simplified sequence diagram of decision making on boot.

4.3.4. Interface Design Concept

The design concept for the interface in figure 34 shows the UI for the Android application. In the starting screen, the device specific page and details of the unit, including the status, release time, battery, and magnet position can be seen. If the unit is unarmed, the user will see the prompt to arm the device. This page also contains a button at the bottom to take you to the unit settings. The middle screenshot shows the datetime picker which allows the user to set the date and time for the R.O.L. to release. The unit settings screen, shown on the right, shows the time on both the device running the app and the R.O.L. itself. It contains the ability to sync the R.O.L. time with the device time, attach the magnet, release the magnet, and return to the R.O.L. control page. While this app is designed for Android devices, since it runs from a wireless access point, it can also be accessed from any device with access to a web browser.



STATUS: ARMED
Releasing at Thu Apr 13 2023 22:50:00 GMT-0400 (Eastern Daylight Time)

Battery: 87%
Magnet Position: Attached

Release time and date:
04/13/2023, 10:50 PM

STATUS: UNARMED

Set date and time

The current time on the device is:
Thu Apr 13 2023 21:50:14 GMT-0400 (Eastern Daylight Time)

The current time on the Lobster R.O.L. is:
Thu Apr 13 2023 21:50:12 GMT-0400 (Eastern Daylight Time)

04/13/2023, 9:50:14 PM

Figure 34: Lobster R.O.L. application UI.

5. Testing

5.1. Leak Testing

The first test that was conducted was preliminary water testing in order to ensure the seals were adequate, before the device was submerged multiple feet underwater. This test was conducted in a bathtub, and the device was fully submerged underwater. This first test was just the outer tube with nothing inside, and due to the buoyancy, it had to be held underwater in order to adequately test the seals. After a couple minutes, the device was removed and opened to check for leakage, and there was no water within the pipe.

For the second test, weights were placed in the tube to mimic the weight of the internal core in order to check the buoyancy of the entire device. While the buoyancy of the entire device was calculated and the calculations predicted that the device would float, this test was partially to ensure that our calculations were correct. Since the weight was not evenly distributed, the side that the weight was on did sink, but the other side floated. We left the device alone to ensure that the seals would hold up over time, but the bathtub drain was not fully operational, so after half an hour the bathtub had drained too much to continue with the test. The device was opened again to ensure that there were no leaks, and the inside was completely dry this time as well.

5.2. Pool Testing

Figure 35: Early prototype after pool testing.

5.2.1. Day 1

The first pool test yielded concerning results at first, as the initial submersion of the device led to a great amount of water within the tube. This first test was purely a leak test to ensure that the electronics would not be damaged when the entire device was submerged. After removing the device, there was about an inch of water in the bottom of the tube. We theorized that the teflon tape around the threaded piece on one of the endcaps had not been secured properly and the endcap hadn’t been tightened quite enough. We dried out the device before replacing the teflon tape and securing the endcap, screwing it in much tighter than the previous time. The tube was submerged again and brought down about 10 feet, the same depth as the first test. This time there were a few drops of water in the tube, but we later discovered that this was residual water from the first test.

After leak testing, we chose to go forward with testing the release mechanism as intended, despite the discouraging results from the first leak test. The internal core was placed within the tube with a protective layer of paper towels on top between the threaded end cap and the core, in case there were any leaks. Once the end cap was firmly secured and a release time was set, the full device was thrown in the pool. As predicted, the device floated due to its buoyancy. Since we had predicted this, we had attached a pulley to the lobster trap that had already been placed at the bottom of the pool, and we used rope to pull the device down towards the bottom of the pool.

As the device began to reach the bottom of the pool (around 10 feet), the trap was pulled up from the bottom due to the buoyancy of the device. The entire pool was 14 feet deep. As we were pulling the device down, we found if we pulled it too aggressively, the magnet would detach too early. We had already theorized that we might need a stronger magnet or that the inside magnet was not reaching the end of the tube. Before we had gone to the pool, we had tested the magnet strength by holding the entire device by just the magnet, and the magnet was not capable of holding the weight of the device in air without detaching. We pulled the device up and reattached the magnet before pulling the device back down the bottom, stopping before the trap started to be pulled up. We let the device sit for 2 minutes, before it was released. The internal mechanism worked as it was designed to and the outer magnet was detached from the device, allowing the release system to resurface. We then performed a second test with the release mechanism. We set another release time, reattached the outer magnet, and tossed the device back in the pool. We pulled it back down again, making sure to stop before the device pulled the trap upwards. The system released on time, and the release mechanism worked as intended.

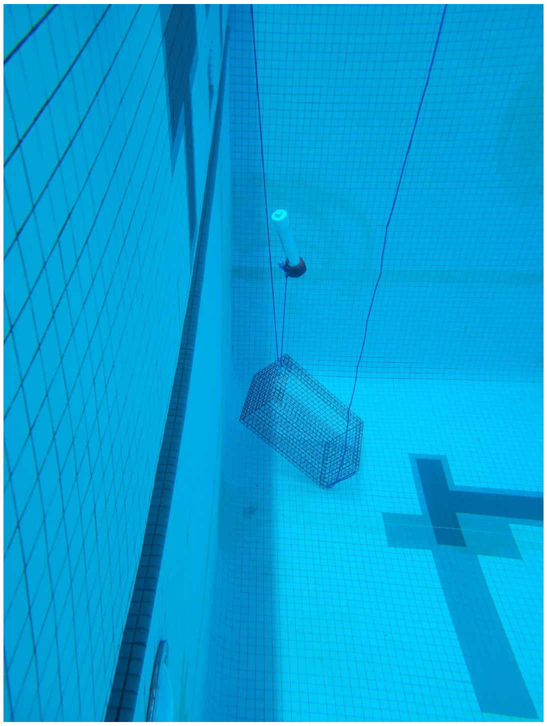


Figure 36: Device during testing.

After we opened the tube, we discovered that the coupler between the motor and lead screw was being pulled apart. While we weren't completely positive at the time, we were pretty confident that the inner magnet was not reaching the end of the tube. This also accounted for why the outer magnet was able to detach too easily. After examining more thoroughly after the test, we confirmed the magnet was only extending part way.

5.2.2. Day 2

The second round of testing worked similarly to the first test, but unveiled many issues that needed to be addressed. The first test conducted was performed in about 10 feet of water, and the device and new rope bag worked perfectly. Between the two days of pool testing, more rope management, as explained in section 4.3.1.2, was implemented, and this pool test was largely to test the new rope system.

The following tests were not as successful. The release mechanism was incredibly reliable and the R.O.L. released every time. However, the rope did not pull out of the bag completely, preventing the R.O.L. from floating to the water's surface. It would float halfway up the water column, then stop due to a tangle within the rope bag since the R.O.L. did not have enough buoyant force on its own to undo the knots. On one test, the R.O.L. floated up halfway, paused due to a knot caught in the bag, and then kept rising, as the force of the R.O.L. on this occasion was enough to pull out the knots. This could not happen reliably, so we attached a spare buoy to the R.O.L. to increase the buoyancy force pulling on the rope. Unfortunately, the buoyancy force was too strong for the magnet to support, and the R.O.L. automatically released once the trap hit the bottom of the pool.

5.2.3. Day 3

The third day of pool testing was the most successful test to date. Out of 8 tests, 7 were completely successful. Between day 2 and 3, multiple changes were implemented. The endcap was redesigned to better hold onto the magnet, and a lever arm was introduced to keep the magnet from popping off prematurely. A buoy was also tied to one end of the device, as we realized that we needed more buoyancy to reliably work with the rope. Rope management was improved upon, as a more efficient and reliable way to coil the rope was implemented and the rope pulled out of the mesh bag, without issue, every time. Two bridles were attached to the short ends of the lobster trap, which kept the rope bag and the R.O.L. on opposite sides of the trap to prevent any lines from tangling. The one test that failed was due to the hinge pin on the new endcap being oversized, which was fixed following testing. When the R.O.L. released, the pin became stuck on the bridle. This prevented the device from rising to the surface. All other tests were successful.

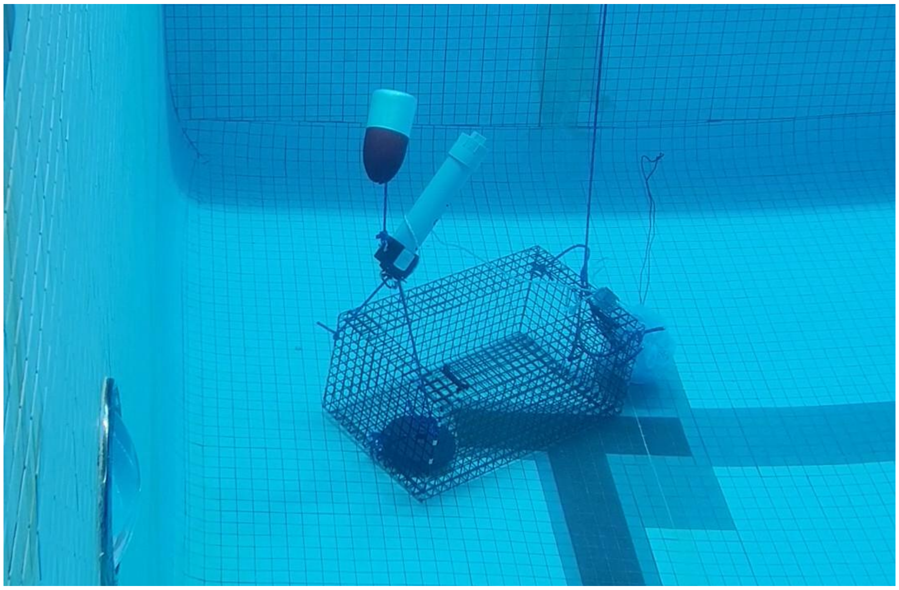


Figure 37: Final prototype during pool testing.

5.3. Ocean Testing

After the success of the pool tests, we elected to test our device in Narragansett Bay to test the viability of the device in deeper depths. The first test we conducted failed, as the same issue that led to one of our failed tests in the pool happened again, where the hinge pin on the designed end cap was much too long. We had planned to fix this before the ocean test, but we were unable to find the right pin needed in time.We assumed that the device would release properly since the failure was so uncommon in our pool tests. We had tied a separate life preserver to the trap as a safety line in case something were to go wrong, and this line was used to bring the trap back up in this case. We determined the issue was indeed due to the pin after reviewing the footage we had recorded from a GoPro camera attached to the trap. We decided to replace this pin with two zip ties in order to continue with testing, and later replaced the pin with the correct size.

Figure 38: Lobster R.O.L. deployed in 45 feet of water.

After fixing the pin issue we conducted four more tests, all in 45 feet of water. All four of these tests were successful and the R.O.L. came back up to the surface all four times. The rope had zero issues at this depth, and reached the surface each time and was able to be used to pull the trap up following each test. The lever arm additionally had no issues keeping the magnet from releasing prematurely, even with the buoyancy of both the R.O.L. and buoy.

After performing the five ocean deployments, we decided to do an overnight test. We left the trap and device armed in slightly over 8 feet of water at the end of the boat's dock and set a release time. The device, as predicted, released exactly at the right time, just as it had with the other tests.

Figure 39: Device after successfully releasing overnight.

5.4. Rope Management Testing

For initial rope testing, the rope was simply thrown in the trap and pulled out the side with no restrictions on the rope's movement, other than it had to come out of the trap between the wire sides. This was to see how the rope moved and reacted to being pulled at a fast rate. This was done a couple times, and provided key insight on how the rope moved and to how wuzzles formed. After these tests, and designing, two solutions were tested. The first one consisted of using a mesh bag to hold the rope tightly against one side of the trap. With the first test, the rope was coiled, and then placed into the trap before the bag was tightened against the sides. This technique ultimately failed testing, as multiple wuzzles were formed that were too big to pass through the side of the trap. As a secondary test, the rope was fed into the trap and was allowed to place itself, using the confines of the mesh bag and the trap walls to contain it. Once all of the rope was in, the rope was quickly pulled out again, and this test resulted in no wuzzles.

The second design solution involved a cinch bag separate from the trap. This was designed to avoid impacting the trap in any capacity. The rope was placed in the bag and the bottom of the bag was rolled and tied to decrease the amount of space the rope had to move around in. The rope was coiled in a figure 8 pattern, as the sink line we used was double stranded, and double stranded rope naturally wants to form a figure 8 pattern when being coiled. Once the rope was placed in the bag, it was cinched and left with an opening that was about a quarter inch in diameter and was just slightly larger than the diameter of the rope. The end of the rope that came out of the opening was tied to the R.O.L., while the other end was tied to a carabiner. There were two holes cut in the bag to slide the carabiner through to attach to the trap. This setup worked in above ground testing and there were several successful tests of using human force to pull the rope out of the bag. As mentioned in the pool testing sections, this design failed to be adequate in underwater testing. The piece of mesh between the two holes that the carabiner relied on broke on the first test. Additionally, the coiling method proved to be ineffective and the rope bag had too many degrees of freedom. The trap fell on the rope bag multiple times, requiring readjustment of where the trap was laying, which would not be possible in a real life setting. The rope would also get snagged in a corner of the trap, adding friction and preventing the rope from coming out as well. After this test, it was obvious that the rope bag needed a more stable attachment point.

During our third pool test, rope management was significantly improved upon. The attachment of two bridles, one for the R.O.L. to attach to and one to hold the rope bag, was the main factor in this improvement. In this test, the rope was able to pull completely out of the bag without tangling, pull the full weight of the trap up without breaking, and was much easier to reset due to the new coiling technique. The only issue that occurred was due to a pin in the hinge mechanism, as stated earlier in day 3 of the pool testing section. The following ocean test yielded similar results and the rope had no issues with varying depths from 14 feet in the pool to 45 feet in the ocean.

5.5. Testing Results

Type of test	Result
Initial Leak Testing	● Good seal, no residual water in the tube ● Very buoyant
Pool Testing: Day 1	● Need secondary seal to ensure no leakage ○ If the end cap is not secured very tightly currently the device could be destroyed ● Coupler pulled apart by magnet ○ Length of tube needs to be reassessed ● Need stronger outer magnet, current one cannot support the weight of the device ● Very buoyant
Pool Testing: Day 2	● Rope bag needs less freedom to move ● Rope needs to be attached to the trap in a way to not pull on the rope bag ● Rope bag needs to be on the opposite side of the R.O.L. to prevent the different ropes from becoming entangled ● Combination of device and buoy has too much buoyancy to be supported by the magnet ● R.O.L. needs more force pulling on the rope
Pool Testing: Day 3	● Hinge pin needs to be shortened ● Lever arm adequately supports the force of the device and buoy to prevent a premature release ● Bridles on both sides of the trap adequately support the device and the rope bag and prevent them from becoming entangled
Ocean Test: 45 feet	● Pin needs to be replaced with the correct size pin lengthwise

	• R.O.L. appears to leak around the light pipe slightly, needs more epoxy
Ocean Test: Overnight	• Magnet can corrode over extended use

6. Conclusions and Future Recommendations

6.1. Conclusions

The goal of this project was to create a usable and inexpensive lobster trap add-on to eliminate the need for a static buoy line in the vertical water column. This device had a material cost of $208, but with different manufacturing techniques and bulk ordering of components, this price would decrease substantially. With more and more regulations and mandates limiting a lobsterman's ability to fish, the need for this device has been rapidly increasing. The low material cost for this device is very promising, as at this price point, units for purchase would be under $300-400 depending on markup, which is significantly cheaper than most other devices on the market. The most important thing about this price point is that it provides accessibility, allowing for smaller businesses or independent fishers to have a better chance of obtaining a ropeless device and avoid being shut-down by regulations. This project was driven by the more visible issue of protecting the whales, but as we researched and interviewed lobstermen, we discovered our secondary mission: protect the lobster fishing industry. This industry is the backbone of many shoreline communities, especially in Maine, and its collapse would massively impact hundreds of communities and livelihoods.

6.2. Future Recommendations

Throughout the course of this project, there were many things that were discovered that would make our device work better and would put our device above competitors, but were unable to be implemented due to scope and timeline of the project. The following recommendations would be some of our next steps, granted we were to continue working on this device after the completion of this project.

6.2.1. Replace a timer based release system with an acoustic release system

After interviewing numerous lobstermen, we discovered multiple issues with implementing a timer based release system into a final product that could be sold. Many lobstermen expressed concern with the timer, as their jobs are weather dependent and not always predictable. They were concerned that if they set a release time and a storm unexpectedly rolled in, they would not be able to make it back for the time they set the release for. This would lead to a static buoy line in the water for an extended period of time, which this device aims to eliminate. Many lobstermen we talked to said they would only use a ropeless system given they can use it on-demand. We chose to use the timer based system as a proof of concept, as there was not enough time during this project to learn enough about acoustic systems to be able to implement one into our system now. In the future, this product should integrate with an acoustic system, whether that be existing or a developed one.

6.2.2. Adapting mechanism for deeper depths

Currently, our mechanism has only been tested up to 45 feet. Our initial goal was to make a system that worked for deep sea fishing, however, we quickly realized creating this mechanism would extend beyond the scope of this project and we pivoted to work for inshore fishers, up to 100 to 200 feet. If this project were to continue, adapting the mechanism to work with deeper depths (300-500 feet) would be highly recommended. This would entail ensuring the device can handle the pressure associated, the length of rope needed, and other factors that have not been considered.

6.2.3. Create a more robust rope storage bag

Right now, the rope bag used works well and will continue to work for the scope of this project. However, if this were to be used by a lobsterman in its current state, the lobsterman may find themselves having to replace the bag. The current system is an adapted mesh laundry bag, and if were to rip, it would need to be replaced. For future iterations of this project, designing and manufacturing a bag that can be adjusted for different amounts of rope like the current bag can while being made of a stronger, more robust material, would greatly increase the longevity of the device.

6.2.4. Durability and Longevity

Due to the limited time available, we were unable to test the durability or longevity of this device. While the device withstood several rounds of testing, each of these testing rounds incorporated new and improved changes, so very few components were used in all of the tests performed. This device should be tested in conjunction with a willing lobsterman to test how many deployments it can handle and how well it holds up under the conditions of its intended use. After our 24 hour test, we noticed a significant increase in corrosion on the outer magnet due to salt water and salt crystals had formed on our printed end caps. Additionally, while PVC can provide a durable and pressure resistant housing, PVC can become brittle when exposed to UV rays. Providing a solution to protect the PVC housing would be critical for real time deployment of this device.

6.2.5. Increase Manufacturability

One goal of this project was that of turning this device into a manufacturable and therefore marketable product. This objective fell to the back burner as time and the scope of this project quickly caught up to us. We did create a manufacturable design through the use of an additive manufacturing process, but 3D printing requires significant manufacturing and processing time, while compromising on tolerances and strength. If given more time, we feel that the internal cores could be redesigned to be compatible with injection molding. Injection molding provides tighter tolerances with a significantly reduced production time [36].

In addition to changing the manufacturing process, we feel that many design changes could be made to simplify the assembly. Firstly, researching a way to combine the designed end caps with that of the PVC end caps could decrease complexity and assembly. This would remove the need for fasteners on the outside of the enclosure, saving time and money. Many of the fasteners used within the internal core could be replaced with snapfits to further simplify the assembly. Lastly, a redesign of the battery and light pipe alignment fixture and handle would be required to ensure ease of use and maintenance.

6.2.6. Electronics Upgrades

While the R.O.L. electronics are extremely power efficient right now, they could become even more efficient. Changing the microcontroller from an ESP8266 to an ESP32 would reduce current consumption in sleep by 10 uA, but it would also remove the need for the wake circuit because the ESP32 can wake from deep sleep with a GPIO pin. This would remove the need for the GPIO expander too, simplifying the board. Additionally, this change would let the R.O.L. communicate over Bluetooth Low Energy (BLE) which would lower power consumption even further. WiFi would still be an option, since it would be better for programming multiple units on the boat at once. Programming multiple units at a time should be added in the future. Finally, since the ESP32 is dual core, it could run the motor faster while still servicing the WiFi/Bluetooth loops and watchdog timer, allowing the system to be more responsive and reducing power consumption even further. The battery pack could be custom made from 18650 cells, cutting the price of the battery by 50%.

6.2.7. App Improvements

While the app in its current state is functional and user friendly, there are many improvements that can be made to it. The following is a list of app improvements that are critical to the Lobster R.O.L. being employed in commercial lobster fishing:

- Map with the ability to mark the location of the R.O.L.
- Ability to handle multiple units in app

The following is a list of improvements that if made would enhance user experience and ensure better functionality:

- Instruction manual

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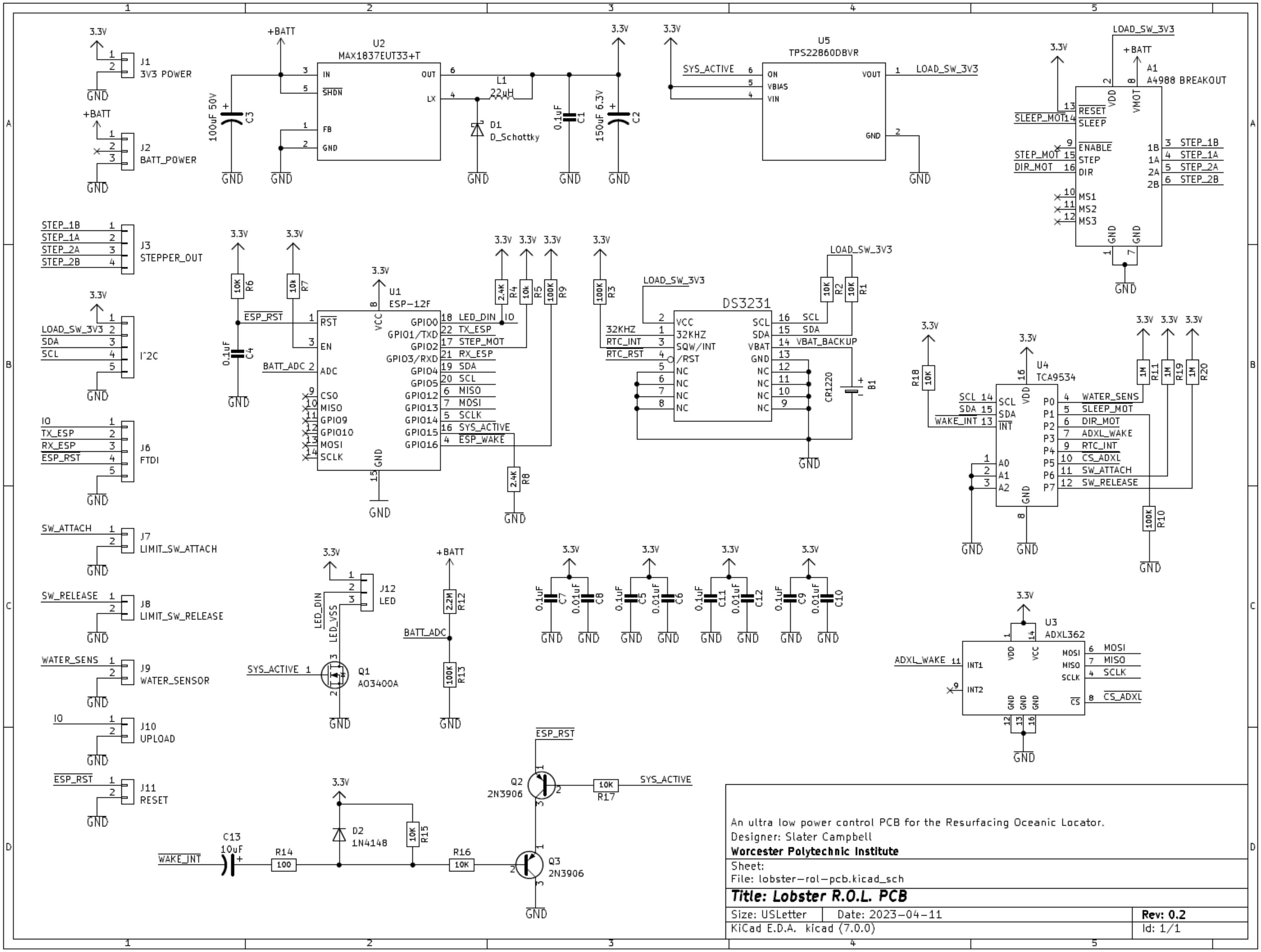
Appendices

Appendix A: Full PCB Schematic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3V3 POWER
J2
BATT_POWER
J3
STEPPER_OUT
STEP_1B
STEP_1A
STEP_2A
STEP_2B
I²C
LOAD_SW_3V3
SDA
SCL
J6
FTDI
IO
TX_ESP
RX_ESP
ESP_RST
J7
LIMIT_SW_ATTACH
SW_ATTACH
J8
LIMIT_SW_RELEASE
SW_RELEASE
J9
WATER_SENSOR
WATER_SENS
J10
UPLOAD
J11
RESET
+BATT
3.3V
GND
U2
MAX1837EUT33+T
IN
SHDN
FB
OUT
LX
C3
100uF 50V
L1
22uH
D1
D_Schottky
C1
0.1uF
C2
150uF 6.3V
U5
TPS22860DBVR
SYS_ACTIVE
ON
VBIAS
VIN
VOUT
LOAD_SW_3V3
A1
A4988 BREAKOUT
RESET
SLEEP
SLEEP_MOT
ENABLE
STEP
STEP_MOT
DIR
DIR_MOT
MS1
MS2
MS3
VDD
VMOT
1B
1A
2A
2B
R6
10k
R7
10k
ESP_RST
C4
0.1uF
BATT_ADC
U1
ESP-12F
RST
EN
ADC
CS0
MISO
GPIO9
GPIO10
MOSI
SCLK
VCC
GPIO0
GPIO1/TXD
GPIO2
GPIO3/RXD
GPIO4
GPIO5
GPIO12
GPIO13
GPIO14
GPIO15
GPIO16
LED_DIN
TX_ESP
STEP_MOT
RX_ESP
SDA
SCL
MISO
MOSI
SCLK
SYS_ACTIVE
ESP_WAKE
R4
2.4K
R5
10k
R9
100K
R8
2.4K
R3
100K
DS3231
32KHZ
RTC_INT
RTC_RST
VCC
SQW/INT
/RST
NC
SCL
SDA
VBAT
VBAT_BACKUP
R2
10K
R1
10K
B1
CR1220
R18
10K
U4
TCA9534
WAKE_INT
INT
A0
A1
A2
P0
P1
P2
P3
P4
P5
P6
P7
WATER_SENS
SLEEP_MOT
DIR_MOT
ADXL_WAKE
RTC_INT
CS_ADXL
SW_ATTACH
SW_RELEASE
R11
1M
R19
1M
R20
1M
R10
100K
J12
LED
LED_DIN
LED_VSS
Q1
AO3400A
R12
2.2M
R13
100K
C7
0.1uF
C8
0.01uF
C5
0.1uF
C6
0.01uF
C11
0.1uF
C12
0.01uF
C9
0.1uF
C10
0.01uF
U3
ADXL362
ADXL_WAKE
INT1
INT2
VDD
VCC
MOSI
MISO
SCLK
CS
CS_ADXL
Q2
2N3906
R17
10K
D2
1N4148
R15
10k
C13
10uF
R14
100
R16
10K
Q3
2N3906
An ultra low power control PCB for the Resurfacing Oceanic Locator.
Designer: Slater Campbell
Worcester Polytechnic Institute
Sheet:
File: lobster-rol-pcb.kicad_sch
Title: Lobster R.O.L. PCB
Size: USLetter
Date: 2023-04-11
Rev: 0.2
KiCad E.D.A. kicad (7.0.0)
Id: 1/1

Appendix B: Buoyancy Calculations

In order to determine the buoyancy of both the R.O.L. and the buoy, each element was placed in a plastic tub filled with water. The water line was marked before the element was added, then the new water line was marked. The element was then taken out of the water, and water was added to the plastic tub until the water line was at the new water line. The amount of water needed to get to this point was measured and used to calculate the buoyancy.

Buoyancy of the R.O.L.

$Fb = \rho g V$

Where ρ is the density of water, g is the acceleration due to gravity, and volume is the volume water displaced when the R.O.L. was placed in water.

$Fb = 997\, kg/m^3 (9.81\, m/s^2)(0.00331224\, m^3) = 32.396\, N$

$Force\ on\ the\ magnet = Fb - mg = 32.396\, N - 2.651 kg(9.81\, m/s^2) = 6.389\, N\ upwards$

Buoyancy of the Buoy:

$Fb = \rho g V$

Where ρ is the density of water, g is the acceleration due to gravity, and volume is the volume water displaced when the buoy was placed in water.

$Fb = 997\, kg/m^3 (9.81\, m/s^2)(0.00260247\, m^3) = 25.454\, N$

$Force\ on\ the\ magnet = Fb - mg = 25.454\, N - 0.212\, kg(9.81\, m/s^2) = 23.374\, N\ upwards$

Appendix C: Lever Arm Calculations

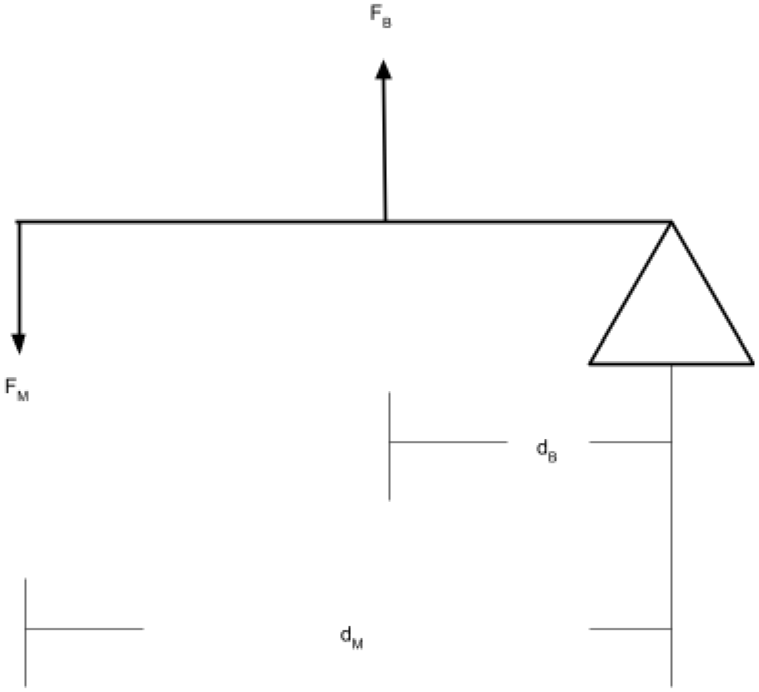
To find the strength of the magnetic field used in the Lobster R.O.L., a spring scale was used to measure the force required to pull the magnets apart. This force was then used in conjecture with the buoyancy forces to determine the locations of features on the lever arm.

Total Buoyancy(F_B): 29.763 ~30 N

Magnet strength (F_M):~9.81 N

$F_m * d_m = F_B * d_B$

For



d_M was determined to be .07m or 70mm as this would be half of the diameter of the end cap.

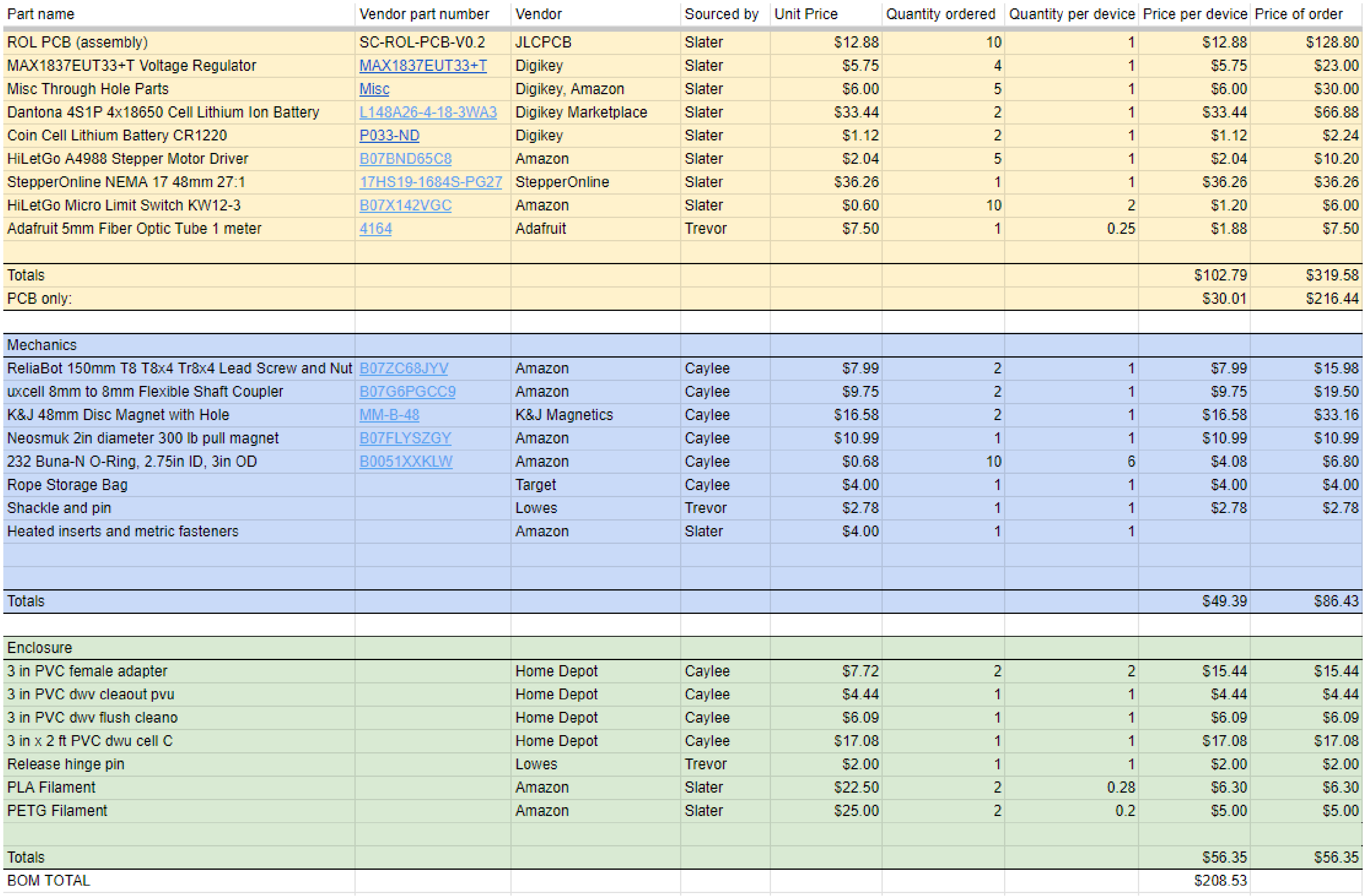
The goal was to have the force be equal to 1.5x the strength of the magnet.

$1.5 = .6867 \text{ Nm} / (30\text{N} * X \text{ m})$

$X \text{ m} = .6867 \text{ Nm} / (30\text{N} * 1.5)$

$X = .015\text{m}$

Appendix D: Bill of Materials



Part name	Vendor part number	Vendor	Sourced by	Unit Price	Quantity ordered	Quantity per device	Price per device	Price of order
ROL PCB (assembly)	SC-ROL-PCB-V0.2	JLCPCB	Slater	$12.88	10	1	$12.88	$128.80
MAX1837EUT33+T Voltage Regulator	MAX1837EUT33+T	Digikey	Slater	$5.75	4	1	$5.75	$23.00
Misc Through Hole Parts	Misc	Digikey, Amazon	Slater	$6.00	5	1	$6.00	$30.00
Dantona 4S1P 4x18650 Cell Lithium Ion Battery	L148A26-4-18-3WA3	Digikey Marketplace	Slater	$33.44	2	1	$33.44	$66.88
Coin Cell Lithium Battery CR1220	P033-ND	Digikey	Slater	$1.12	2	1	$1.12	$2.24
HiLetGo A4988 Stepper Motor Driver	B07BND65C8	Amazon	Slater	$2.04	5	1	$2.04	$10.20
StepperOnline NEMA 17 48mm 27:1	17HS19-1684S-PG27	StepperOnline	Slater	$36.26	1	1	$36.26	$36.26
HiLetGo Micro Limit Switch KW12-3	B07X142VGC	Amazon	Slater	$0.60	10	2	$1.20	$6.00
Adafruit 5mm Fiber Optic Tube 1 meter	4164	Adafruit	Trevor	$7.50	1	0.25	$1.88	$7.50
Totals							$102.79	$319.58
PCB only:							$30.01	$216.44
Mechanics								
ReliaBot 150mm T8 T8x4 Tr8x4 Lead Screw and Nut	B07ZC68JYV	Amazon	Caylee	$7.99	2	1	$7.99	$15.98
uxcell 8mm to 8mm Flexible Shaft Coupler	B07G6PGCC9	Amazon	Caylee	$9.75	2	1	$9.75	$19.50
K&J 48mm Disc Magnet with Hole	MM-B-48	K&J Magnetics	Caylee	$16.58	2	1	$16.58	$33.16
Neosmuk 2in diameter 300 lb pull magnet	B07FLYSZGY	Amazon	Caylee	$10.99	1	1	$10.99	$10.99
232 Buna-N O-Ring, 2.75in ID, 3in OD	B0051XXKLW	Amazon	Caylee	$0.68	10	6	$4.08	$6.80
Rope Storage Bag		Target	Caylee	$4.00	1	1	$4.00	$4.00
Shackle and pin		Lowes	Trevor	$2.78	1	1	$2.78	$2.78
Heated inserts and metric fasteners		Amazon	Slater	$4.00	1	1		
Totals							$49.39	$86.43
Enclosure								
3 in PVC female adapter		Home Depot	Caylee	$7.72	2	2	$15.44	$15.44
3 in PVC dwv cleaout pvu		Home Depot	Caylee	$4.44	1	1	$4.44	$4.44
3 in PVC dwv flush cleano		Home Depot	Caylee	$6.09	1	1	$6.09	$6.09
3 in x 2 ft PVC dwu cell C		Home Depot	Caylee	$17.08	1	1	$17.08	$17.08
Release hinge pin		Lowes	Trevor	$2.00	1	1	$2.00	$2.00
PLA Filament		Amazon	Slater	$22.50	2	0.28	$6.30	$6.30
PETG Filament		Amazon	Slater	$25.00	2	0.2	$5.00	$5.00
Totals							$56.35	$56.35
BOM TOTAL							$208.53	