SPARK

South Pasadena High School

South Pasadena, CA, USA

Company Personnel

- **Ryan Arlett**: CEO, operations
- **Andrew Jin**: Government and regulatory affairs, design integration
- **Carl Christopher Liebe:** Systems engineering, testing
- **Victor Chen**: CFO, Fund-raising
- **Carl Sebastian Liebe**: Marketing, media outreach

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Abstract

SPARK is a small company dedicated to providing clients with the finest quality aquatic ROVs (remotely operated vehicles) for a wide range of tasks. Here we describe our latest ROV: SPARKY, capable of picking up trash, assessing climate change and contributing to the maintenance of healthy waterways - all in one compact, nimble product. SPARKY accomplishes most tasks by making use of its multipurpose claw - a claw so versatile it can be used for a range of tasks from transplanting delicate pieces of coral to removing and replacing eel traps in designated areas. SPARKY's custom electronics enable precise control over both speed and direction; enabling SPARKY to perform such delicate tasks as collecting a sponge sample for pharmaceutical research and performing maintenance on a floating seabin. SPARKY also includes custom features such as a net for the collection of surface debris, modelled after a pool skimmer, and a removable extension that gives SPARKY a 10ft reach while maintaining the ability to move and navigate. The latter is a detachable accessory ensuring SPARKY can be compactly stored and transported, with a maximum dimension of 57cm. The extension enables SPARKY to reach into a pipe and extract a soil sample for testing. Here we outline how SPARKY can accomplish the tasks laid out in the MATE 2021 ROV Competition RFP. At 12.2kg SPARKY is a lightweight solution to all your ROV needs and SPARK is ready to tackle real-world challenges with the same ingenuity and creativity used to approach these demonstration tasks.

Teamwork

Project Management

<u>Company</u>

SPARK is a small company dedicated to providing clients with the finest quality aquatic ROVs (remotely operated vehicles) for a wide range of tasks. Built on the prospect of innovation, the ROVs are constructed almost entirely from scratch and constantly upgraded with new features.

Figure 1: SPARK personal (left to right): Sebastien Liebe, Ryan Arlett, Victor Chen, Christopher Liebe, Andrew Jin

<u>Personnel</u>

SPARK's personnel consists of a small group of individuals with a wide variety of skills and expertise, forming a strong company covering every aspect of running a successful company. The company members, shown in Figure1, are:

- **Ryan Arlett**

    - The CEO, pilot, and overseer of operations
- **Andrew Jin**
    - Manager of government and regulatory affairs and design integration

- **Carl Christopher Liebe**
    - Systems engineer and overseer of testing
- **Victor Chen**
    - The CFO, tether manager, and head of fund-raising
- **Carl Sebastian Liebe**
    - Executive of marketing and media outreach

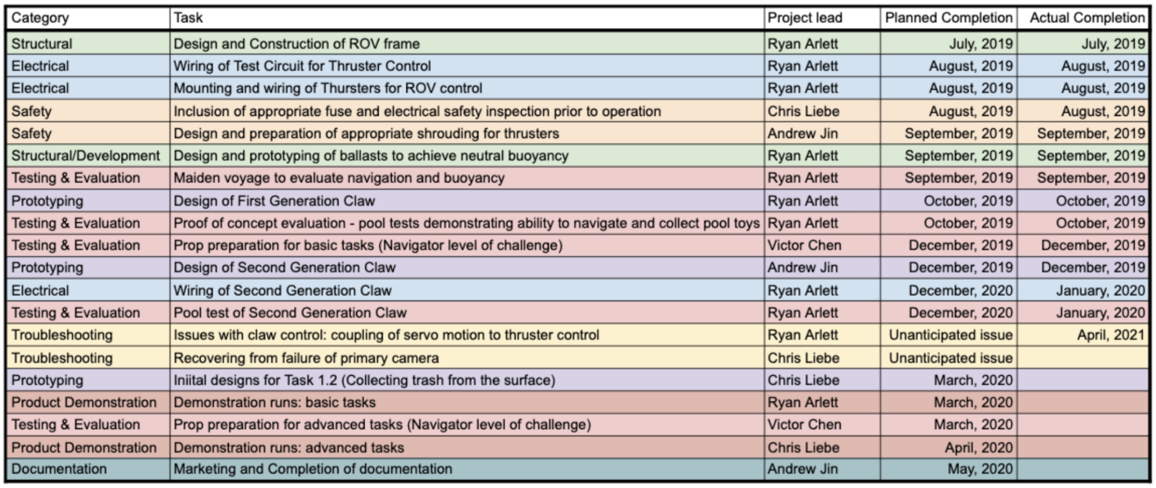
<u>Schedule</u>

The unexpected challenges brought about by the COVID-19 pandemic brought about significant departures from our originally planned schedule. Nonetheless it also enabled significant redesign and improvement as we worked separately on aspects of the solution during the 12 month period from March 2020 - March 2021 during which we did not have any in person meetings but continued to work separately and meet over zoom to strategize on how to improve on our design. SPARK is pleased to announce product completion on time with a product capable of achieving all tasks laid out in the MATE 2021 Competition RFP.

Initial Schedule:
Two of the members of the current team were founding members of SPARK, a team founded in July, 2018 which competed in the 2018-2019 season in the Navigator class at the Southern California regional tournament. The 2018-2019 team had an ambitious goal - to design an ROV from scratch without ever having worked on any aspect of underwater robotics. The team overcame many challenges that year, but were unable to successfully complete any of the challenges at the time of the 2019 regional tournament.

Following the completion of the 2019 tournament, it was clear that a complete redesign of the structure and functionality of the ROV was required. Ryan Arlett and Andrew Jin set out to complete this task, recruiting two new members to the team (Chris Liebe and Victor Chen) in late summer (Sebastian Liebe joined the team much later, in April, 2021 with a focus on marketing and development).

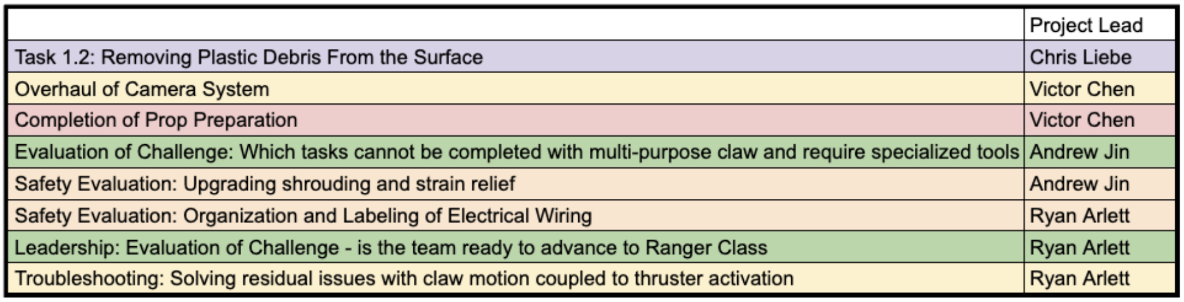
The team set out with an ambitious schedule and was largely able to stay on schedule up until the shutdown precipitated by the COVID-19 pandemic (Figure 2). This was accomplished through significant cooperation and teamwork, including brainstorming together to work out key roadblocks to success and designating a project leader for each key area of focus to ensure nothing was forgotten. Project leads did not complete the tasks alone, rather they tapped into the diverse expertise of all team members for innovative and creative solutions.



Category	Task	Project lead	Planned Completion	Actual Completion
Structural	Design and Construction of ROV frame	Ryan Arlett	July, 2019	July, 2019
Electrical	Wiring of Test Circuit for Thruster Control	Ryan Arlett	August, 2019	August, 2019
Electrical	Mounting and wiring of Thursters for ROV control	Ryan Arlett	August, 2019	August, 2019
Safety	Inclusion of appropriate fuse and electrical safety inspection prior to operation	Chris Liebe	August, 2019	August, 2019
Safety	Design and preparation of appropriate shrouding for thrusters	Andrew Jin	September, 2019	September, 2019
Structural/Development	Design and prototyping of ballasts to achieve neutral buoyancy	Ryan Arlett	September, 2019	September, 2019
Testing & Evaluation	Maiden voyage to evaluate navigation and buoyancy	Ryan Arlett	September, 2019	September, 2019
Prototyping	Design of First Generation Claw	Ryan Arlett	October, 2019	October, 2019
Testing & Evaluation	Proof of concept evaluation - pool tests demonstrating ability to navigate and collect pool toys	Ryan Arlett	October, 2019	October, 2019
Testing & Evaluation	Prop preparation for basic tasks (Navigator level of challenge)	Victor Chen	December, 2019	December, 2019
Prototyping	Design of Second Generation Claw	Andrew Jin	December, 2019	December, 2019
Electrical	Wiring of Second Generation Claw	Ryan Arlett	December, 2020	January, 2020
Testing & Evaluation	Pool test of Second Generation Claw	Ryan Arlett	December, 2020	January, 2020
Troubleshooting	Issues with claw control: coupling of servo motion to thruster control	Ryan Arlett	Unanticipated issue	April, 2021
Troubleshooting	Recovering from failure of primary camera	Chris Liebe	Unanticipated issue	
Prototyping	Iniital designs for Task 1.2 (Collecting trash from the surface)	Chris Liebe	March, 2020	
Product Demonstration	Demonstration runs: basic tasks	Ryan Arlett	March, 2020	
Testing & Evaluation	Prop preparation for advanced tasks (Navigator level of challenge)	Victor Chen	March, 2020	
Product Demonstration	Demonstration runs: advanced tasks	Chris Liebe	April, 2020	
Documentation	Marketing and Completion of documentation	Andrew Jin	May, 2020	

Figure 2: Project schedule for key tasks as laid out prior to the COVID-19 pandemic with projected and actual dates of completion.

The COVID-19 shutdown led to significant uncertainty - California was under a complete lockdown against gatherings of individuals from different households and the 2020 tournaments were cancelled. The team was unable to work together, but continued to work individually on improvements to our overall system and on new approaches to parts of the challenge we still needed to solve. From our initial brainstorming, two challenges stood out: removing floating debris and retrieving a sediment sample from a pipe could not be accomplished with a simple claw. So, the company decided to split the different tools between company members. After a lot of effort and work put into the tools, they were finally ready to be applied to the ROV for testing.We met periodically over zoom. We divided up key areas of responsibility (Figure 3).



	Project Lead
Task 1.2: Removing Plastic Debris From the Surface	Chris Liebe
Overhaul of Camera System	Victor Chen
Completion of Prop Preparation	Victor Chen
Evaluation of Challenge: Which tasks cannot be completed with multi-purpose claw and require specialized tools	Andrew Jin
Safety Evaluation: Upgrading shrouding and strain relief	Andrew Jin
Safety Evaluation: Organization and Labeling of Electrical Wiring	Ryan Arlett
Leadership: Evaluation of Challenge - is the team ready to advance to Ranger Class	Ryan Arlett
Troubleshooting: Solving residual issues with claw motion coupled to thruster activation	Ryan Arlett

Figure 3: From March, 2020 through March, 2021 the team was unable to meet in person due to California's COVID-19 restrictions. However, the team met over zoom and agreed on tasks and priorities to focus on individually to ensure the team would be ready to push forward when in person work was able to resume.

Due to the uncertainties over what tournaments would take place and when as well as the evolving COVID-19 restrictions, our schedule for the past six months has been an evolving and adaptive document. For example, after the Southern California regional tournament was cancelled in Long Beach, we became focused on the specific tasks required for the World Championships Qualifier. Because our target deadlines and focus necessarily evolved, here we focus on the dates by which tasks were accomplished. Considering the uncertainties, we were able to plan, adapt our schedule in real time and complete all tasks by key deadlines. The final schedule by which tasks were completed is provided in Figure 4.

Task	Proect Lead	Completed
Validation of New Camera System	Victor Chen	February, 2021
1st prototype for surface collection of ping pong balls	Chris Liebe	February, 2021
Electrical control: isolation of servo motor to reduce coupling	Ryan Arlett	February, 2021
Design of Third Generation Claw	Ryan Arlett	March, 2021
Completion of all props requried for world championships qualifier	Victor Chen	April, 2021
Validation of Third Generation Claw	Ryan Arlett	April, 2021
Final safety inspection and validation of all safety requirements	Andrew Jin	April, 2021
Camera system modification: additional zoomed out camera to aid in navigation	Chris Liebe	April, 2021
Camera system modification: additional camera to aid in coral collection	Andrew Jin	April, 2021
Design and Validation of Fourth Generation Claw	Ryan Arlett	May, 2021
Completion of Required Tasks for World Championships Qualifier	Ryan Arlett	May, 2021
Completion of all props required for World Championships	Victor Chen	May, 2021
Camera system modification: camera with surface view to aid in ping pong ball collection	Chris Liebe	May, 2021
Succesful validation of collection of ping pong balls from surface	Chris Liebe	May, 2021
Camera system modification: downward pointing camera for transect line	Andrew Jin	May, 2021
Improved tether management protocol	Andrew Jin	May, 2021
Prototype Vaildation and Iterative Improvement for Successful Removal of Sample from Drain Pipe	Ryan Arlett	May, 2021
Completion of Required Documentation and Marketing Display	Andrew Jin	May, 2021

Figure 4: Completion of final tasks.

<u>Managing Resources, Procedures, and Protocols</u>

Resources, procedures, and protocols were managed to meet mission objectives and solve day to day operation problems. Weekly zoom meetings enabled the team to brainstorm, track progress and discuss next steps. Each aspect of the challenge was discussed and assigned to a team member as the project lead, who coordinated efforts on the project among team members. New team members were trained in appropriate safety and operating protocols by the company CEO before beginning work on the project. COVID-19 safety protocols were followed at all times including social distancing and use of masks.

Design Rationale

Engineering Design Rationale

Several key principles guided the design of our vehicle:

1) It should have neutral buoyancy for optimal control
2) It is better to have a small number of multi-purpose tools whose operation is flexible enough to solve most tasks rather than specialized tools for every aspect of the challenge. Tasks were therefore sorted into those tasks which could be accomplished with a generic claw and those that required a specialized approach.
3) Two aspects of the challenge, namely:
    1.2: Removing floating debris from the surface and
    3.1: Retrieving a sediment sample from inside a drain pipe to analyze for contaminants

    were identified as necessarily requiring highly specialized tools for those particular tasks. Team members were identified early on to focus on these tasks and develop specialized solutions separate from the more generic approach to the remaining tasks
4) Customized control of the electronics with a Raspberry Pi was used to develop a system enabling full control and suitable for autonomous operation where required.
5) Four thrusters were used. This allowed balance operation and full navigational control
6) We found careful camera positioning to play a huge role in our ability to efficiently navigate the tasks. Cameras were therefore added in multiple orientations to allow the needed visibility.

Innovation

Many innovations were made in the production of the ROV, reducing costs and increasing efficiency. One innovation is the design of the main claw. The claw was specifically designed to be able to pick up items with ease. The claw was 3D-printed which makes it light and strong, qualities that make it well suited for its application. It uses a waterproof servo motor to rotate the clamping arm, giving it a strong grip. Additional innovations were made for specific tasks including the collection of items from the surface and removal of a sediment sample from a long pipe. The company's novel approach to these challenges, described later, enables a wide range of efficient solutions to the problems at hand.

Problem Solving

All of our ideas went through stages from early prototyping and testing to full scale production, assembly and reliability testing. Due to the COVID-19 pandemic, much of the team's brainstorming took place over zoom. The team discussed ideas and approaches as a group, then reflected individually and came up with new ideas that were shared as a group at the next meeting. An online discussion board was used to share ideas between meetings.

Systems Approach

SPARKY was designed with a holistic approach to the overall system. The system focuses on versatility with a multipurpose claw designed to accomplish a broad range of tasks. Reliability and efficiency was a key consideration of all design decisions. Custom electronics allow precise control over motor speed and direction enabling precise navigation. The five cameras enable multi-directional views including stereo vision with two cameras focused on the primary claw for efficient and precise manipulation tasks including where delicacy is required. Finally SPARKY includes innovative tools for specialized tasks such as the collection of surface debris and collection of debris from inside a drain pipe.

Vehicle structure

SPARK was strongly motivated to develop a compact, nimble vehicle capable of solving all tasks in a tight environment. Key considerations included the pool in which we operate and test our vehicle which is a small HOA pool that generally requires tight operation to complete the tasks in a limited space as well as the additional points available for smaller vehicles.

We elected to construct a cubic frame 32cm on a side at the core of our vehicle. This size was chosen to allow ample space for tools on the outside of the vehicle as well as the tether and other required components within the 60cm hoop for maximal points and also to enable ease of operation. We felt a smaller vehicle would make sharper turns, enabling us to move more efficiently through the tasks.

The vehicle structure evolved from iterative knowledge gained building off preliminary testing with a very different model, custom built for the 2019 competition (figure 5, left). In this previous generation vehicle, SPARK made use of motors at the front to drive and roll, and one at the back to pitch the craft. While this plan was carefully thought out, it turned out to be almost impossible to control. In typical use the ROV would end up spinning around on multiple axes, leading to a loss of control.

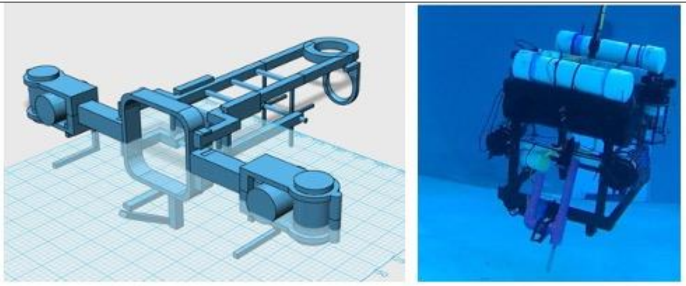


Figure 5: Vehicle structure underwent a complete redesign after problems were identified. Two members of SPARK first competed as a Navigator class team with a sleek, custom-designed vehicle with an entirely 3D printed frame in 2019 (left). Based on what the team learned attempting to control and operate that ROV, the team did a complete redesign of the vehicle for the 2019-2021 season. The new design with a welded steel cube-shaped frame is sturdy and reliable (right). The dimensions of the steel frame are 30cm x 31.5cm x 31.5cm.

As a result, SPARK made the decision to completely overhaul the ROV. The new design takes a much simpler and easy to control approach. We welded a steel cube as the chassis, and then put PVC tubes full of air on the top to keep it from sinking. This made the ROV automatically turn itself to stay upright, as the air-tubes on top would want to float up while the steel chassis tried to sink. This made the ROV far easier to control, as we could simply drive forward, steer, and go up and down without worrying about rolling around.

Vehicle Systems

The versatile claw was designed and 3d printed so that if any modifications were needed they could be performed easily. 3d printed parts are also significantly cheaper than many other machined parts. The structure of the propeller guards are 3d printed so they could be customly fit to the sides of the pump motors. A sturdy metal mesh was attached to the frame to prevent anything from touching the moving parts on the motors. Lastly, the ping pong collector utilized a non stretch net that would prevent it from entanglement and was directly attached to the top of the ROV to prevent material costs on excessive framework, and using the frame of the ROV as the frame for the net also makes assembling it easier as well as making the entire ROV less complex, making it more user friendly.

Control/Electrical system

Vehicle's Electronic Design and Cabling

To pilot our ROV we needed a control system to control each of the 4 motors individually as well as the servo motor controlling the claw. The power and ground for each motor is sent through the tether. The servo has wires for power, signal, and ground going through the tether.

To control the speed of the motors we made use of a 16-channel PWM controller. PWM modulation enables us to modulate the fraction of time that a motor is on, allowing full control over the speed. The control lines for each motor are wired through an H-bridge circuit using relays to reverse the direction current flows through the motor. This allows us to run all motors in either direction under the control of a Raspberry Pi inside the control box. The electronics are shown in figure 6.

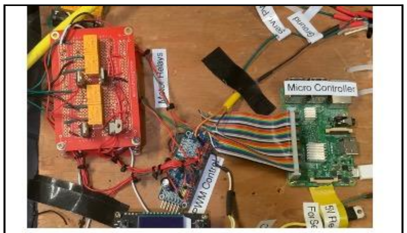


Figure 6: Custom electronics enable full control over speed and direction of thruster and claw motion

For the servo motor, its power is taken from the 12V supply, but it passes through a 5V regulator as that is the voltage required by the servo. The signal wire comes from the Raspberry Pi. However, while running the servo we noticed it jittered and would move when the motors were running even though it shouldn't. We determined that this was an issue with the ground at the servo not being the same at either end of the tether due to its long length, and this was amplified by the additional power draw from the motors. In order to solve this we added an optical isolator to the servo's wiring at the ROV end of the tether.

The choice of inexpensive electronic components for vehicular control plays a central role in keeping the overall cost of the ROV reasonable.

Control System Design

Below is the code run on the Raspberry Pi to control the motors and servo. We used the pygame library to get keyboard inputs. The middle part of the code checks the keyboard inputs and determines how much power each motor should get as a result and what position the servo should be in. The last third uses this to set the PWM controllers, relays, and the servo signal line. The code can be switched to automated mode using the “autoStraight” parameter to fly autonomously in a straight line.

```
import pygame, time
from pygame.locals import *
import RPi.GPIO as GPIO
from SunFounder_PCA9685 import PCA9685
f_s = 0
t_s = 0
u = 0
clawServoPos = 1.7
servopin = 14
relay_pin = 0
pwn_pin = 0
autoStraight = False
autoLeft = -1
autoRight = 0.7
autoUp = 1
pwm = PCA9685.PWM()
pwm.setup()
pwm.frequency = 200
pygame.init()
screen = pygame.display.set_mode((50, 50))
pygame.display.set_caption('ROV Control')
pygame.mouse.set_visible(0)
while True:
    for event in pygame.event.get():
        keys=pygame.key.get_pressed()
        if autoStraight:
            if keys[K_h]:
                autoStraight = False
            fl = autoLeft
            fr = autoRight
            u = autoUp
        else:
            fl = 0
            fr = 0
            u = 0
            if keys[K_h]:
                autoStraight = True
            if keys[K_w]:
                fl = -10
                fr = 10
            if keys[K_s]:
                fl = 10
                fr = -10
```

```
            if keys[K_a]:
                fl = fl + 5
                fr = fr + 5
            if keys[K_d]:
                fl = fl - 5
                fr = fr - 5
            if keys[K_q]:
                u = -10
            if keys[K_e]:
                u = 10

            if fl > 10:
                fl=10
            if fl < -10:
                fl=-10
            if fr > 10:
                fr=10
            if fr < -10:
                fr=-10
            fl=fl/10
            fr=fr/10
            u=u/10
            if keys[K_f]:
                clawServoMove = 0.0005
            elif keys[K_c]:
                clawServoMove = -0.0005
            else:
                clawServoMove = 0
        relay_pin = 9
        pwm_pin = 3
        if fl >= 0.0:
            pwm.write(relay_pin,0,0)
            pwm.write(pwm_pin, 0, int(4095*fl))
        else:
            pwm.write(relay_pin,0,4095)
            pwm.write(pwm_pin, 0, int(-4095*fl))
        relay_pin = 8
        pwm_pin = 0

        if fr >= 0.0:
            pwm.write(relay_pin,0,0)
            pwm.write(pwm_pin, 0, int(4095*fr))
```

```
        else:
            pwm.write(relay_pin,0,4095)
            pwm.write(pwm_pin, 0, int(-4095*fr))
        relay_pin = 13
        pwm_pin = 5

        if u >= 0.0:
            pwm.write(relay_pin,0,0)
            pwm.write(pwm_pin, 0, int(4095*u))
        else:
            pwm.write(relay_pin,0,4095)
            pwm.write(pwm_pin, 0, int(-4095*u))
        relay_pin = 12
        pwm_pin = 4

        if u >= 0.0:
            pwm.write(relay_pin,0,0)
            pwm.write(pwm_pin, 0, int(4095*u))
        else:
            pwm.write(relay_pin,0,4095)
            pwm.write(pwm_pin, 0, int(-4095*u))
    if clawServoPos < 2:
        if clawServoPos > 1.1:
            clawServoPos = clawServoPos + clawServoMove
            pwm.write(servopin,0,int(clawServoPos*1000))
        else:
            clawServoPos = 1.1005
    else:
        clawServoPos = 1.9995
pwm.write_all_value(0, 0)
```

Figure 7: SPARK developed custom code for the Raspberry Pi to control the thrusters and servo.

Tether Management

The team that deploys and docks the ROV feeds and receives excess tether when necessary to prevent the tether from entangling around any of the life and obstacles in the environment as well as the equipment used in the procedure. Additionally a tether management device (extension cord reel) is used to assist in managing the tether for the non-ROV

Figure 8: Tether management device used to minimize the risk of the non-ROV power cord tangling with itself or the ROV tether

device used to power the Seabin to minimize the risk of this separate cord tangling with either the ROV tether or itself.

Propulsion

Four thrusters were used. Two on the top to control up and down motion and two in front for moving forward and backwards, as well as turning. This provided for much more simple and reliable motion than the five motors controlling things like pitch and roll that we used for the 2019 competition. In addition, both pairs of motors were counter rotating to eliminate any unintended rotation on the ROV from the motors.

Our first generation ROV used in 2018-2019 used motors we had worked with in previous robotics competitions (not underwater) that we waterproofed ourselves by putting them in film containers and sealing them with Epoxy. The thrust provided by these motors was limited and we had significant issues with leaking in the region where the rotating shaft emerged from the canister. It was clear that the quality of the seal and maintenance required (we explored various gels at the seal) would not meet our long term needs. Therefore, while recognizing that commercially waterproofed motors were more expensive, this seemed an essential investment for the team to move forward and compete at a higher level. We selected the Johnson 28572 750GPH bilge pump motor. This motor was selected for a number of reasons. It operated on 12V, was waterproof, we were able to find commercially available motor mounts and propellers. The 3A max current draw ensured that we could easily run all four motors at max with a significant safety margin, while staying within the allowed system limits and have the necessary power budget to control additional tools and for future expansion to additional thrusters if needed. There was also significant online documentation suggesting that this type of thruster would make a good choice for our ROV.

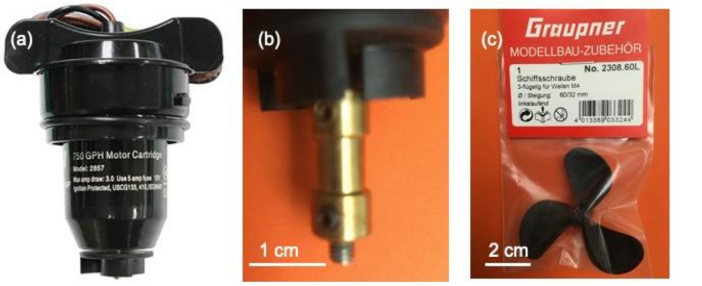


Figure 9: SPARK developed a custom thruster-propeller assembly for reliable propulsion. (a) 12V, 750GPH Johnson Bilge pump motors were used for reliable waterproof motors (b) coupling connectors enabled the connection of the propeller to the pump motor. (c) A left- and right- handed pair of propellers was used for each pair of motors (up/down and left/right)

We tested a number of propellers and methods of attachment. Ultimately we settled on the Graupner 60mm propellers shown in figure 9. These propellers are available as a matched left- and right- handed pair and we have found them to provide reliable thrust to our ROV when coupled with the Johnson bilge pump motor. To connect the propeller to the thruster we made use of rigid 3.17mmx4mm connector adapters and M4 - 12mm long corrosion-resistant stainless steel threaded rod (figure 9). Heavy Duty Loctite was used to help secure the propellers to the threaded rod after several fell off in early test runs.

Buoyancy and Ballasts

The decision to use a weldable steel frame means that the structure of our core comprises the bulk of the weight of our ROV. Balancing this requires sizeable ballasts. The required ballasts were determined by trial and error. We found that two large ballasts from 11” pieces of 2.5” diameter PVC with end caps and trapped air were sufficient to balance the weight of the frame and lead to stable operation. Later we added another smaller pair of PVC tubes to provide additional buoyancy. Adjustments were made with pieces of a pool noodle as components were added altering the balance.

The long tool used for removal of the sediment sample for task 3.1 requires its own ballasts to enable navigation and control. Segments of a pool noodle were used to make it almost neutral buoyancy. We found it helpful to have it point slightly downward since the pipe rests on the lower surface of the pool, it was therefore intentionally balanced to droop every so slightly when immersed in water.

Payload and Tools

Versatile Claw

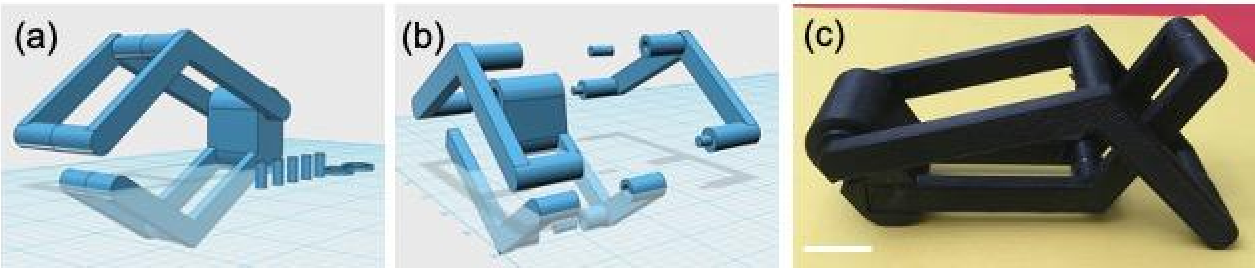


Figure 10: Second Generation SPARK claw is highly versatile and capable of performing a large variety of the challenge tasks. (a,b) Design files for claw (c) 3D printed claw. The white scale bar represents 2cm.

We saw that the majority of the tasks could be solved by the use of a claw to pick up and carry various things. Our first generation claw was intended only for quick prototyping and is described under testing and troubleshooting. The 3D model of our second generation claw design is shown in figure 10. When we 3D printed and attached it to a waterproof servo motor, it functioned fairly well and was able to pick up most things, although it had a few problems. The first problem was that it was too wide to pick up the coral because the width of the claw exceeded the gap between the two upright parts. The second problem is that sometimes it would jam while closing because the top arm of the claw would be a bit too far to the left or right and would hit the bottom arm, preventing the bottom from passing through the middle of the top arm and stopping the claw from closing fully.

Figure 11: Third Generation Claw. The white scale bar shown in the lower left represents a length of 2cm. This claw was able to perform most tasks and was used for the World Championships Qualifier. However, the connectors were flimsy and it quickly broke and was replaced with a sturdier design (fourth generation claw).

Spark's third generation claw, shown in figure 11, fixed both of these problems by reducing its width and putting a larger gap for the top arm to prevent the jamming.

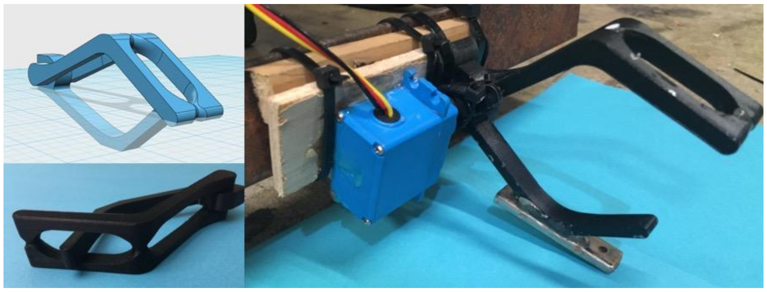


Figure 12: Fourth Generation Claw. This claw is able to perform all tasks other than those specifically identified as requiring specialized tools. The sturdier design has proved reliable in repeated testing. The neodymium magnet on the lower side of the claw is used to remove the pin and release the ghost net. It is 6cm in length and can therefore be used as a reference for scale of the image.

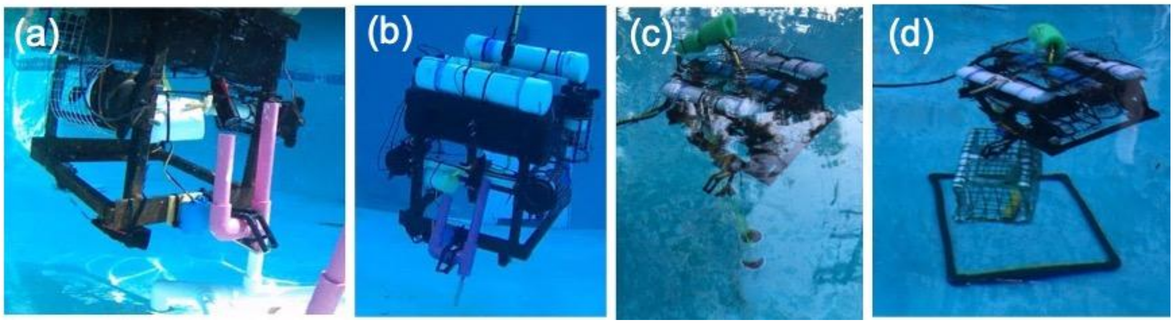


Figure 13: Our claw is highly versatile and capable of performing a large variety of the challenge tasks. Length scale can be determined from the green square for positioning the eel trap in (d) which is 45cm on each side.

However, while testing it, the cylinders connecting the left and right halves of the top arm broke. To prevent this from happening again, our final design, shown in figure 12, made those cross-connecters much more sturdy. In addition, we realized we could pull the pin out of the net by using a magnet, which we glued to the bottom of the claw. We used a 6cm neodymium rare earth magnet with a vertical breakaway force specification of 30kg. This magnet is able to easily remove and hold onto the pin from the ghost net. A final modification was made to the claw to make it easier to pick up and drop off the eel traps (figure 13, d). Specifically we realized that by angling the claw slightly downward we could accomplish this task much more effectively without impacting our success on other tasks. A downward angle was achieved with a wedge of wood between the claw/motor system and the frame of the ROV (Figure 12). Figure 13 highlights the versatility of our third generation claw which is able to accomplish the vast majority of the tasks in this challenge.

Tool for Removal of Floating Debris from the Surface

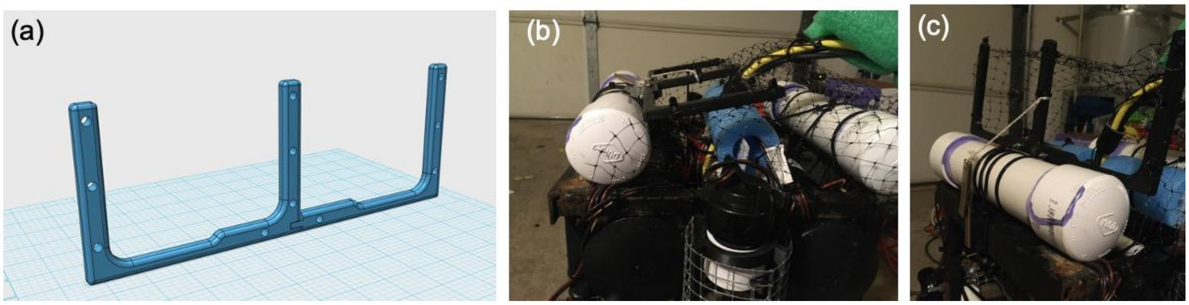


Figure 14: A custom designed net allows for efficient removal of floating debris from the surface. (a) A 3D printed component is used to provide structure to the net and permit the collection of ping pong balls from the surface. The lower beam has a width of 29cm. By collecting surface debris across the entire width of the ROV the collection efficiency is increased. (b) A hinge connection to the support structure coupled with the collapsable net enables the structure to lie flat, ensuring the vehicle complies with the <60cm dimension for maximal points (c) A magnet allows for efficient positioning of the net after measurement

The ping pong collector was innovated through multiple stages of brainstorming and prototyping. The original idea was to have a funnel that would collect the debris through a vertical funnel, then after the funnel have a system of tubes that would trap the debris in a container that would be nearly impossible to escape either under or out of water. The approach was complex, expensive, and most likely unreliable. A simpler solution was needed. The simpler solution would use a similar approach to the commercial use of a pool skimmer. The concept of a pool skimmer is to have a net that would use forward motion to trap the debris in the back of the net. The concept was applied to the top of the ROV and slightly modified to keep debris with a strong upwards float force from escaping the net while cruising underwater. The frame of the ping pong collector net can be seen on Figure 14.

The modifications applied to the net:

- Pointed roof (so debris would float to there rather than out of the net)
- Tighter net (to prevent entanglement and ensure consistency of net efficiency)
- Made net collapsible (so the dimensions of the ROV wouldn't become a problem)

Tool for extracting a sediment sample from a 10ft long pipe

Our original plan to solve this task was to deploy a second, smaller ROV with its own claw that would travel down the pipe and grab the sample, however we realized this would be very complicated as making an ROV small enough to fit inside the pipe would not be easy, considering all the motors and components it would require. We had an idea to solve this problem by making the smaller ROV with a cylinder that would barely fit inside the pipe, so it would not turn and would just need a single motor for driving forward and backwards. However, we decided it would be easier to make a long arm that could be disassembled to fit inside the size requirements, and then reassembled and attached to the ROV when we needed it. Our first prototype of this was made from PVC tubes with straight PVC connectors, however it severely limited our ROV's turning speed as the inertia of the water stuck inside the long pipe weighed it down. We then tried a pipe with a smaller diameter, however it still turned extremely slowly. Our final design was made of ½" aluminum angle. It can be reassembled by quickly bolting the parts of L beam together during the 5-minute set-up period with wing nuts used to ensure ease of assembly. It also has a tennis ball with velcro on the end to grab the sediment sample (figure 15). The pole extends 10ft 8" from the end of the ROV enabling the sediment sample to be easily collected and can be connected and disconnected from the ROV to be used exclusively for this one task.

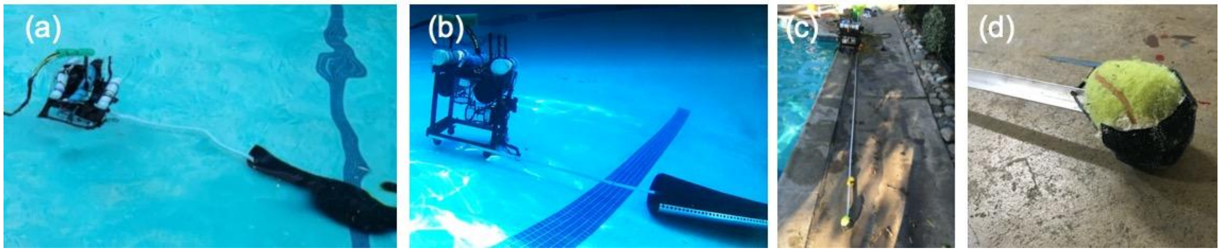


Figure 15: SPARK's ROV makes use of an extended disassemblable arm to remove the the sediment sample from the long pipe. (a) a PVC pipe was used for prototyping but the waterfilled pipe was found to have too much inertia for easy control (b) The specialized tool can be seen in action (c) The extended arm made of aluminum angle. The angle is cut in 57cm segments and quickly assembled with bolts and wingnuts allowing the components of the tool to fit within the 60cm ring and pass inspection. When assembled the arm extends 10ft8" from the edge of the ROV. (c) A tennis ball is used at the end of the extended pole - the round ball ensures the devices does not catch on the rough surface of the pipe. Industrial strength velcro is glued to the tennis ball using a combination of marine epoxy and Krazy glue. The velcro is able to easily and reliably remove the sediment sample from the pipe.

Cameras

The number and choice of cameras is an area in which our design has significantly evolved over the past two years.

Our first design in the summer of 2019 made use of two cameras. These cameras were car back-up cameras which we purchased from the SeaMate store together with a waterproofing kit. These cameras worked well for about about 9 months at which time one of the cameras failed, we believe due to waterproofing issues although the exact failure mechanism wasn't clear. The second camera failed about 6 months later. At that point we made a decision to replace the cameras with commercial waterproofed cameras, reducing points of failure. We found cameras intended for fishing that had a suitable length tether, and also included LEDs which were helpful since in the winter we often work, test and operate in the pool after dark. These cameras were also less expensive ($110) than the cameras (with waterproofing kits) that we had purchased from the Seamate store ($135). We found two different cameras to work well for our operation. The first was the "Ovetour Underater fishing camera". A waterproof camera with a 50ft tether, intended for fishing applications. This camera provides a very close, zoomed in image. This has proved extremely useful for direct visibility of our claw, and for task 2.1: Flying a transect line over a coral reef and mapping points of interest which requires a zoomed in image in order to not see the outer red pipes.

One issue that we had to address is that these cameras came with a built-in battery in the monitor that not only powered the monitor but the camera as well, something we recognized isn't permitted. We found that this was easily bypassed by opening the casing of the monitor and disconnecting the battery. We were able to quickly determine that the USB feed intended to charge the monitor and battery could be used to power the monitor and camera with the battery disconnected. We used a 12V to 5V voltage converter to power a USB hub to power our set of cameras.

In May 2021, when we were able to resume in person testing of the ROV following the ebbing of COVID-19 restrictions in our community, we quickly realized that an additional camera was needed that might provide a more zoomed out image for ease of operation. We had had sufficient success with the fishing cameras purchased previously that we looked for a similar camera with a more zoomed out image. We found the Hanrico portable underwater fishing camera perfect for our needs. Positioning one of these for navigation enabled us to get where we need to be.

We also found additional cameras with specific view angles necessary for specific tasks. Here we described the five cameras we finally settled on in our final design. Several of these cameras are only required for specific tasks. We therefore are able to operate them with the permitted 3 monitors, by switching between cameras for specific tasks.

The five cameras used in our final product are shown in figures 16 through 18 and are listed below:

1) Camera #1: Navigation - this camera provides a zoomed out view of the area in front of the ROV to locate targets and navigate and position the ROV for tasks (figure 16)

Figure 16: Three of Sparky's cameras enable navigation and manipulation of environmental objects with the primary claw. Red circle: Forward pointing camera (camera #1) provides a clear view ahead for navigation. Aqua circle: Camera #2 focuses directly on the claw to aid in grasping and releasing items. Green circle: Camera #3 also focuses on the claw but with a side view that includes the region just below the claw. The ability to view the claw from two angles aids in completion of tasks such as inserting the Seabin power connector (top right), viewed from two different angles, camera #2 (center right) and camera #3 (lower right).

2) Camera #2: Claw - this camera provides a zoomed in view of the claw and its contents. It allows us to focus what we are trying to pick up or drop off and appropriately position the ROV to do so (figure 16)
3) Camera #3: Region immediately below claw. This camera gives us a side angle view showing the claw and the region immediately below it. Before adding this claw we had particular difficulty with the task requiring picking up a piece of the coral reef. We found that if the ROV was slightly out of position it would knock the coral causing it to rotate rather than closing around it. We found it difficult to avoid this and accurately position using only cameras #1 and #2. When we added the third camera we were able to position the ROV much more accurately, picking up the coral essentially every time. The depth through stereovision provided by having two cameras focus on the same object plays a central role in the efficiency with which Sparky can pick up and manipulate objects. (figure 16)
4) Camera #4: Surface Camera: This camera is specifically for task 1.2: Removing floating debris from the surface - none of our other cameras give us a view of the surface. This camera is therefore needed to be able to find and capture the ping pong balls on the surface. We used a zoomed out camera of the same type as camera #1 - this allows these two cameras to share a monitor. (figure 17).
5) Camera #5: Camera pointing straight down: This camera is specifically for Task 2.1 Flying a transect line over a coral reef and mapping points of interest - with our other cameras that point forward it is not possible to position the camera to meet the criteria of seeing the blue rods and not the red rods. A camera of the same type used for camera #2 and camera #3 worked well as long as it was carefully positioned in the ROV. Positioning it under the ROV

required the ROV to swim relatively high to have both in view, while positioning it on either side meant the other side blocked the view of one of the blue poles. We found that by positioning it centered in the ROV, we were able to see both blue poles reliably without seeing the red poles. (figure 18)

Figure 17: Custom mounted camera for improved surface viewing. A custom 3D printed camera mount was made to mount the camera above the ROV. This camera is essential to collecting debris from the water's surface. With this mount, if the ROV is positioned as the surface for surface trash collection, the camera is above the water, providing a clear view of surface debris and avoiding a situation where the camera dips in and out of the water leading to poor optics. (a,b): design for camera mount, (c,d): mounted camera, (e): view from camera, (f) successful camera-guided collection of surface debris.

Figure 18: Downward facing camera (camera #5, green circle) provides view of appropriate regions when flying transect.

required the ROV to swim relatively high to have both in view, while positioning it on either side meant the other side blocked the view of one of the blue poles. We found that by positioning it centered in the ROV, we were able to see both blue poles reliably without seeing the red poles. (figure 18)

Key Decisions: Build vs. Buy, New vs. Used

Other than the waterproof motors, cameras, and Raspberry Pi, everything in our ROV we built, wired, and coded ourselves. We 3D printed a large number of our parts, such as the claw, camera mounts, and motor covers, as we could design them to fit our needs exactly. For the 2019 competition, we tried to waterproof our motors and cameras ourselves using Epoxy, however it proved to be very unreliable, so as part of our complete redesign we made a decision to purchase waterproof motors and cameras.

This complete redesign has been a two year effort. The extent of the makeover, including an entirely new geometry for the frame, a different type of motor, different cameras and a full redesign of the claw including a commercial waterproofed servo motor meant that no components of the 2019 ROV were reused other than the tether and some of the electronics. That said we were able to reuse our tether (both the thruster and control lines) as well as the Raspberry Pi controller which saved us som expense.

The cameras we used at $110 were much less expensive than other competing cameras we compared such as the SS-aquacam ($495). We found using five of these less expensive cameras gave us a diverse range of viewpoints to accomplish the required tasks. We would not have been able to purchase five of the more expensive cameras within our budget limitations.

Safety

Safety is of central importance to Spark's mission. As such SPARK has taken a comprehensive approach to safety, both during manufacturing and operation of the SPARKY ROV.

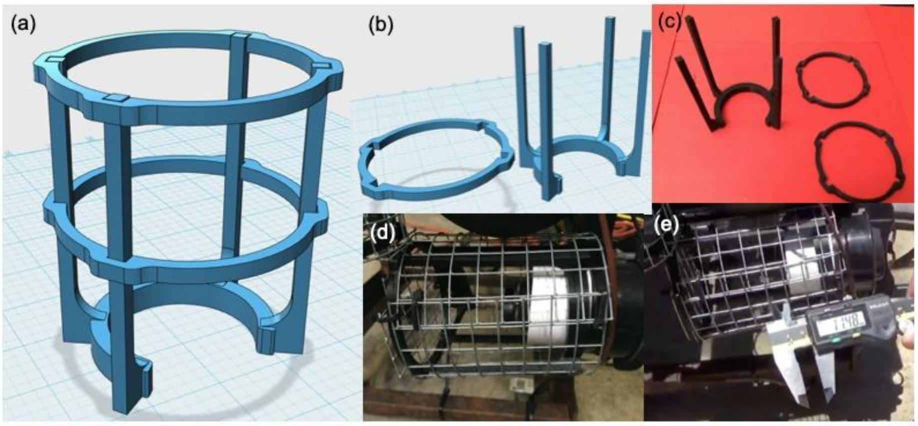


Figure 19: Team-designed thruster guards shroud all thrusters. Thruster safety guards were designed (a,b) and 3D printed (c). The guards were shrouded with a metal mesh (d) with a spacing <12mm (e), meeting the IP-20 safety standard.

Key safety features of SPARKY's design include custom 3D printed motor guards (figure 19) which were enshrouded with a metal mesh that meet IP-20 standards. This standard ensures that operator fingers and sealife (>12.5mm) will not reach and be harmed by the propeller and also protects the propellers from being damaged or trapped by marine life, pool walls, rocks, or debris.

Strain relief was used at both ends of the tether (figure 20) to ensure safe operating and long term reliability of the vehicle. Rubber is used between the strain relief and wires to minimize abrasion. SPARKY does not use fluid power.

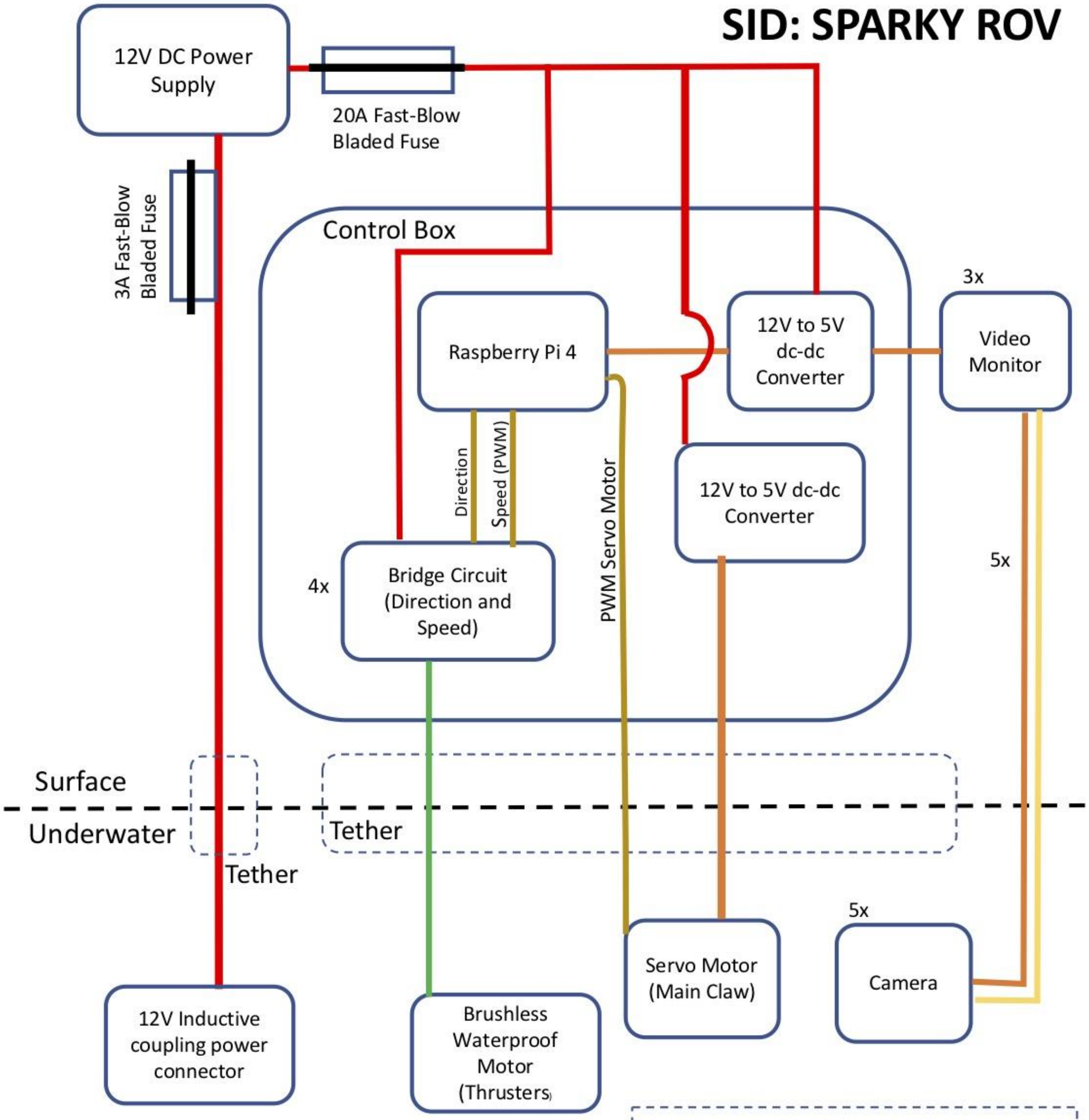
Figure 20: Appropriate strain relief at both ends of the tether protects the operation and lifetime of the ROV.

Safety: Electrical

The electrical SID is provided on page 20.

The SPARK ROV has a maximum current draw of 13.3A as indicated on the SID. A 20A fuse is therefore used within 30cm of the Anderson Powerpole connection in accordance with the specifications. Similarly, and following the specifications, a 3A fuse is used on the non-ROV device within 30cm of the connections. Both fuses include 150% overcurrent protection, a full calculation of the current draw of the devices is provided on the SID.

SID: SPARKY ROV



<u>ELEC-008R Requirements</u>

ROV

4 motors, 3A each = 12A
3 cameras, 300mA each = 0.9A
1 servo motor, 400mA = 0.4A

Total current at full load: 13.3A
Overcurrent protection: 150% * 13.3A = 19.95A
Fuse Used: 20A

Non-ROV device
1 inductive coupling power connector = 0.7 A
Overcurrent protection: 150%*0.7A = 1.05 A
Fuse Used: 3A

Legend

🟥 12V
🟧 5V
🟨 Analog Video
🟫 DIO (5V PWM)
🟩 Thruster Motor (Variable -12V to +12V dc)

Note that while the system has 5 cameras a maximum of 3 are connected at the same time

An outlet with GFCI is used at all times to power the 12V power supply when operating the ROV. The 12V power supply we use for tests is set-up with two connections to power the ROV and non-ROV device, each with a 25A fuse on the power supply side of the Anderson powerpole connector matching the set-up used for MATE tournaments. The polarity of the Anderson Powerpole connector follows standard conventions.

Electronics are housed in a control box which is kept closed during use and positioned by the control station well away from the edge of the pool. There is no exposed wiring and the control box is neatly organized.

Safety Procedures

Task	SAFETY: area of concern	SPARK Safety procedures
Manufacturing: Welding	Danger of burns and damage to eyesight	Full use of personal protective equipment required, including helmet, appropriate gloves, long pants, long sleeved shirt, and closed toed shoes. Safety training required before use along with appropriate supervision.
Manufacturing: Power tools	Danger of cuts and burns	Safety training required before use along with appropriate supervision. Buddy system: another trained user must be in the room while using power tools. Goggles required. Closed toe shoes required. No loose clothing or jewelry.
Transportation	Dropping ROV, cuts, items breaking	Smoothing down all edges, moving at a slower pace when carrying, first aid kit.
Electrical	Electrocution, short circuits, open wires, wires breaking	Using waterproof heat shrink to cover soldering, strain relief, appropriate use of fuses, use of GFI. No operation of electronics when wet.
Tether Control	Cuts, scratches, tripping	Two people on tether management, trimming corners on zip ties.
First Aid	Falling in pool, health problems	All team members were CPR certified, know how to swim, first aid kit.
Testing	Propellers cutting fingers	Propeller guards with less than 12mm per opening.

Critical Analysis

Testing and Troubleshooting

All parts of our ROV went through multiple prototypes and extensive testing. This has truly been a three year effort. The first year we focused entirely on trying different approaches to waterproofing, propulsion and balance. This gave us a set of principles we used to develop

SPARKY. Our testing protocol began with our custom design frame. Even before adding motors we pool tested and adjusted the ballasts until appropriate buoyancy was achieved. After adding motors and completing the navigation software we attached a spoon and experimented with collecting pool toys from the bottom of the pool. After several successful attempts in which objects were collected but later fell off we added a waterproof servo motor with a simple plastic element to complete a very rudimentary claw (figure 20a). This was SPARK's first proof of concept and convinced us that we were prepared to tackle the challenge. Since it could successfully pick up pool toys, we moved forward to the later claw designs and to the tasks laid out in the MATE competition RFP. Both the tools for collecting surface debris and the sediment sample also took many stages of prototyping and testing in the pool, early prototypes for these are shown in figure 20, b and c. In each case, our approach to prototyping first took advantage of readily available materials to test a proof of concept and then took into consideration additional challenge considerations (such as size limitations and reliability) for the final design.

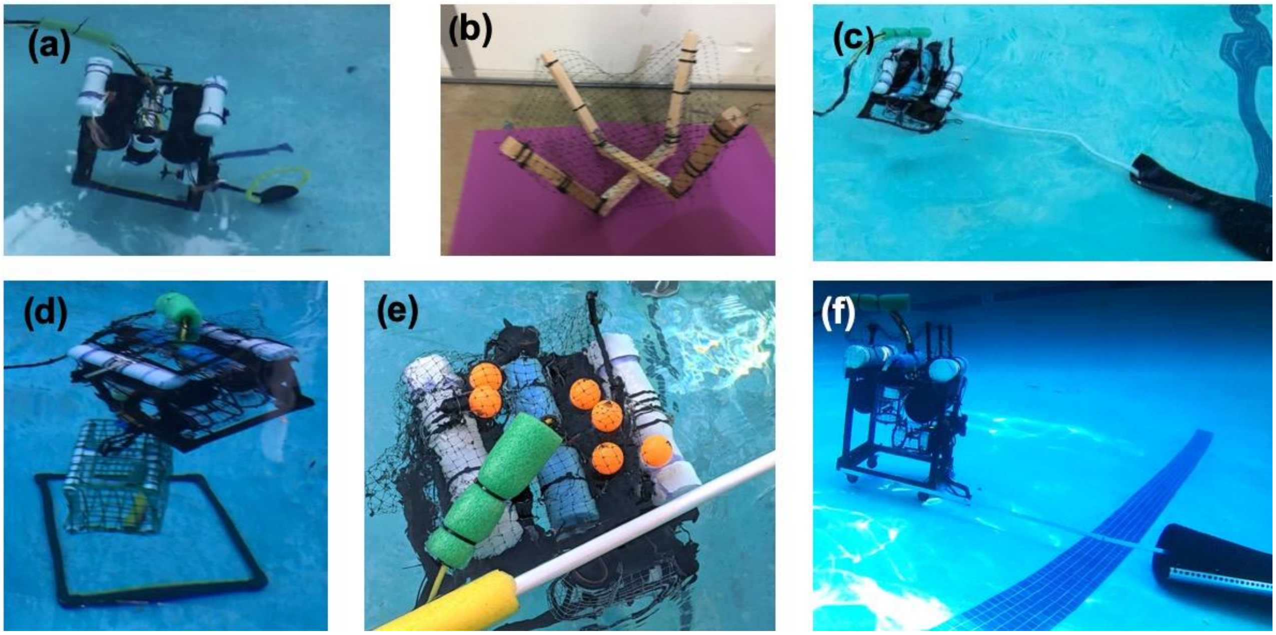
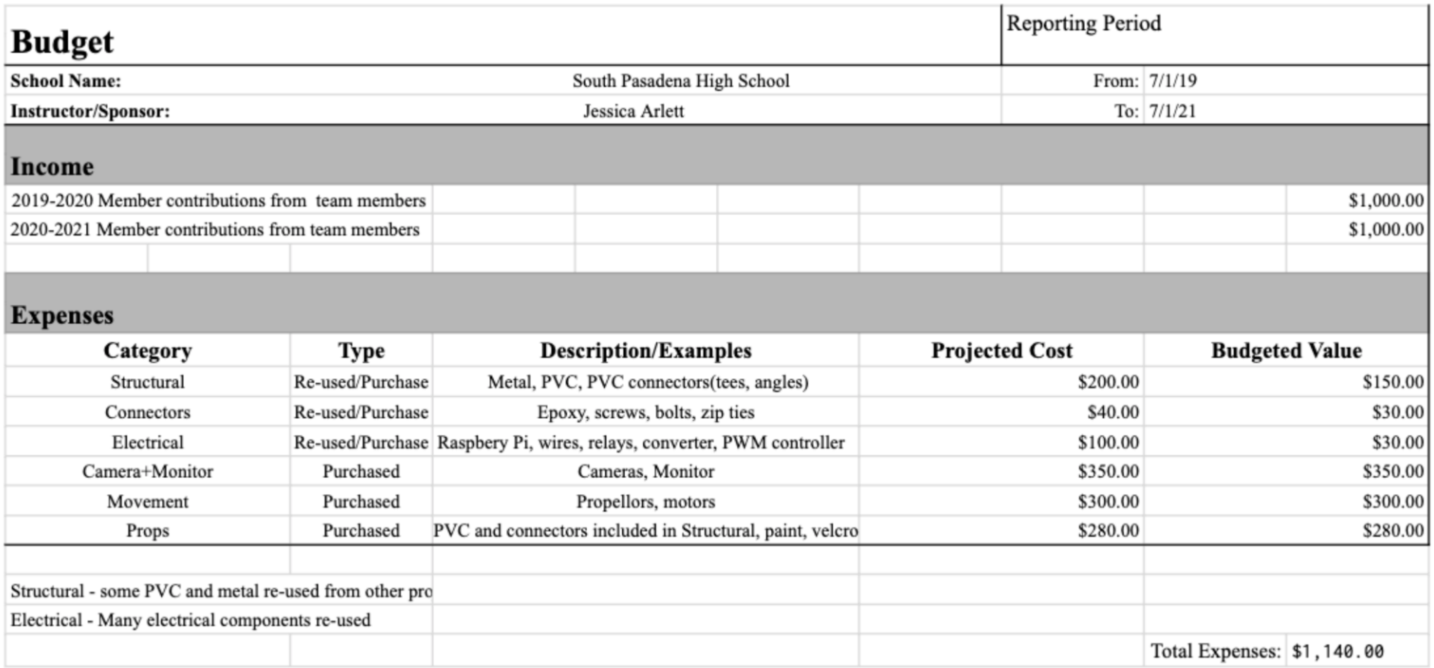


Figure 20: Prototyping is central to SPARK's approach to ROV development. Top row: early prototypes of (a) claw (b) net for collection of surface debris and (c) custom "long reach" arm for removal of sediment samples from the end of a drain pipe. Bottom row: Final versions implemented on SPARKY, reliably accomplish the tasks while meeting challenge criteria.

SPARK has a long term commitment to innovation and product development. We continue to build and improve on our designs. Features allowing for future expansion include custom in house software allowing for flexible modifications, inclusion of additional sensor/control lines on the primary tether to facilitate future expansion, and a strong, stable frame for the attachment of additional tools.

Accounting

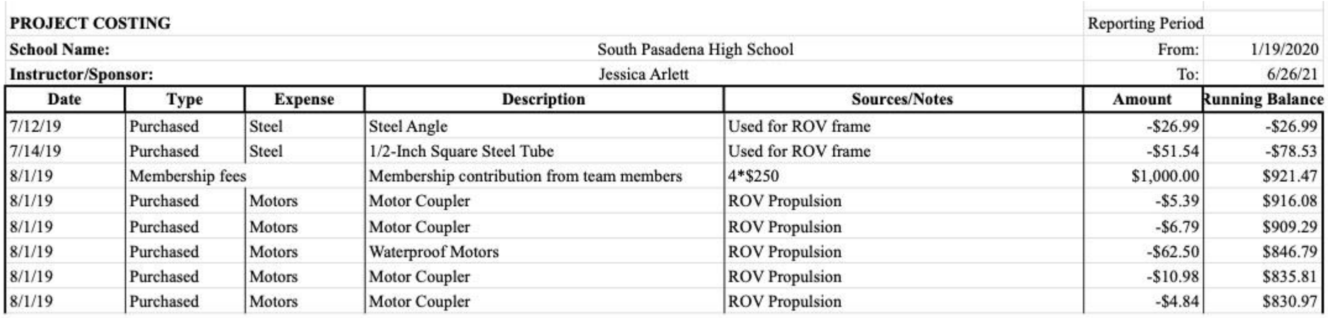
Budget



Budget			Reporting Period	
School Name:		South Pasadena High School	From:	7/1/19
Instructor/Sponsor:		Jessica Arlett	To:	7/1/21
Income				
2019-2020 Member contributions from team members				$1,000.00
2020-2021 Member contributions from team members				$1,000.00
Expenses				
Category	**Type**	**Description/Examples**	**Projected Cost**	**Budgeted Value**
Structural	Re-used/Purchase	Metal, PVC, PVC connectors(tees, angles)	$200.00	$150.00
Connectors	Re-used/Purchase	Epoxy, screws, bolts, zip ties	$40.00	$30.00
Electrical	Re-used/Purchase	Raspbery Pi, wires, relays, converter, PWM controller	$100.00	$30.00
Camera+Monitor	Purchased	Cameras, Monitor	$350.00	$350.00
Movement	Purchased	Propellors, motors	$300.00	$300.00
Props	Purchased	PVC and connectors included in Structural, paint, velcro	$280.00	$280.00
Structural - some PVC and metal re-used from other pro				
Electrical - Many electrical components re-used				
			Total Expenses:	$1,140.00

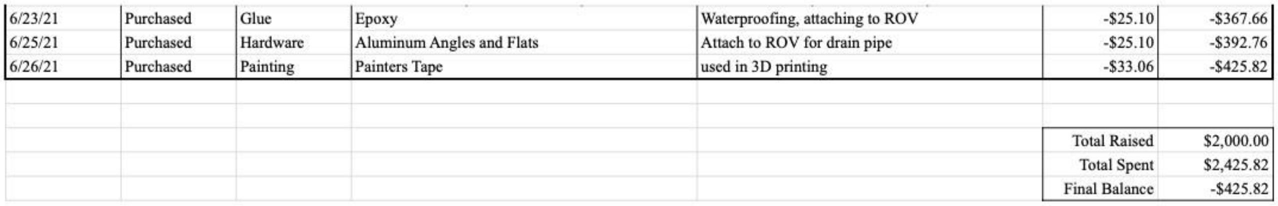
Cost Accounting

Our initial budget was intended for a 1 year challenge which turned into 2 years due to the disruption of the 2019-2020 season. During that time we did a complete overhaul of the camera system including the purchase of five new cameras. This is the primary difference between the projected expenses (laid out at the start of the 2019-2020 season) and actual expenses. However, the extension of the season to a second year also meant we had an additional year of revenue from team member dues. This ensured adequate budget for the complete overhaul of SPARKY's camera system. Due to the ongoing pandemic the team elected to compete in the telepresence category and did not incur any travel expenses.



PROJECT COSTING					Reporting Period	
School Name:			South Pasadena High School		From:	1/19/2020
Instructor/Sponsor:			Jessica Arlett		To:	6/26/21
Date	**Type**	**Expense**	**Description**	**Sources/Notes**	**Amount**	**Running Balance**
7/12/19	Purchased	Steel	Steel Angle	Used for ROV frame	-$26.99	-$26.99
7/14/19	Purchased	Steel	1/2-Inch Square Steel Tube	Used for ROV frame	-$51.54	-$78.53
8/1/19	Membership fees		Membership contribution from team members	4*$250	$1,000.00	$921.47
8/1/19	Purchased	Motors	Motor Coupler	ROV Propulsion	-$5.39	$916.08
8/1/19	Purchased	Motors	Motor Coupler	ROV Propulsion	-$6.79	$909.29
8/1/19	Purchased	Motors	Waterproof Motors	ROV Propulsion	-$62.50	$846.79
8/1/19	Purchased	Motors	Motor Coupler	ROV Propulsion	-$10.98	$835.81
8/1/19	Purchased	Motors	Motor Coupler	ROV Propulsion	-$4.84	$830.97

8/1/19	Re-used	Electrical	Extension Coord	Provide power to electronics	-$12.97	$818.00
8/1/19	Re-used	Electrical	Tether	Re-used from 2018-2019 season	-$197.35	$620.65
8/3/19	Re-used	Electrical	120v AC to 12v DC converter	Re-used from past years in other competitions	-$23.99	$596.66
8/3/19	Purchased	Electrical	Fuse		-$6.27	$590.39
8/15/19	Purchased	Electrical	12v to 5v Converter		-$12.99	$577.40
8/20/19	Re-used	Electrical	Raspberry Pi	Re-used from past years in other competitions	-$35.00	$542.40
8/20/19	Re-used	Electrical	Motor Relays	Re-used from past years in other competitions	-$27.74	$514.66
8/22/19	Purchased	Electrical	PWM Controller	Used for control of motor speed	-$16.99	$497.67
8/22/19	Purchased	Electrical	Wires		-$15.00	$482.67
8/22/19	Re-used	Wood	Wood Board	Re-used from past years in other competitions	-$1.95	$480.72
8/29/19	Purchased	Motors	Waterproof Motor for Thrusters	ROV Propulsion	-$62.68	$418.04
10/2/19	Purchased	Electrical	Waterproof Servo Motor	Used for moving the claw.	-$43.94	$374.10
10/3/19	Purchased	Motors	Motor Coupler	ROV Propulsion	-$10.99	$363.11
10/3/19	Purchased	Motors	Motor Coupler	ROV Propulsion	-$8.99	$354.12
10/3/19	Purchased	Motors	Propeller Kit	ROV Propulsion	-$41.33	$312.79
12/20/2019	Purchased	Laundry Bag	Cut for mesh	Props	-$5.46	$307.33
12/20/2019	Purchased	Net	Fishing Net	Props	-$7.65	$299.68
12/20/2019	Purchased	PVC	PVC Tees	Props	-$19.14	$280.54
1/29/20	Re-used	Bucket	5-gallon Bucket	Re-used from past years in other competitions	-$3.25	$277.29
1/29/20	Re-used	Plastic Bag	1-gallon plastic bag	Re-used from past years in other competitions	-$0.34	$276.95
1/29/20	Re-used	Rope	Bucket filled with rope	Re-used from past years in other competitions	-$10.49	$266.46
1/29/20	Purchased	Pin	Tent pin	Props	-$10.35	$256.11
1/29/20	Purchased	U-bolt	Bolt shaped like a U	Props	-$2.92	$253.19
1/29/20	Re-used	Checkers	Bag of checkers	Props	-$4.99	$248.20
7/24/20	Purchased	Camera	Camera Power Filter Kit	Camera Power	-$15.23	$232.97
7/24/20	Purchased	Camera	Fishing Camera	Camera view for controller	-$146.81	$86.16
8/1/20	Membership fees		Membership contribution from team members (4*$2		$1,000.00	$1,086.16
8/3/20	Purchased	Transportation	Waterproof Container	Control box	-$27.21	$1,058.95
8/5/20	Purchased	Electrical	Thruster Cable	Connects ROV, container, computer/monitors	-$86.45	$972.50
8/13/20	Purchased	Glue	Krazy Glue	Connecting components	-$8.05	$964.45
8/14/20	Re-used	Filament	PLA Filament	Filament for 3D printer used for various component	-$24.99	$939.46
8/18/20	Purchased	Glue	Loctite	Strong glue for connections	-$12.99	$926.47
8/29/20	Purchased	Hardware	Threaded Bulkhead	Connector	-$3.93	$922.54
8/30/20	Purchased	Motors	Motor Mount	Used to mount motors on	-$15.23	$907.31
8/30/20	Re-used	Pool	Pool Noodle	Props/ROV Buoyancy	-$3.98	$903.33
9/6/20	Purchased	Electrical	Optoisolator	Isolate the Servo Motor	-$6.86	$896.47
9/8/20	Purchased	Electrical	BNC Splitter	Cameras and control box (not used in final product)	-$5.99	$890.48
9/8/20	Purchased	Electrical	Coax Adapter	Connect wires	-$12.74	$877.74
9/8/20	Purchased	Electrical	Splitter Cable	Split wires in control box.	-$8.99	$868.75
9/8/20	Purchased	Electrical	S-Video Cord	Camera view for controller - not used in final produ	-$5.49	$863.26
9/15/20	Purchased	Pool	Dive Rings	Practice controlling ROV	-$9.84	$853.42
10/1/20	Purchased	Camera	Underwater Camera	Camera view for controller	-$110.24	$743.18
10/17/20	Purchased	Waterproofing	Sealant/Tape/Epoxy	Connecting/Waterproofing	-$45.69	$697.49
10/18/20	Purchased	Cleaning	Acetone Wipe	Cleaning workplace	-$13.90	$683.59
11/22/20	Purchased	Motors	Stepper Motor Controller (E-bay)	Explored as alternative option for controlling claw	-$16.61	$666.98
11/24/20	Purchased	Motors	Stepper Motor	Explored as alternative option for controlling claw	-$68.49	$598.49
12/14/20	Purchased	Motors	Waterproof Motor	ROV Propulsion	-$31.25	$567.24
12/15/20	Purchased	PVC	2" and 3" Diameter PVC Pipe and caps	Props	-$52.60	$514.64
12/15/20	Purchased	PVC	PVC Primer	Seal PVC Pipes to keep air inside	-$6.41	$508.23
2/18/21	Purchased	Tools	Netting	Tool for collecting surface debris	-$26.90	$481.33
3/29/21	Purchased	PVC	1/2" PVC Pipe, Tees, 45s, 90s, straights	Props	-$116.13	$392.10
3/29/2021	Re-used	Zip-ties	Box of different sized zipties.	Props	-$13.98	$378.12
3/29/2021	Purchased	Paint	Berry Pink, Black, Yellow, Red, Blue, Green Spray I	Props	-$114.99	$263.13
3/29/2021	Purchased	Tape	Pack of colored tape.	Props	-$19.83	$243.30
4/6/2021	Purchased	Plastic	Corrugated Plastic Sheets	Props	-$23.13	$220.17
4/6/2021	Purchased	PVC	PVC Reducer	Props	-$10.68	$209.49
6/1/2021	Purchased	Camera	Underwater Camera	Camera view for controller	-$99.21	$110.28
6/1/2021	Purchased	Camera	Underwater Camera	Camera view for controller	-$110.24	$0.04
6/4/21	Purchased	Connectors	Wiring and powerpole connectors	Competition criteria for connection	-$63.37	-$63.33
6/7/21	Purchased	Magnets	Magnet	Used for specific tasks, namely pin removal	-$31.09	-$94.42
6/9/21	Purchased	USB	USB Hub	Control box wires - split 5V to power Pi & cameras	-$28.65	-$123.07
6/11/21	Purchased	USB	USB Hub	Control box wires - split 5V to multiple cameras	-$13.43	-$136.50
6/11/21	Purchased	Electrical	Female Adapter	Connecting wiring	-$5.57	-$142.07
6/14/21	Purchased	Scientific	Plastic Test Tubes	Props	-$13.22	-$155.29
6/17/21	Purchased	Glue	Waterproof Epoxy	Props	-$19.83	-$175.12
6/18/21	Purchased	Sports	Ping Pong Balls	Props	-$9.05	-$184.17
6/18/21	Purchased	Glue	Glue Sticks	for adhesion for 3D printing	-$6.60	-$190.77
6/18/21	Purchased	Camera	Underwater Camera	Camera view for controller	-$121.26	-$312.03
6/19/21	Purchased	Drain	Drain Pipe	Props	-$30.53	-$342.56



6/23/21	Purchased	Glue	Epoxy	Waterproofing, attaching to ROV	-$25.10	-$367.66
6/25/21	Purchased	Hardware	Aluminum Angles and Flats	Attach to ROV for drain pipe	-$25.10	-$392.76
6/26/21	Purchased	Painting	Painters Tape	used in 3D printing	-$33.06	-$425.82
					Total Raised	$2,000.00
					Total Spent	$2,425.82
					Final Balance	-$425.82

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