Fall 2023

MEMS 411: In-Beach Pressure Sampler Design Report

Alex McCormick
Washington University in St. Louis

Mark Lipkin
Washington University in St. Louis

Nirvan Patel Masini
Washington University in St. Louis

Austin Bick
Washington University in St. Louis

Washington University in St. Louis
JAMES MCKELVEY SCHOOL OF ENGINEERING

Mechanical Engineering Design Project
MEMS 411, Fall 2023

In-Beach Pressure Sampler

The in-beach pressure sampler will be used to measure air pressure and temperature at the depths of sea turtles in the Pacuare Natural Reserve in Costa Rica. The customer hypothesizes that crashing waves and receding tides causes air pressure propagation which is important in allowing the sea turtle eggs to breathe and receive fresh air. The device will be used to test this hypothesis.

The design must be weatherproof to withstand the beach conditions, it must have a portable power source due to no access to electricity, and it must store pressure and temperature data over a long period of time.

The chosen design utilizes a PVC shaft to allow a pressure gauge and temperature sensor to reach sea turtle nest depths. A sand anchor is attached to the shaft at the bottom to secure the device into the sand. A hole covered in mesh was drilled at the correct depth in the PVC shaft to allow for the air pressure to be measured, but no sand to get into the device. Another hole was drilled at the bottom of the anchor to allow for any sand to be removed. Finally, a resealable weatherproof electronics box is attached to the top of the PVC shaft houses all the electronics used to measure and store data. The design uses rechargeable batteries and a solar panel to power itself. Finally, the data is stored using an Arduino and removable SD card.

This chosen design was proven to be adequate by performing three tests: recording time stamped pressure data over 24 hours while immersed, retrieving data and resealing the device in under 2.5 minutes, and ensuring there is sufficient battery life and data storage.

These goals were achieved and, because of this, we are confident that the device will be able to measure the beach pressure and temperature at sea turtle depths over a long-period of time and survive the beach conditions.

MCCORMICK, Alex
LIPKIN, Mark
PATEL MASINI, Nirvan
BICK, Austin

Contents

List of Figures **2**

List of Tables **2**

1 Introduction **3**

2 Problem Understanding **3**
- 2.1 Existing Devices . . . 3
- 2.2 Patents . . . 5
- 2.3 Codes & Standards . . . 7
- 2.4 User Needs . . . 7
- 2.5 Design Metrics . . . 8
- 2.6 Project Management . . . 8

3 Concept Generation **10**
- 3.1 Mockup Prototype . . . 10
- 3.2 Functional Decomposition . . . 10
- 3.3 Morphological Chart . . . 12
- 3.4 Alternative Design Concepts . . . 13

4 Concept Selection **17**
- 4.1 Selection Criteria . . . 17
- 4.2 Concept Evaluation . . . 17
- 4.3 Evaluation Results . . . 18
- 4.4 Engineering Models/Relationships . . . 18

5 Concept Embodiment **20**
- 5.1 Initial Embodiment . . . 20
- 5.2 Proofs-of-Concept . . . 24
- 5.3 Design Changes . . . 24

6 Design Refinement **24**
- 6.1 Model-Based Design Decisions . . . 24
- 6.2 Design for Safety . . . 26
- 6.3 Design for Manufacturing . . . 28
- 6.4 Design for Usability . . . 32
- 6.5 Design Considerations . . . 33

7 Final Prototype **33**
- 7.1 Overview . . . 33

Appendix A Software Code - MATLAB **37**

Appendix B Parts List **38**

List of Figures

1 MPM4730 Digital Pressure Transmitter (Source: Microsensor Corp) 3
2 Seismo Seismic Detector (Source: RBtec Perimeter Security Systems) 4
3 XMP i (Source: BD Sensors) 5
4 Patent Images for Beach Umbrella Stake. 6
5 Patent Images for Beach Umbrella Anchor. 6
6 Gantt chart for design project 9
7 Mock-up Pictures. 10
8 Function tree for In-Beach Pressure Sampler, hand-drawn and scanned 11
9 Morphological Chart for In-Beach Pressure Sampler. 12
10 Concept 1: Spikey 13
11 Concept 2: Bluetooth Shovel Stake. 14
12 Sketches of Robotic Arm concept 15
13 Sketches of Robotic Arm concept 16
14 Analytic Hierarchy Process (AHP) to determine scoring matrix weights 17
15 Weighted Scoring Matrix (WSM) for choosing between alternative concepts 17
16 Pressure transducer PSI requirement. 18
17 Lithium ion battery sizing. 19
18 Stress amplitude vs. number of cycles till failure for four different means stresses for PVC [citation number]. 20
19 Assembled projected views with overall dimensions. 21
20 Assembled isometric view. 22
21 Exploded view with BOM. 23
22 Pressure transducer PSI requirement. 24
23 Pressure transducer PSI requirement. 25
24 Heat map of risks. 27
25 Image of Box and PVC Tube 28
26 Image of Perfboard 29
27 Image of the Anchor 30
28 Illustration of Modified Design 31
29 Overall picture of project. 34
30 Electronics box. 34
31 Inside electronics box. 35
32 Mesh. 35
33 Pressure gauge inside PVC shaft. 36

List of Tables

1 Interpreted Customer Needs 8
2 Target Specifications 8
3 Factors considered for design solution 33
4 Contexts considered for ethical judgments 33

1 Introduction

The objective of this design project is to develop a device that can measure and record the pressure differential beneath the sand at the shoreline of the Pacuare Natural Reserve in Costa Rica. The customer is doing research aimed at defining how microplastics are influencing beaches, specifically sea turtles. To do this, researchers are investigating how waves play a role in how air gets into turtle nests, and whether the rise and fall of the tide impacts airflow to the beach. To do this effectively, the device should be secured well into the ground, water-tight, reach the typical depth of turtle nests, run on battery, and have a useful user interface for storing and retrieving data.

2 Problem Understanding

2.1 Existing Devices

To design our In-Beach Pressure Sampler, we found three similar devices to 1) see what exists in the market, 2) isolate competitors, and 3) benchmark from existing designs. A general pressure transmitter, a seismic recorder, and an extreme environment pressure transmitter.

2.1.1 Existing Device #1: Digital RS485 HART Pressure Transmitter

Figure 1: MPM4730 Digital Pressure Transmitter (Source: Microsensor Corp)

Link: https://www.microsensorcorp.com/Product-details_Digital-RS485-HART-Pressure-Transmitter-MPM4730.html
Description: The MPM4730 Digital RS485 HART Pressure Transmitter measures the pressure (gauge, absolute, sealed gauge) of fluid flow, and is utilized in hydrological water resources, the petroleum industry, and for hydraulic and pneumatic control. The pressure transmitter accurately

measures the pressure of fluid flow through pipes, in water reservoirs, or in tanks. The transmitter can measure up to 1000 bar, and functions in a temperature range of -20 to 80℃. The device outputs digital and analog signal output and is small enough to fit in your hand.

2.1.2 Existing Device #2: The Seismo Standalone Buried Seismic Detectors

Figure 2: Seismo Seismic Detector (Source: RBtec Perimeter Security Systems)

Link: https://www.rbtec.com/perimeter-sensors-and-underground-protection/buried-underground-sensors/unattended-ground-sensor-security-system-ugs/
Description: The Seismo ground security system is a home/building security system that is installed underground and receives seismic waves to detect vehicles and people moving nearby. The sensors are buried around a foot beneath the surface, and have a measurable radii of ten meters. The sensors send the seismic activity to a box which measures variability of seismic activity.

2.1.3 Existing Device #3: precision pressure transmitter XMP i

Figure 3: XMP i (Source: BD Sensors)

Link: https://www.bdsensors.de/en/pressure/pressure-transmitter/details/produkt/xmp-i/
Description: The XMP i pressure transmitter is specifically made for the oil, gas, and processing industry and measures in extreme temperature and pressure conditions. It is made from stainless steel, and can measure pressures up to 600 bar and temperatures up to 300°C. It measures pressures in gases, steam, fluids, and dust.

2.2 Patents

2.2.1 Patent 1: Beach Umbrella Stake (WO2001077464A1)

This patent deals with a beach umbrella stake comprised of three main pipe shafts. There is two larger shafts and one smaller shaft. The smaller shaft sits in between the two larger shafts. The smaller shaft is able to insert itself into the lower, larger shaft. This means that, when pushed downwards, the higher, larger shaft impacts with the lower, larger shaft causing a hammering effect. This hammering effect allows for the stake point to be pushed down and secured into the sand. This also allows for the stake to be extracted with reverse movements.

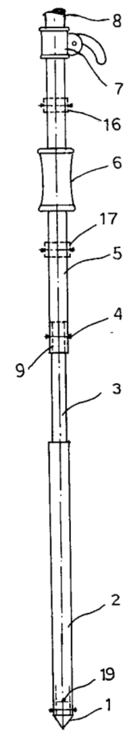


Figure 4: Patent Images for Beach Umbrella Stake.

2.2.2 Patent 2: Beach Umbrella Anchor (USD421532S)

This patent deals with anchoring a stake into beach sand. The beach stake anchor's design is a spiral with increasing radius in the downward direction. This anchor gets twisted and drilled into the beach sand. Once in the sand, the spiral secures the stake because of the increased surface area which causes more sand to be holding down the stake.

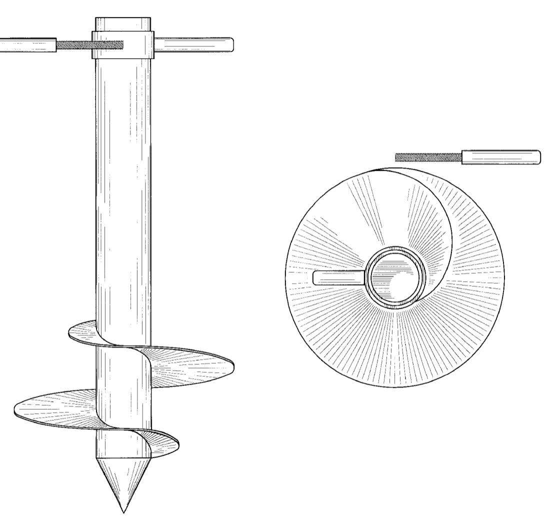


Figure 5: Patent Images for Beach Umbrella Anchor.

2.3 Codes & Standards

2.3.1 Endangered Species Act (ESA)

The ESA would likely require some permits from the U.S. Fish and Wildlife Service (USFWS) or the National Marine Fisheries Service (NMFS). It is likely that the customer, based on employment, has already handled or knows how to handle this. We also may be required to conduct an analysis on environmental impact, which is also likely to be the responsibility of our customer. Based on an analysis, we may have to make changes to our device to meet some specific requirements.

2.3.2 Degrees of Protection Provided by Enclosures (IEC 60529)

Based on our use case, we will probably need a device that is IP 67 or IP68. Since sand particles can be smaller then 1.0 mm, we must be able to protect our electronic parts from all dust. As for the water protection, the devices will be at the shoreline and will hence be subjected to wet sand which could be considered either periodic or continuous immersion in water.

2.4 User Needs

2.4.1 Customer Interview

Interviewee: Charles Suskin
Location: Zoom
Date: September 8^{th}, 2023
Setting: The interview began with introductions from each team member, followed by a brief project overview from the interviewer. Our team then went through a list of prepared questions that we had for the interviewee, listening and taking notes on his responses. The interview lasted ∼45 min.

Interview Notes:
What are the typical depths of turtle nests in this area?
- Turtle nests typically reside at about 75 cm below the surface on this beach front.

What software will researchers be using for data collection and what kind of data transmittance is preferable?
- The scientists can use any software you choose, Matlab, excel, python, etc. In terms of data transmittance, the best methods would likely be bluetooth or USB output if possible.

How long should the device be able to remain in the ground taking data?
- As long as a year. It is okay if it is less but as long as is possible is preferable, as it will reduce scientist labor.

What importance does environmental impact play into your goals as a customer?
- While it is important that it is environmentally friendly, we feel that the best way to achieve this is by making it robust, rather than biodegradeable so that it does not float away and become beach trash and can be reused.

Is there a specific sample rate that would work best?
- Obviously with a higher sample rate, battery life will be decreased. Aim for at least a few samples a day, one at high tide, and one at low tide.

2.4.2 Interpreted User Needs

From the interview, the user needs can be interpreted and their importance can be evaluated. These needs revolve around effectiveness and impact and are listed below.

Table 1: Interpreted Customer Needs

Need Number	Need	Importance
1	The device stays in place when waves crash and recede	4
2	The device is sand and water tight	5
3	The device is battery powered	5
4	The device can be found after use	3
5	The device has minimal environmental impact	3
6	The device allows easy data retrieval	4
7	The device accurately reads pressure at different points of the coast	5
8	The device is portable and easily installed	3

With these needs in mind, a device that works well, and satisfies the customer can be developed.

2.5 Design Metrics

From the customer needs, design metrics were formulated as a way to quantify the goals of the project. These expectations will help guide us to tangible results, creating a better overall result.

Table 2: Target Specifications

Metric Number	Associated Needs	Metric	Units	Acceptable	Ideal
1	2	Dust and Water Protection	IP	67	68
2	3	Battery life	*days*	> 100	> 365
3	7	Pressure Reading Precision	Pa	$+-1$	$+-0.1$
4	4	Distance seen from	m	< 15	> 30
5	1	Number of drops from hip height onto hard surface before malfunction	integer	> 10	> 50
6	6	Time to download data	minutes	< 5	< 1
7	7	Weight of device	lbs	< 5	< 2

2.6 Project Management

The Gantt chart in Figure 6 gives an overview of the project schedule.

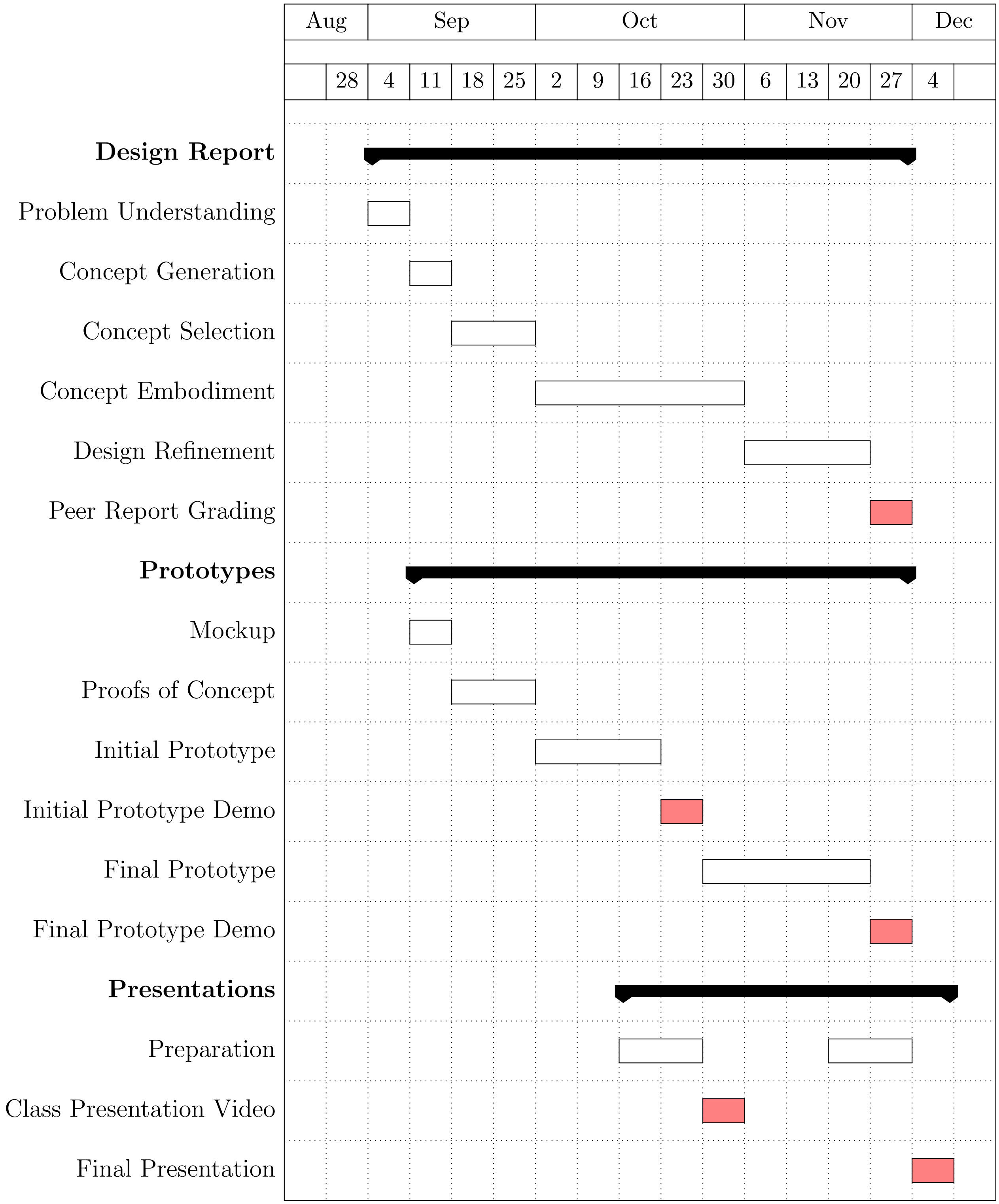


Figure 6: Gantt chart for design project

3 Concept Generation

3.1 Mockup Prototype

It influenced our thoughts on the device in three ways: 1) We were able to conceptualize ambiguous design ideas, as well as determine and understand relative scaling between different components in a tangible, touchable product. 2) We were able to generate ideas and converge on the fabrication process of the product. For example, we will need to develop and inward-out process, starting with our core components (Arduino, pressure sensor, etc) and ending with the casing around. Box construction for the mock-up is similar to how we will make the actual box. 3) We were able to standardize fabrication processes for different sub-parts. For example, the casing for the Arduino and the pressure gauge will be made similarly. We won't have to reinvent the wheel for each sub-part.

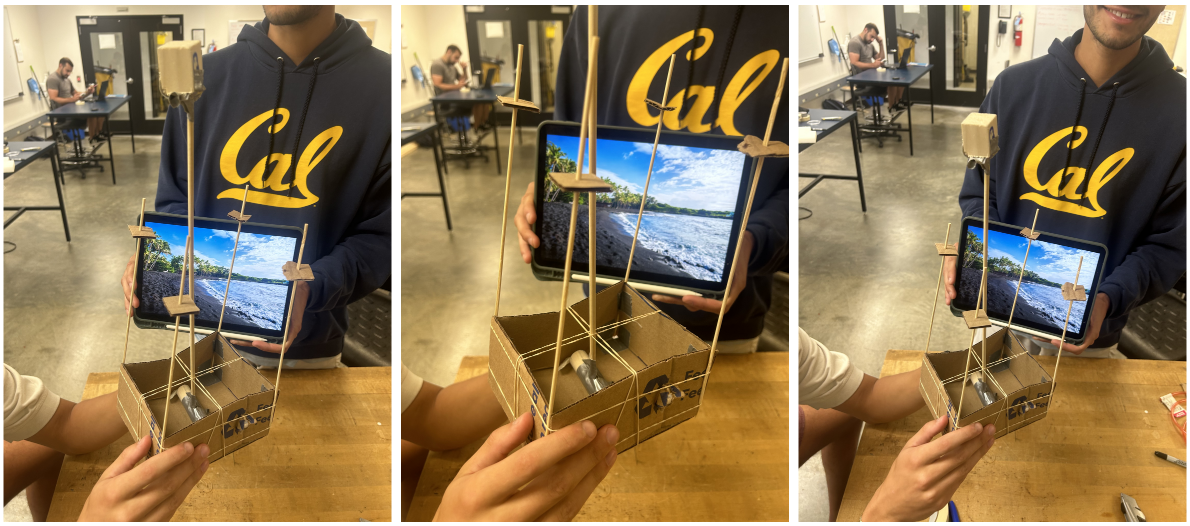


Figure 7: Mock-up Pictures.

3.2 Functional Decomposition

For the design, we broke down the overall function into multiple sub-functions to better guide our design process.

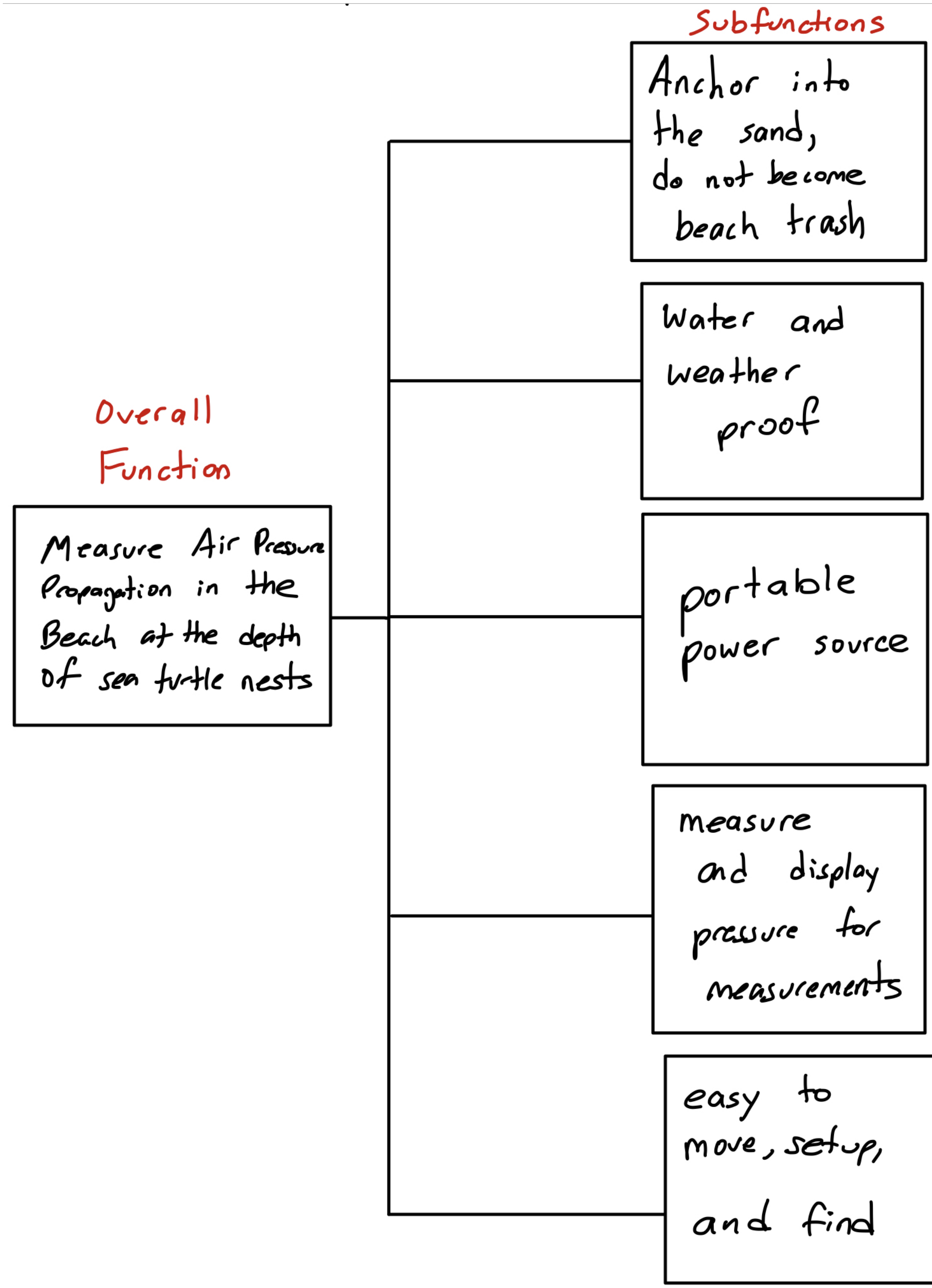


Figure 8: Function tree for In-Beach Pressure Sampler, hand-drawn and scanned

3.3 Morphological Chart

The morphological chart displays multiple, potential design solutions for each sub-function.

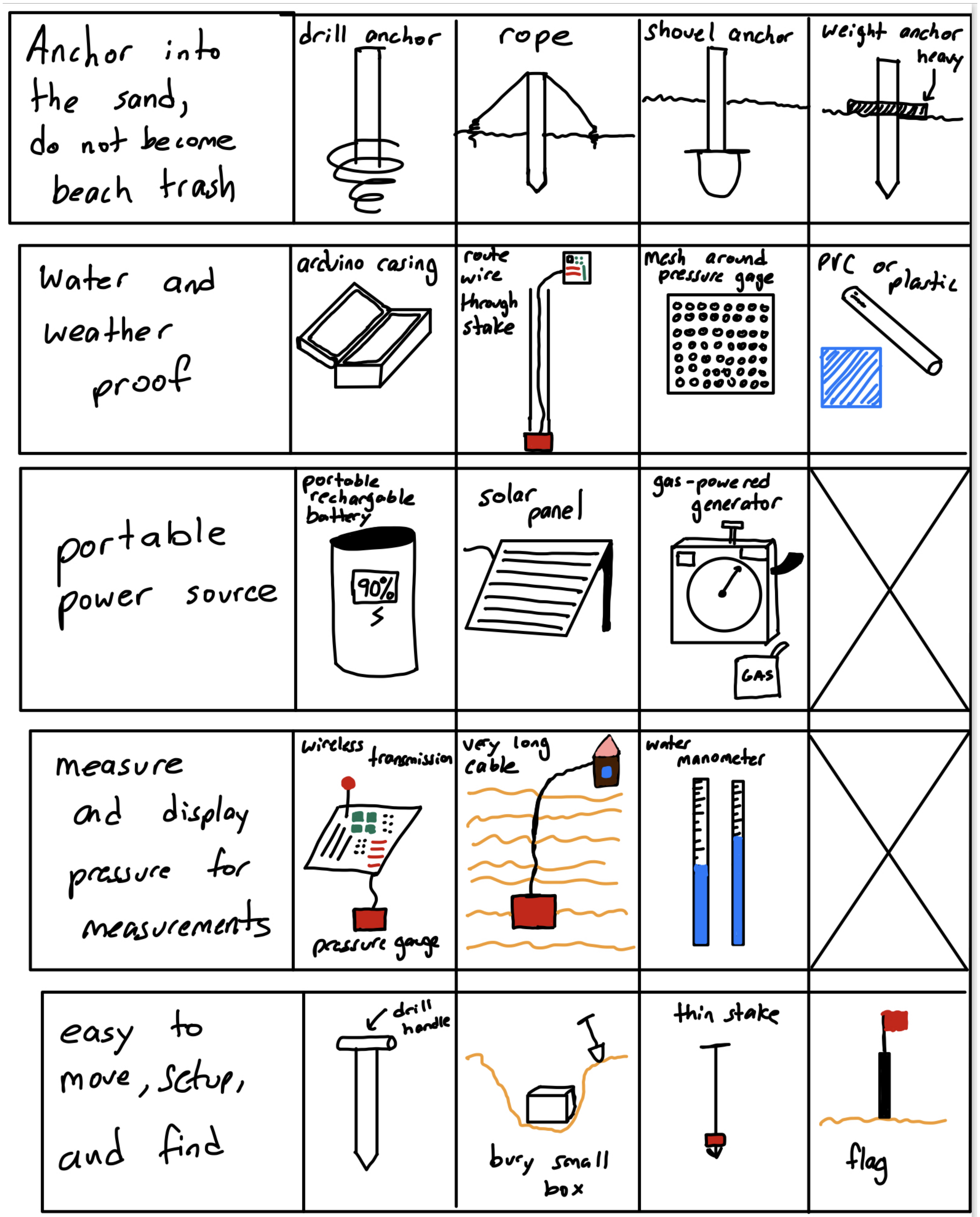


Figure 9: Morphological Chart for In-Beach Pressure Sampler.

3.4 Alternative Design Concepts

3.4.1 Concept #1: Spikey

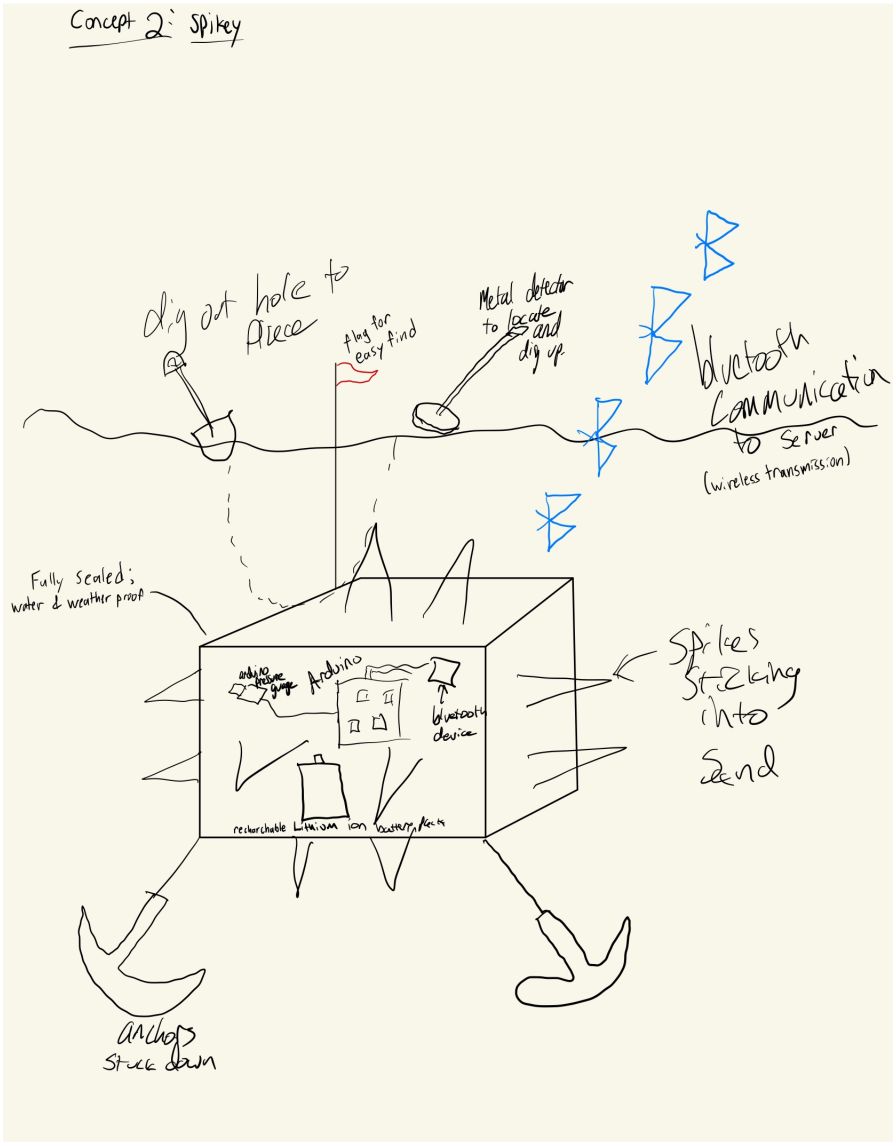


Figure 10: Concept 1: Spikey

Description: This design is fully sealed to prevent any water or weather damage. The device is powered with batteries that can be recharged. It transmits data via bluetooth and is anchored into the sand with large spikes and ship-like anchors. It is installed with a hole dug out manually and leaves a small flag to identify its location. If the flag fails or breaks, the box should be able to be found with a metal detector.

3.4.2 Concept #2: Bluetooth Shovel Stake.

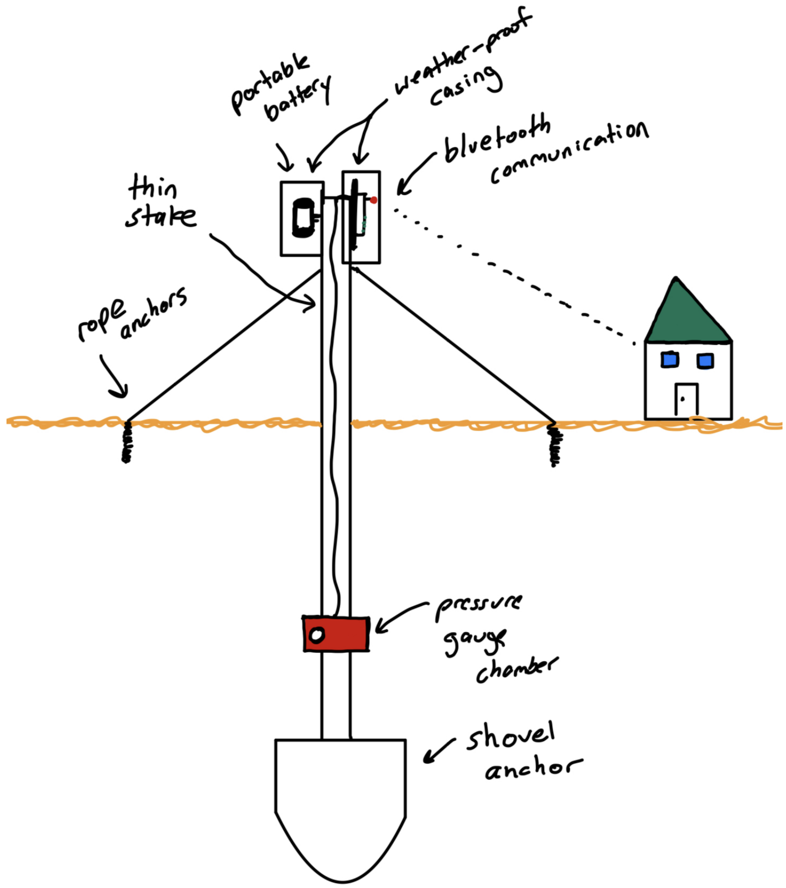


Figure 11: Concept 2: Bluetooth Shovel Stake.

Description: This concept utilizes a shovel head for both digging the initial hole for stake placement and anchoring the stake into the sand. Ropes are also used for anchoring. A mesh cage encloses a pressure gage. The mesh ensures no sand touches the gauge, but air is able to pass through. The wire connecting the gauge to the Arduino is routed through the stake. The battery and the Arduino are enclosed by weather-proof cases. Finally, the pressure data is transmitted via Bluetooth.

3.4.3 Concept #3: Orbital Measuring

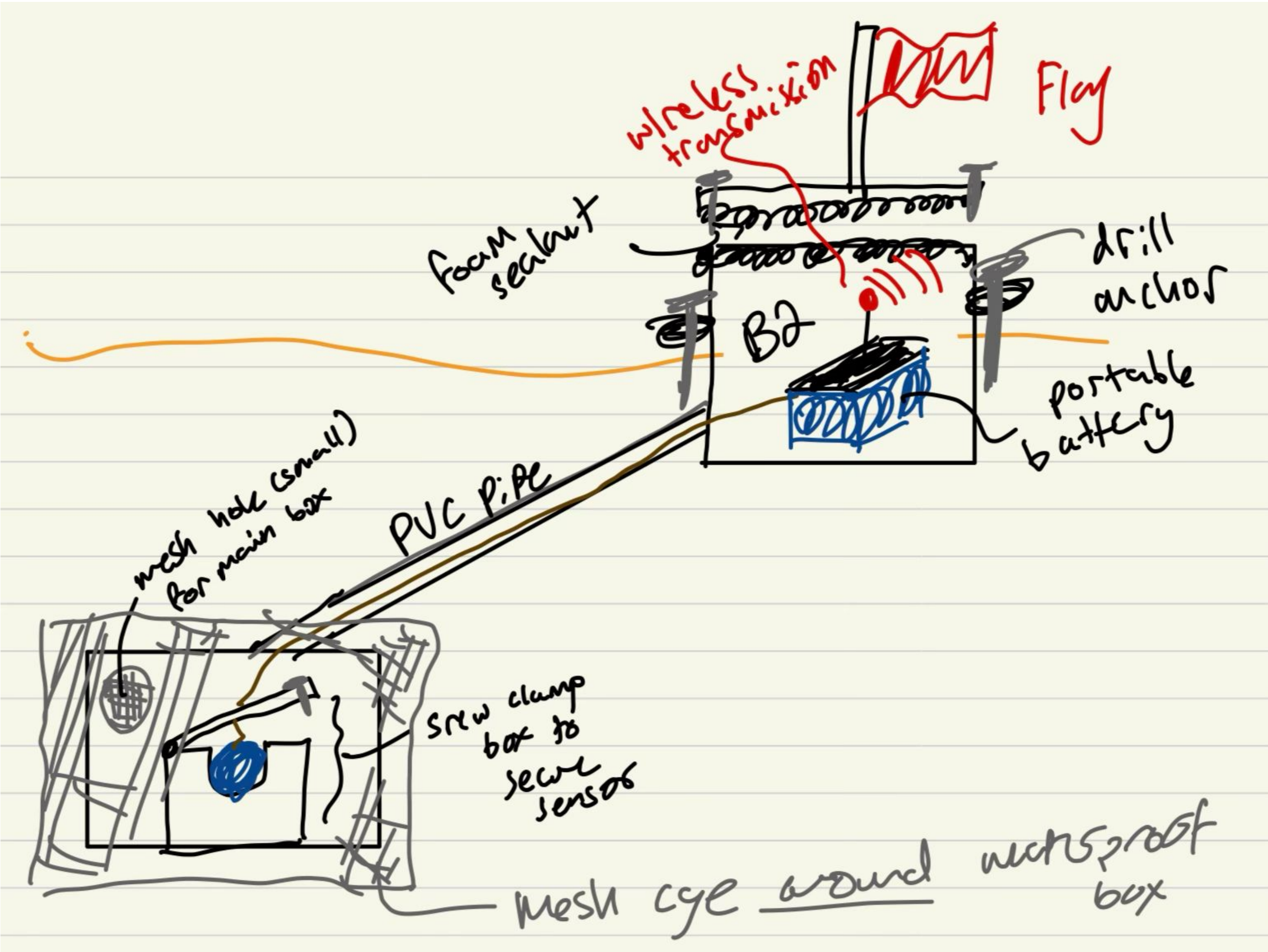


Figure 12: Sketches of Robotic Arm concept

Description: This concept has screw shaped anchors drilled deeply in the surface of the sand to keep the top box in place. A PVC pipe protects the chord that connects two waterproof boxes together (Arduino connected to pressure sensor). The lower box has a mesh hole that is big enough that will allow the air pressure to reach equilibrium with the air pressure of the sand around it. A flag at the top of the box ensures it is visible. The waterproof box is to protect the electrical equipment while the mesh around the box enables air to flow while stopping sand and most water.

3.4.4 Concept #4: The Faux-Nest

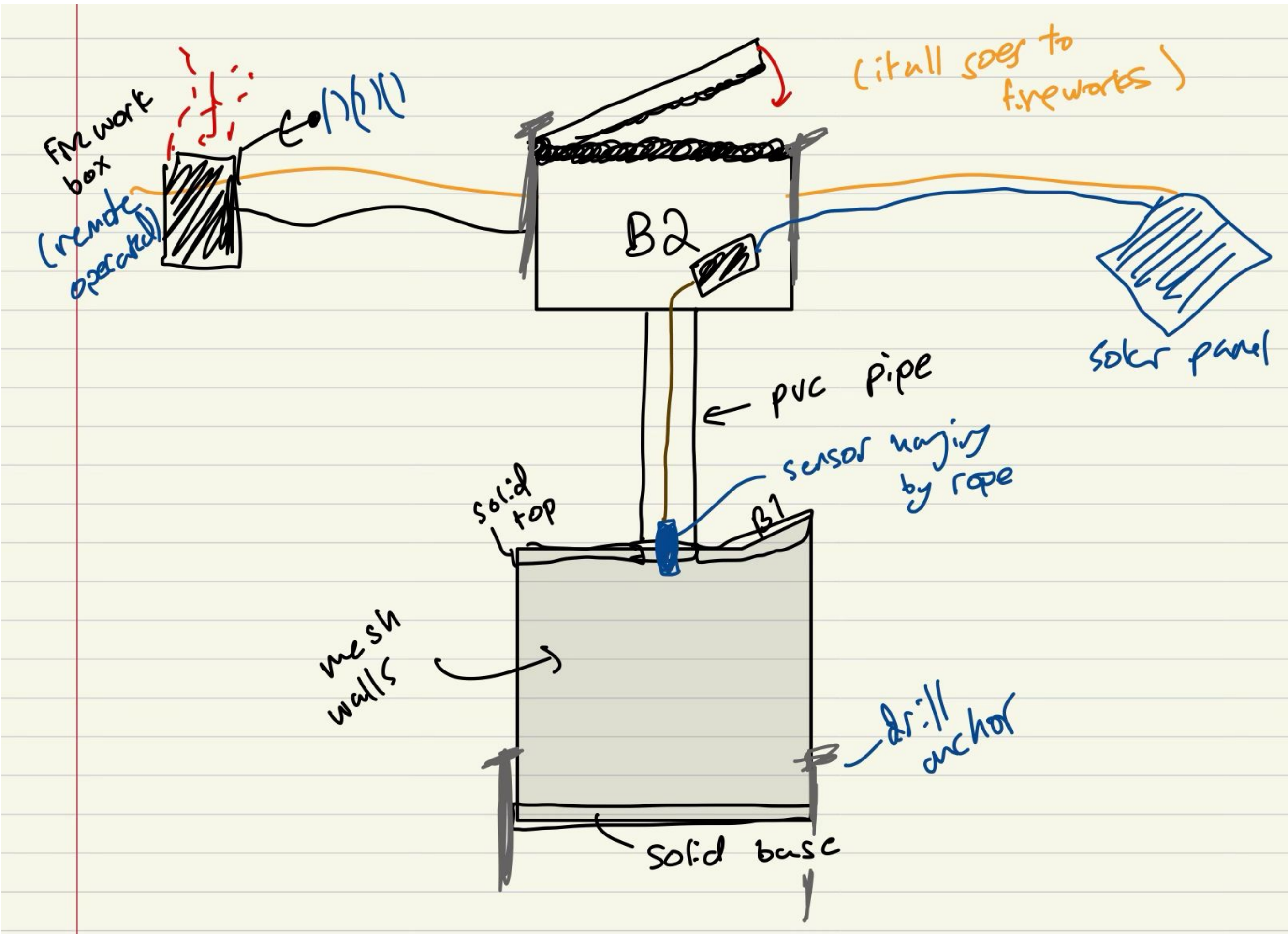


Figure 13: Sketches of Robotic Arm concept

Description: This design is based on an actual sea turtle nest. A submerged mesh cage the size of the average sea turtle nest has an opening on the top which a pressure sensor will be fixed in place at. The sensor is connected to an Arduino at the surface (powered by solar power), and the chord is encased by PVC piping. A firework box will trigger once bluetooth connection is lost.

4 Concept Selection

4.1 Selection Criteria

The analytical hierarchy process shown below is used to determine relative weight of each of the selection criterion.

	Weather/Water Proof	Sturdy in Sand	Portable	Easy to Install	Easy to Measure Pressure		Row Total	Weight Value	Weight (%)
Weather/Water Proof	**1.00**	1.00	3.00	7.00	1.00		13.00	0.26	26.27
Sturdy in Sand	1.00	**1.00**	3.00	7.00	1.00		13.00	0.26	26.27
Portable	0.33	0.33	**1.00**	5.00	0.20		6.87	0.14	13.87
Easy to Install	0.14	0.14	0.20	**1.00**	0.14		1.63	0.03	3.29
Easy to Measure Pressure	1.00	1.00	5.00	7.00	**1.00**		15.00	0.30	30.31
						Column Total:	**49.50**	**1.00**	**100.00**

Figure 14: Analytic Hierarchy Process (AHP) to determine scoring matrix weights

4.2 Concept Evaluation

The weighted scoring matrix below shows four potential concepts that were developed, and uses the scoring matrix weights developed in Fig. 14. The concepts are ranked 1-4 using the composite score that is calculated.

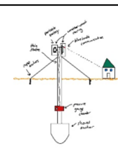
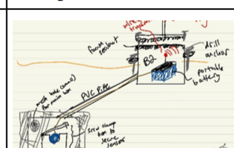
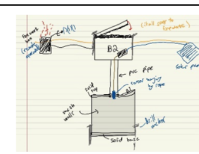
Alternative Design Concepts		**Concept #1: Spikey**		**Concept #2: Stake**		**Concept #3: Orbital Measure**		**Concept #4: Faux Nest**	
									
Selection Criterion	**Weight (%)**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Weather/Water Proof	26.27	5	1.31	4	1.05	4	1.05	4	1.05
Sturdy in Sand	26.27	5	1.31	4	1.05	4	1.05	4	1.05
Portable	13.87	2	0.28	4	0.55	2	0.28	2	0.28
Easy to Install	3.29	1	0.03	4	0.13	1	0.03	2	0.07
Easy to Measure Pressure	30.31	2	0.61	4	1.21	4	1.21	5	1.52
	Total score	**3.544**		**4.000**		**3.624**		**3.960**	
	Rank	**4**		**1**		**3**		**2**	

Figure 15: Weighted Scoring Matrix (WSM) for choosing between alternative concepts

4.3 Evaluation Results

The concept evaluation results show that concept 2, "Stake," is the most fit for our needs. This concept uses a stake to anchor the device into the sand at the correct depth. It has strings going out from the sides to assist in anchoring. The Arduino is housed in the top, above the sand, in a weatherproof box, and Bluetooth is used to communicate date to the scientists. With ratings of 4 across all 5 criterion: weather/water proof, sturdy in sand, portable, easy to install, easy to measure pressure,it scored a total of 4, just barely beating the "faux nest" score of 3.96. It was a given a 4 for weather-proof because all the electronics are inside a weather box and the data is transmitted by Bluetooth, meaning it can be completely sealed up. However, the pressure gauge is exposed to air, making a potential weather problem. It was given a 4 for being sturdy in the sand because it is anchored in two different ways: strings and a sand anchor. It was given a 4 for being portable because it is thin and light, but it is a somewhat weird shape. It was given a 4 for being easy to install because the shovel anchor makes it convenient for for digging the hole in the sand, and the strings are not hard to install. Finally, it was given a 4 for being easy to measure pressure because the Bluetooth communication and pressure gauge makes the data collection completely automatic, but Bluetooth communication can be unreliable at points. The results of the matrix were not particularly surprising, as this concept has always stood out as an all around good solution to our needs. With very few shortcomings, it will provide the fewest roadblocks to overcome throughout the design process. One thing that can be noted is that "Faux Nest" was so competitive with "stake" due to its' superior ease of measuring pressure. We as a team can look at this model and try to find ways that we can incorporate this strength into the "stake" concept.

4.4 Engineering Models/Relationships

The first model deals with the pressure guage's range. The equation developed below can be used by the team to determine the required pressure transducer range for the application. Using the depth beneath the sand and an estimation of the density of the medium it will be submerged in, we can calculate the approximate range of pressures that will be read. **[Mark Lipkin, 2023, Pressure Transducer PSI Requirement]**

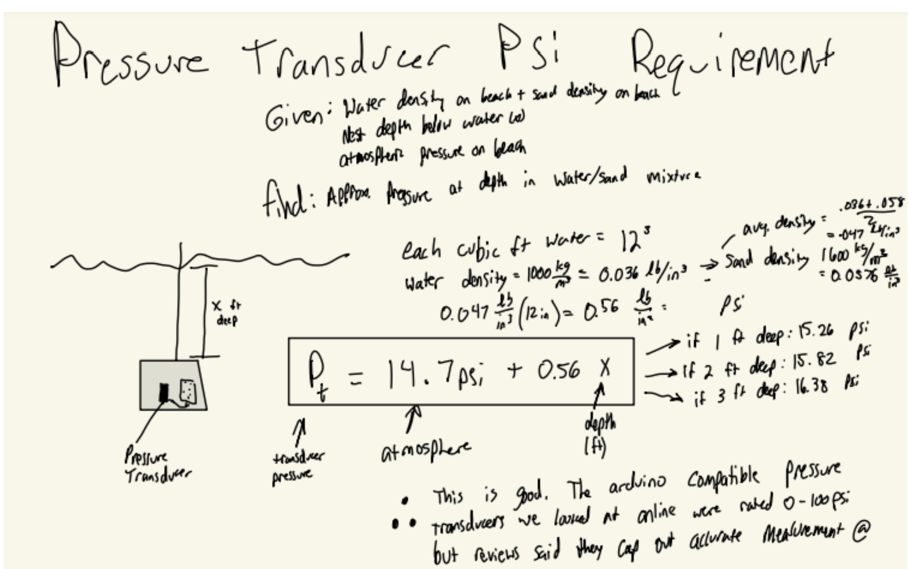


Figure 16: Pressure transducer PSI requirement.

The next model deals with lithium batteries. The equations below will be useful in determining how large of a battery will be needed for our application, which can help us decide on an enclosure to use that will minimize volume but still fit all of the necessary components. By finding the total amperage necessary, the amp-hour requirement. This can then be plugged into the equation for battery size in square inches. [**Mark Lipkin, 2023, Lithium Ion Battery Sizing**]

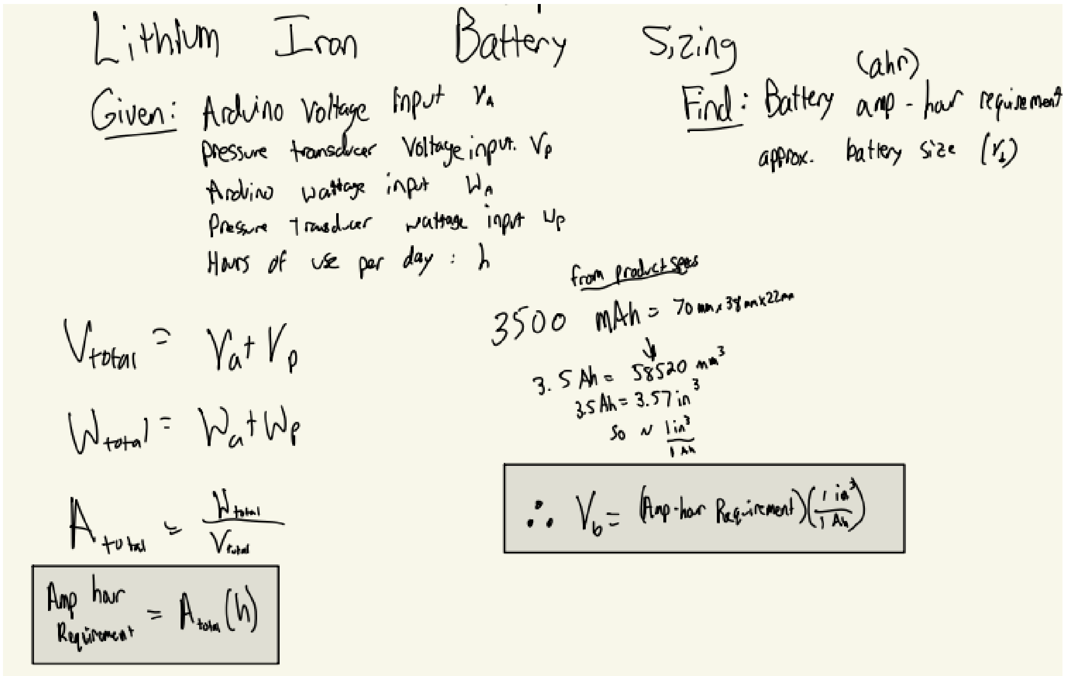


Figure 17: Lithium ion battery sizing.

The las model deals with cylic stresses. Cyclic stresses will be helpful for designing the in-beach pressure sampler because it is possible for the sampler to be hit with periodic ocean waves, inducing a cyclic stress. Periodic stresses lead to a more complex failure method. Designing beyond the static, maximum stress induced by a wave is needed because the period nature of waves can fail the sampler even though it never reaches the maximum failure stress. Figure 18 displays the stress amplitude vs. number of cycles till failure for four different means stresses for PVC. PVC was chosen because this is the most likely material for the stake. Since this sampler needs to be in equilibrium, solid mechanics to solve for the required cross-sectional area (A) of the device in contact with the waves given the force function of the waves, frequency of the waves, and any material parameters (Elastic Modulus). **Source (will update later): Folkman, S., Parvex, J., 2020, "PVC Pipe Cyclic Design Method," Buried Structures Laboratory, Utah State University, Uni-Bell PVC Pipe Association**

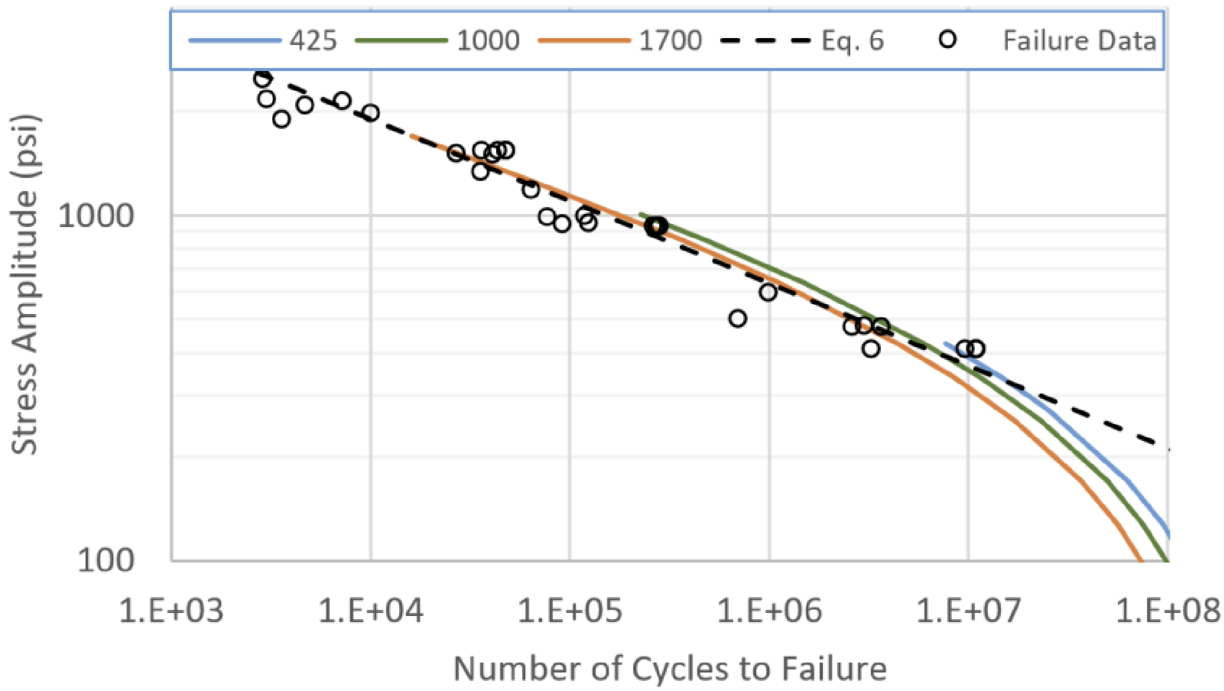


Figure 18: Stress amplitude vs. number of cycles till failure for four different means stresses for PVC [citation number].

5 Concept Embodiment

5.1 Initial Embodiment

The design of our initial prototype was aimed at meeting our team's prototype performance goals. These goals were developed as a way to determine whether the prototype would be useful to the customer in a quantifiable way. The three goals are as follows:

1. The device can record timestamped pressure data over a period of 24 hours while immersed in water/sand mixture that mimics beach conditions).
2. The SD card can be removed, uploaded to a computer, and replaced (including any sealing and unsealing steps) in < 2.5 minutes.
3. The device has sufficient battery life and data storage to last for > 3 months.

The performance goals 1 and 2 were directly tested once the prototype was built. To reach goal number 3, the batteries would have to be connected to a solar panel and coded in the Arduino. This challenge proved a large one, and it was decided that for the initial tests, the first two goals should have focus directed to them, and the third would be met moving forward with the project.

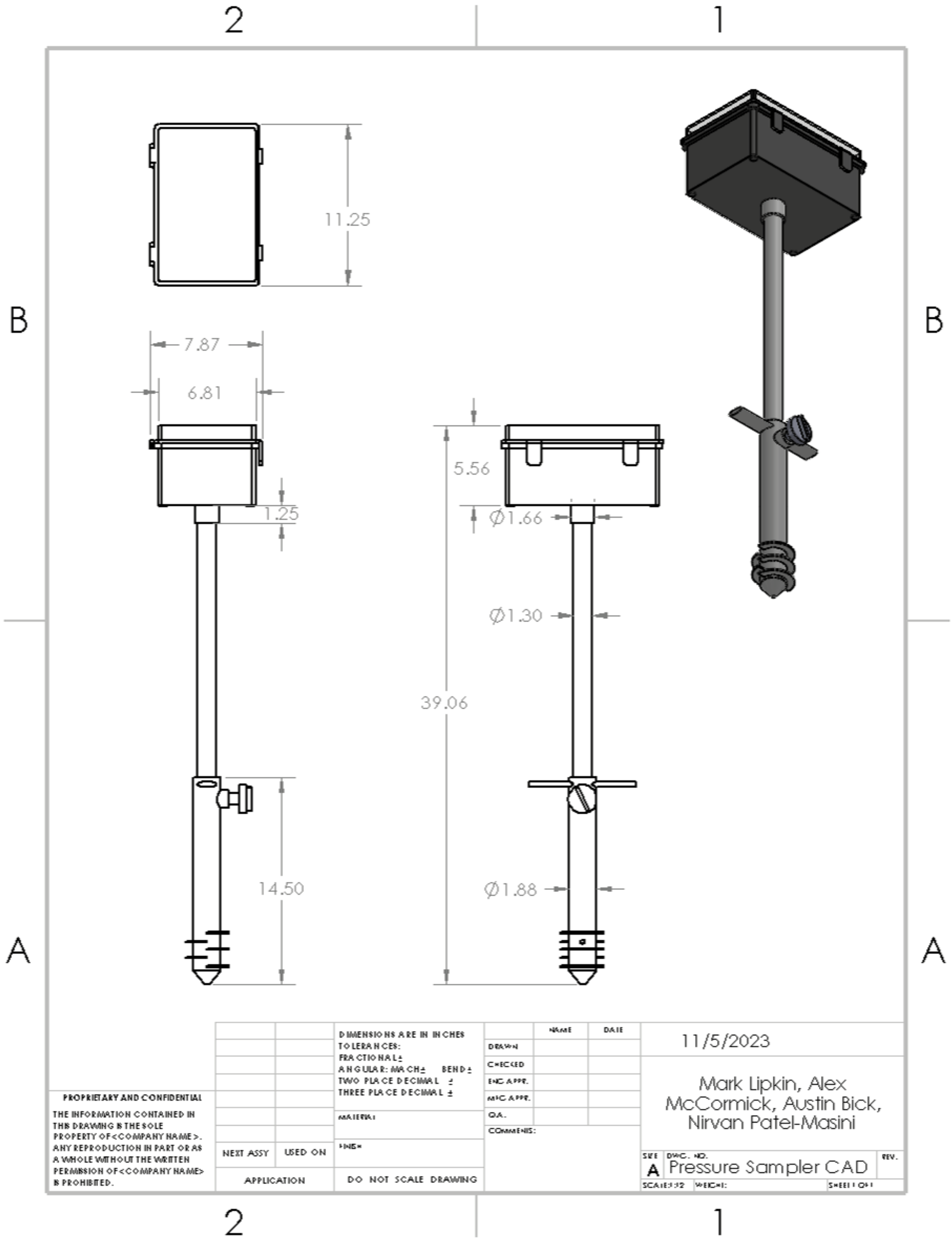


Figure 19: Assembled projected views with overall dimensions.

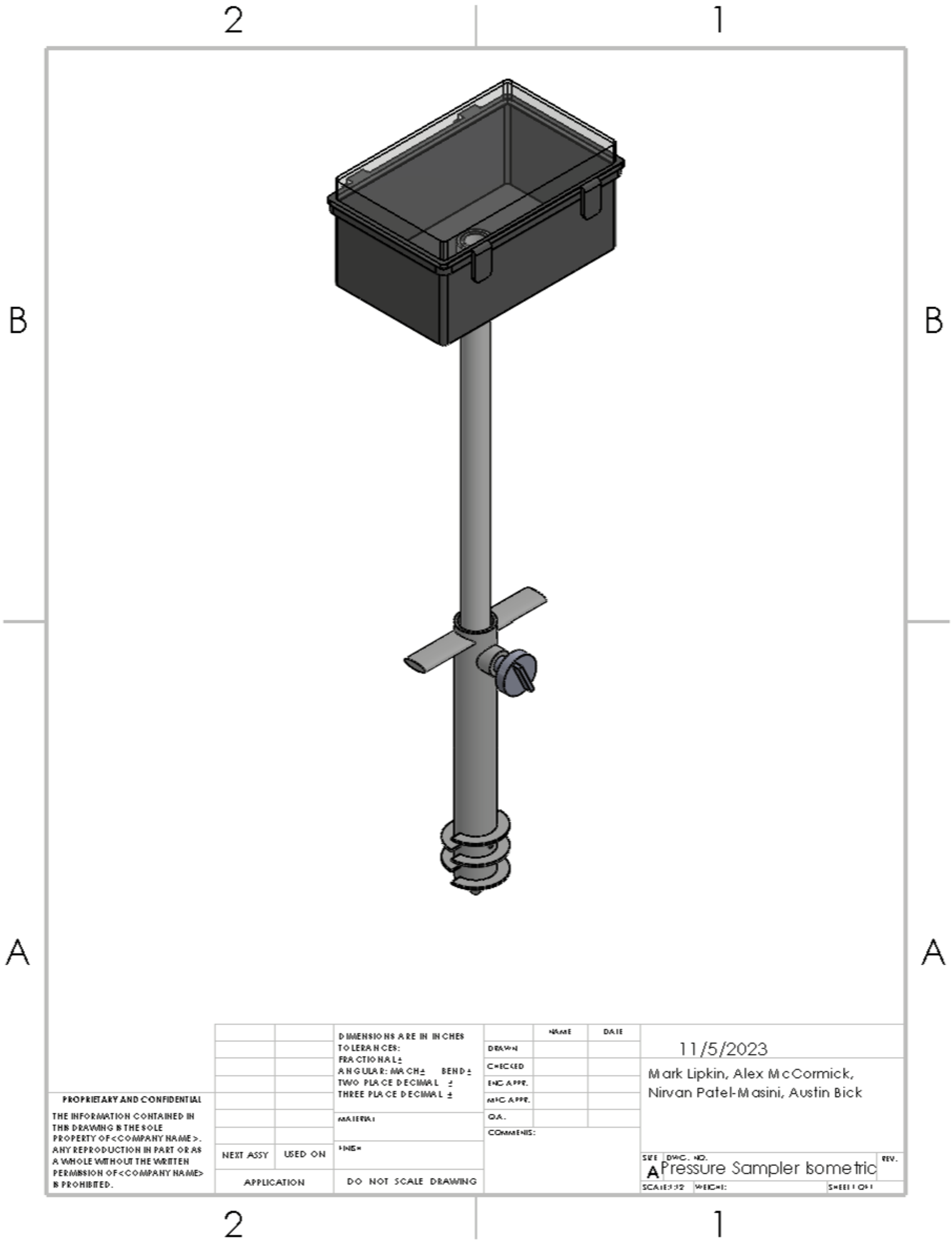
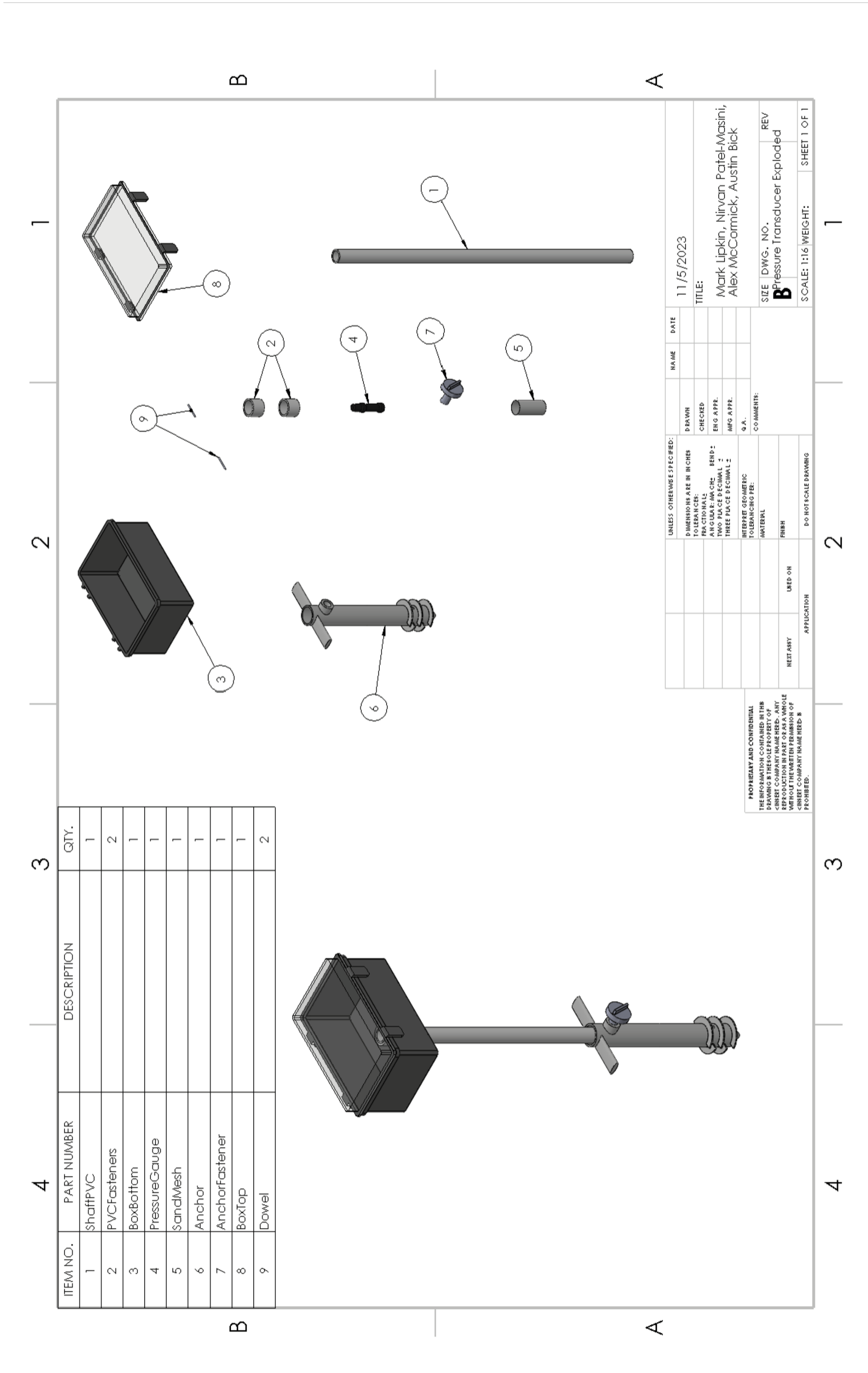


Figure 20: Assembled isometric view.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	ShaftPVC		1
2	PVCFasteners		2
3	BoxBottom		1
4	PressureGauge		1
5	SandMesh		1
6	Anchor		1
7	AnchorFastener		1
8	BoxTop		1
9	Dowel		2

Figure 21: Exploded view with BOM.

5.2 Proofs-of-Concept

The proof-of-concept testing and prototypes did not have a large influence on the design for the initial prototype. This is mainly due to the meticulous planning that went into the initial prototype, as we were using more expensive parts and did not want to have to reorder. The one change that did come from the process of prototyping and proof-of-concept was a small hole located in the bottom of the screw anchor. This was after trials in sand and seeing that there would inevitably be a bit of and getting into the securing device, which would need a way to get out.

5.3 Design Changes

Our initial prototype and selected concept from Section 4 are very similar, with only a few changes to the anchoring and pressure data transmission techniques. For the anchoring technique, the bottom anchor was changed from a shovel anchor to a screw anchor because the screw anchor seemed more stable, and it was assumed that the user will have a shovel. Also, securing ropes were not utilized because the electronic box was designed to barely extend past the surface. Finally, the data transmission technique was switched from Bluetooth to SD card retrieval and upload. Although Bluetooth is more convenient, it is less reliable, and it is more important to be reliable than convenient because of the extended period of use of the pressure sampler.

6 Design Refinement

6.1 Model-Based Design Decisions

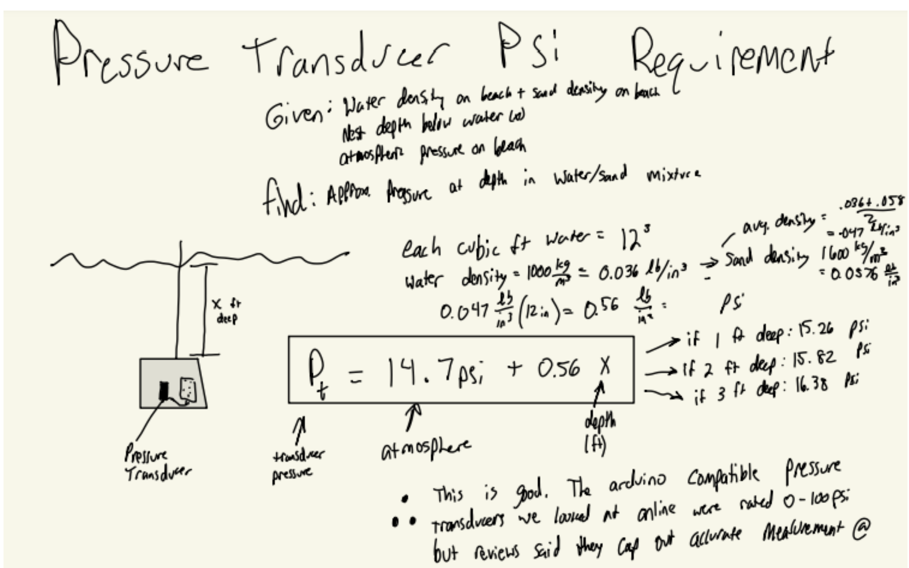


Figure 22: Pressure transducer PSI requirement.

Shown above in figure 22 is the calculation for the required PSI maximum that was needed for the pressure transducer. An equation was developed using atmospheric pressure and the density of water, which was used to determine the increase in pressure per foot (x). Using this, it was determined that the pressure should only reach a value of between 15 and 17 PSI. This calculation was used to confirm that the pressure sensor purchased from Amazon, which was rated up to 100 PSI, would be suitable for the requirements of the project. In order to use this equation, a few assumptions were made. Namely, the assumption that the pressure is increasing solely due to the weight of the water as we go deeper, which is justified by the fact that water is much denser than sand, so any error should err on the side of safety. Additionally, assuming that the atmospheric pressure at the point of application is PSI, which should be close enough to the exact value at that location.

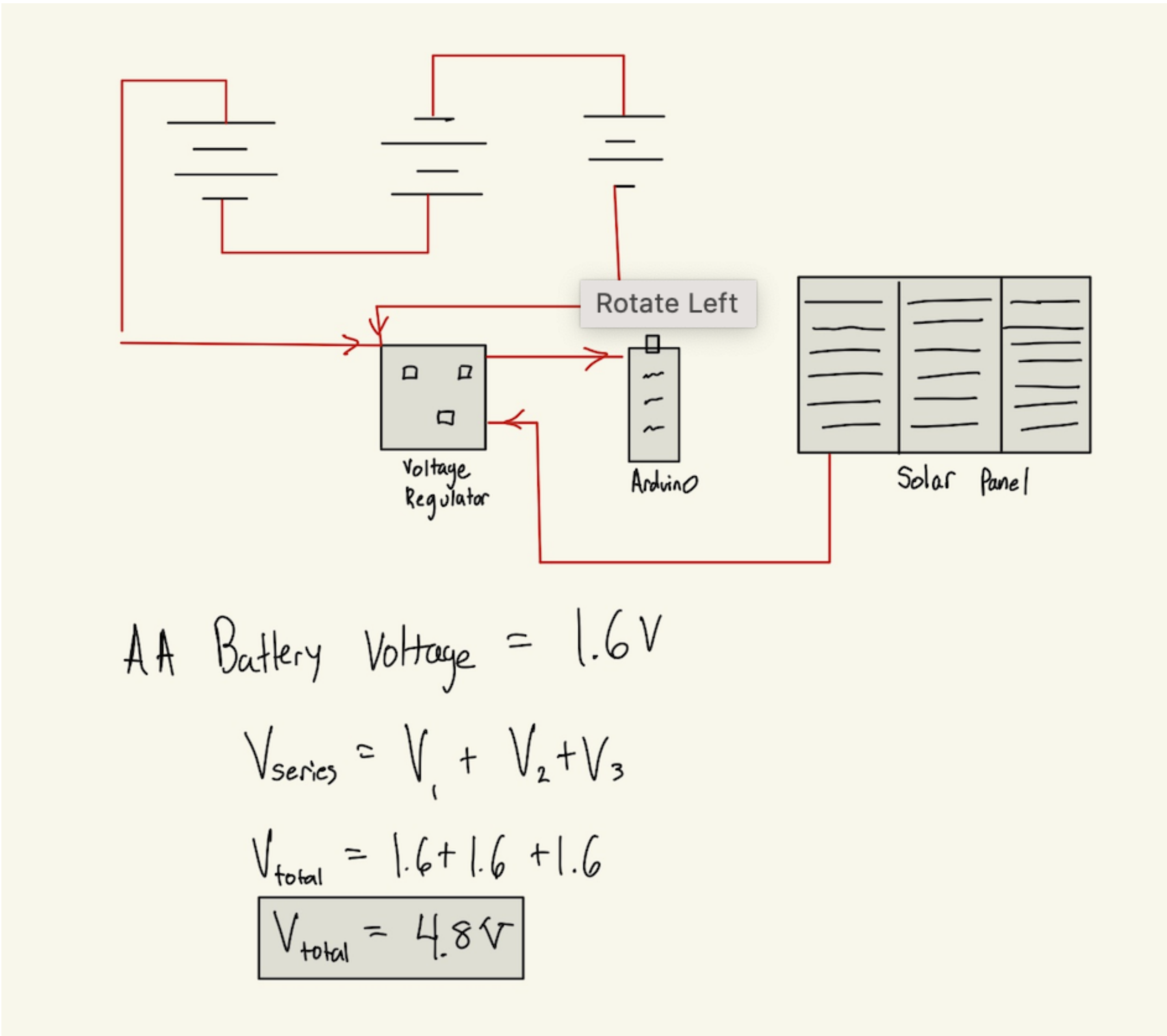


Figure 23: Pressure transducer PSI requirement.

Figure 23 shows the design calculations used to determine the number of batteries and type of battery connection required to power the Arduino. The Arduino runs on an approximate voltage of 5V. Each rechargeable AA battery was rated for 1.6V. In order to achieve a voltage comparable to that required by the Arduino, the batteries had to be placed in series, as shown in the schematic. Using the properties of a series connection shown above, the total voltage was calculated to be 4.8V, which, by testing on the Arduino, proved to be enough to power the control system. In this calculation, it is assumed that the voltage losses due to the resistance of the wires are 0, and that the batteries produce exactly the voltage that they are listed at.

6.2 Design for Safety

The following section walks through the areas of highest safety risk in the context of the project. The risk is addressed in terms of severity, probability, and the mitigating steps taken to eliminate or diminish it.

6.2.1 Risk #1: Sharpness of device

Description: The device has some sharp corners and a point at the end of the anchor. It is possible for users to get punctured or cut when handling the device.

Severity: The severity risk is critical. Getting punctured or cut could lead to bleeding. Bleeding could be difficult to stop on the beach, making i critical.

Probability: The probability of this happening is likely. The anchor point is large and must be sharp in order to be effective.

Mitigating Steps: Carry the device by the round PVC shaft and always point the anchor towards the ground when handling the device out of the sand.

6.2.2 Risk #2: Hurt Back

Description: This design relies on the user digging a hole in the sand before installing the device into the beach. This action can lead to back injuries and fatigue.

Severity: The severity is marginal. A back injury can be hard to treat, but can be recovered from with rest.

Probability: The probability is occasional. The user must only dig the hole once before installing the device for a long time.

Mitigating Steps: The user can use proper lifting techniques when shoveling the sand out. Remember, always lift with your legs. Also, the user can drink a lot of water and not dig the entire hole in one go.

6.2.3 Risk #3: Sea turtle harm

Description: Because the device could be in close contact with sea turtles and their nests, it is important that it does not cause them any harm in the process of performing its goals.

Severity: Catastrophic. Benefiting the sea turtles is the research and device's primary goal, any harm to them would be very bad.

Probability: Seldom. The device has been designed to mitigate turtle harm risk, this is defined in the steps below.

Mitigating Steps: The device is designed to be non-intrusive, taking up as little space in the turtle's habitats as possible. It is durable, and should never dissapear or fall apart, leaving little to no unwanted material in the turtle's habitat as pollution. Furthermore, the device is constructed of materials that should not harm turtles if they come in contact with it.

6.2.4 Risk #4: Tripping

Description: Since the device is low to the ground and very secure, it would be easy to trip on if someone isn't paying attention.

Severity: Negligible. The device is in sand so falling shouldn't have any severe repercussions

Probability: Occasional. The device will be on a beach which has pretty consistent topography. The device will look out of place and can easily be avoided.

Mitigating Steps: The device is white and glossy. Not only will it stick out compared to the black sand that it sits on, but it will also reflect the sun on its edges if it is bright outside.

6.2.5 Risk #5: Battery explosion

Description: The batteries could overheat and cause a small explosion.

Severity: Marginal. Upon a battery explosion, the entire device could be destroyed. It is likely that some amount of it could be salvageable, but the expensive electronics would be most at risk.

Probability: Unlikely. Batteries don't explode very often and the box is somewhat UV-protected. The device is also partially underground which should help keep the main portion cool (or not, our device's measurements will give us that info).

Mitigating Steps: The device is large with open space and the batteries can be kept slightly further away from the other electronics. This should help keep the more important things out of harms way if the batteries explode.

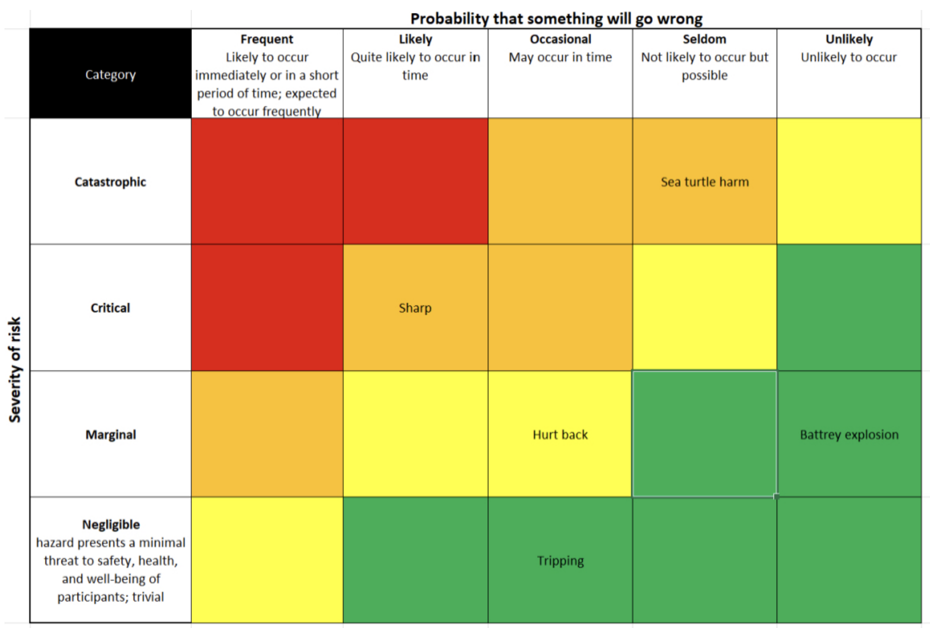


Figure 24: Heat map of risks.

The different risks are prioritized as follows: Battery explosion and tripping are the two least prioritized, with hurt back being the next most important. After that is sea turtle harm and sharpness, being of the highest importance. These were taken into consideration in our design, with the mitigation steps described above. Most significantly, safe materials were used, and a robust design was produced to eliminate pollution and waste. Additionally, instructions will be given as to how to carry and operate the device so that the sharp end is not used in a harmful way. These mitigation steps should serve to diminish the risks associated with using this device.

6.3 Design for Manufacturing

1. Number of Parts and Fasteners: If each part is decoupled from larger assemblies, there are **fifteen** individual parts. There is only **one** threaded fastener in our design, as glue is the primary adhesive.

2. Theoretically Necessary Components (TNC): There are four TNC's.

- Protective box and containment PVC
- Perfboard and Electrical Components
- Sensing Devices*
- Anchor

Protective Box and Containment PVC:
Figure 25 illustrates the protective box which will hold the electronics, as well as the containment PVC which protects the wires from the environment as the sensing devices are placed around two feet underground. The box and PVC are connected using glue. This needed to be a separate assembly because we designed this around the parameters for the dimensions of a sea turtle nest. We needed to build a casing that achieved the required depth as well as have a main control box where data could be collected. Since the electronic components are modular and require wires for connection, we figured we could adjust their design to fit the casing required. We could have worked on the wiring first and then build around it, but we decided to use a pre-made waterproof box and this helped create a solid frame which the electronics could easily adapt to. Hence, this is a TNC.

Figure 25: Image of Box and PVC Tube

Perfboard and Electronic Components:
Figure 26 displays the Perfboard and Electrical Components. The parts making up the assembly are the solar panel, solar power manager, battery pack, Arduino real time clock, Arduino SD card reader, and Arduino Microprocessor (Pololu A-Star). The parts are all attached to the perfboard,

and connected via wires and soldering. This assembly must be separated from the protective box and anchor because we designed our electronics around the dimensions of the protective box. Furthermore, we needed to have flexibility and space in designing the circuit that isn't confined by the walls of the box, and furthermore enable parallel manufacturing with other components.

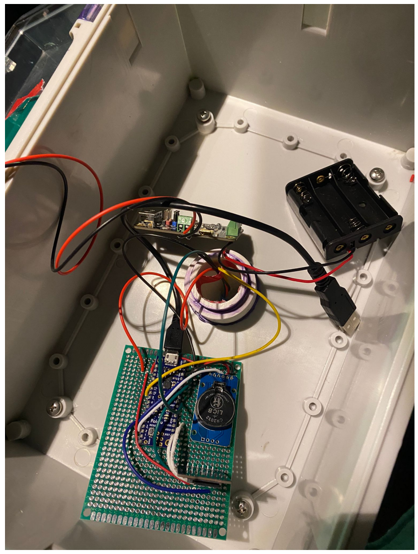


Figure 26: Image of Perfboard

Sensing Devices:
The sensing devices include the pressure gauge and temperature sensor. There is an asterisk in the list for this component because it is almost a TNC. The sensing devices were connected to a smaller perfboard located in the shaft of the protective covering, which is connected via wires to the main perfboard and microprocessor. The sensor cables were not long enough to reach the main perfboard from the depth of the protective shaft, and the temperature sensor needed an additional resistor to calibrate/smooth out the data being collected. Due to these reasons, these were built separately and then connected to the main perfboard.

Anchor:
Figure 27 displays the anchor. The anchor was built separately as we needed to first move the sensing devices down the tube to the desired depth. This was done purely because once the anchor is screwed in place, the sensors are inaccessible and unable to validate their location.

Figure 27: Image of the Anchor

3. Manufacturing Optimization:

While we have a minimum number of TNC's, it could be possible to increase the number. We could decouple the SD card reader (although it will still need to be wired to the main board) in its own smaller perfboard that is more accessible and distinct from the rest of the electronics. The rationale is that the SD card is the only thing that the user should be interacting with, and if the elimination of access to wires and circuits when the box is opened can be achieved, then it would be optimal. Figure 28 gives an illustration of what this would look like. The addition of a cover would be necessary.

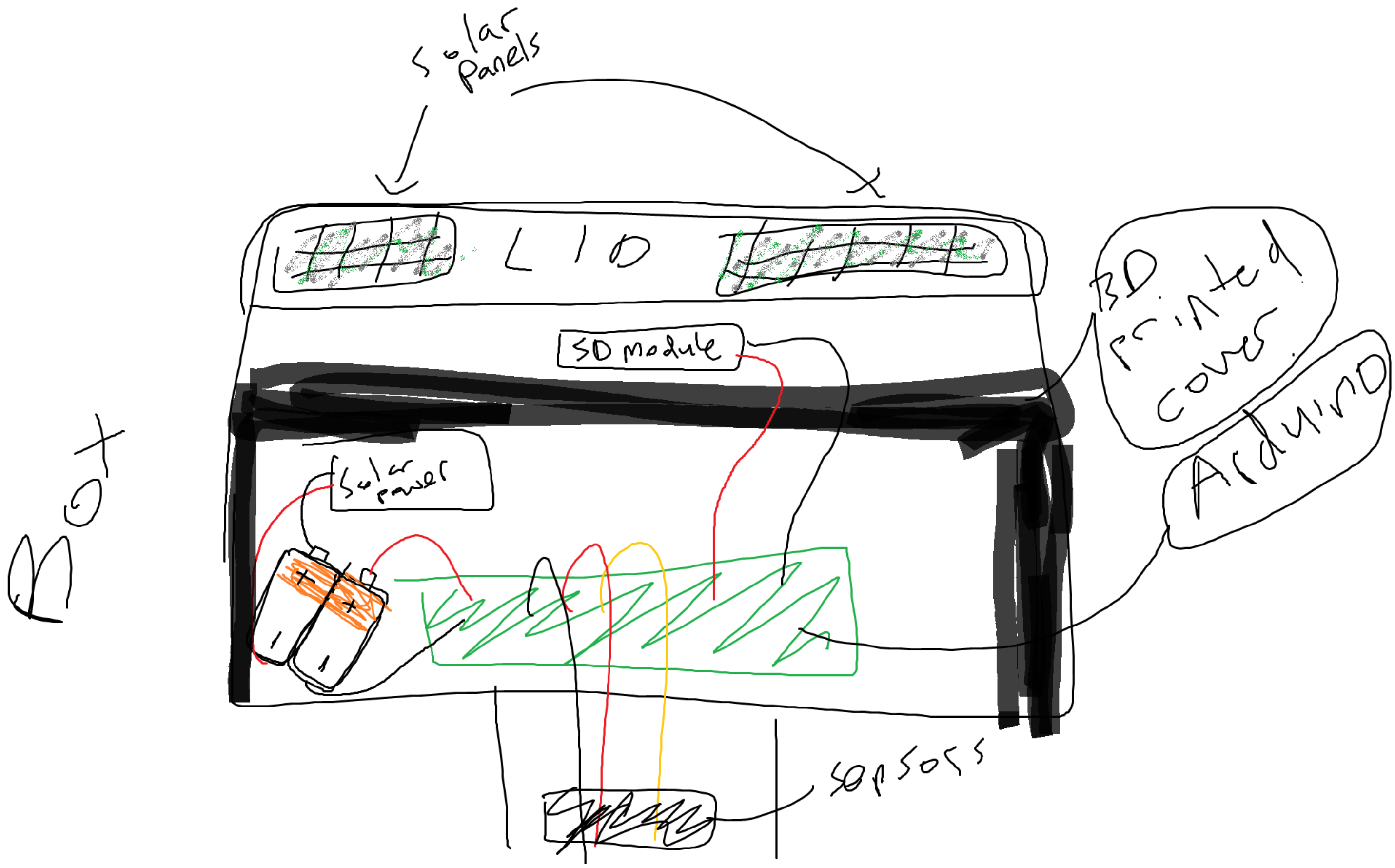


Figure 28: Illustration of Modified Design

6.4 Design for Usability

1. Vision Impairment.

The protective/external shell of our device is very visible due to its larger size and relatively simple design/shape. Opening the box to access the electronics, the main concerns for person's with visual impairments would be the small microSD card and locating the reset button. The SD card and reset button are in the millimeter scale, and for those with difficulty with short-sightedness or precise vision, these may be difficult to access. This may be problematic, however with a video demonstration or very clear user guidelines, this issue can be solved easily. Furthermore, although this device is robust and designed to not break, there is a chance the wires may snap or get damaged. For those with color blindness, since the wires have colors it may be difficult to distinguish which wire goes with which, especially if multiple wires are broken. Should be able to follow the trail though. I think we could label each wire with a small tag at the beginning and end that states what it connects to.

2. Hearing Impairment.

Since our device has no mechanical components or moving parts, as well as any devices which emit noises, there should not be an issue for people with hearing impairments to use our device. No sound from the device means that regardless of if you are deaf or have full hearing, you will not hear anything. No fixes need to be made.

3. Physical Impairment.

Physical impairments pose the greatest threat to the usability of our device. Firstly, if someone is weak-fingered or jointed, they will have difficulty opening the box which cases the electronics since it is secure and made to be difficult to open from natural causes. We can elongate the lever which opens the box and apply more torque, or even make a small, 3D printed tool that is inserted in the clip to open the box. The device itself weighs around five-to-ten pounds, which is not incredibly heavy but may pose an issue for those with weak muscles or ailments. In order to install the device, a hole must be dug in sand. This process can be strenuous if the sand is wet and rocky, and if any physical limitations plague the user. We would recommend installing the box on a hot day, removed from rainfall and during high tide. Furthermore, the SD card and reset button require precise movements. We will make these more accessible by making it clear what space they occupy and maybe making a larger button contraption.

4. Control Impairment

Our device is relatively simple to use. It only mandates the removal and re-installation of the SD card, and the pressing of the reset button. Because of this, we do not believe impairment issues should be that influential. The main concern would be the installation of the SD card if someone is intoxicated or unable to maintain stable motion as they could snap the card or the card holder. A fix to this could be a sheath that funnels the SD card into position and then has the user do a bulk, imprecise push that will get the SD card loaded.

6.5 Design Considerations

Table 3: Factors considered for design solution

Design Factor	Applicable	Not Applicable
Public Health		X
Safety	X	
Welfare		X
Global		X
Cultural		X
Societal		X
Environmental	X	
Economic		X

Table 4: Contexts considered for ethical judgments

Situation	Applicable	Not Applicable
Global context	X	
Economic context		X
Environmental context	X	
Societal context		X

7 Final Prototype

7.1 Overview

Final pictures of the project are shown below. This design achieved all three of the prototype performance goals.

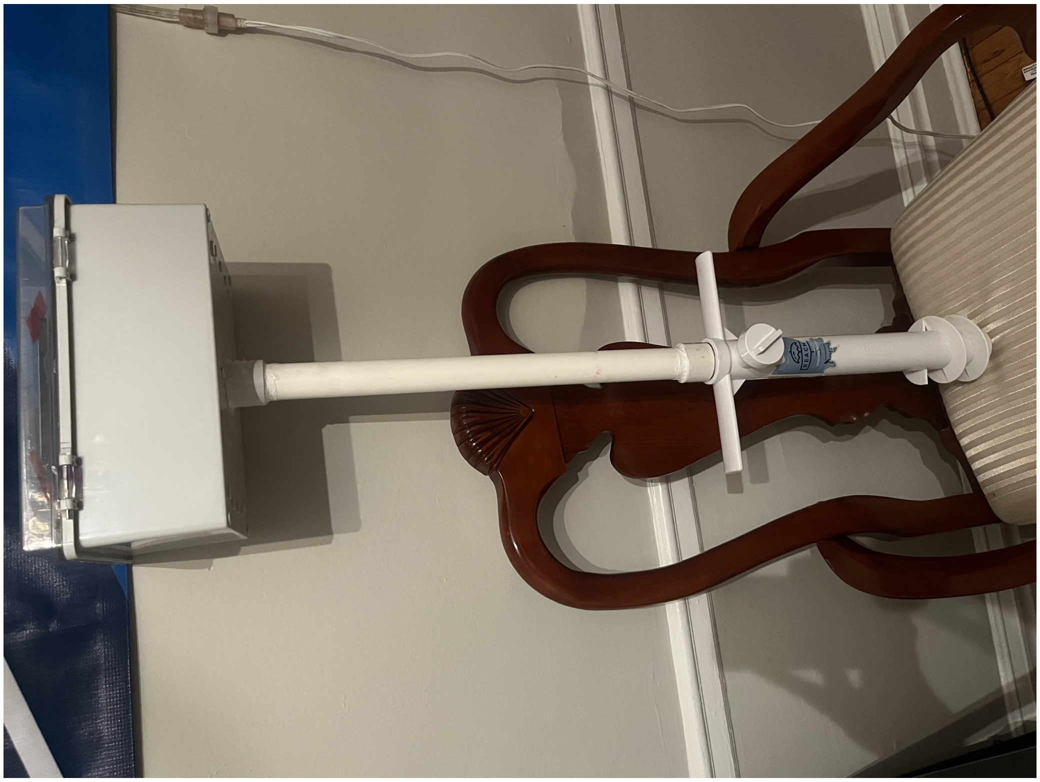


Figure 29: Overall picture of project.

Figure 30: Electronics box.

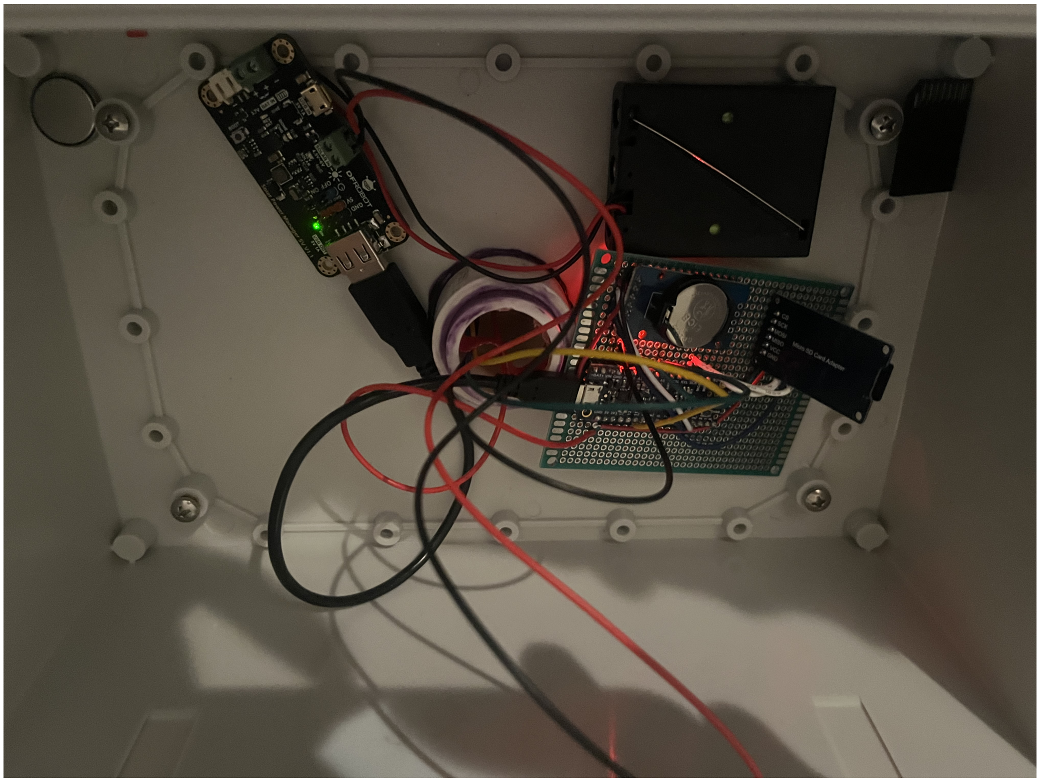


Figure 31: Inside electronics box.

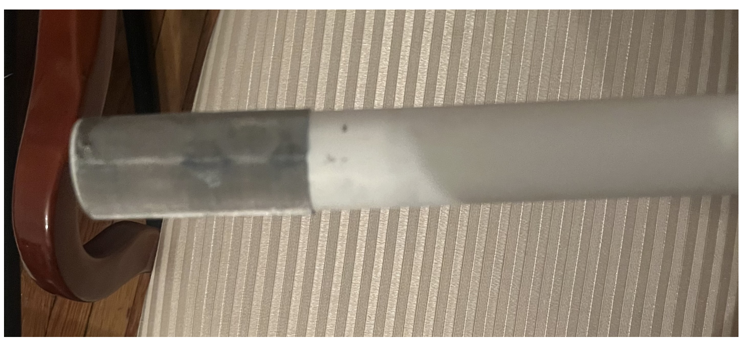


Figure 32: Mesh.

Figure 33: Pressure gauge inside PVC shaft.

A Software Code - MATLAB

```
t_step = .001; t_end = .1; %(time step and end time, seconds)
t = 0:t_step:t_end;        % create time vector
m = 20;         % mass of ball(lb*s^2/in)
k = 5;      % spring rate (lb / in)
c = 0;      % damping (lb / (in/sec))
% forcing function: ramp from 0 to 10 lb
f = zeros(size(t)); f(1:.01/t_step) = linspace(0,10,.01/t_step);
% initialize velocity and position
x = zeros(size(t));
x(1)=0; v=0; % initial conditions

for n = 1:length(t)-1
    a = (f(n)-k*x(n)-c*v)/m;  % solve for acceleration
    x(n+1) = x(n) + v*t_step; % next disp is curr disp plus increment
    v = v + a*t_step;       % solve for velocity
end
```

B Parts List

	Part	Source Link	Supplier Part Number	Color, TPI, other part IDs	Unit price	Tax ($0.00 if tax exemption applied)	Shipping	Quantity	Total price
1	12 OZ LONG RING NECK CLEAR PLASTIC DRESSING BOTTLE-CASE OF 10	Amazon	B01C1X443W	Clear Plastic	$14.99	$0.00	$0.00	1	$14.99
2	Rubber Sheet, Heavy Duty, High Grade 60A	Amazon	RSBLK12x12x116-0-01	Black	$11.86	$1.19	$0.00	1	$13.05
3	Plastic Water Solenoid Valve - 12V - 1/2"	Adafruit	997	White/Black	$6.95	$0.00	$9.16	6	$50.86
4	3M VHB Tape RP25 1in w x 5yd length	Amazon	1-5-RP25	White	$10.73	$0.00	$0.00	1	$10.73
5	HUAHA 10 pcs O.D. 1/4" 3 Ways Shaped Tube	Amazon	HUAHA-TCT001	White Ts	$10.99	$0.72	$0.00	1	$11.71
6	Spring Tempered Compression Spring	McMaster Carr	9620K57	Steel	$5.63	$0.00	$12.00	1	$17.63
7	10 Pack - CleverDelights Solid Rubber Stoppers - Size 8	Amazon	RS-Black-8-10	Black rubber	$13.88	$0.00	$0.00	1	$13.88
8	Valve Adapter	McMaster	5346K46	Brass	$8.02	$0.00	$0.00	2	$16.04
9	Press Fit Inserts	McMaster	97191A150	Steel	$8.83	$0.00	$0.00	1	$8.83
10	Set Screws	McMaster	97705A406	Steel	$2.73	$0.00	$0.00	1	$2.73
11	Elegoo UNO Project Basic Starter Kit	Amazon	EL-CB-001	Black	$13.95	$0.00	$0.00	1	$13.95
12	Speaker Wire	Amazon	B006LW0WDQ	Red	$8.49	$0.00	$0.00	1	$8.49
13	U Brackets	McMaster Carr	3192T55	White	$7.63	$0.00	$0.00	1	$7.63
14	Motor Control	Pololu	3284	red	$69.95	$0.00	$3.95	1	$73.90
Total:									$264.4