

An Electronic Input System for Saltwater Animal Enclosures

Submitted in partial fulfillment of the requirements for the degree of
Bachelor of Science in
Electrical Engineering and Electrical Engineering Technology

by

Chris Dombrosky	EE
Brandon Carroll	ELTN
Nathaniel Collum	EE
Hayden Lampert	ELTN

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Faculty Advisor: Dr. Dieter Vanderelst
External Advisor: Dr. Katie Kalafut

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Abstract

In this project, we designed a prototype input collection system for use in interactive electronic systems in saltwater animal enclosures. Increasing interactivity in enclosures has the potential to improve animal welfare and allow for research and behavior monitoring. Implementing an input device underwater is made difficult by the lack of premade input devices that function underwater, waterproofing requirements, and the ineffectiveness of wireless communication methods underwater. To address these challenges, we designed a prototype input system that includes a custom submersible pushbutton, fiber optic communication, wirelessly rechargeable battery, and extensive waterproofing features. This prototype functions as a pushbutton that can be installed underwater and connected to an Arduino through a fiber optic cable. It provides a tactile input for animals while maintaining safety by not exposing wires or electronics to water. Although it only functions as a pushbutton in its current state, this prototype was designed to be easy to use and easy to add additional sensors or input devices to. Overall, it meets the basic needs presented by our advisors while also making future work and improvements easier.

Introduction

Motivations

The goal of this project is to develop a prototype input collection system that can be used by zoos to give animals control over systems and devices in their enclosure. An example application is an electronic feeding system in which animals can control when food is dispensed. In this application, the control system for the feeder would need to be connected to an input device such as a pushbutton or lever that is accessible to the animals. This is a straightforward task for terrestrial animal enclosures, but not for aquatic enclosures. In this project, we will work to develop an input collection system that zoos can use safely and easily in aquatic enclosures.

The primary motivation for developing such a system is to improve the welfare of captive animals. A 2011 research article on the use of technology in zoos states that “control over the environment is important for animal welfare” [1]. This paper also lists temperature and outdoor access as things animals can be given control over. As previously mentioned, our prototype will be designed to allow zoos to connect the control systems of these types of enclosure features to a device animals can interact with.

Another use intended for our prototype is data collection. In the example of an animal-controlled feeder device, the feeder’s controller could also log records of when inputs from our prototype were received. This would provide a record of when and how frequently animals requested food. An obvious use for this data is research and monitoring animal behavior, but it could also be used to improve the visitor experience where it is used as dynamic graphics, which has been shown to be more interesting and informative to visitors [1]. Our prototype will not only provide zoos with the means to give animals control over electronics, but it will also provide an opportunity to collect data on animal behavior.

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Background

The use of technology for improving animal welfare and visitor experience at zoos has become increasingly studied, particularly with great apes [2]. An example of this is the use of a touchscreen computer with orangutans at the Atlanta Zoo. A 2012 paper studied the effects of this computer on the orangutans and zoo visitors [3]. The computer involved the orangutans completing simple tasks such as matching images or drawing on the screen to sometimes be rewarded with food. This paper found that zoo visitors were generally positive towards the idea of technology being used in animal enclosures, and that the experience of visitors was improved when animals were observed interacting with the device. Although this use of technology provided some enrichment for the orangutans, the focus was more on research than animal welfare.

Similarly, existing technologies designed for aquatic animals are also research focused. For example, a 2019 study involved monitoring penguin behavior using time-depth recorders attached to the penguins [4]. This device allowed for monitoring the penguins' behavior in water but did nothing for improving their welfare. Another example is a 2018 paper that details the use of acoustic sensors to monitor dolphins in their natural environment [5]. Once again, this device was useful for research purposes but couldn't be used by zoos for improving animal welfare.

Through our research and discussions with our advisors, we determined that there is a lack of existing devices and systems designed for improving animal welfare. Plenty of papers state the potential that technology has for this purpose, but there are few that provide examples of how it might be done. This is especially true for aquatic animals as we couldn't find any mention of technological enrichment for aquatic enclosures. Our project aims to fill this gap and provide a generalized solution for adding technological enrichment to aquatic zoo enclosures.

Problem

At the start of the project, our advisors explained that they wished to implement an enrichment system such as an animal-controlled feeder in the enclosures of aquatic animals but did not have the technical expertise to realize such a system. One major challenge they encountered was devising a way to provide an input device for animals to interact with. This could be easily accomplished with a robust pushbutton or an equivalent in a land enclosure, but standard input devices can't be used underwater.

Even if an underwater pushbutton was available, safety requirements forbid the installation of copper wires in the water which brings up the issue of communication. A possible solution is to connect the theoretical button to a waterproofed microcontroller and communicate to another controller on the surface via Bluetooth or Wi-Fi. However, standard 2.4 GHz RF frequency has been shown to be ineffective at distances greater than 18 cm underwater [6]. Other wireless communication methods exist, such as optical or acoustic communication [7], but these involve specialized equipment and their own drawbacks such as potentially interfering with nearby animals.

In this project, we solve this problem of devising a way to provide an input device to aquatic animals and communicating when the device is triggered. After discussion with our

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advisors, we chose to leave the design of a system that uses this information for future work. In the feeder example, the feeder itself could remain on the surface and thus require fewer design challenges and be more within the capabilities of our advisors. Instead, we focused on designing a system that is robust, reliable, and well thought out.

Solution

Our solution is to use a reed switch (a magnetically triggered switch) and magnet to create a pushbutton that functions underwater and use fiber optics to communicate the button's state to the surface. The reed switch is housed in a waterproofed enclosure alongside a microcontroller, fiber optic transmitter, battery, and battery management components. A custom 3D printed button moves a magnet close enough to trigger this switch when pressed. The microcontroller detects when the switch is closed and sends this information over a fiber optic cable with the help of the transmitter. The fiber optic cable reliably transmits the data to the surface without risk to the animals as the signal is low power and the cable has a plastic core. All components are powered by a small lithium polymer (LiPo) battery and a wireless charging receiver is included so the battery can be charged through the enclosure's walls. Our prototype also includes a battery fuel gauge so the microcontroller can determine how much charge is left in the battery and send this information over the cable. Overall, this prototype functions as a large pushbutton that can be installed underwater and connected to an Arduino with a receiver that we also designed. The output is designed to function with Arduino's serial functions to make integration easy. This prototype also has the advantage of including custom components that are designed to be versatile and easily modified. Although our prototype functions as a pushbutton, it can be easily modified to include further devices or sensors.

Credibility

All team members, Nathaniel Collum, Hayden Lampert, Brandon Carroll, and Chris Dombrosky are all in the final year of a degree in the college of Engineering and Applied Science at the University of Cincinnati. Chris Dombrosky and Nathaniel Collum are pursuing a degree in Electrical Engineering and Brandon Carroll and Hayden Lampert are pursuing a degree in Electrical Engineering Technology. All members have a similar core education, but each member has their own specialized expertise based on their individual co-op experiences.

Chris Dombrosky gained much experience in the areas of soldering, PCB design, and microcontroller programming during co-op semesters at Valco Melton. He often used these skills in combination with each other. For example, one project involved the design of a PCB controlled by a microcontroller. He designed the PCB in EAGLE, soldered all components to the PCB, and programmed the microcontroller. These skills were helpful in the project as it involved all three of these tasks.

Brandon Carroll has obtained experience in the areas of programming, soldering, and understanding documentation for electronics through his co-op semesters at Valco Melton and his schooling at the University of Cincinnati. These skills were helpful when completing the tasks of writing a function for the battery state of charge, ordering necessary electronics, and soldering wires to the battery management boards.

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Hayden Lampert procured critical thinking skills from his diverse roles at Heapy Engineering that helped him devise a way to waterproof the electronics inside the enclosure. As well as make an enclosure rated to withstand the demanding environment the button will be placed.

Nathaniel Collum has gained experience in the areas of microcontroller programming, wiring, soldering through his co-op at Rite Track. These skills were used to connect the fuel gauge with the PIC microcontroller and program the I2C communication between the two boards.

Goals

1. Design an input device that animals can use and can function underwater. As previously mentioned, standard input devices are unable to function underwater. Because the whole point of this project is to enable aquatic animal interactivity with electronics, a primary goal was to design an input device that works for this purpose. Key objectives in this goal were to make the input method simple and something animals could easily do.

2. Design the prototype to be submersible and durable. Another key goal was to design our prototype in a way that made it waterproof and durable. Waterproofing is an obvious issue as exposure of the electronics to water would both destroy the prototype and present a risk to the animals. Durability was also required to ensure the animals can't easily damage the prototype.

3. Implement a communication method that allows the system to output data without wires. A design restriction imposed by our advisors was that our prototype was not to require wires present in the water. This is because doing so would open up the risk of animals biting through the wires and getting hurt. However, our prototype needs to transmit data out of the water somehow so designing a way to do so safely is an important goal.

4. Design and implement all necessary components to power the prototype with a battery. The lack of wires also makes powering the electronics inside the prototype a challenge. We decided to power the prototype with a battery, so this goal includes determining the battery to use and choosing and implementing components to charge and monitor the battery without compromising waterproofing.

5. Design the prototype to be modifiable and easy to use. As mentioned in the description of the problem, we are not designing an output device/system to work with our prototype. Because other people will be integrating our prototype in another project, it is important that our prototype is designed in a way that is versatile and easy to work with.

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Discussion

Design Overview

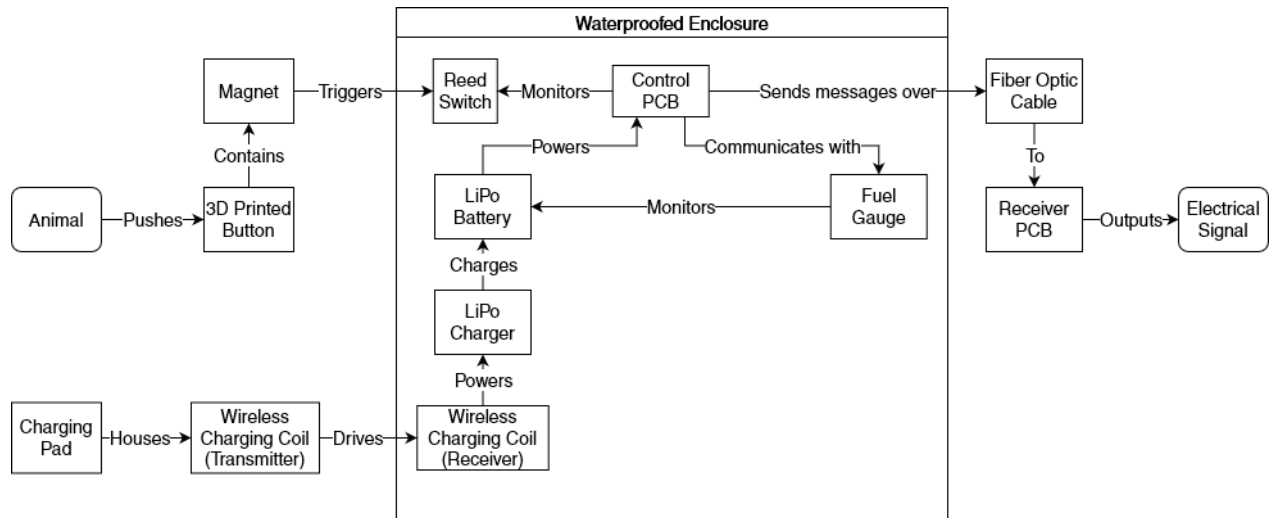


Figure 1: Prototype Overview Block Diagram

Our prototype is designed to function as a large pushbutton that can be mounted underwater and connected to an Arduino (or equivalent) via a fiber optic cable and fiber optic receiver PCB. When the button is manipulated, messages are sent in a serial format over the fiber optic cable. An example message is “BTN01\r” which signifies that the button was pressed. The receiver PCB is attached to the other end of the fiber optic cable and converts optical signals into electrical signals. It is designed to be powered and used by an Arduino. When the output pin of this PCB is wired to the RX pin of an Arduino, the output of this prototype can be easily read by the Arduino’s Serial functions.

Figure 1 shows an overview of our prototype’s design and main components. The main components of our prototype are the 3D printed button with magnet, waterproofed enclosure and its contents, and the fiber optic cable. Additionally, these components are the only ones designed to be submersible. The charging pad and receiver PCB are components designed to make our prototype easier to implement and use. These two components are designed for use outside the water.

All electronics are housed in a durable, waterproofed enclosure to keep them protected from animals and water. The primary electronic components are a reed switch, control PCB, LiPo battery, battery fuel gauge, battery charger, and wireless charging receiver coil. These components are discussed in further detail later in this report. In short, the reed switch and magnet are key components in a submersible pushbutton, the control PCB contains a microcontroller and fiber optic transmitter to detect a button press and send output messages over a fiber optic cable, a battery powers that PCB, and components are included to allow the wireless charging of said battery.

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Figure 2 shows an example diagram of how this prototype might be mounted in a zoo enclosure. The main prototype sits underwater so it is accessible to aquatic animals. The fiber optic cable sits on the enclosures floor and comes out of the water to a main control system. The main control system would then use the prototypes output to trigger an output device such as a feeder.

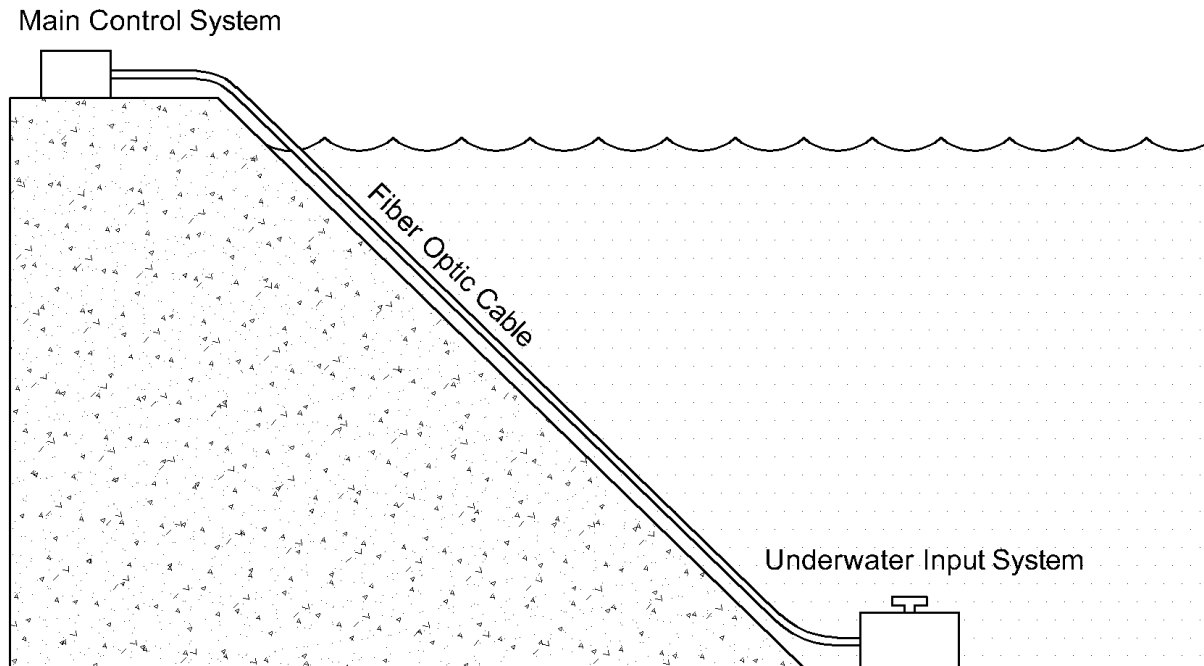


Figure 2: Example Application Layout

Design Objectives

- 1. Make the system submersible.** The combination of using a watertight polycarbonate enclosure and filling it with Raytech silicone gel is enough to make the enclosure submersible and able to protect the electronics.
- 2. Easy to charge.** With wireless charging and a custom-made charging pad, charging is very easy. The pad simply needs a 5VDC source and for the enclosure to be placed on top for charging to proceed.
- 3. Button that doesn't breach the enclosure lid.** A 3D printed button houses a magnet that activates a reed switch when the button is compressed. The reed switch remains on the inside of the enclosure and the magnet is on the outside, with this we do not have to mount anything to the lid of the enclosure or make a hole in it for a wire to go through.
- 4. Communication cable that minimizes risk of electrical shock.** Instead of having a copper wire, that carries current, running through the water, we are using a fiber optic cable. The fiber optic cable consists of a plastic tube that carries light and is of no harm to the animal if the cable gets damaged.

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Animal Input Detection Design

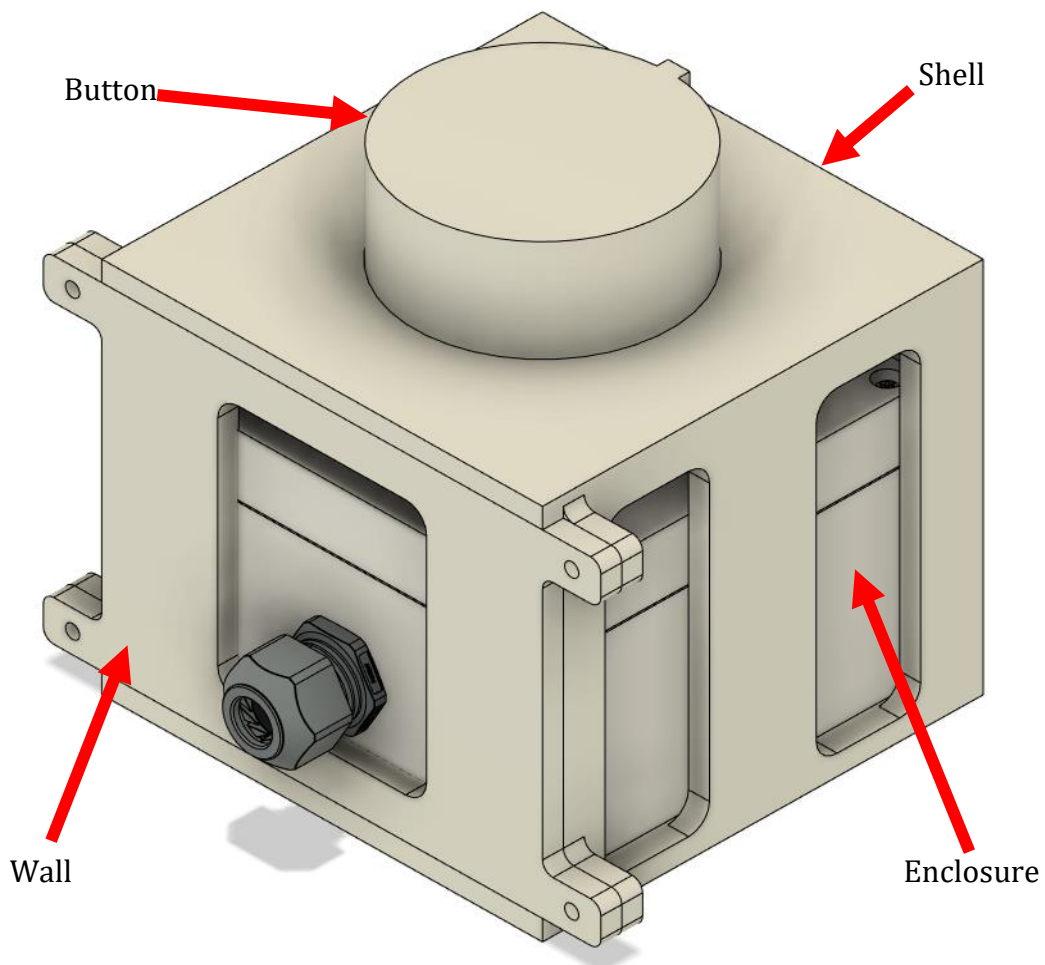


Figure 3: 3D Printed Mechanism

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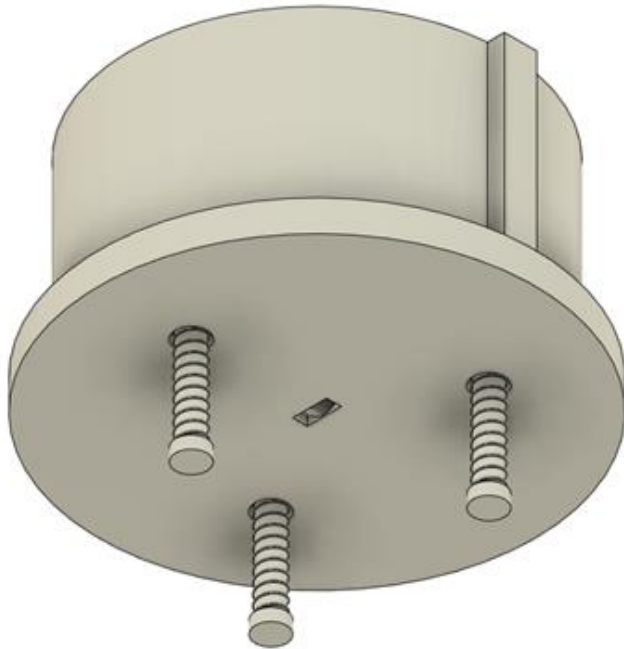


Figure 4: 3D Printed Button

Our prototype includes a reed switch that is mounted inside the enclosure and wired to an I/O pin on the microcontroller. A reed switch is a type of switch that closes (or opens in the case of a normally closed switch) when subjected to a strong enough magnetic field. Reed switches can be used as input devices by having a physical mechanism move a magnet in and out of triggering range of the switch. For our prototype we designed and 3D printed a custom button mechanism, picture in Figure 3, that moves a small magnet close to the reed switch when pressed. This provides a large pushbutton for animals to interact with that doesn't compromise waterproofing as the plastic walls of the enclosure do not affect the magnetic field.



**Figure 5:
Button
Spring**

The 3D printed mechanism consists of two main components: the button itself and a shell that holds the button and main prototype enclosure in place. All components were modeled using Autodesk Fusion 360 and printed by Dr. Vanderelst. The button is pictured above in Figure 4. The top of the button is 3 in. in diameter, large enough for animals to easily press. The button includes a rectangular protrusion to keep it from rotating when pressed and a flange on the bottom so it does not fall out of the shell. The bottom of the button includes holes for the magnet and 3 springs. As seen in Figure 5, we modeled and printed small posts for the springs to rest on. These posts ensured that the springs did not deflect to the sides when compressed.

The 3D printed shell is seen below in Figure 6. This part is designed to hold both the main enclosure and pushbutton in place so that the magnet is always aligned with the reed switch. There is a cutout for the button to move within on the top surface and there are cutouts on the walls to minimize the amount of material required and to allow the main enclosure to be strapped in place. One side is left open for the enclosure to slide in, and this side includes holes to allow wall in Figure 7 to be screwed in place so the enclosure does not fall out.

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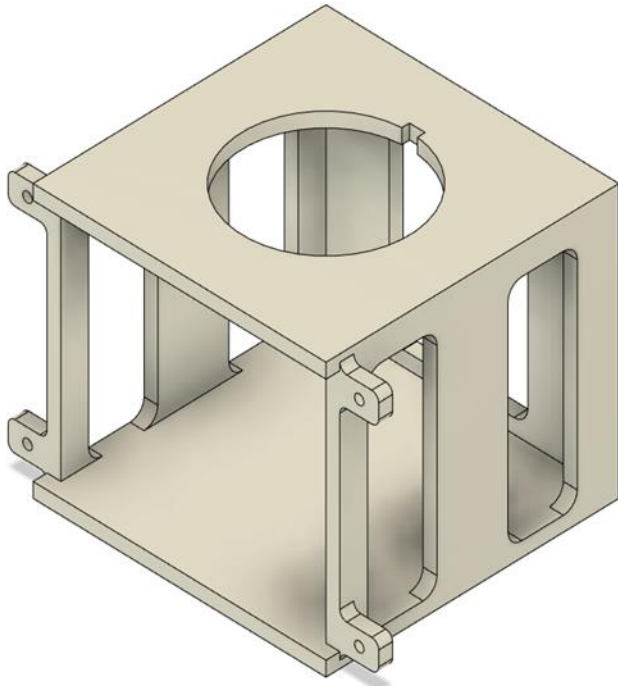


Figure 6: 3D Printed Shell

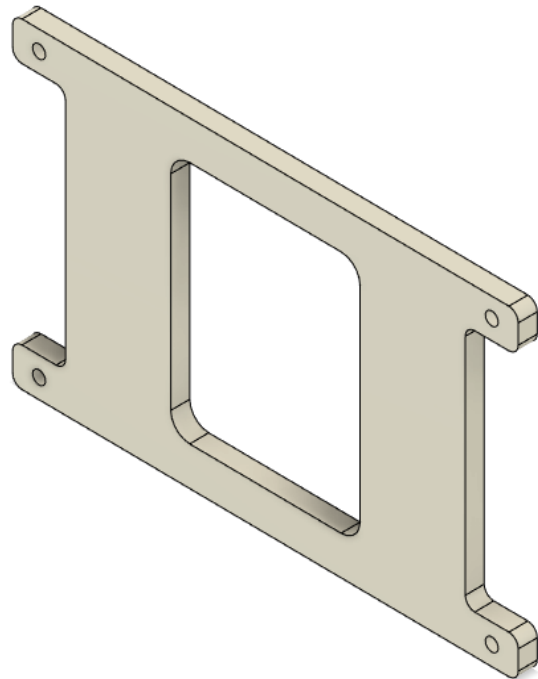


Figure 7: 3D Printed Wall

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Testing

Switch	Magnet	Air		Tap Water		Saltwater	
		Trigger (in)	Release (in)	Trigger (in)	Release (in)	Trigger (in)	Release (in)
59170-1-S-00-A	.25" Round	0.35	0.43	0.31	0.35	0.31	0.35
	.35" Round	0.55	0.59	0.51	0.59	0.51	0.59
	.6" Round	0.83	0.91	0.79	0.83	0.83	0.91
	Cube	0.75	0.83	0.63	0.67	0.63	0.67
59165-1-S-00-A	.25" Round	0.39	0.43	0.35	0.39	0.43	0.43
	.35" Round	0.55	0.59	0.55	0.55	0.55	0.55
	.6" Round	0.91	0.94	0.87	0.87	0.98	0.98
	Cube	0.79	0.79	0.67	0.67	0.71	0.71
59165-1-U-00-A	.25" Round	0.28	0.31	0.20	0.24	0.24	0.28
	.35" Round	0.43	0.51	0.43	0.55	0.43	0.55
	.6" Round	0.67	0.83	0.67	0.83	0.59	0.67
	Cube	0.59	0.67	0.51	0.59	0.51	0.59
MITI-7-6-10	.25" Round	0.39	0.51	0.31	0.39	0.31	0.47
	.35" Round	0.55	0.67	0.55	0.71	0.51	0.71
	.6" Round	0.83	1.02	0.71	0.83	0.71	0.83
	Cube	0.75	0.91	0.59	0.71	0.59	0.75
RI-02GP1520	.25" Round	0.31	0.35	0.28	0.31	0.28	0.31
	.35" Round	0.47	0.51	0.47	0.51	0.43	0.51
	.6" Round	0.71	0.79	0.67	0.75	0.67	0.71
	Cube	0.67	0.71	0.55	0.59	0.55	0.59
ORD 324/10-15 AT	.25" Round	0.43	0.51	0.35	0.43	0.39	0.51
	.35" Round	0.67	0.79	0.59	0.67	0.59	0.71
	.6" Round	0.98	1.14	0.91	1.02	0.75	0.94
	Cube	0.87	0.98	0.79	0.91	0.71	0.79

Table 1: Reed Switch Test Results



Figure 8: Reed Switch Test Setup

Neither the datasheets of reed switches or magnets provide enough information to predict the range at which a certain magnet will trigger a certain reed switch, so we tested a variety of different switch and magnet combinations to find which best met our needs. As seen in Figure 8, we wired an LED to the reed switches and used a ruler to measure when the magnet triggered the switch. We repeated this test in air, normal water, and saltwater for each pair. The saltwater contained 3.5% table salt by mass to simulate seawater. As

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seen in the results in Table 1, the environment had no definitive impact on the switch's range. Based on these results, we chose to use the switch HE633-ND as it had a plastic body and some of the most consistent results (i.e. the trigger range was almost always the same as the release range). We also chose to use the 0.25 in. diameter magnet as we arbitrarily decided it's trigger range to be suitable for our purposes. We then designed the 3D printed shell in Figure 6 to have a 0.75 in. gap between the button and the enclosure so that the switch is triggered when the button is roughly half pressed.

Implementation

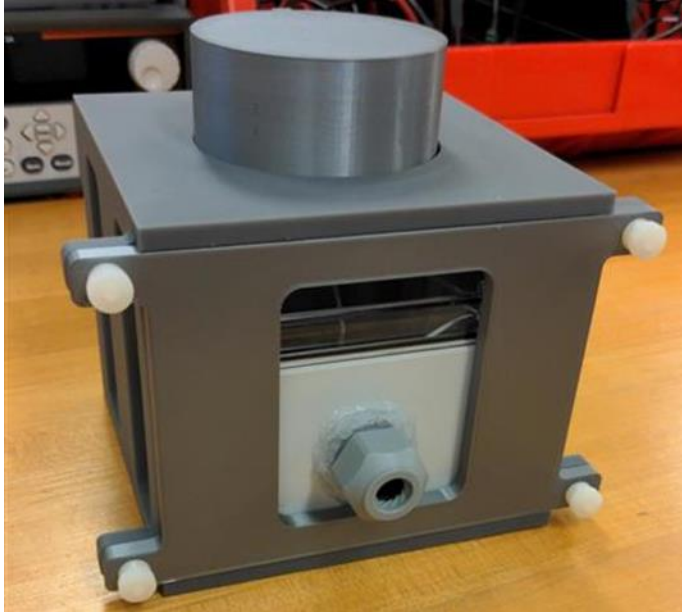


Figure 9: Implemented Button Mechanism

The assembled components are shown in Figure 9. As seen, the removable wall is attached to the shell using nylon screws and thumb nuts. These were chosen to be corrosion resistant in saltwater and easily removed and replaced by hand when the enclosure is removed for battery charging. We also purchased 1 in. long corrosion resistant springs from McMaster Carr. These springs have a compressed length of about 0.25 in. so they are perfect for the 0.75 in. travel distance of the button. We also chose springs with the lowest spring rate possible (0.89 lbs/in), so the button does not require too much force to press. After assembly, we found that these components worked exactly as

planned. The button easily moved up and down and triggered the reed switch when pressed. The shell and wall held the button and enclosure in place, and always kept the magnet aligned with the reed switch.

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Control PCB

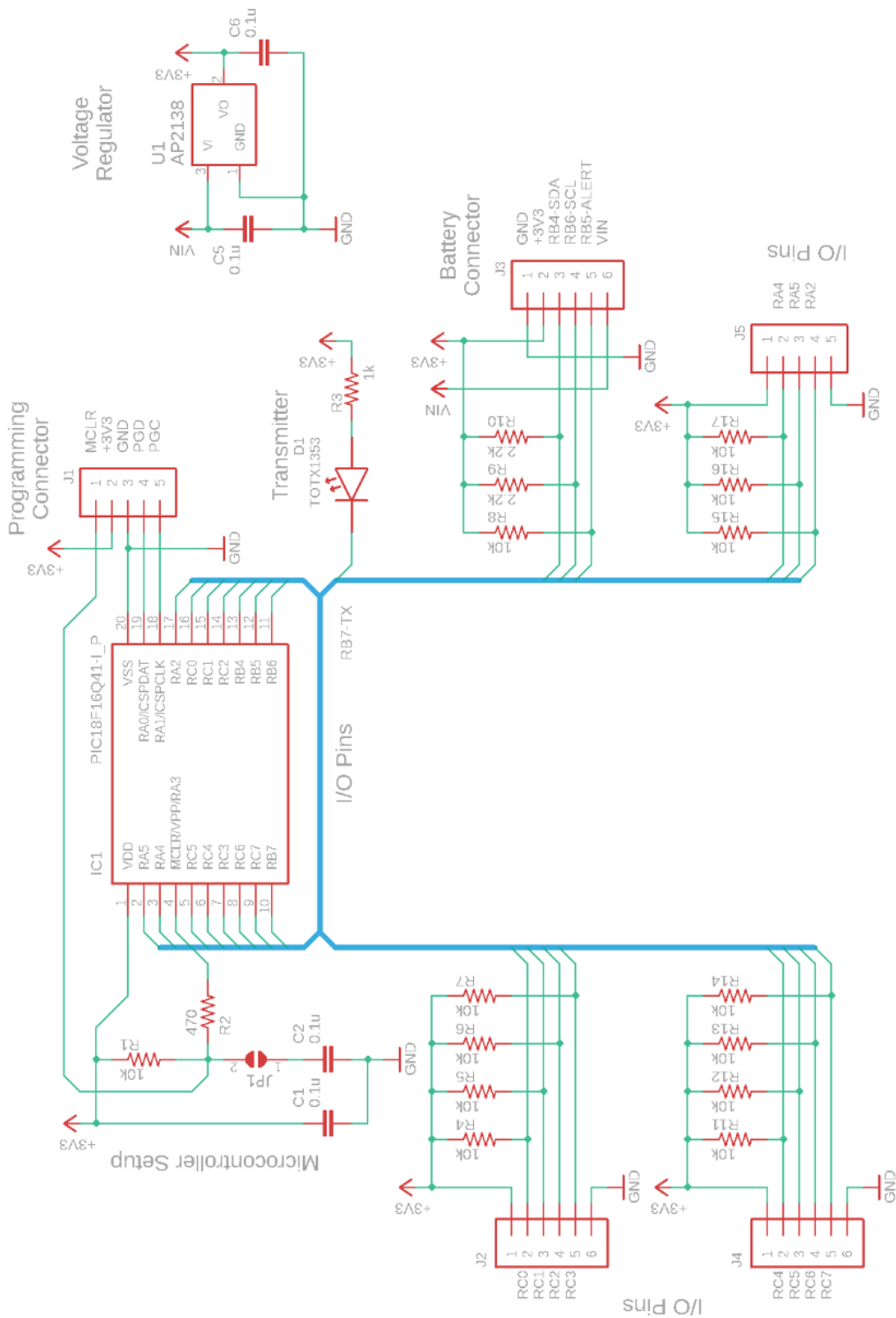


Figure 10: Control PCB Schematic

Chris Dombrosky, Brandon Carroll,
Nathaniel Collum, and Hayden Lampert, 2021-2022

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Design

The control PCB is a custom PCB designed to streamline the process of implementing sensors and input devices in a waterproofed enclosure. The primary components are the microcontroller (MCU) and a fiber optic transmitter. The general concept of this PCB is that sensors are connected to the MCU via I/O ports and the transmitter transmits serial output data from the MCU over an attached fiber optic cable. This optical output method reliably and safely carries information from the MCU through water and to the surface where a corresponding receiver converts the optical signal back to an electrical signal. The PCB also contains a linear voltage regulator to supply the MCU and transmitter with a constant voltage and solder pads for pullup resistors for each MCU I/O pin. Overall, this PCB contains all components necessary to collect, process, and transmit data from sensors underwater while minimizing size, cost, and power consumption.

The microcontroller used is the Microchip PIC18F16Q41 microcontroller. This microcontroller was chosen because it is low-cost, readily available, offered in easily soldered footprints, has a low-power sleep mode, and has UART and I2C peripherals. A PIC family microcontroller was chosen because our team had prior experience with these microcontrollers.

The MCU (item operates over the range of 1.8 to 5.5 V and can be programmed using In-Circuit Serial Programming (ICSP) [8]. The voltage, oscillator, and programming pins were connected as recommended in the device datasheet. The MCU transmits data serially using its universal asynchronous receiver transmitter (UART) module. UART is a simple and common serial data protocol that transmits data at a defined rate in bits/second (baud rate) using the operating voltage to represent logic 1 [9]. Our MCU outputs data at the arbitrarily chosen baud rate of 9600. The MCU is put into sleep mode after transmitting data after the button is pressed or released. This minimizes the current draw of this PCB and maximizes the battery life of our prototype.

The fiber optic transmitter is a TOSLINK general-purpose optical transmitting module. This module consists of a JIS F05 fiber optic connector and a low current red LED. This module converts electrical signals to optical signals that are carried over a connected fiber optic cable. The specific model used in our project is the TOTX1350 which can handle transmissions of 0 to 10 Mb/s [10]; the 9600 b/s output of our MCU is well within this device's capabilities. This device is functionally an LED with a forward voltage of 1.8 V at an operating current of 1.5 mA. As a result, it requires a current limiting resistor dependent on the operating voltage of the MCU with a value of $R_{lim} = \frac{V_{DD} - 1.8V}{1.5mA}$. For $V_{DD} = 3.3V$, the current limiting resistor would be 1k Ω . Clearly a constant operating voltage is required to maintain the correct transmitter current as the current limiting resistor will have a static value.

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This PCB is powered by a LiPo battery, so it needs a voltage regulator to provide a constant voltage as the battery's voltage varies. The battery has a nominal voltage of 3.7V, a max voltage of 4.2V while charging and at full charge, and a cut-off voltage of 2.8V when depleted. We chose a 3.3 V linear regulator as it is a standard operating voltage and will function over most of the battery's voltage range. The battery will eventually go below 3.3V, but this will occur towards the end of the battery's capacity, and it should be topped off frequently enough to avoid this issue. Specifically, we chose a AP2138N-3.3TRG1 regulator from Diodes Incorporated as it has a low dropout voltage (to maximize how long it can be driven by the battery), good efficiency, and a low quiescent (low load) current so it does not cause the battery to drain too quickly.

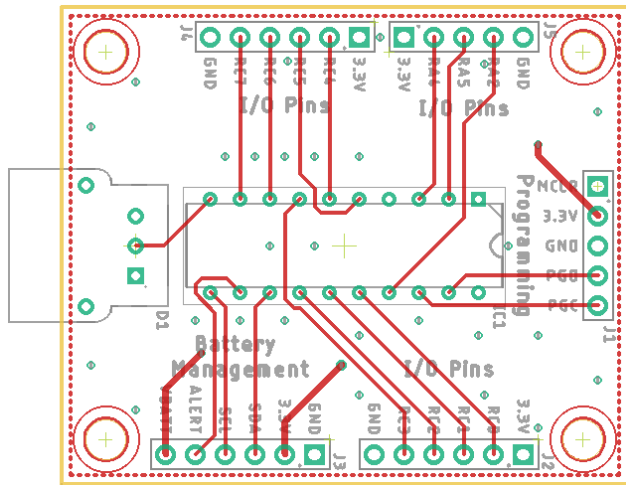


Figure 11: PCB Top Layer

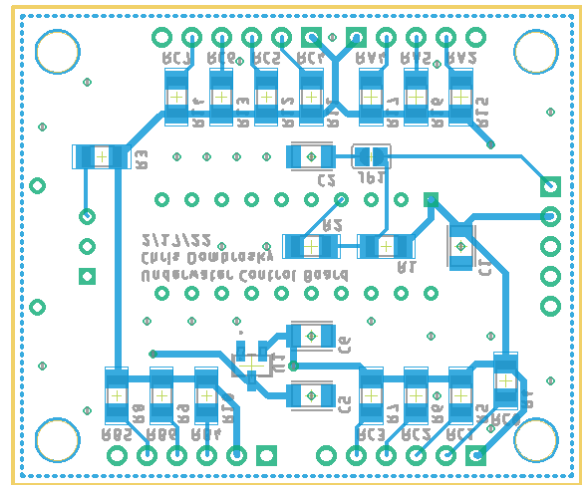


Figure 12: PCB Bottom Layer

The schematic for the PCB is shown in Figure 10. The top and bottom layers of the PCB are shown in Figure 11 and Figure 12. All connectors have a general label for their purpose and individual pin labels. There are also holes for mounting the PCB to standoffs with #4 size thread. The MCU is labeled as IC1, the transmitter is D1, and the voltage regulator is U1. As seen, the transmitter's cathode is connected to the MCU's UART transmit pin and the anode is connected to 3.3V and a current limiting resistor. This configuration inverts the output (the transmitter is off when the transmit pin is high) which is necessary as UART idles high and we don't want the transmitter to drain the battery by always being on.

Connector J1 is used for programming the MCU. It is the only connector with a header connector attached (see Figure 15), all other connectors are left as solder holes for soldering individual wires to. Programming the MCU involves connecting the MPLAB SNAP programmer to this connector with pin 1 on the SNAP (marked by a black arrow) connecting to pin 1 on connector J1 (labeled MCLR). Once the two are connected, the MCU can be programmed through MPLAB X IDE.

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Connectors J2, J4, and J5 are meant for connecting sensors or other devices to the MCU. Each connector contains a pin for 3.3V and GND for powering attached devices. Each other pin is labeled with the MCU pin it is connected to. Additionally, the bottom side of the PCB contains pads for adding 1206 package pullup resistors to pull any of these pins to 3.3V. These resistors are seen near the connectors in Figure 12 and are labeled with the MCU pin they pull up. Our prototype only uses pin RA2 on connector J2 and its corresponding pull up resistor for connecting the reed switch. All other pins and resistor pads are unused but available for further expansion.

Connector J3 is used for connecting this PCB to the Qwiic Fuel Gauge. The pins marked VBATT and GND connect this PCB to the corresponding battery terminals. The SDA and SCL connect to the fuel gauges' communication lines. The ALERT pin connects to the alert pin on the fuel gauge, although this is currently unused by our prototype. Finally, the 3.3V pin can be connected to the fuel gauge to power pullup resistors for its communication lines, but these lines are already pulled up on this PCB so connecting this pin is unnecessary. The pins on this connector are labeled the same as the corresponding pins on the fuel gauge to make assembly easier.

Testing

We tested the control PCB circuit design by replicating it on a breadboard as pictured in Figure 14. This allowed us to test key functionality such as programming, the fiber optic output, the regulated voltage, and sleep current. We found that this design allowed the microcontroller to operate and program without any issue. The optical output was tested by connecting an oscilloscope to the input of the transmitter and to the output of a fiber optic receiver and comparing the waveforms. As seen in Figure 13, the output waveform was identical (besides being at a different voltage) to the input waveform from the microcontroller. This proved that the transmitter and cable would be capable of carrying UART data reliably. We also tested a variety of voltage regulators to ensure they would perform well in our design. We tested a variety of input voltages over the operating range of our battery and monitored the regulated voltage and sleep current of the circuit. As seen in Table 2, all regulators performed about equally and maintained a low sleep current which is crucial for maximizing battery life. We ended up choosing the AP2138N regulator because it had the easiest footprint to solder.

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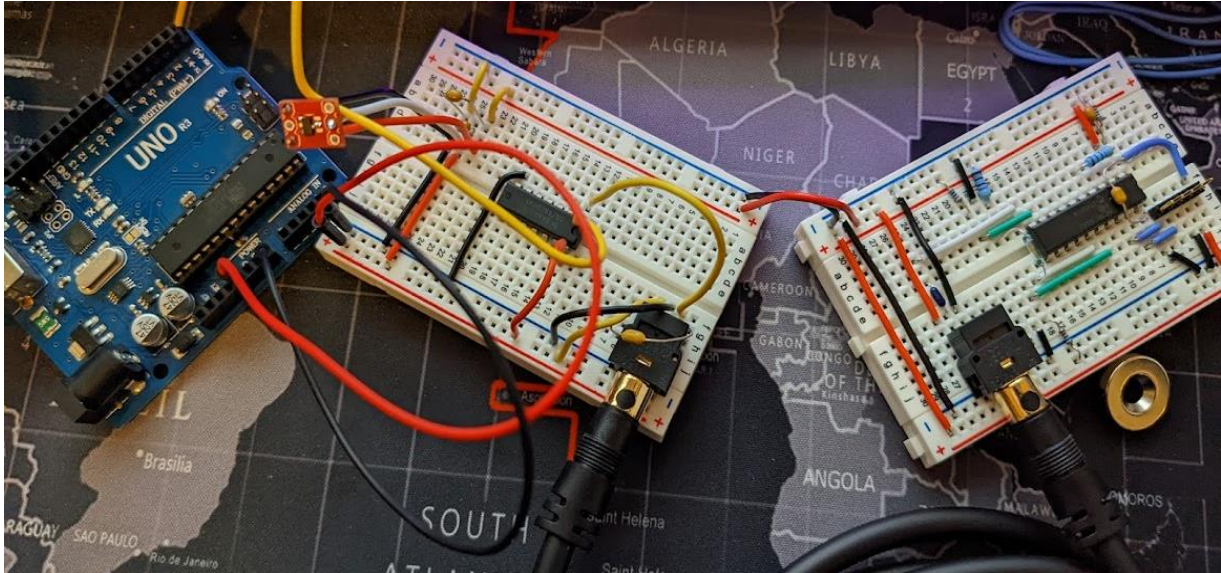


Figure 14: Breadboard Test Setup

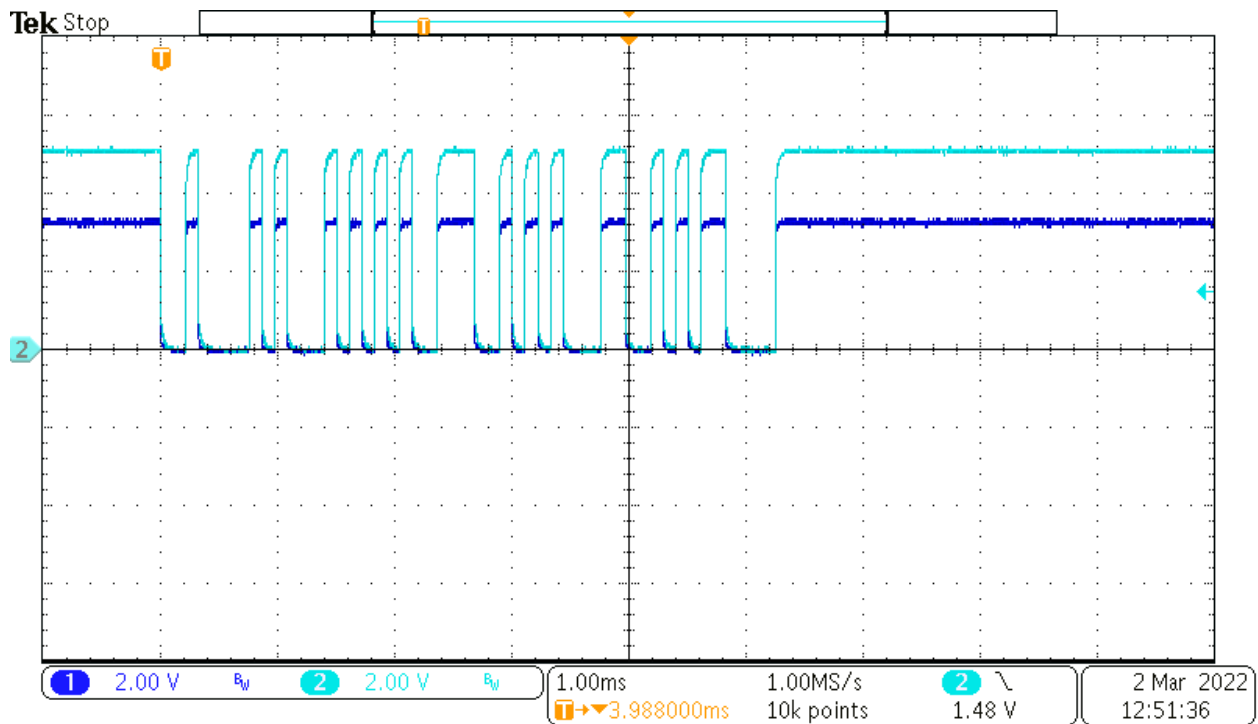


Figure 13: Fiber Optic Input and Output (Channel 1: Input, Channel 2: Output)

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RH5RL33AA		
Supply Voltage (V)	Output Voltage (V)	Sleep Current (uA)
4.2	3.311	17.71
4.1	3.311	17.71
4	3.311	17.71
3.9	3.311	17.71
3.8	3.311	17.71
3.7	3.311	17.71
3.6	3.311	17.71
3.5	3.311	17.71
3.4	3.311	17.71
3.3	3.298	17.69
3.2	3.198	17.61
AP2138N		
4.2	3.314	17.44
4.1	3.314	17.43
4	3.314	17.43
3.9	3.314	17.43
3.8	3.314	17.43
3.7	3.314	17.43
3.6	3.314	17.43
3.5	3.314	17.43
3.4	3.314	17.43
3.3	3.298	17.41
3.2	3.198	17.35
AP7354		
4.2	3.318	16.3
4.1	3.318	16.3
4	3.318	16.3
3.9	3.318	16.3
3.8	3.318	16.3
3.7	3.318	16.3
3.6	3.318	16.3
3.5	3.318	16.3
3.4	3.318	16.3
3.3	3.298	16.25
3.2	3.198	16.17

Table 2: Voltage Regulator Test Results

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Implementation

Once we validated the circuit design of the control PCB using breadboards, we designed the PCB in EAGLE and had it manufactured by JLCPCB. We were very careful to ensure component footprints matched the component's dimensions in their datasheet. We also made sure that features such as trace width and spacing were well within the manufacturer's capabilities. We used surface mount resistors and capacitors as the 1206 footprint is small enough to keep the board's size down while still being large enough to hand solder. We also included #4 sized mounting holes so this PCB could be mounted on standoffs. We soldered all components to the PCB using lead free solder. We then repeated the functional tests described above and validated that the PCBs worked without any issues. The assembled PCB is pictured below in Figure 15 with the transmitter on the left and MCU in the center.

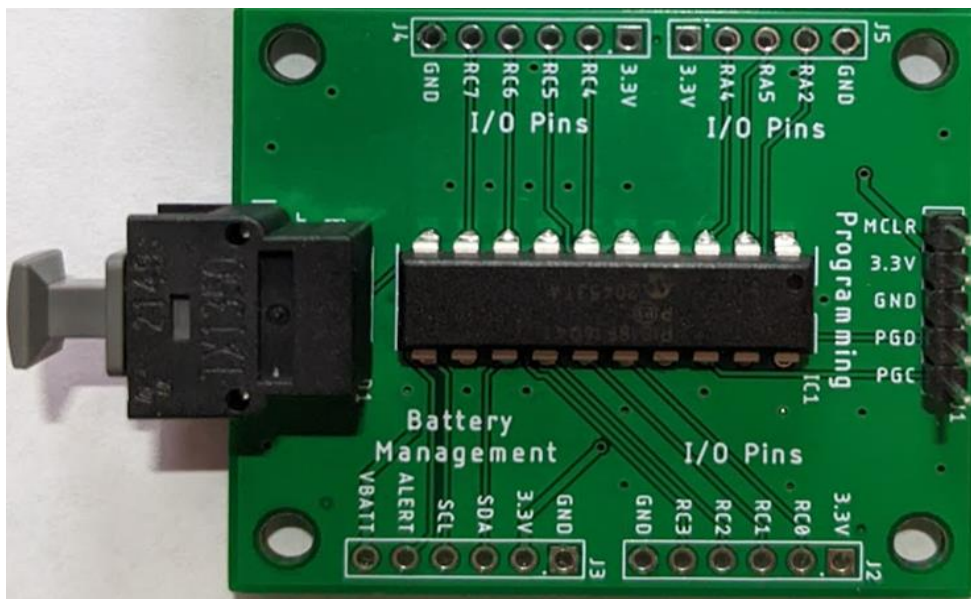


Figure 15: Assembled Control PCB

Optical Receiver

The receiver PCB is a small and simple PCB designed to convert the optical signal carried by the fiber optic cable into a 5V UART signal to be read by an Arduino or other microcontroller. The board is supplied with 5V by the Arduino through its header pins. The receiver is implemented according to its datasheet and is designed for DC to 10 Mb/s signals [11]. It converts optical signals on the attached cable into electrical signals on its output pin, with an output of 5V when the optical signal is high and an output of 0V when it is low. As stated previously, the transmission signal was inverted on the control PCB to avoid driving the transmitter during idle, so the receiver's output is wired to a data inverter to return the signal to its original state. Both the inverted and plain output from the receiver is available on the header pins. The header connector is a standard 0.1" female header so that this PCB can be easily connected to an Arduino with jumper wires. The schematic for this PCB is pictured in Figure 16.

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This PCB was designed in EAGLE and ordered from JLCPCB along with the control PCB. It was also soldered with lead free solder. As intended, this PCB simplified the task of reading the output of our prototype by attaching to the cable and needing only 3 wires connected to an Arduino. Reading and utilizing the output of our prototype is as simple as connecting the 5V and GND pins to an Arduino's power pins and the OUT_INV pin to the Arduino's RX pin. The Arduino's Serial code module makes the output data easy to implement once it is set to 9600 baud. The assembled PCB is shown in Figure 17.

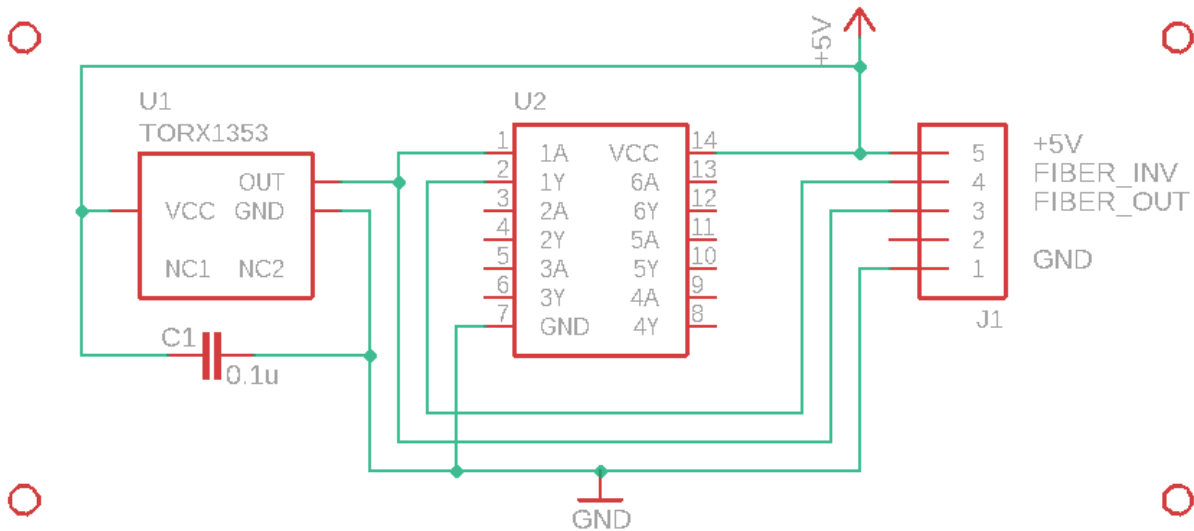


Figure 16: Receiver PCB Schematic

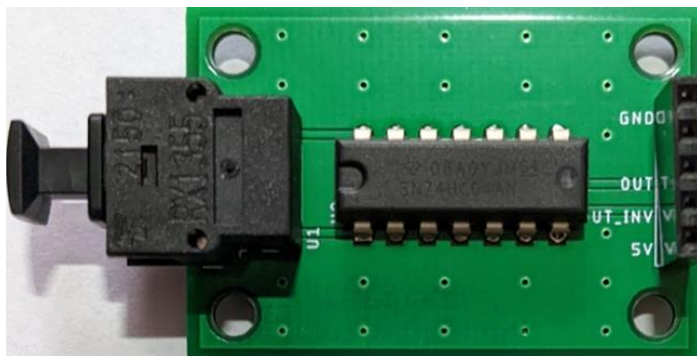


Figure 17: Receiver PCB

Battery Management

Design

The second module in the system is the battery management module. The battery management module is responsible for power management, power protection, and controlling and monitoring battery charge and discharge. This section discusses the general design in Figure 18 as well as the functionality and usage of specific battery management ICs. These ICs were originally identified for use in a custom-made battery management PCB but are now being used as a reference for choosing development boards to achieve the

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same functionality. The choice to use development boards was made to ensure our system has the desired battery management functionality but with a lower chance of design issues.

The battery being used is a 3.7V lithium-ion battery with a charge capacity of 400mAh. We can get away with a small battery capacity because the device will stay in sleep mode for the majority of time and draw only 17uA of current. The small capacity also provides for a small physical battery size, providing more space inside of the enclosure. For wireless charging, a Qi receiver was originally chosen, but due to its low power, a wireless receiver and transmitter combination, which are not Qi compatible, were chosen instead. The finalized wireless transmitter and receiver modules (106990017) provide for a larger transmission distance between the two, allowing the battery to reliably charge through the enclosure. Both the battery and wireless receiver connect to the charge management board. The charge management board is equipped with an IC (MCP73831) that helps regulate the steady 5VDC charge from the wireless receiver into the battery, since it is dangerous to directly charge a lithium-ion battery without any management system. With an input of 5V the battery management IC regulates an output voltage of 4.2V [12]. The charge management board features reverse discharge protection, thermal regulation, and a default charge current of 100mA. It also has two LEDs equipped, a red LED to signify that the battery is charging and a green LED to signify that the battery is done charging. By soldering together a jumper, labeled 500mA, the charge current can change to 500mA instead of 100mA. Doing so is not recommended for this project since we are using a battery with a capacity of 400mAh, and the charge current should not exceed the capacity of the battery.

To track the discharge of the battery we are using a Qwiic fuel gauge board. The fuel gauge board comes equipped with a MAX17048 IC, which uses I²C communication and transmits data over to the microcontroller mentioned earlier. There are three different communication terminals that connect to the microcontroller, SDA, SCL, and ALRT. SDA is the data line and SCL is the clock line, while ALRT is an interrupt. All three communication terminals are connected, however the ALRT interrupts are not utilized in this project. The fuel gauge uses its own ModelGauge algorithm to track the state of charge (SOC) of the battery. The value for SOC of the battery is stored in register 0x04 of the MAX17048 IC, this register automatically updates to variation in battery size because the ModelGauge naturally recognizes relative SOC [13]. Lastly, the LED solder pads located on the back side of the fuel gauge board was disconnected. This was done for the purpose of reducing any additional power consumption. The LED's only use is to signal that the board is receiving power and is unnecessary for this project.

Testing

To test the battery management circuit the first step was to ensure that the wireless charging worked. As mentioned earlier, the Qi charger that was originally chosen would not reach through the enclosure without perfect alignment and a decent amount of pressure applied to it. After choosing our final transmitter and receiver we found that it was easily able to transmit through the enclosure. To test this, we simply connected the receiver coil and battery to the charge management board and placed those inside of the enclosure. The receiver coil was taped to the bottom of the enclosure and the enclosure was then placed over top of the transmitter coil. We then observed to see that the red

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charging LED would brightly turn on. Next, we needed to test if the battery was charging. To do this we connected a multimeter to two wires that were connected to both terminals of the battery and observed on the multimeter display that the DC voltage of the battery was increasing. Lastly, we did a burn-in test with all the parts put together, see Figure 18 for circuit diagram. A burn-in test involves extended periods of activation of the system, so throughout the day we had the battery connected and supplying the microcontroller and we would occasionally activate the reed switch, which would pull the microcontroller out of sleep mode and draw more current from the battery. After a day we observed that the system was still working properly, and the battery percentage only decreased by 1%. Additionally, we placed the wireless charge receiver over top of the transmitter, with the entire circuit connected, and let that sit overnight. We found that the battery charged at a slow rate but did not have any complications with the charging.

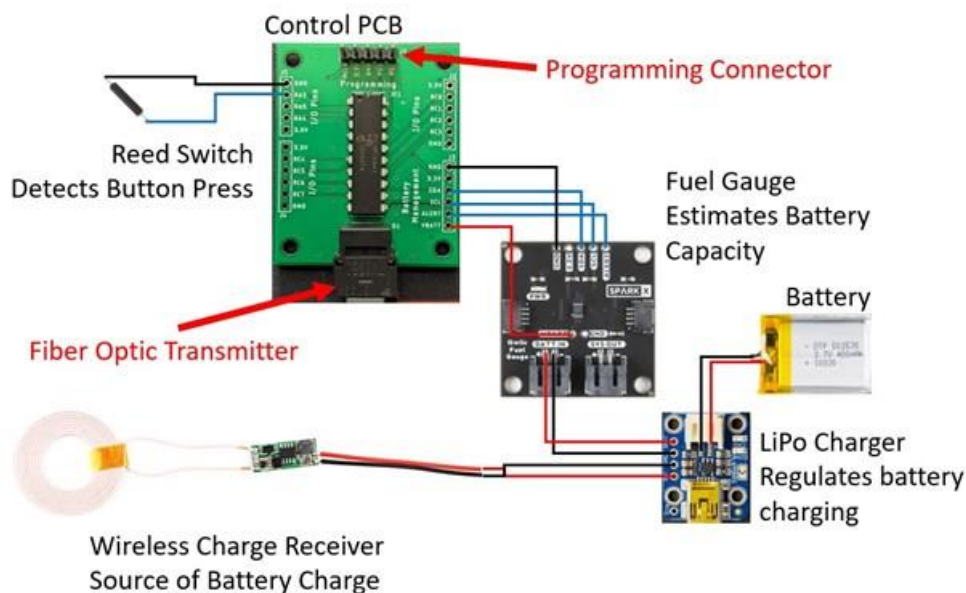


Figure 18: Battery Circuit Diagram

Custom Charging Pad

The wireless charging transmitter and receiver used in this project only work with each other and arrive as bare coils with an attached PCB and leads as seen in Figure 18. Additionally, both coils need to be aligned for charging to occur. To make the process of lining up the coils easier and to make the charging setup more visually presentable, we designed a custom wireless charging pad to house the transmitter coil. With this pad, charging the prototype is as simple as removing the main enclosure from the water and placing it on the pad.

The 3D model of this charging pad is pictured below in Figure 19. The main feature of this pad is a circular stand in the center to hold the charging coil with slots on either side to make space for the connecting wires. Also included to the left is an opening and housing for a barrel jack adapter used to connect the wires from the charging coil to an AC to 5VDC adapter. A thin plate sits on top of the coil. Thin walls extend above the plate to hold the

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enclosure in place and the inner dimensions of these walls are just slightly larger than the enclosure's dimensions. The receiver coil is mounted in the center of the enclosure and the transmitter coil is mounted in the center of the charging pad so charging will occur no matter how the enclosure is placed on the pad. Like the button mechanism, this part was modeled in Fusion 360 and printed by our advisor.

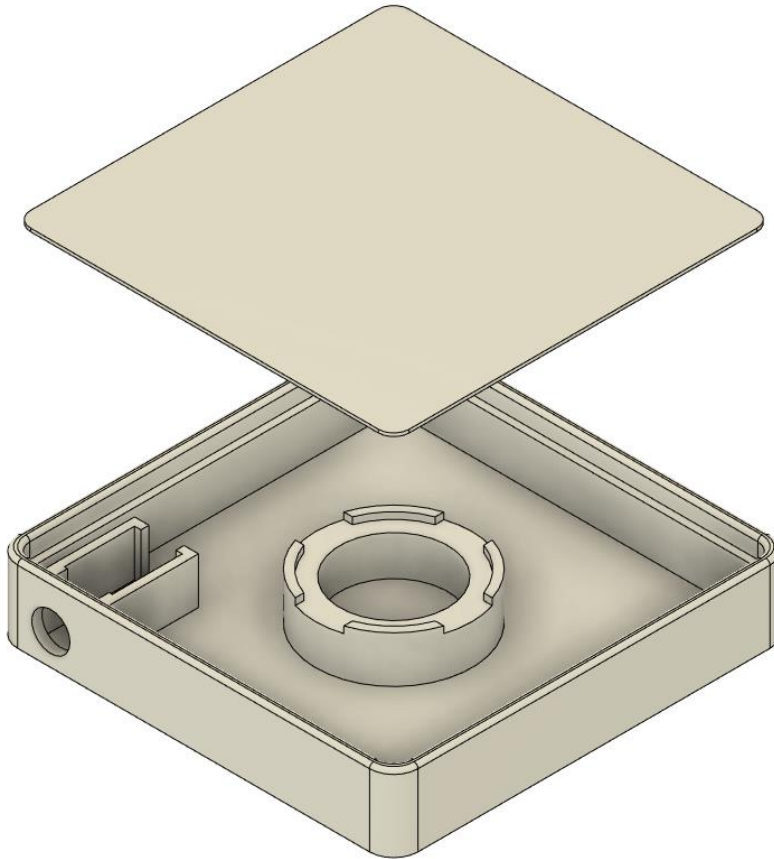


Figure 19: Charging Pad

Implementation

After testing the circuit to ensure reliability over an extended period, we were ready to begin orienting the circuit into the enclosure. We decided that the microcontroller was the only board that needed mounting and the other boards were free to suspend in the air because they are very small and lightweight and have stiff wires to hold them in place. Additionally, the Raytech Power gel that would eventually cover the electronics would also keep them in place. Since the fuel gauge and charge management controller boards were not mounted, we covered the solder joints on both boards in a silicone paste to prevent them from shorting out on the metal mounting plate. The wireless charging receiver coil is taped underneath the mounting plate so that the transmitter coil can be as close to the receiver coil as possible. The battery can be placed anywhere on the plate so long the wires can reach that far. For a visual representation, charging pad included, refer to Figure 20.

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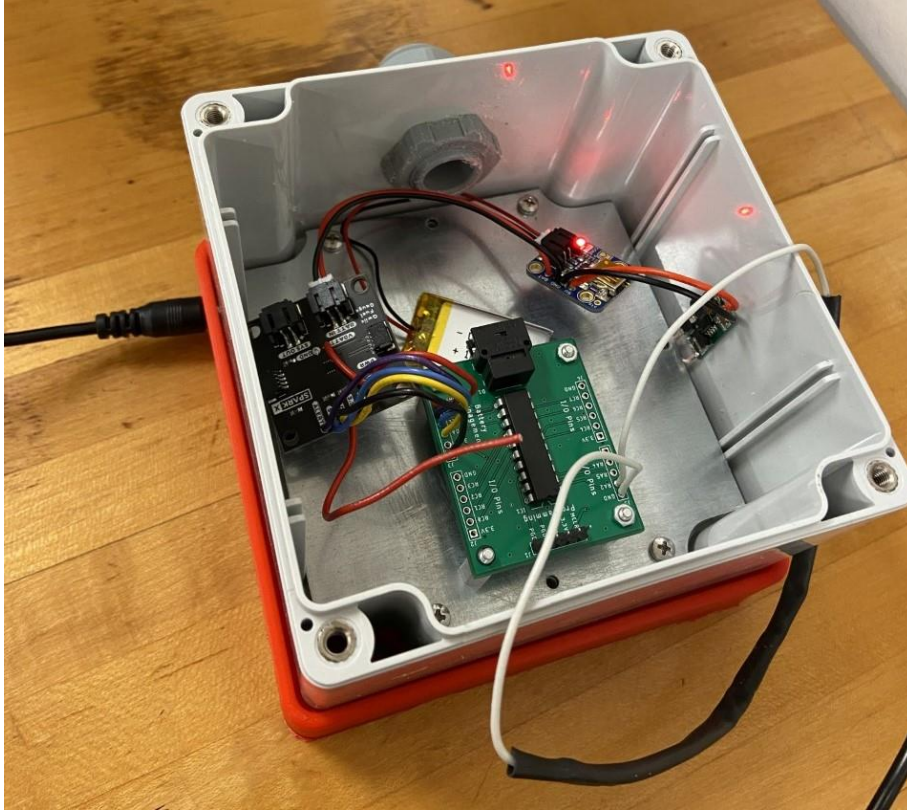


Figure 20: Circuit Implemented and Charging

Enclosure and Waterproofing

Design

This section covers the hardware used for the prototype and tactics for waterproofing. The hardware for this project protects the electronics inside as well as creates the base for the push button. Due to our design being fully submerged, additional waterproofing had to be done to thoroughly protect the electronics inside.

The base enclosure is an IP-68 rated polycarbonate submersible enclosure with a see-through lid shown in Figure 21. Dimensions are as follows, 4-3/4" x 4-3/4" x 3-1/8". The enclosure dimensions needed to be just big enough for all components to fit, but small enough to where our prototype could be easily mounted in confined spaces (the intention here is that our device could be multipurposed for other animal enclosures). The enclosures' purpose is to protect the components inside while also creating a base for our spring pushbutton to work against. The enclosure came with a mounting plate that was used to elevate the PCB off the base of the enclosure. This was necessary to create a solid connection for the fiberoptic cable as well as ensuring a 360-degree seal of RayTech Power Gel.

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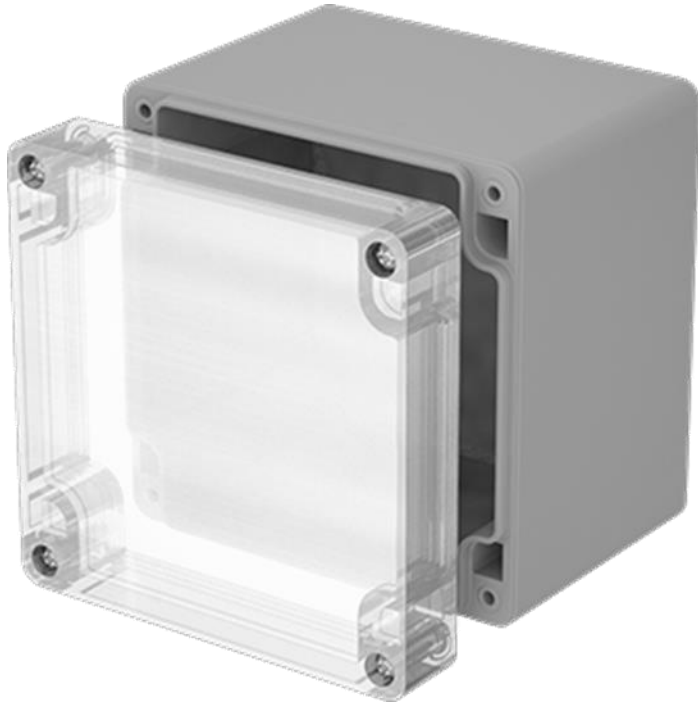


Figure 21: Polycarbonate Enclosure w/ See-Through Lid

An IP-68 rated CG-32 Cable Gland, Figure 22, was used to create the pathway through the enclosure for the fiberoptic cable. Using a $\frac{3}{4}$ " drill bit, a hole was dug out of the wall of the enclosure. The cable gland was inserted after a silicone layer was placed. Finally, one more layer of silicone was run around the edge of the cable gland, both inside and out, to ensure no water leakage through the cracks of the drilled hole. This successfully created a watertight pathway for the fiber optic cable to connect to the PCB inside.



Figure 22: CG-32 Gray Cable Gland

Although the hardware could more than likely keep the prototype completely waterproof on its own, we wanted to ensure that there was no chance for our design to become susceptible to water damage. For this reason, our electronics will be completely encased in Raytech Power Gel 1000. The product starts as a liquid, that once mixed and set, turns into

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a conductive gel that protects anything it is covered with. Additionally, the crack around the lid of the enclosure will be sealed with silicone before being submerged.

Testing

As a result of not having access to a large pool of salt water, testing was done to the best of our abilities. A demo enclosure with a CG-32 cable gland was sunk in a cooler filled with salt water for 3-4 weeks without being disturbed. The enclosure was filled with salt to notice if any water leaked in. The results showed a small amount of water leakage near the bottom of the enclosure opposite the cable gland. The conclusion was that the cable gland worked flawlessly, and the water leakage was due to an old rubber gasket. This is how we figured to use silicone around the crack of the lid.

The Raytech Power Gel was tested in the same conditions, Figure 23. Using the demo enclosure, we covered a cheap PCB in the gel and let it sit completely exposed to water for 3-4 weeks. The PCB never took on any water damage and was able to be recognized by my computer the whole time. However, it is noted that once covered in Raytech Gel, a fragile electrical component is extremely hard to retrieve without damaging.

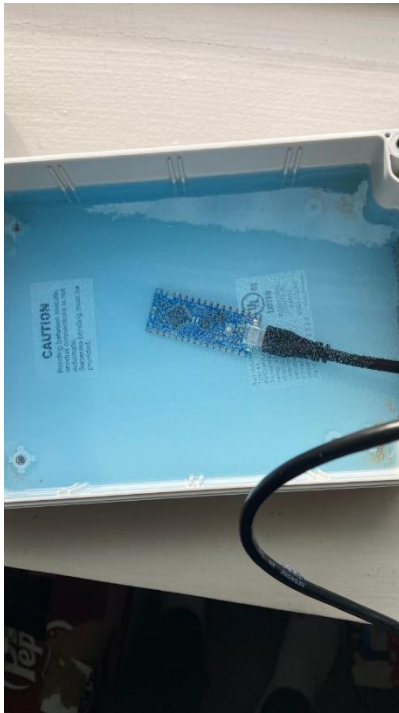


Figure 23: Raytech Power Gel 1000 Test

Implementation

After testing proved our enclosures durability and the waterproofing's effectiveness, the final prototype was assembled. The design was a perfect fit for our electronics as well as a seamless transition for the outer shell. It was agreed upon that pouring the Raytech Gel would be the very last step due to its permanence. The idea is that the zoo can figure out exactly how they wish to implement the device before making the final decision to pour the gel.

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Software Design

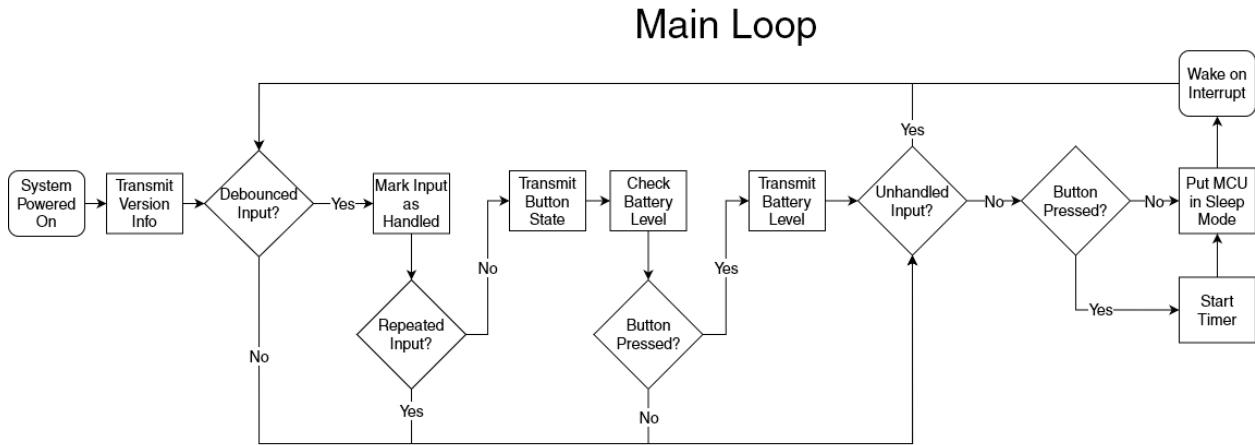


Figure 24: Main Loop Flowchart

The software for our prototype’s microcontroller was developed in MPLAB X IDE, the manufacturers proprietary developing environment. Also used was an add-on to MPLAB called MPLAB Code Configurator (MCC). MCC is a tool that allows users to set up the MCU and desired peripherals using a graphical user interface. Once settings are selected or changed, MCC generates several functions for initializing and using the MCU and its peripherals. We used MCC to set up core MCU features such as oscillator frequency and pin selections. We also used MCC to set up and use the UART peripheral for sending output messages, the I2C peripheral for communicating with the fuel gauge, the timer 0 peripheral for generating a timed interrupt, and the pin manager module for creating an interrupt-on-change (IOC) on the reed switch input pin.

Figure depicts a flowchart of the MCU’s main loop. The first step in the main loop is to debounce the pushbutton input. This is done by storing the button’s state in a temporary variable, waiting a few milliseconds, and continuing if the button is still in the same state. This process prevents the MCU from reacting to inputs that are too short to be the result of an animal’s interaction. Next a variable is set to indicate that a debounced input was handled, this allows the software to check if any new inputs have occurred during the loop. The software then checks that the input isn’t repeated (for example, two button presses cannot happen without a button release in between). If the input is valid, the software gets the battery’s charge level from the fuel gauge and sends output messages. If no new inputs need to be processed, the MCU is put to sleep. The use of the timer before this step is discussed in further detail in the Problems Encountered section.

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Reed Switch Interrupt on Change



Timer Interrupt



Figure 25: Software Interrupt Flowcharts

When the MCU is put to sleep at the end of the main loop, it halts code execution and resumes at the next line upon waking up. As a result, our main loop runs only until the MCU is put to sleep. When an interrupt occurs, the MCU is woken and it resumes code execution at the start of the loop. An interrupt halts execution of the main program, executes its code, and then resumes normal execution. The two interrupts used in our software are shown in Figure . The interrupt-on-change (IOC) occurs when the button changes states and the timer interrupt occurs when one timer period (set as 1s) passes. Both interrupts store the button's current state in a variable that the main loop checks. The IOC also unsets the variable indicating if an input was processed to let the main loop know a new input occurred. This interrupt's primary purpose is to wake the microcontroller when the button is manipulated so the MCU can process it and output data. Once again, the timer interrupt is discussed in the Problems Encountered section.

Output messages are sent using the MCU's UART module. This module is set up to operate at 9600 baud and only include transmission. MCC generated a basic function for transmitting a single character, so we designed a simple function to transmit strings. All output messages share the same structure: the first three characters are the message type, the next two characters are the message data, and the final character is always a carriage return. The messages used in our prototype are "BTN00\r" for the button is released, "BTN01" for the button is pressed, and "BAT##\r" for the battery is at ##%.

The fuel gauge is connected to the PIC microcontroller through the I2C protocol. MCC provides an I2C module similar to the UART module to implement communication. This module allows the user to set the clock speed for I2C transmission and use generated functions to read and write bytes from the PIC controller Master to the fuel gauge Slave. In our implantation, we set the clock to 100000 Hz using the Medium Frequency Internal Oscillator (MFINTOSC). Additionally, we used two MCC generated functions to request the state of charge from the fuel gauge. First, the PIC sends two bytes to the fuel gauge using the I2C1_Write2ByteRegister function. This action ensures that fuel gauge is connected to the I2C slave chain and requests that the fuel gauge responds to the PIC by sending the state of charge. Then, the PIC reads the fuel gauge response by using the I2C1_Read2ByteRegister function and saves the result in a data variable. If the PIC does not

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receive a response or the fuel gauge is not connected, it will retry the two functions up to three times.

Testing

The I2C MCC generated functions are extremely undocumented due to their constant updates. So, to begin testing I2C communication we connected the PIC controller to an Arduino. The PIC was acting as the master and the Arduino the slave. On the Arduino, we slightly modified a pre made slave receiver example to output any I2C messages to the Serial Monitor. This allowed us to monitor and familiarize ourselves with how the MCC functions operated on both ends of communication. Both the read and write functions mention in the previous sections were tested on the Arduino. Next, we moved on to initial testing with the fuel gauge. We used the same functions that were used previously on the Arduino.. However, the fuel gauge has specific hexadecimal numbers assigned to each of its registers. To read data from fuel gauge, the PIC must first send the hexadecimal of the desired register to the fuel gauge. The fuel gauge will then respond by sending back the data in that register. We tested this method by retrieving the fuel gauge's version number from the 0x08 register. Then we moved onto the state of charge and current voltage registers and compared the value to the voltage measured on a voltmeter.

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Budget

Project Bill of Material					
Part	Category	Part Price	Qty.	Subtotal	
Mini Lipo Charger	Battery Management	\$6.95	1.00	\$6.95	
PRT-13851 battery	Battery Management	\$4.95	1.00	\$4.95	
Qwiic Fuel Gauge	Battery Management	\$5.95	1.00	\$5.95	
Seed wireless charger	Battery Management	\$8.50	1.00	\$8.50	
MPLAB Snap Programmer	Boards	\$31.61	1.00	\$31.61	
AP2138N-3.3, 3.3V Linear Reg.	Electronics Parts	\$0.38	5.00	\$1.90	
Capacitor 0.1uF SMD	Electronics Parts	\$0.09	10.00	\$0.85	
Connector HDR, 5P, F	Electronics Parts	\$0.64	5.00	\$3.20	
Connector HDR, 5P, M	Electronics Parts	\$0.24	5.00	\$1.20	
PCB Bareboards	Electronics Parts	\$25.10	1.00	\$25.10	
PIC18F16Q41	Electronics Parts	\$2.03	3.00	\$6.09	
Resistor 10k SMD	Electronics Parts	\$0.04	50.00	\$1.80	
Resistor 1k SMD	Electronics Parts	\$0.07	10.00	\$0.74	
Resistor 470 SMD	Electronics Parts	\$0.08	10.00	\$0.76	
SN74HC04 Inverter	Electronics Parts	\$0.60	5.00	\$3.00	
Switch, Reed, NO (59165-1-S-00-A)	Electronics Parts	\$1.70	2.00	\$3.40	
TORX1355	Electronics Parts	\$13.40	2.00	\$26.80	
TOTX1350	Electronics Parts	\$11.08	2.00	\$22.16	
#4-40 Aluminum Standoff 1/2" (4694)	Hardware	\$0.66	4.00	\$2.64	
#4-40 Hex Nut (4694)	Hardware	\$0.10	4.00	\$0.40	
CG-32 Cable Gland	Hardware	\$2.86	1.00	\$2.86	
KabelDirekt fiber optic cable	Hardware	\$12.99	2.00	\$25.98	
Magnet, 0.25"DIA (Radial Magnets 8005)	Hardware	\$0.45	1.00	\$0.45	
Nylon Screw 1.125" (3408320112)	Hardware	\$0.11	4.00	\$0.44	
Nylon Thumb Nut (0800832TNA)	Hardware	\$0.19	4.00	\$0.76	
Raytech Gel	Hardware	\$60.00	1.00	\$60.00	
Springs (Pack of 6) (1986K58)	Hardware	\$3.60	1.00	\$3.60	
Straps (29695T29)	Hardware	\$4.84	2.00	\$9.68	
Submersible Enclosure (4058N21)	Hardware	\$35.42	1.00	\$35.42	
3.3V Regulator (AP7354-33W5-7)	Prototyping Supplies	\$0.52	1.00	\$0.52	
3.3V Regulator (RH5RL33AA-T1-FE)	Prototyping Supplies	\$1.19	1.00	\$1.19	
Cable, HDR, 5P, F-F	Prototyping Supplies	\$3.54	1.00	\$3.54	
Capacitor 0.1uF TH	Prototyping Supplies	\$0.39	10.00	\$3.85	
Magnet, 0.35" DIA (8008)	Prototyping Supplies	\$0.45	1.00	\$0.45	
Magnet, 0.6" DIA (8074)	Prototyping Supplies	\$1.74	1.00	\$1.74	
Magnet, Cube ()	Prototyping Supplies	\$0.99	1.00	\$0.99	
PIC18F16Q41 Evaluation Board	Prototyping Supplies	\$19.37	1.00	\$19.37	
Resistor 10k TH	Prototyping Supplies	\$0.11	30.00	\$3.30	
Resistor 1k TH	Prototyping Supplies	\$0.63	5.00	\$3.15	
Resistor 470 TH	Prototyping Supplies	\$0.22	10.00	\$2.20	
Tested Reed Switch (59165-1-U-00-A)	Prototyping Supplies	\$1.70	1.00	\$1.70	
Tested Reed Switch (59170-1-S-00-A)	Prototyping Supplies	\$2.09	1.00	\$2.09	
Tested Reed Switch (MITI-7-6-10)	Prototyping Supplies	\$2.51	1.00	\$2.51	
Tested Reed Switch (ORD 324/10-15 AT)	Prototyping Supplies	\$0.65	1.00	\$0.65	
Tested Reed Switch (RI-02GP1520)	Prototyping Supplies	\$0.51	1.00	\$0.51	
Total				\$344.95	

Table 3: Project Bill of Material

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The total budget for this project came out to be \$344.95. As you can see in Figure 26, the hardware section accounts for almost half of our budget. This makes sense because waterproofing electronics is a difficult task and requires plenty of creative thinking and more expensive materials. If this project were to have been used above the surface, we could have simply used copper wire rather than purchasing a magnet, a reed switch, and a fiber optic cable. We also would not have needed to purchase Raytech gel or a submersible enclosure, which if you refer to Table 3 are the most expensive items in our budget. But, because this project requires the enclosure to be submersible, we thought it would be best to invest more money into quality products rather than taking the cheap route and risk damaging our electronics. The battery management portion of this project was the cheapest and as you can see in Table 3 it only required the purchasing of four fairly inexpensive products. Overall, the budget came out to be a fair price for the quality of the finished system.

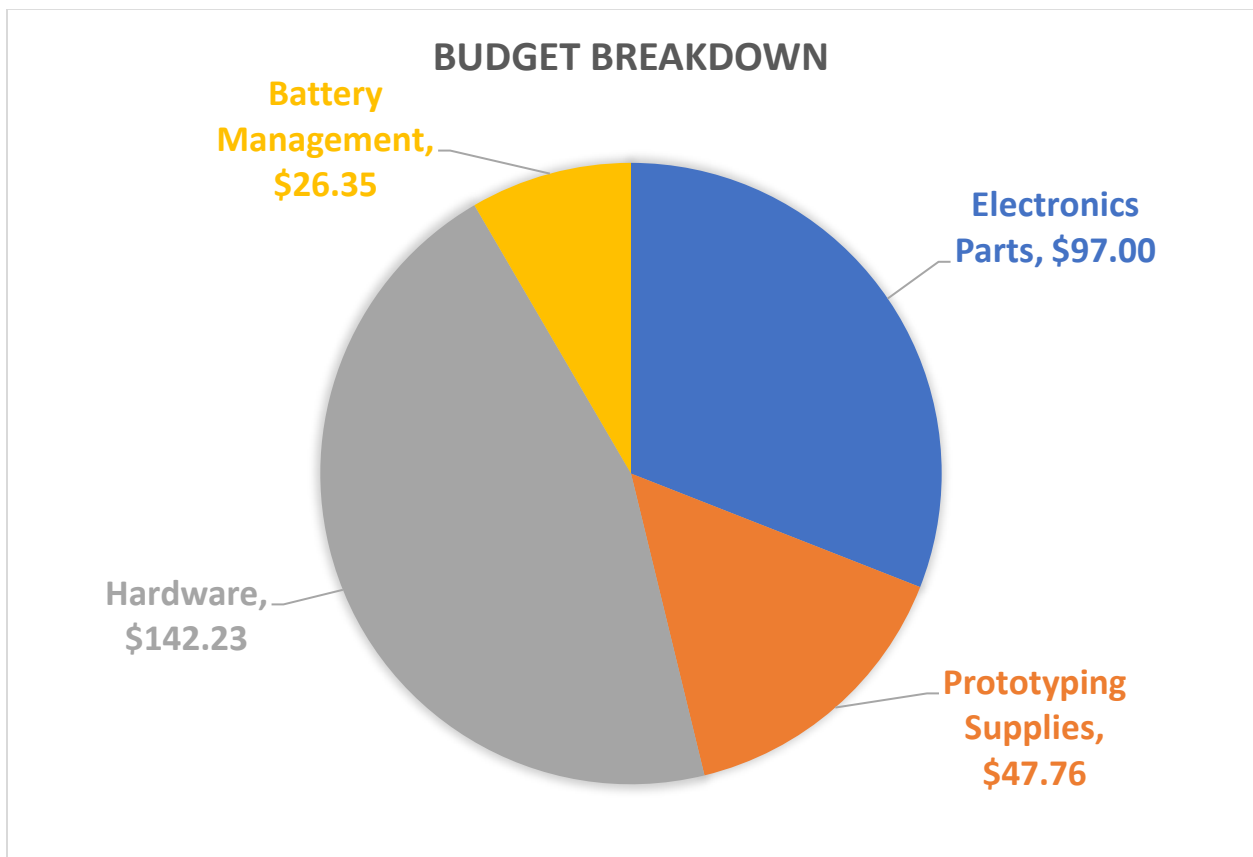


Figure 26: Budget Breakdown

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Timeline

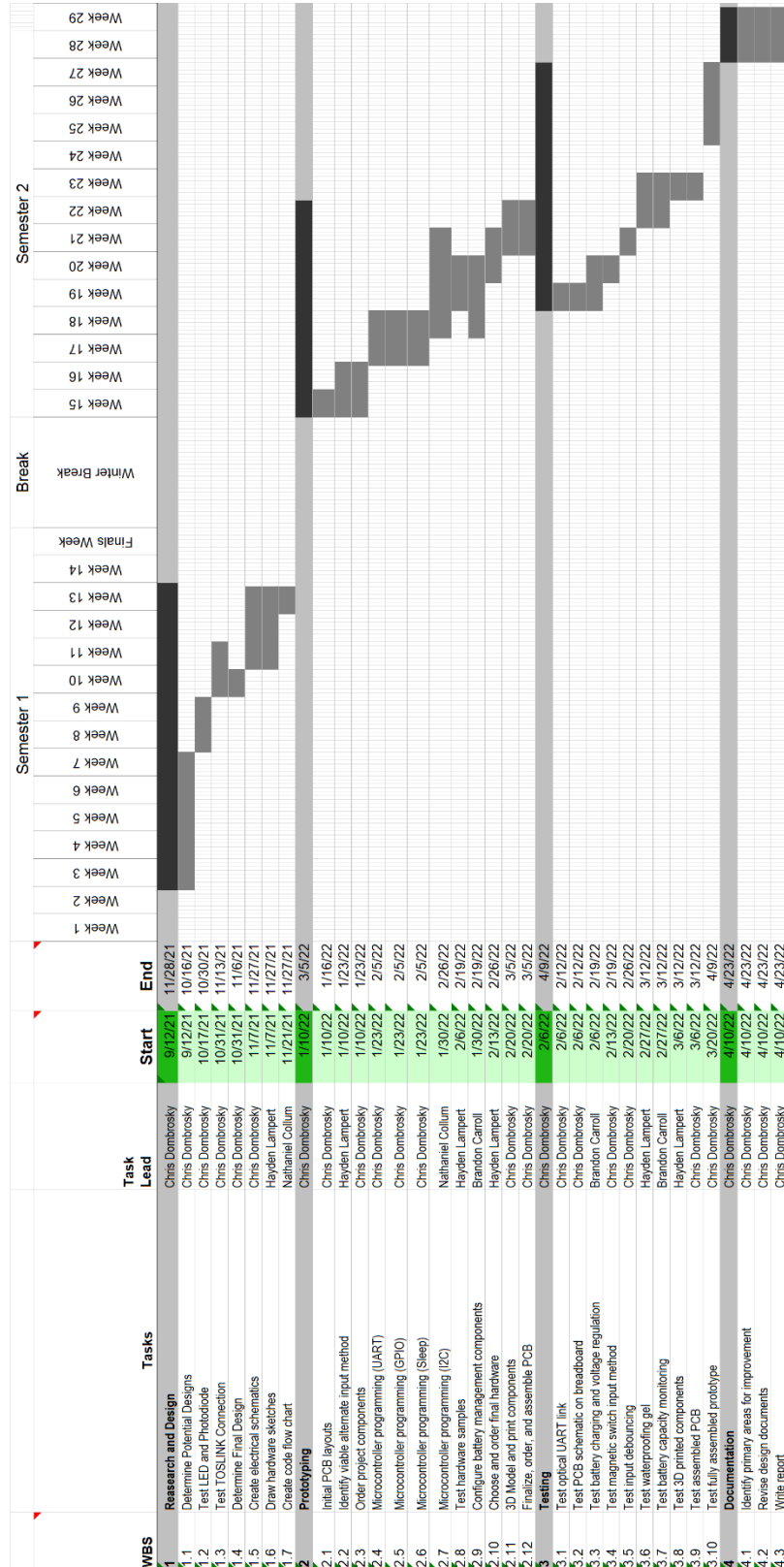


Table 4: Project Timeline

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Problems Encountered and Lessons Learned

A problem encountered early in the project was that we spent too much time trying to brainstorm an idea. Rather than deciding on a concept and beginning design and prototype work early, we spent about 1.5 months considering and slightly testing a few different ideas. As a result, we only had about 1 month to flesh out our proposed design concept during semester 1. This also led to us having no prototyping work done at the start of semester 2. Our solution was to keep our design relatively simple and small in scope so that we would have enough time to make sure our prototype was fleshed out and operational. This plan was successful as we were able to do everything we initially planned, and even a bit more. However, this taught us the value of settling on a design and goal early because if we had done so we may have been able to increase the scope and functionality of our project.

One problem encountered early in the second semester was that our initial idea for an input device fell through. We had planned to purchase a premade pushbutton rated to work underwater and mount it to the outside of our enclosure. However, the company selling the button never responded to our inquiries about price and availability. As a result, we had to rush to think of and design the custom pushbutton described in this report. This taught us the importance of ensuring that everything the project's design requires is a valid choice early in the design process.

A problem encountered while testing the prototype is that brief button presses would sometimes cause a button pressed message to send, but no button released message. After further testing, we found that the problem was caused by the button being released when the interrupt from the button press was still occurring. This resulted in the software ignoring the button release. Our solution was to initialize a 1 second timer when the MCU is put to sleep after a button press. This timer would trigger an interrupt after 1 second that would wake the MCU from sleep and check the button's state. This allowed the software to periodically check for a button release for as long as the button was pressed. This successfully solved this specific problem. This issue taught us the importance of having a strong understanding of how the software will function to help prevent and understand bugs such as this.

Our initial button design had the springs simply glued to the bottom of the button. While this would work ideally, we found that the springs were so thin and long that they would often deflect to the sides when the button is pressed. We solved this problem by designing the support posts seen in Figure 5 to ensure the springs could only move linearly. This taught us to expect unanticipated issues when designing hardware and to not assume everything would work first try.

Future Recommendations

As previously mentioned, this prototype only functions as a simple pushbutton but allows for more functionality to be added. One recommendation we have is to better utilize the control PCB by adding additional sensors such as a thermistor to monitor enclosure and/or water temperature. Another recommendation we have is to do more testing on the prototype's waterproofing as we did not have enough time in the semester to do so. Finally, we recommend designing an output system that uses our prototype and testing if animals can be trained to utilize it.

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Conclusion

Overall, the prototype produced during this project met the goals we set for it at the start. The custom button design works perfectly through the walls of the enclosure, is large and easy to press, and is designed in a way that makes it easy to modify or replace. Although we did not have enough time to fill the enclosure with Raytech gel and test it underwater, the testing we performed during the project leaves us with confidence that the electronics will be safe upon doing so. The combination of the 3D printed outer enclosure and purchased inner enclosure also adds to the durability of the prototype. The fiber optic cable was able to transmit data in a UART format without any issue and presents no danger to animals if damaged. The battery and associated components successfully power the prototype, track the battery's capacity, and charge the battery wirelessly. The custom PCBs make connecting the prototype to an Arduino an easy process and allow for further expansion on this design. Additionally, we designed a custom charging tray and provided components to assemble and program more PCBs to make the use and expansion of this prototype easier for our advisors. There is still more work to be done to finalize and implement our design, but we believe our prototype provides our advisors with a strong starting point for developing full enrichment systems for aquatic animals.

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Appendix B: 3D Model Files

<https://github.com/dombrosky/Senior-Design/tree/master/3D%20Models>

Appendix C: PCB Files

<https://github.com/dombrosky/Senior-Design/tree/master/PCB%20Files>

Appendix D: PCB Component Lists

Control PCB Parts List				
Label	Description	Value	Package	Required?
C1	Microcontroller decoupling capacitor	0.1uF	1206 SMD	Required
C2	MCLR Pin Capacitor (See 4.3 of PIC18F16Q41 Datasheet)	0.1uF	1206 SMD	Required
C5	Voltage regulator decoupling capacitor	0.1uF	1206 SMD	Required
C6	Voltage regulator decoupling capacitor	0.1uF	1206 SMD	Required
D1	Fiber Optic Transmitter (TOTX1350 or equivalent)	n/a	Unique	Required
J1	Programming connector (0.1" Pitch 5 pin male header)	n/a	0.1" Pitch TH	Required
J2	I/O pin connector (0.1" Pitch 6 pin female header)	n/a	0.1" Pitch TH	Optional
J3	Battery connector (0.1" Pitch 6 pin female header)	n/a	0.1" Pitch TH	Optional
J4	I/O pin connector (0.1" Pitch 6 pin female header)	n/a	0.1" Pitch TH	Optional
J5	I/O pin connector (0.1" Pitch 5 pin female header)	n/a	0.1" Pitch TH	Optional
JP1	MCLR capacitor solder jumper (See 4.3 of PIC18F16Q41 Datasheet)	n/a	SMD	Required
R1	MCLR pullup resistor (See 4.3 of PIC18F16Q41 Datasheet)	10kΩ	1206 SMD	Required
R2	MCLR current limiting resistor (See 4.3 of PIC18F16Q41 Datasheet)	470kΩ	1206 SMD	Required
R3	Fiber transmitter current limiting resistor (See TOTX1353 datasheet)	1kΩ	1206 SMD	Required
R4	I/O optional pullup resistor	10kΩ	1206 SMD	Optional
R5	I/O optional pullup resistor	10kΩ	1206 SMD	Optional
R6	I/O optional pullup resistor	10kΩ	1206 SMD	Optional
R7	I/O optional pullup resistor	10kΩ	1206 SMD	Optional
R8	Fuel gauge alert pullup resistor	10kΩ	1206 SMD	Optional
R9	I2C SCL line pullup resistor	2.2kΩ	1206 SMD	Required
R10	I2C SDA line pullup resistor	2.2kΩ	1206 SMD	Required
R11	I/O optional pullup resistor	10kΩ	1206 SMD	Optional
R12	I/O optional pullup resistor	10kΩ	1206 SMD	Optional
R13	I/O optional pullup resistor	10kΩ	1206 SMD	Optional
R14	I/O optional pullup resistor	10kΩ	1206 SMD	Optional
R15	Reed switch pullup resistor	10kΩ	1206 SMD	Required
R16	I/O optional pullup resistor	10kΩ	1206 SMD	Optional
R17	I/O optional pullup resistor	10kΩ	1206 SMD	Optional
IC1	PIC18F16Q41 microcontroller	n/a	20 DIP/DIL	Required
U1	AP2138N-3.3TRG1 linear voltage regulator (3.3V out)	n/a	SOT23-3	Required

Table 5: Control PCB Component List

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Receiver PCB Parts List				
Label	Description	Value	Package	Required?
U1	Fiber Optic Receiver (TORX1355 or equivalent)	n/a	Unique	Required
U2	Hex Inverter (SN74HC04 or equivalent)	n/a	PDIP-14	Required
C1	Capacitor	0.1 uF	1206 SMD	Required
J1	Header (0.1" Pitch 5 pin female header)	n/a	0.1" Pitch TH	Required

Table 6: Receiver PCB Component List

Appendix E: Microcontroller Program

https://github.com/dombrosky/Senior-Design/tree/master/Senior_Design.X

Appendix F: Component Datasheets

<https://github.com/dombrosky/Senior-Design/tree/master/Datasheets>