Pacific Garbage Patch

Midpoint Report

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DISCLAIMER

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EXECUTIVE SUMMARY

The Pacific garbage patch team aims to simulate cleaning up the Great Pacific Garbage Patch. This will be accomplished with an autonomous solar powered boat, which uses a grabber to pick up ping pong balls and stores them in a container. The team used the customer requirements from the client to generate concepts. The team weighted to concepts based on importance to the design. The customer requirements were then used to create engineering requirements. The engineering requirements selected had targets and tolerances for those targets. The capstone team selected the testing procedures from 1-8. The group created a house of quality to organize the customer requirements with the engineering requirements. Thereafter, the team looked at existing designs to create new ideas. The team researched each sub component of the design of the existing designs. This included the Ocean CLEANUP, which is currently picking up plastic in the ocean. The team also looked at RC boat designs. We also looked at autonomous cars. The team then created a functional decomposition using a black box model and a functional model/work-process diagram/hierarchical task analysis to better organize the project. The team then broke down the project into subsystems for the existing designs. The team then selected the design with provided rational. The rational includes a decision matrix for the entire project in addition to pugh charts for some subsystems. The design is then described in detail. The team created a proposed design.

ACKNOWLEDGEMENTS

The group tremendously appreciates the guidance of Dr. Trevas through design improvements. The team also has received great assistance in improving aspects of our design by Brandon Begay through his experience.

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1 BACKGROUND

1.1 Introduction

In the Pacific Ocean, there are tons of plastic garbage floating throughout the water. This project required the team to develop a model of a device that cleans up the Great Pacific Garbage Patch. The garbage patch damaged the ecosystem in the Pacific Ocean. The plastic was an issue for multiple reasons. The plastic when consumed, endangers the wildlife. This translated to affecting humans. When the wildlife consumed, the "garbage" was then consumed as well. The objective of the project was to create an autonomous boat that collects ping pong balls in water to model a larger future device. This project sponsor, Dr. Trevas, wanted the device to recognize where the ping pong balls were located and pick them up autonomously, with solar panels in order to negate the need for charging. This project was important to simulate the test concept in order to pick up plastic autonomously in the Pacific Garbage Patch. Through this project, we hoped to model a device that may autonomously clean up the garbage, restoring the oceans ecosystem for the future.

1.2 Project Description

The Pacific Garbage Patch Cleanup team created a device that simulates the cleanup of the Great Pacific Garbage Patch. The group collected ping pong balls in a pool of water using a solar powered autonomous boat, with a camera to locate the plastic. The grabber will transfer the balls to on board the boat, into a container.

1.3 Original System

This project involved the design of a completely new aquatic plastic collector. There was no original system when this project began.

2 REQUIREMENTS

The client for the Great Pacific Garbage Patch cleanup gave the team customer requirements. The team used this information to create engineering requirements. These requirements were combined to form the house of quality.

2.1 Customer Requirements (CRs)

The customer requirements were general requirements from the client. The sponsor gave the team 12 main requirements for the design. The complete system must meet these requirements as well as the individual subsystems of the boat, grabber, navigation, solar power, and camera detection. Each requirement was weighted on the importance of the requirement. The objective was to make a autonomous device to collect plastic in an effective and fast process using solar power. As the goal was to aid the oceans ecosystem in recovery, the requirement to not damage the ecosystem was weighted as a quarter of the requirements. The customer requirements were summarized in Table 1.

Table 1: Customer Requirements

Customer Requirement	Weight
1. Doesn't damage ecosystems	25
2. Autonomous	20
3. Solar Powered	20
4. Collects 20 ping pong balls	5
5. Sensors	10
6. Effectiveness	10
7. Fast	5
8. Waterproof	5

2.2 Engineering Requirements (ERs)

The customer requirements were used to create the engineering requirements. The team applied the qualitative customer requirements and turned them into quantitative engineering requirements. All of the customer requirements were taken into account, with the requirements receiving the most weight were the most influential in creating the targets and tolerances in the engineering requirements. The group selected each engineering requirement target and tolerance specifically, with the input from the client. The tolerances were roughly 1/10-1/5 of the target value. The engineering requirement relating to reliability and durability is the useful life in years. All engineering requirements used metric units. Each engineering requirement had certain targets and tolerances as seen in Table 2.

Table 2: Engineering requirements

	Engineering Requirement	Mass (kg)	Plastic removal (%)	Power (W)	Velocity (m/s)	Plastic collection (pieces/day)	Useful life (years)
Target(s)		20	90	50	10	200	5
Tolerances(s)		5	5	5	5	25	1

2.3 Testing Procedures (TPs)

Through measurements and/or trials, the team will test the engineering requirements ensuring we meet the client's requirements. With the decided upon subsystems products, necessary power and total weight of the system may be calculated (TP #1 and TP #2). As the velocity was dependent primarily on the motor, once a power efficient motor has been chosen, the speed of the decided motor may be tested (TP #3). Once the system is constructed, the plastic removal may be tested with the effectiveness of device (TP #4). Using the effectiveness of the detection as well as the speed of the boat, the plastic collect per day may be modelled (TP #5). Once the device is finalized, the lifetime of the device may be modelled factoring in the effectiveness of the solar cells (TP #6).

2.4 House of Quality (HoQ)

The house of quality combines the customer requirements and engineering requirements. Each customer requirement was weighted by importance. The intersection of the customer and engineering requirements were given a correlated score. A higher score indicates the requirements were more correlated. The numbers are tallied up in the absolute technical importance with a higher number indicating more importance. The relative technical importance gave the lowest score to the most important engineering requirement.

The weights ranged from 5-25. The most important customer requirement was that it doesn't damage the ecosystem with a weight of 25. The most important engineering requirement was the power with a absolute technical importance of 445 and relative technical importance of 1. This indicates that each subcompent of the design must focus directly or indirectly on energy efficiency. All of the data was shown in Table 3 below.

Table 3: House of Quality

House of Quality (HoQ)								
Customer Requirement	**Weight**	**Engineering Requirement**	Mass (kg)	Plastic removal (%)	Power (W)	Velocity (m/s)	Plastic collection (pieces/day)	Useful life (years)
1. Doesn't damage ecosystems	25			9	1		9	
2. Autonomous	20				9			3
3. Solar Powered	20		3		9	3		6
4. Collects 20 ping pong balls	5			9	3		9	
5. Sensors	10			6	3		9	
6. Effectiveness	10			3			3	1
7. Fast	5				3	9	3	
8. Waterproof	5		9					6
Absolute Technical Importance (ATI)			105	360	445	105	405	220
Relative Technical Importance (RTI)			5	3	1	6	2	4
Target(s)			20	90	50	10	200	5
Tolerances(s)			5	5	5	5	25	1
Testing Procedure (TP#)			2	4	1	3	5	6

3 EXISTING DESIGNS

This section discusses existing designs that were applicable to this project. Each design had a component that was required to meet the needs in the house of quality. There were not any autonomous boats out on the market that clean up trash. However, RC boat can work autonomously when the team provide the other components that will be discussed further in the report. Meanwhile, this section discussed design research and system level of our design.

3.1 Design Research

The team used The Ocean CLEANUP to get ideas for our project. The benchmark study helped create an autonomous prototype that could be used to help clean up the Pacific Garbage Patch. The Ocean

CLEANUP used ocean currents to passively clean the plastic, while the prototype was an active system. The active system might be better for certain areas of the garbage patch.

3.2 System Level

There were several designs that satisfy different requirements for the design. This include The Ocean CLEANUP, RC Boats, and Autonomous cars. Each design satisfied different parts of the requirements. The Ocean CLEANUP was the most applicable design on the market, that will help us to clean up the Great Pacific Garbage Patch. The team was using this design as inspiration on how to make our product better. It was the main component cleaning up the plastic. The RC boat was used as the vehicle on the water to find the trash. The features in the autonomous car was used to modify the RC boat in order to change it to a fully autonomous boat. The autonomous features must identify the location of the ping pong balls, go over to them, pick them up in the boat, and then dump it in a specific location.

3.2.1 Existing Design #1: The Ocean CLEANUP

The Ocean CLEANUP was just launched into the Pacific Ocean to clean up plastic. This system used ocean currents to passively pick up trash in the ocean. The device was a 600m long floater that goes 3m underwater [2]. The goal was to capture 50% of the plastic in just 5 years and 90% by 2040 [2]. The four steps were capture, accumulation, extraction, and landing. This design had minimal negative impact on the ecosystem. A picture of the design was displayed in Figure 1.

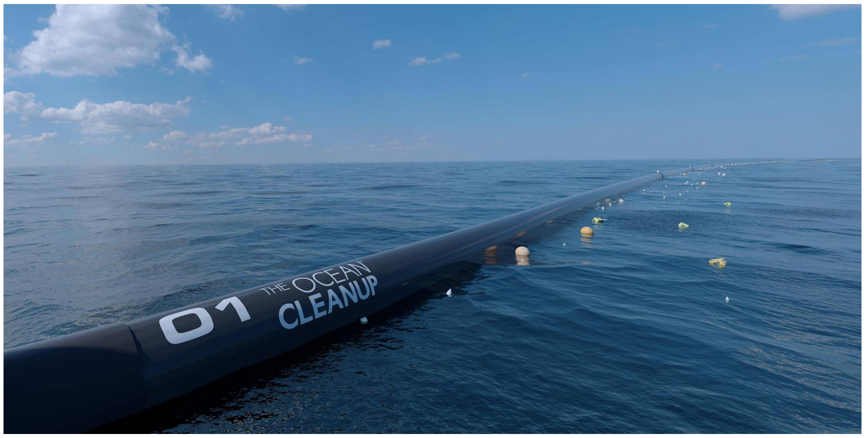

Figure 1: The Ocean CLEANUP [1]

3.2.2 Existing Design #2: RC Boat

There are numerous RC boats purchasable today. The models vary in designs and dimensions. The popular designs were speed boats and catamarans. Though the catamaran was better balanced and often larger than the speed boat design. Each model had drawn different amounts of power and travels at different speeds. The power and speed was determined primarily by the motor and thus independent of the boat design. The RC allowed the boat to change speed and direction. The team needed to choose a boat that had a dedicated place to store the plastic. There also needed to be a set location for the solar panels. Some examples are shown in Figure 2 below.

Figure 2: RC Boats

3.2.3 Existing Design #3: Autonomous Car

Autonomous cars were being tested on the road. None of them had received approval to be fully autonomous. The cars used sensors throughout the vehicle. It sensed the road conditions, speed of the car, the distance and speed of other cars, traffic signals, and much more. The Tesla autopilot system was the most famous in Figure 3. The features included eight surround cameras provide 360 degrees of visibility around the car at up to 250 meters of range. Twelve updated ultrasonic sensors complement this vision [3]. Some had claimed that this software was safer than human drivers.

Figure 3: Tesla Model 3 with Autopilot [3]

3.3 Functional Decomposition

The functional decomposition helped the team organize the design into different functions based on inputs and outputs. The functional decomposition aided the team to develop all the necessary parts to create boat the picks up ping pong balls autonomously. This included the black box and functional models shown 3.3.1 and 3.3.2.

3.3.1 Black Box Model

The black box model depicted the inputs and outputs needed for this project depicted in Figure 4. In this case it was used for the autonomous garbage clean up boat. The inputs were the trough grabber and ping pong balls, solar energy and camera. These inputs corresponded to the storage, electrical and mechanical energy, and navigation respectively. For example, the trough grabber was used to pick up the ping pong balls and dispense them into the storage. Solar energy powered the boats electrical and mechanical energy. The camera helped the autonomous clean up boat identify the ping pong balls through navigation

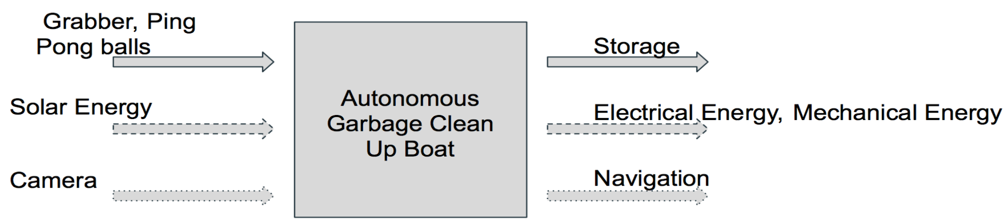

Figure 4: Black Box Model

3.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

The functional model broke down the black box in step by step method. The functional model showed the process of the design and how it worked based on the tasks that the team needed to accomplish in Figure 5. The figure above showed that the solar panel played a significant role in this design by providing energy to the device and was stored in a battery. The energy was transformed to mechanical energy, which powered the plastic grabber. Some of the energy in the battery turned into electrical energy powering the sensor to locate the ball. The thermal camera helped the device to identify the ping pong ball so the grabber can collect it. Meanwhile, since the solar energy generated mechanical energy, the boat moved due to the mechanical energy.

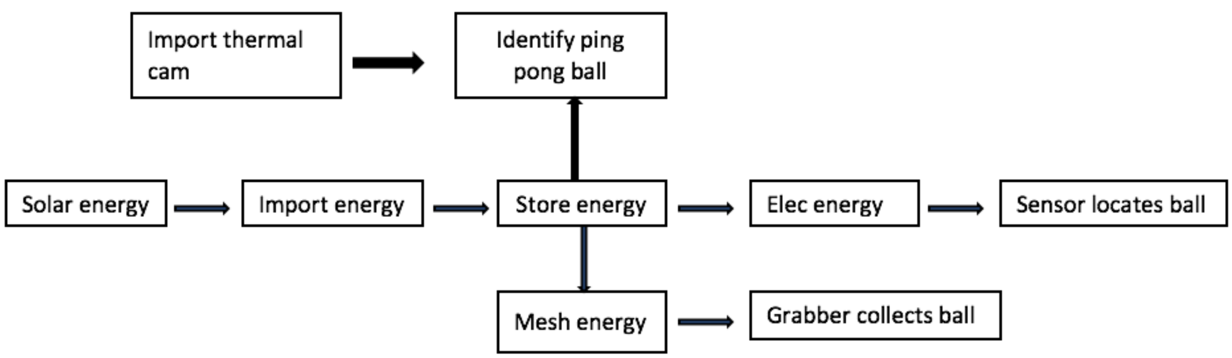

Figure 5: Functional Model

3.4 Subsystem Level

The total design consisted of multiple subsystems in order to complete specific tasks. These included a grabber to collect the ping pong ball from the water, a sensor to identify the ping pong balls, and navigation to accurately move the boat to the ping pong ball.

3.4.1 Subsystem #1: Grabber

The grabber was the mechanism that collected the trash out of the ocean. This design picks up ping pong balls in a swimming pool for the simulation. One end of the grabber was attached to the boat. The other end went into the water and grabbed the ping pong balls and placed them in the boat. All of the designs used solar power. The three main designs were the trough, arcade claw, and ice cream scooper.

3.4.1.1 Existing Design #1: Front Loader Bucket

The front loader bucket was often used with construction equipment in order to scoop and transfer material. This design carried various materials with different weight, density and volume. This design was applied for a water draining trough. The water draining trough can collect plastic, while its mesh design allows for water drainage. This design allows microorganisms to move through the mesh, while the larger animals can swim away. This design has minimal effect on the aquatic ecosystem.

3.4.1.2 Existing Design #2: Arcade Claw

The arcade claw was used in arcades around the world. The most common was the three prong design. It collected different materials including stuft animals, and jewelry. This tool was effective in collecting different material shapes with the prongs. The arcade claw picked up the ping pong balls just like it picked up items in a arcade game. Though to capture the ping pong balls, it needed to drop down at the right location and angle. The claw dropped the ball into the boat faster than the trough. It did not damage the ecosystem provided that the tips of the claw were soft.

3.4.1.3 Existing Design #3: Ice Cream Scooper

An ice cream scooper function was to scoop spherical pieces of ice cream. The ice cream scoop shape and size was similar to ping pong balls. The scooper could have collected ping pong balls in the same way ice cream was scooped. The spherical shape was perfect for capturing ping pong balls. However, there was no drainage for water or small microbial life. This design collected too much water and put it into boat, possibly sinking it.

3.4.2 Subsystem #2: Sensor

A sensor was used to identify and locate the ping pong balls.

3.4.2.1 Existing Design #1: Thermal Camera

Using the temperature of the ping pong ball against the water to identify the object. played an important role for our project. thermal camera was used to detect the ball in the swimming pool and we thought about using it to find the signal of the ball and the the signal would had shown in the camera, so we found the exact location for the ball. by the thermal camera we could have seen what our eyes cannot, so we could had found the spot of each ping pang ball in the swimming pool easily. by using the thermal camera we might have saved the time and find all the spots of each ball. One of the most important benefit that the group noticed in the thermal camera, that the team can look for the ball even in the night because during that time the camera will truly shine, so based on the customer requirements the team decided to go with the thermal camera until they notice that there are a better camera can support the project more than the thermal camera.

3.4.2.2 Existing Design #2: Capacitive Sensor

Registers the type of plastic in order to identify the ping pong ball. Also it's designed for plastic detection and provided accurate level detection in the plastic industry. This type of sensor might had been very useful to our design. Capacitive sensor worked by measuring in an electrical called capacitance.

3.4.2.3 Existing Design #3: POV Camera

POV Camera was a shortcut of (Point of View Camera) it's one type of digital camera. This kind of camera designed to captured the scene in front of anyone use it. its small camera, so most of people who like sports used it , because it was attached in the helmet and hat.

3.4.3 Subsystem #3: Boat

The boat subsystem contained and had each of the other subsystems mounted on it. It was the body of the device and acted as the storage of the plastic.

3.4.3.1 Existing Design #1: Speed Boat

The speed boat contained a sleeker body to allow for faster and more agile movement. These allowed for quicker movements using a motor to navigate.

3.4.3.2 Existing Design #2: Catamaran

The catamaran was a wider and thus more balanced boat. The increased balance allowed for better distribution of the other subsystems to ensure no submerging. The catamaran was also equipped with a motor to navigate.

3.4.3.3 Existing Design #3: Sail Boat

The sail boat had a sleeker body allowing for more agile movements in the water. The boat used air currents with its sail to navigate.

4 DESIGNS CONSIDERED

Using the existing subsystem designs, the team used combinations of them to create total designs. These designs were considered for the final product. The four main designs were listed in section 4. The remaining six designs were listed in Appendix C: Alternative Designs.

4.1 Design #1: Trough Grabber with Electric Motor and Thermal Camera

This design, shown in Figure 6, combined the best of each subsystem and puts it together. The solar powered electric motor powered the thermal camera. This camera identified the location of the ping pong balls. The automated system told the electric motor to drive the boat over to the balls. The trough grabber went into the water and scoops up the balls and put them in the plastic storage area of the boat.

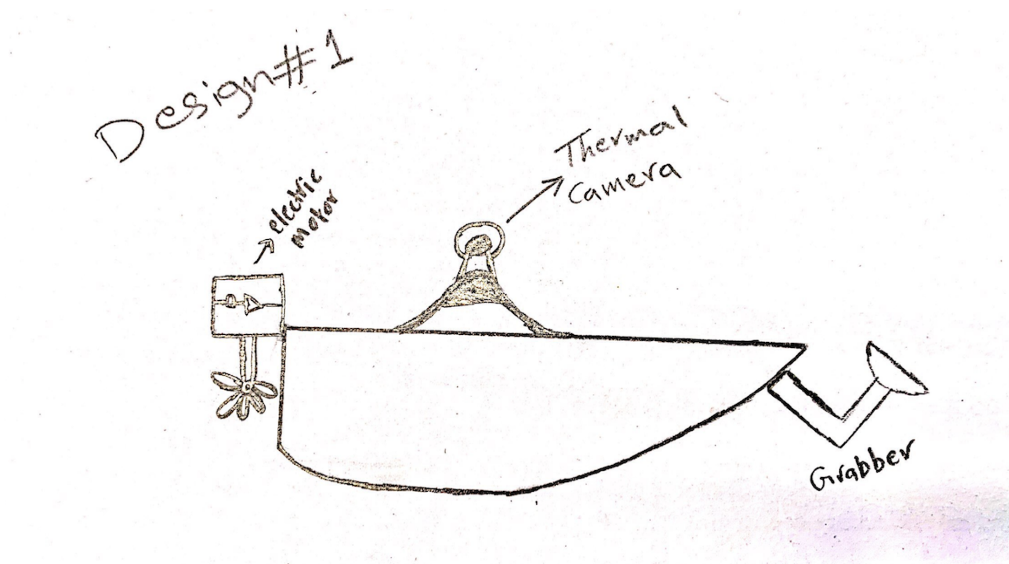

Figure 6: Design #1

Pros

- Collects more plastic
- Durable
- Effective
- Easy Operation

Cons

- Cost

4.2 Design #2: Arcade Claw with Capacitance Sensor and Rudder

The arcade claw with the capacitance sensor and rudder was one of the designs considered depicted in Figure 7. The rudder was a great way to steer the boat towards the trash. However, the arcade claw cannot collect the small pieces of trash. The plastic grabbed by the claw was easily dispensed into the boat.

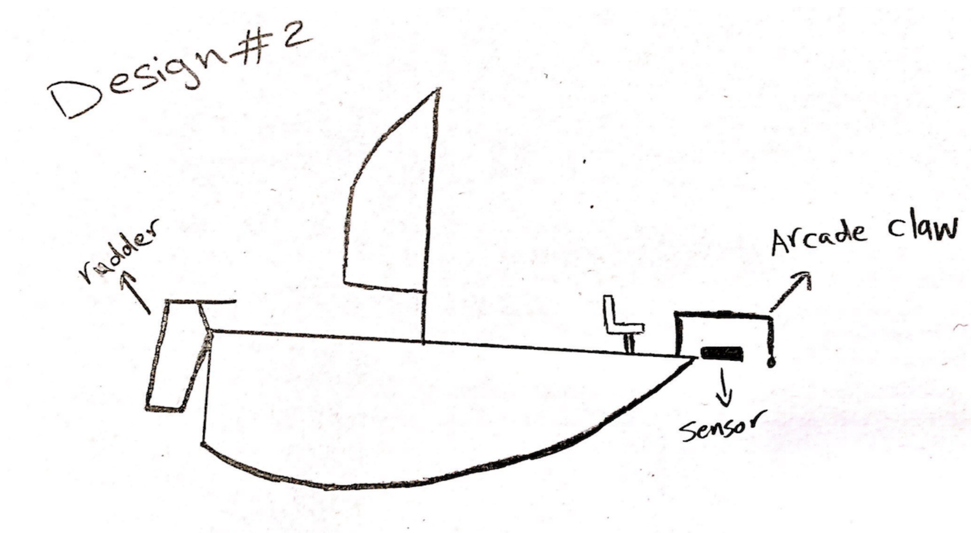

Figure 7: Design #2

Pros

- Easy to maneuver
- Releases plastic into the boat

Cons

- Arcade claw cannot collect small pieces of plastic

4.3 Design #3: Ice Cream Scooper with POV Camera and Oar

The ice cream scooper with POV camera and Oar was not as functional as other designs as seen in Figure 8. The ice cream scooper damaged the ecosystem by killing small microorganisms. Yet, it did the best job collecting the smallest pieces of plastic.

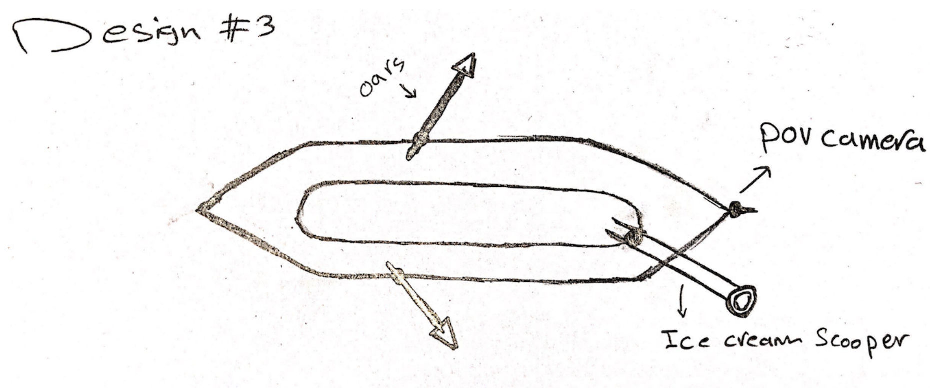

Figure 8: Design #3

Pros

- Collects the smallest pieces of plastic

Cons

- Ice cream scooper damages the ecosystem
- Grabber collects too much water
- Slow steering and movement

4.4 Design #4: Reach grabber with the Iphone camera and sail

This design was the datum design in Figure 9. Overall it was a poor design. It was cheap to manufacture and run. It was easy to release the plastic into the boat. However, the Iphone camera was easy to scratch without protection

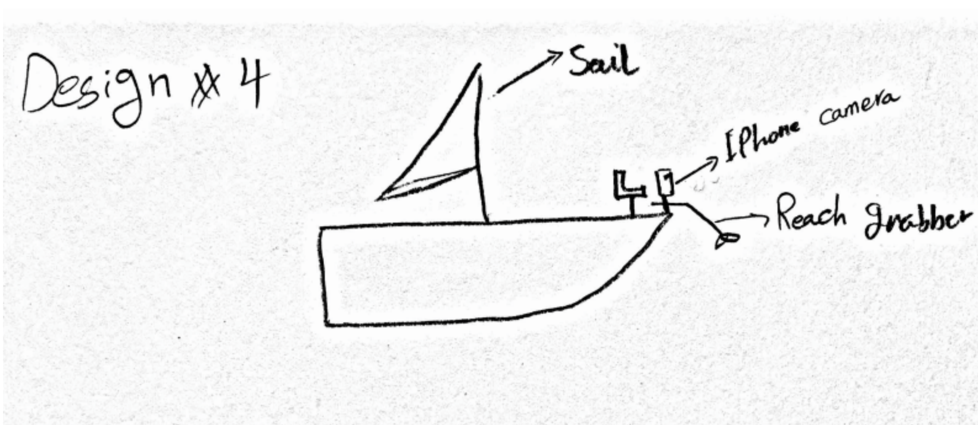

Figure 9: Design 4

Pros

- Cheap
- Fast release into the boat

Cons

- Camera can scratch

- Sail does not work in low winds
- Cannot grab small pieces of plastic

5 DESIGN SELECTED – First Semester

The team needed to choose a final design. The team used a decision matrix and multiple pugh charts to help with this process. This design needed to satisfy the customer needs, engineering requirements, and received the best score for each component on the pugh charts.

5.1 Rationale for Design Selection

The team selected Design #1: Trough grabber with electric motor and thermal camera. The group used a decision matrix to compare each subsystem to the customer requirement criteria to select this design as seen in Table 4. The team lowered the weights compared to the house of quality. The scores were shown on a 1-5 scale. The highest number was the most important subsystem. Furthermore, some subsystems had a pugh chart as a tool to help select the best design depicted in Tables 5-7. Design #1 scored the highest on the pugh charts.

Table 4: Decision Matrix

		Camera		Solar Panels		Grabber		Boat		Navagation	
Criteria	Weight	Score (1-5)	Weighted	Score (1-5)	Weighted	Score (1-5)	Weighted	Score (1-5)	Weighted	Score (1-5)	Weighted
Doesn't damage ecosystems	5	1	5	1	5	5	25	5	25	3	15
Durable	1	5	5	5	5	5	5	5	5	5	5
Portable	1	2	2	1	1	4	4	4	4	2	2
Picks up trash down to 5 mm in length	1	1	1	1	1	5	5	1	1	1	1
Waterproof	3	5	15	5	15	3	9	5	15	5	15
Solar powered	3	3	9	5	15	3	9	3	9	2	6
Sensors	3	5	15	4	12	2	6	1	3	5	15
Cheap	1	4	4	3	3	2	2	4	4	2	2
Fast	1	1	1	1	1	3	3	3	3	2	2
Safety	1	1	1	1	1	3	3	4	4	1	1
Effectiveness	3	5	15	4	12	5	15	2	6	3	9
Easy operation	1	2	2	1	1	5	5	1	1	2	2
Total		35	75	32	72	45	91	38	80	33	75

The decision matrix compares the customer requirements, labeled criteria, with the different components of the design. The criteria is weighted on a scale of 1-5. The group determined that each component was very important. The weighted scores ranged from 72-95.

Table 5: Grabber Pugh Chart

		Design Concepts			
Criteria	Weight	Trough grabber with holes	Arcade claw	Ice cream scooper	Reach grabber
Doesn't damage ecosystems	5	(+)	S	(-)	DATUM
Durable	1	(+)	S	(+)	DATUM
Portable	1	S	S	S	DATUM
Picks up trash down to 5 mm in length	1	(+)	(-)	(+)	DATUM
Waterproof	3	S	S	S	DATUM
Solar powered	3	S	S	S	DATUM
Sensors	3	S	S	S	DATUM
Cheap	1	(-)	(+)	S	DATUM
Fast	1	(-)	(+)	(-)	DATUM
Safety	1	S	S	S	DATUM
Effectiveness	3	(+)	(-)	S	DATUM
Easy operation	1	(+)	(-)	S	DATUM
Total +		5	2	2	
Total S		5	7	8	
Total -		2	3	2	
Overall Score		3	-1	0	
Weighted Overall Score		9	-3	-4	
Rank		1	2	3	

The grabber pugh chart compared and contrasts the grabber component of the design. The customer needed are labeled criteria, and given a weight of 1-5, just like the decision matrix. The design with the highest +, overall score, and weighted overall score was the best design. This was the trough grabber with water drainage holes.

Table 6: Sensor Pugh Chart

		Design Ideas			DATUM Design
Criteria	**Weight**	**Thermal camera**	**POV Camera**	**Capacitive Sensor**	**IPHONE Camera**
Doesn't damage ecosystems	5	S	S	S	DATUM
Durable	1	(+)	S	S	DATUM
Portable	1	S	S	S	DATUM
Easy to find garbage	3	S	S	S	DATUM
Waterproof	3	(+)	(+)	(+)	DATUM
Solar powered	3	S	S	S	DATUM
Sensors	3	S	S	S	DATUM
Cheap	1	(-)	(-)	(+)	DATUM
Fast	1	S	S	S	DATUM
Safety	1	S	S	S	DATUM
Effectiveness	3	(+)	(-)	(-)	DATUM
Easy operation	1	S	S	S	DATUM
Total +		**3**	**1**	**2**	
Total -		**1**	**2**	**1**	
Total S		**8**	**9**	**9**	
Overall Score		**2**	**-1**	**1**	
Weighted Overall Score		**6**	**-1**	**1**	
Rank		**1**	**3**	**2**	

The sensor pugh chart weighted the criteria on a 1-5 scale to judge the design ideas. The thermal camera received the best scare for total +, overall score, and weighted overall score. The worst design was the POV camera which receives the most - score.

5.2 Design Description

The pacific garbage patch cleanup team was creating a device that simulates the cleanup of the Great Pacific Garbage Patch. Our device broke down to 5 main components; RC boat, solar panels, grabber, thermal camera, and motors. The main goal was to collect 20 ping pong ball from a pool of water using these components. The device might have indicated the balls by using thermal camera and collect them by the grabber. The boat was powered by the solar cells, which they were located on the top of the boat to gain power from the sun and store and generate it to the boat. Furthermore, the balls that were collected were stored in a container in the boat. For the motor, we replaced the RC boat motor with a slower motor to let the solar cells gain enough power and to collect the ping pong ball. Since the team was working with the thermal camera, we removed the navigation from the design since it would not have been as efficient as the thermal camera. The assumptions and calculations were listed in Appendix E: Assumptions and Calculations. The ping pong ball had a diameter of 4cm and a mass of 2.7 grams. The volume was 33.51cm^3 for one ping pong ball.

6 PROPOSED DESIGN – First Semester

The team bought the RC boat, thermal camera, hinges, and solar panels. The team created an initial prototype of the trough grabber and beam using MakerBot in the Cline Library at Northern Arizona University. The team fabricated the final trough grabber and beam using ABS plastic from the 3D printers at Northern Arizona University. The autonomous features were first simulated with Arduino. After that, we will write the software. The software directed the boat to detect when a ping pong ball is near the boat. The boat then drove over the ball using the solar powered motor. The grabber then lifted up the ball and dropped it into the storage container using an additional smaller electric motor. The goal was to collect 20 ping pong balls. The team made physical and operational changes when the design failed to meet the requirements. The team tested each component to make sure it meets the customer and engineering requirements. A bill of materials listed the quantity, description, function material, dimensions, cost, and link to cost estimate in Appendix D: Bill of Materials. The budget was $1500. The actual expenses were low because there were unanticipated expenses in the future. The team created a detailed schedule listing the week, start date, agenda item, and assignments due for next semester depicted in Table 7.

Table 7: Detailed Schedule

ME 486C - ME Capstone Spring 2019 Tenative Schedule			
Week	Start Date	Agenda Item	Assignment Due
1	1/14	Team/Staff Meeting	Final Proposal Rewrite and Individual Post Mortem
2	1/21	Team/Staff Meeting	
3	1/28	Team/Staff Meeting	Website Check 1
4	2/4	Progress Presentation	
5	2/11	Team/Staff Meeting	
6	2/18	Hardware Review 1	HR1 Summary and Peer Eval 1
7	2/25	Team/Staff Meeting	Individual Analysis II
8	3/4	Team/Staff Meeting	Midpoint Report
9	3/11	Midpoint Presentation and HR2 combined	HR2 Summary and Peer Eval 2
10	3/25	Team/Staff Meeting	Website Check 2
11	4/1	Team/Staff Meeting	Drafts of Poster and Operation Manual
12	4/8	Final Product Testing Proof	
13	4/15	Team/Staff Meeting	
14	4/22	Final Presentation and Poster	Final Poster and Operation Manual
15	4/29	Team/Staff Meeting	Final Report and CAD package
Finals	5/6		Website and Peer Eval 3

The assembly view exploded view of the CAD model showed each component of the design. Both show the trough grabber, solar panels, camera, and boat. The main motor was hidden on the backside below the solar panels. The components were put together in their proper size and location in the assembly view in Figure 10. The exploded view showed the different components separately, in Figure 11, in order to get a better view of the individual components as there were multiple hidden surfaces in the assembly view.

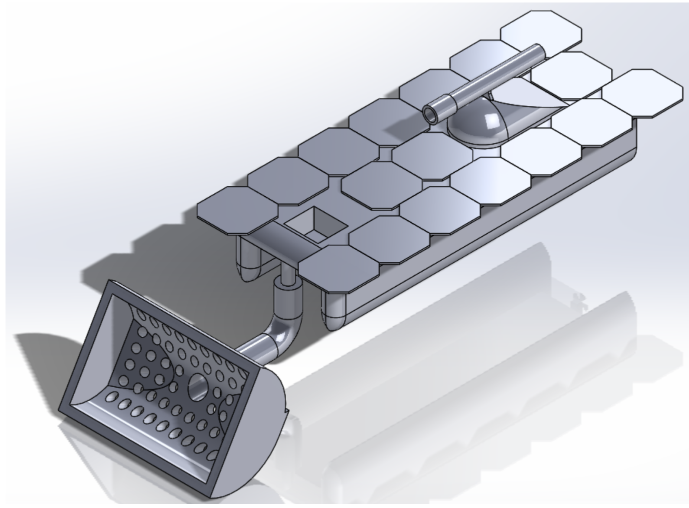

Figure 10: Assembly View of CAD Model

Figure 11 showed the exploded CAD model view. The front solar panels were lifted up to show the front end and trough grabber connection. The thermal camera was lifted to expose the cockpit in the boat and the connection. The main motor was extruded backwards as it is completely hidden in the assembly view.

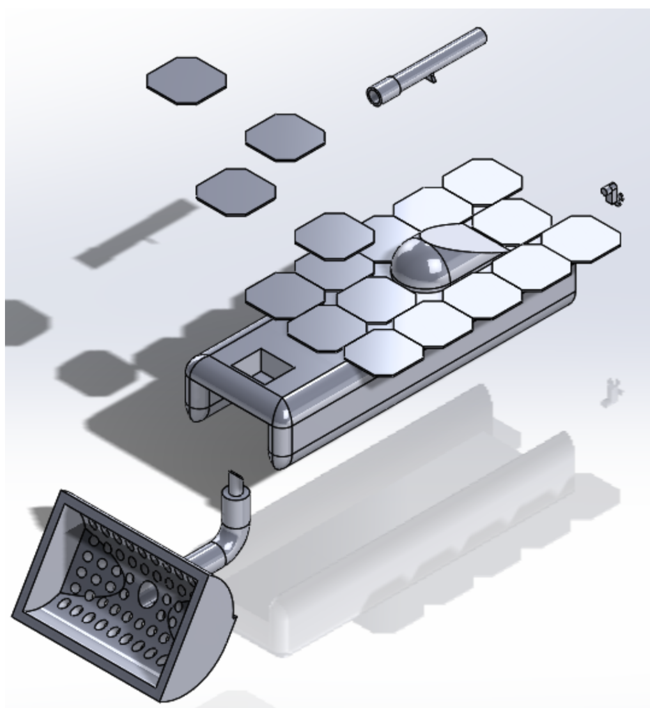

Figure 11: Exploded View of CAD model

7 Implementation

During the designing of the device, components need revising. Revisions may be the result of components being ineffective, uncompatible, or too costly. The device is comprised of numerous subsystems including the boat, the grabber, the camera, the arduino, and the solar cells. The boat, the camera, Arduino, and the solar cells are all purchased and have be redesigned, only the grabber has multiple manufactured versions.

7.1 Manufacturing

The grabber has gone through 3 designs though each used PLA plastic as their material. The critical data includes the dimensions, total mass, and center of mass of the grabber. The grabber was created on SolidWorks CAD software and 3D printed with Makerlab.

While the original design was very unrefined and had a mass of 505.2 g, the second design included a much thinner frame with more holes to allow for less resistance and a large reduction in weight to 292.54 g. The first revision also redimensioned the trough to be wider, shorter, and re-angled . Version 3 of the grabber further reduced the weight to roughly 100 g by making the frame even thinner and reducing material on the sides, the arm connecting the grabber to the motor has also been redimensioned to rotate directly to the collection bin. Due to the unexpected thickness in the front of the boat, the motor to rotate the grabber has been moved towards the center of the boat where its thicker. The motor will then be closer to the control board and will require two shafts and bevel gears. A gearbox will be placed where the motor was originally planned to be, and contains the two bevel gears allowing translation from the motor to the grabber.

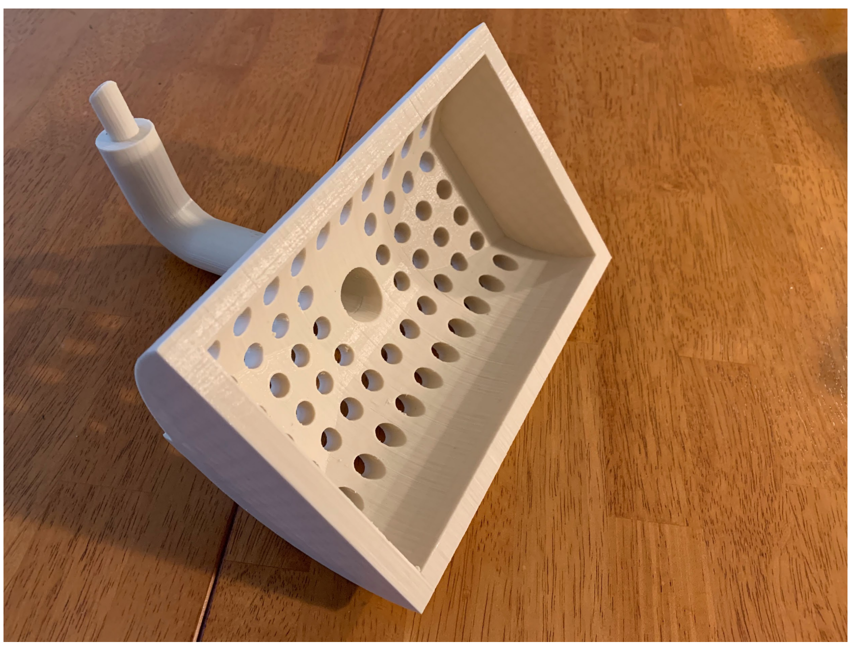

Figure 12: Grabber Version 1

Grabber version 1 was moving in the right direction but had several flaws. The design already had the correct shape and location on the boat. The grabber was already designed to collect the balls and rotate to drop them directly into the boat. The center of mass is just above where the arm connects to the grabber. However the dimensions were wrong in addition to being too massive. The mass needed to be reduced in order to reduce the torque for the motor.

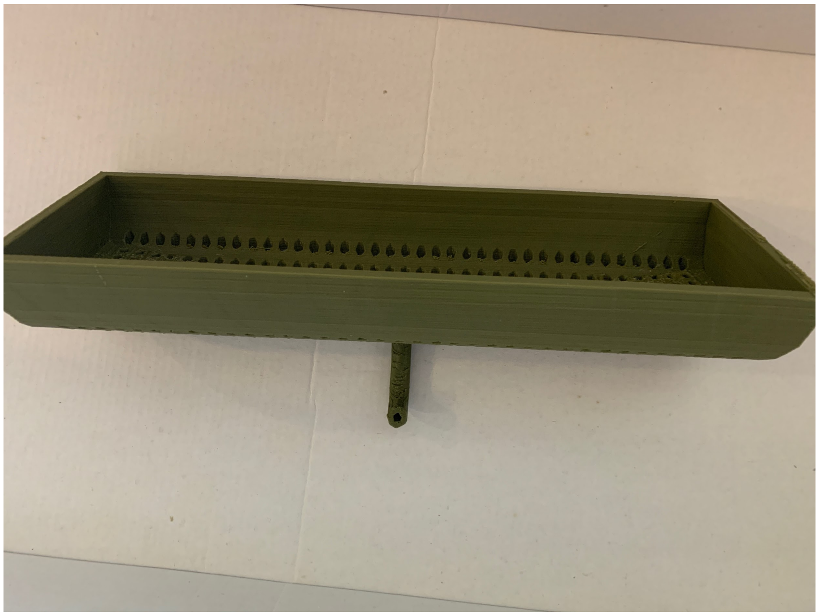

Figure 13: Grabber Version 2

This version of the grabber had the right proportions. The mass was reduced from version one but was still too high.

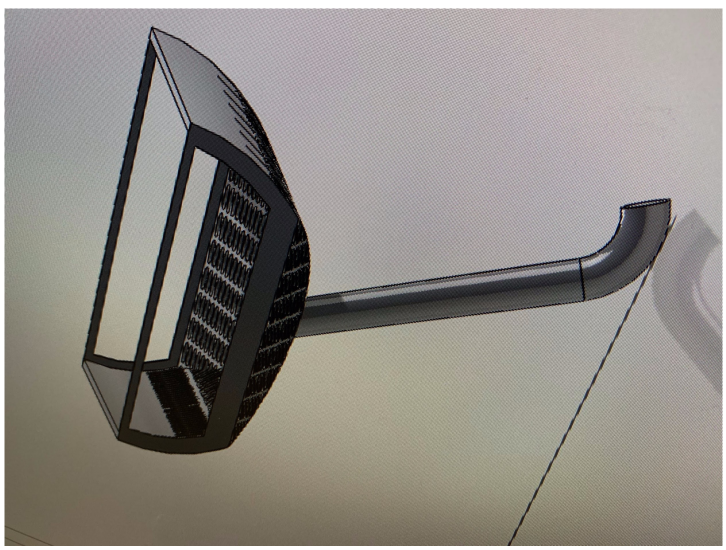

Figure 14: Grabber Version 3

This is the current grabber iteration. It addressed most of the problems from the previous versions. This needs to be confirmed with future testing. The mass of the grabber version 3 is 92.37 grams. The density is 1.07g/cm^3. This is the average density of ABS plastic. ABS plastic will be used for the production version after vigorous testing. A benefit of using ABS plastic is the lower density. This results in the reduction in mass and therefore a reduction of torque needed for the motor. Based on these numbers, the moments of inertia are 1505.97, 7755.58, and 8378.75 g/cm^3 using ABS plastic. The volume of plastic is 86.33cm^3. The torque needed is .966 kg/cm. ABS plastic has an average tensile yield strength of 40.5MPa and a tensile modulus of 2.07GPa [9]. The beam has a diameter of 1 cm. I tried to keep the volume as low as possible in order to reduce the disposal waste of the grabber. The last thing the planet needs is more plastic waste. The cross sectional area of lever arm is 78.54mm^2. The lever arm is the most likely component to break. The water pressure at 10 cm is 0.98 kPa. This is the maximum depth the grabber can potentially be submerged in water.

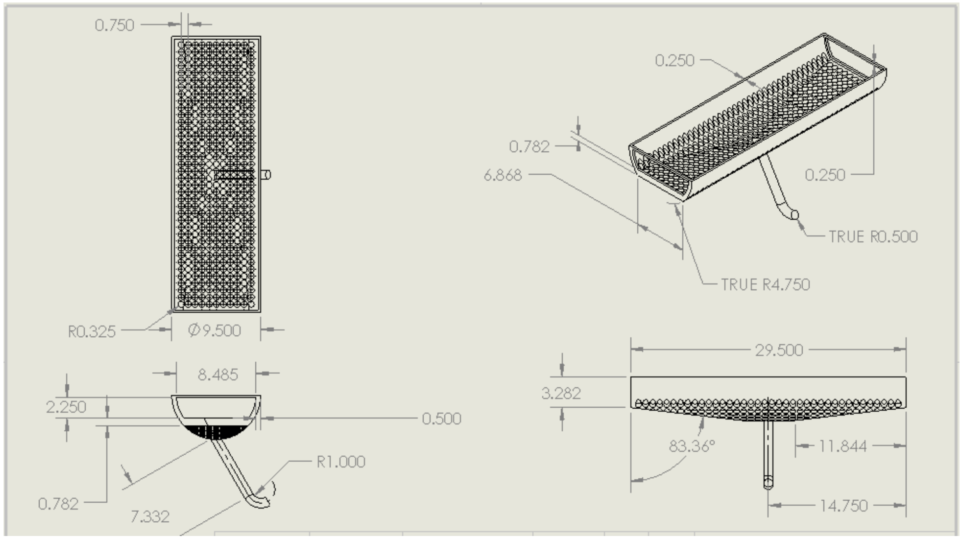

Figure 15: Grabber Version 3 Dimensions

Figure 15 shows a part drawing of the grabber. It is the exact same part as shown in Figure 14. The drainage holes have a radius of 0.325cm. The size prevents the ping pong balls from getting lodged inside the holes while reducing the mass. The 0.75cm spacing between the holes is small to reduce mass, while keeping the bottom of the grabber strong. The 0.25cm rim was chose to satisfy the mass and strength requirements. The mass has been reduced dramatically to meet the mass engineering requirement. The reduction in mass also allows for an increase in speed of both the grabber and the boat. The grabber is still sturdy enough to have a long enough useful life.

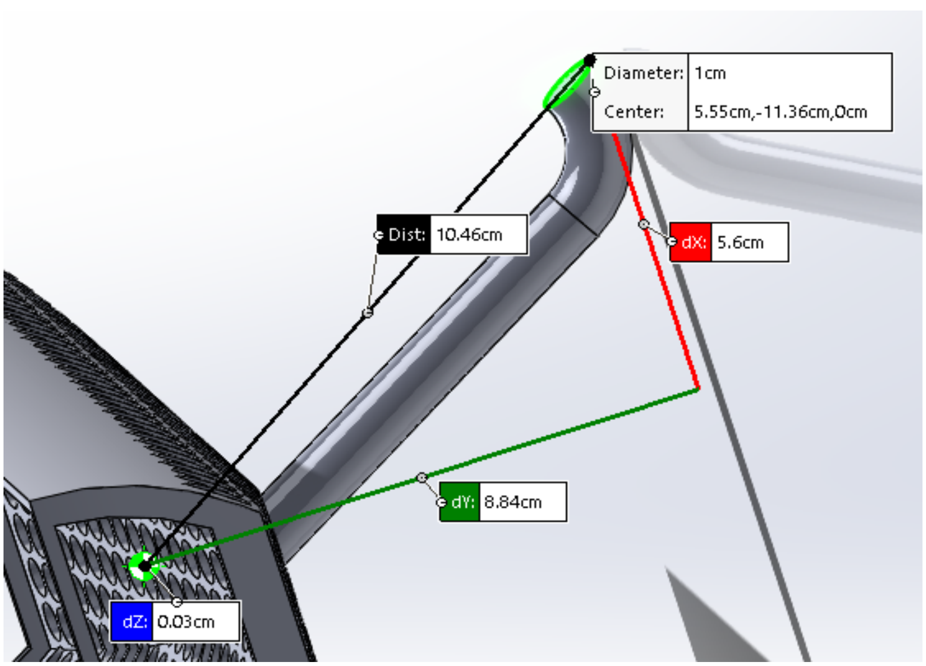

Figure 16: Grabber Lever Arm and Center of Mass

Figure 16 shows the center of mass relative to the lever arm. The distance is 10.46cm. This value used to calculate the torque needed to power the grabber. This number must be kept to a minimum in order to drive the motor autonomously with Arduino. The torque needed is .966 kg/cm. The lever arm length was chosen based on testing from the previous grabbers. The grabber had to be long enough to properly rotate around the front of the boat.

7.2 Design Changes

During the implementation of the components, multiple design changes occurred. Some of the design changes were due to restrictions that arose whether it be the size or cost and some changes were from unexpected issues with components like compatibility.

The camera is vital in the success in the automation of the device as it needs to be able to recognize a ping pong ball efficiently. This may be through IR or through color as the ping pong balls will be orange. During the conceptual designing of the device, an expensive camera was considered however the team determined a cheaper camera may be used while producing an equally efficient product. The camera was then planned to be model OV7670. However, after testing the camera, it did not seem compatible with the projects plans. Due to the problems, the team has moved forward and will be using a new camera, TTL Serial JPEG Camera (Product ID: 613 on adafruit). It is expected to be more compatible with the system along with being weatherproof and can continue working into the night.

To automate the device, the team has opted to use Arduino. The Arduino components are not yet finalized as testing has been done with Arduino Club materials in order to prevent purchasing non-vital components. The code is updated constantly to account for the new component models used. The system can be generalized into pseudocode (Figure 17). Many components however include example codes that may be modified and added to the devices when decided upon.

```
Activate Camera
Is there ball
        no
                rotate boat __ degrees
        yes
                motor towards
                how far
                        far
                                go fast
                        near
                                go slow
                        in front
                                activate grabber
                                        scoop from horizontal into the collection bin
```

Figure 17: Arduino Pseudocode

The cell system has received multiples additions throughout the creation of the device. The team has calculated that roughly 25 cells will be necessary to run continuously. As the boat has insufficient area (on top), the addition of a platform is necessary. The platform will sit above the boat connected with multiple stilts. These stilts will be hollow to allow the cells to be connected to the batteries located in the hull of the boat. The platform will allow a sufficient number of cells to be mounted and will be slightly sloped to still optimize the collection of energy while allowing for water to roll off. While the slant may not be necessary for our model, when scaled and released into the ocean, it will prevent condensing of water on the solar cells.

The team has resisted altering the boat in order to ensure its strength is uncompromised. The team however has decided to redesign the top cover. The one included with the boat is raised and will affect the storage of the balls. The team will create a "flattened" version of the cover. Using the base dimensions, it will sit identical to the current cover however, it will be flat allowing for no interference with the storage. The only compromising necessary will be to locate the motor and gearbox for the grabber.

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[8] "Encyclopedia," *PCMAG*. [Online]. Available: https://www.pcmag.com/encyclopedia/term/62655/pov-camera. [Accessed: 30-Nov-2018].

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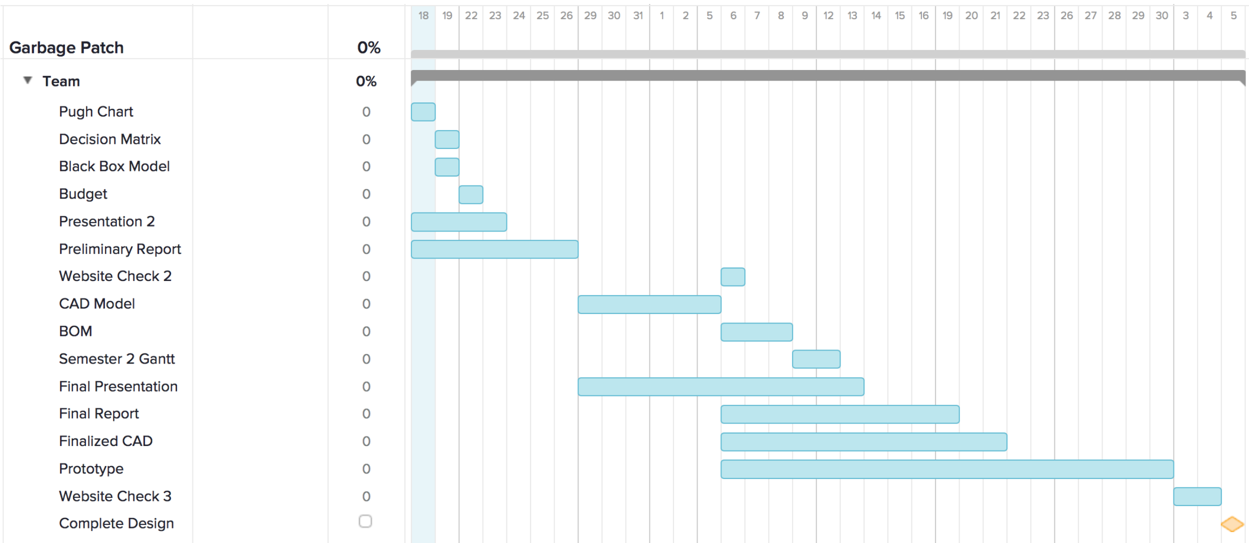
8 APPENDICES

8.1 *Appendix A: Gantt Chart*



8.2 *Appendix B: Budget*

Budget :

Total Budget $1500 available

Anticipated expenses

- **$400 for the boat**
- **$145 for solar panels**
- **$50 for camera**
- **$25 for motor**

Actual expenses to date

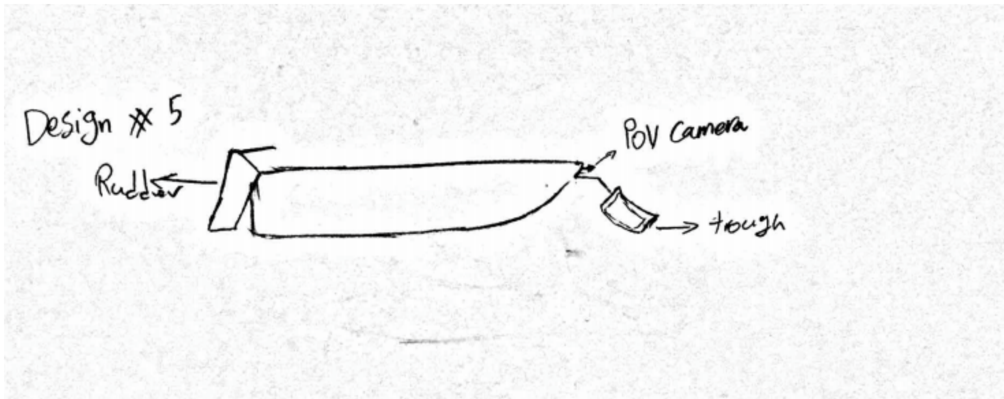
- **$620**

Resulting Balance

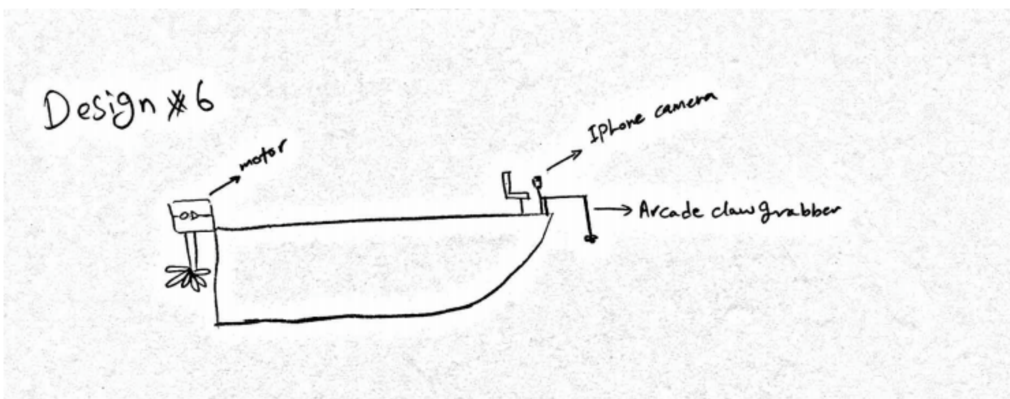
- **$1500**

8.3 Appendix C: Alternative Designs

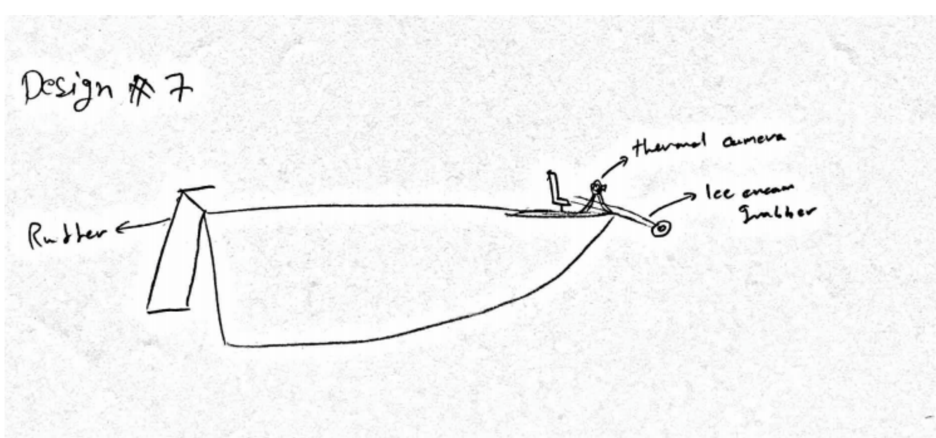
8.3.1 Design #5: Trough with the POV camera and rudder



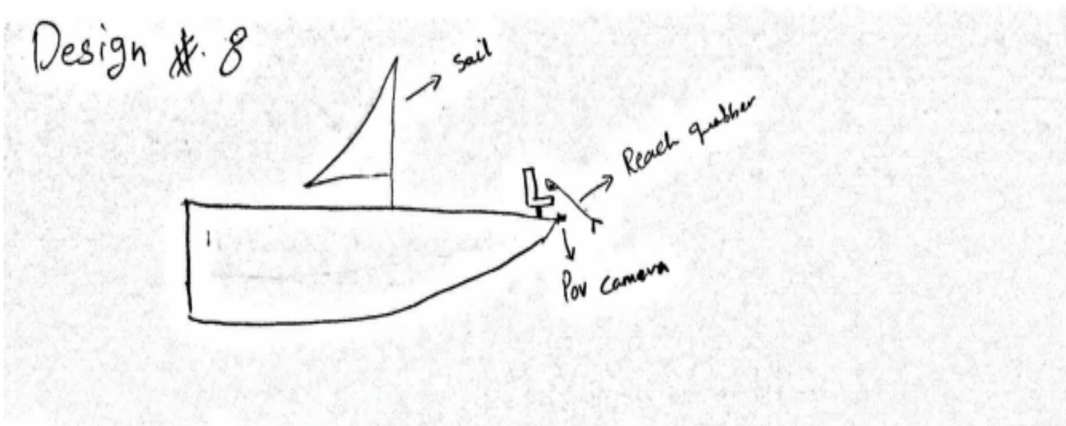
8.3.2 Design #6: Arcade claw grabber with the Iphone camera and motor



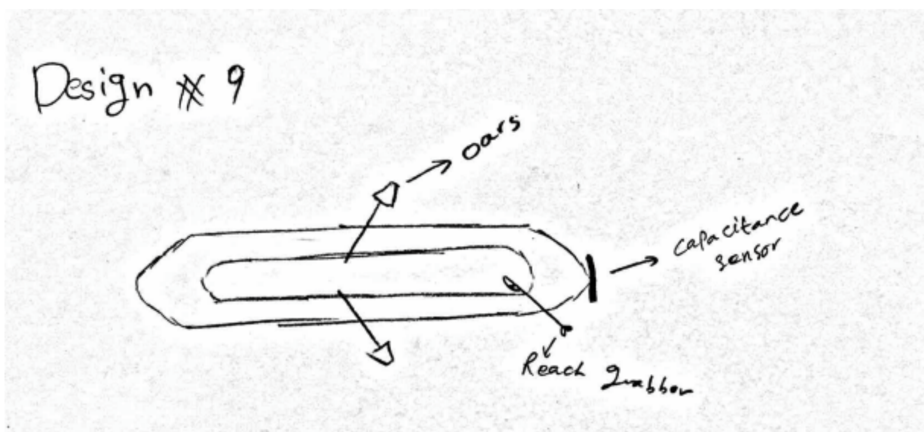
8.3.3 Design #7: Ice Cream grabber with the thermal camera and rudder



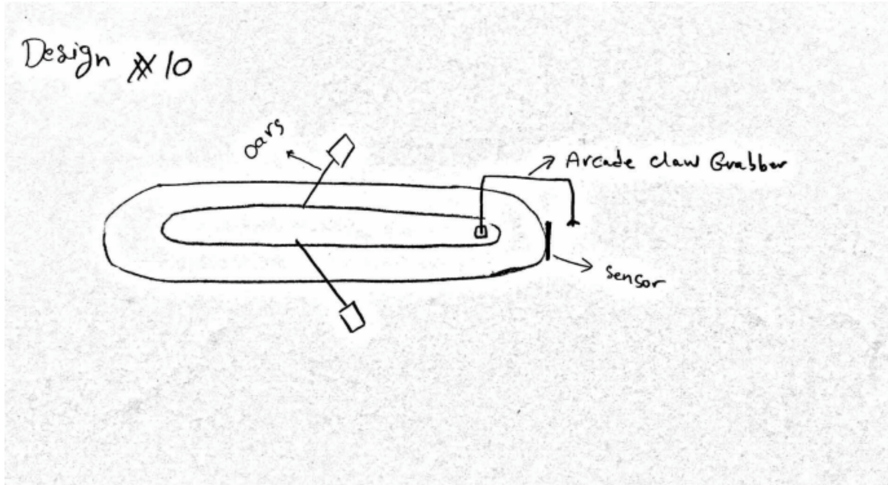
8.3.4 Design #8: Reach grabber with the POV camera and sail



8.3.5 Design #9: Reach grabber with the capacitance sensor and oars



8.3.6 Design #10: Arcade claw grabber with the capacitance sensor and oars



8.4 Appendix D: Bill of Materials

Bill of Materials							
Team: C3							
Qty	Description	Functions	Material	Dimensions	Cost	Link to Cost Estimate	Manufacturer
1	Boat	move	fiber glass	1.02m x 0.30m x 0.25m	$399.99	https://www.horizonhobby.com/AQUB2101?KPID=AQUB2101&CAWELAID=320011980001437484&CAGPSPN=pla&CAAGID=37619207031&CATCI=pla-550124742228&gclid=Cj0KCQiA3IPgBRCAARIsABb-iGJR9dAkOykRdNKKDh2qSB3L8EdfYypU8UGch-n3T_amHkso_NxodX8aAndIEALw_wcB	Aqua Craft Motley Crew FE Brushless Catamaran
1	Camera	detect	fiber glass	HT-02D -20-300C +-2C 274mm x 185mm x 109mm .898kg	$199.99	https://www.amazon.com/Handheld-Resolution-1024Pixels-Temperature-20-300°C/dp/B07D5CKT2J/ref=asc_df_B07D5CKT2J/?tag=hyprod-20&linkCode=df0&hvadid=242022044358&hvpos=1o4&hvnetw=g&hvrand=4347983675219588209&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9030289&hvtargid=pla-539141451732&psc=1	Akozon
1	Trough	collect	ABS plastic	15cmx10cm	$30.00		
2	Trough Beam	hold trough	ABS plastic	2cm dia	$10.00		
15	Hinges	trough movement	Nylon	15.875mm x 28.575mm	$6.25	https://www.towerhobbies.com/cgi-bin/wti0001p?&I=DUBQ2025&P=FR&gclid=Cj0KCQiAuf7fBRD7ARIsACqb8w6JJ7Ijtt77OuITJjtDObTCc7TWaDMtlYX9nZuGGrJiO8sqdUJfOSwaAv1QEALw_wcB	Dubro
20	Solar Panel	power	Silicon	125mmx125 mm	$100.00	https://www.amazon.com/Sunpower-Flexible-Monocrystalline-Tabbing-Efficiency-x/dp/B078KCCY4T/ref=sr_1_2_sspa?ie=UTF8&qid=1543298742&sr=8-2-spons&keywords=sunpower%2Bsolar%2Bcell%2Bc60&th=1	SunPower
Total					$746.23		

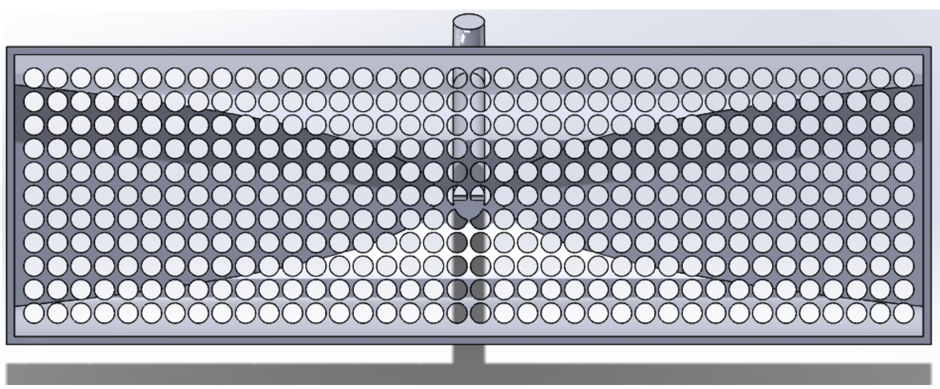
8.5 Appendix E: Assumptions and Calculations

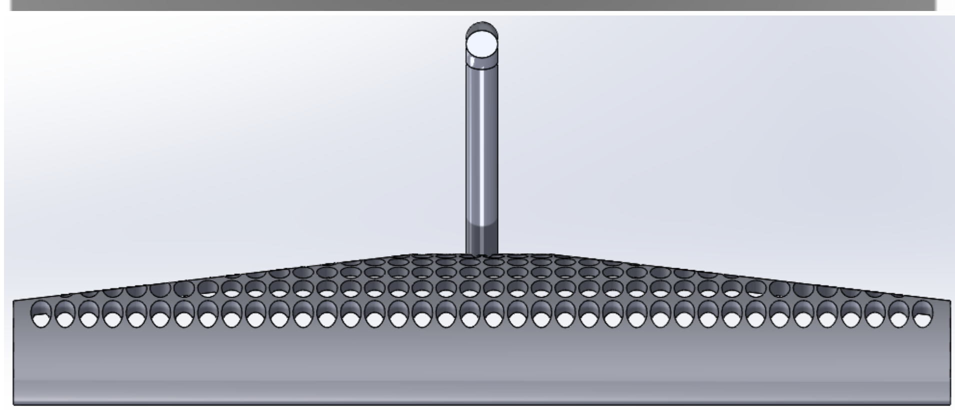
- average diameter of a pingpong ball 4cm

    - volume of a ping pong ball = (4/3)pi(r^3) = 33.51cm^3
        - 20 ping pong balls 20 x 33.51cm^3 = 670.2cm^3
- average mass of a ping pong ball 2.7g
    - 20 ping pong balls x 2.7grams = 54grams
- gravity 9.81m/s^2
    - weight of one ping pong ball 9.81m/s^2 x 2.7g = 26.487N
        - 20 ping pong balls 26.487N x 20 = 529.74N
- air pressure is 1bar
- density of air 1.225kg/m^3
- density of water 997kg/m^3
- Rbar = 8.314kJ/kmol*K
- Molar mass of water 18.02kg/kmol*K
- Molar mass of air 28.97 kg/kmol*K
- Air is an ideal gas
- Specific weight of water 9.807kN/m^3
- specific weight of air 12.01N/m^3

8.6 Appendix F: Manufacturing Iterations

8.6.1 Grabber Version 3





Mass properties of ME486C Grabber Beta 2
Configuration: Default
Coordinate system: -- default --

Density = 1.07 grams per cubic centimeter

Mass = 92.37 grams

Volume = 86.33 cubic centimeters

Surface area = 945.49 square centimeters

Center of mass: (centimeters)
X = 0.20
Y = -2.96
Z = 0.00

Principal axes of inertia and principal moments of inertia: (grams * square centimeters)
Taken at the center of mass.

Ix = (0.00, 0.00, 1.00)	Px = 1505.97
Iy = (0.97, -0.22, 0.00)	Py = 7755.58
Iz = (0.22, 0.97, 0.00)	Pz = 8378.75

Moments of inertia: (grams * square centimeters)
Taken at the center of mass and aligned with the output coordinate system.

Lxx = 7786.42	Lxy = -135.16	Lxz = -0.01
Lyx = -135.16	Lyy = 8347.91	Lyz = 0.62
Lzx = -0.01	Lzy = 0.62	Lzz = 1505.97

Moments of inertia: (grams * square centimeters)
Taken at the output coordinate system.

Ixx = 8593.75	Ixy = -190.77	Ixz = 0.01
Iyx = -190.77	Iyy = 8351.74	Iyz = 0.28
Izx = 0.01	Izy = 0.28	Izz = 2317.14