DEEP OCEAN ROBOTICS

A Homeschool MATE Company
Based in Friendswood, TX, United States of America

James Blaine	Primary 3D Designer, Primary Driver, Electrical Co-Lead
Jacob Blanchard	Mechanical Lead
Lilly McDonald	Marketing/Documentation Coordinator
Nathaniel Kinonen	Shape Recognition and Sensors Lead
Olivia Freeman	Safety Coordinator, Electrical Co-Lead
Shawn Steakley	President

Mentored by:
Matthew Steakley, Corbett Freeman, and Ed Vandenberg

Technical Document 2019

Table of Contents

Abstract

Deep Ocean Robotics was founded after our President volunteered at a MATE competition and decided that he wanted to start a team; so he and a mentor developed a prototype and gathered people for one. In the end, a total of six members formed the DOR. Our plan was to take our first year as a learning experience, as none of us had ever done underwater robotics before. Our schedule was divided up into three sections: phases A, B, and C. The first prototype of our robot consisted of two bilge pumps mounted on a square of PVC. In phase A (the summer before school started) we added a third motor to move vertically and added propellers onto the waterproof bilge-pump motors. At this time all of our electronics remained onshore. In Phase B (before the RFP was released) we moved the Arduino and motor controllers into a watertight PVC tube. We machined metal strips to act as a power hub, and in the end we opted for wire nuts to join the wires in order to save space. In phase C (after the RFP was released) we added the claw, which was made of a bilge pump motor and parts machined by one of our members. We added to our composite video camera and added another tube which contained the Raspberry Pi, digital camera, and temperature sensor. We originally intended that tube to be our mini-ROV, but were restricted by time.

Figure 1.1- The DOR Members : (from Left to Right) Shawn Steakley, James Blaine, Nathaniel Kinonen, Olivia Freeman, Lilly McDonald, Jacob Blanchard

Design Rationale: Mechanical Design

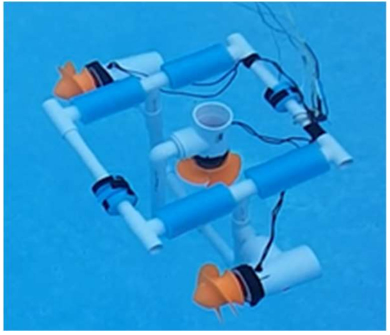
ROV Design

ROV Phases

Our company began the season with a simple, small frame and all electronics on land. After several changes and decisions, the EHT was constructed and the electronics were secured on the robot. With the addition of the EHT, the robot's structure was rearranged, producing the second phase of ROV changes.

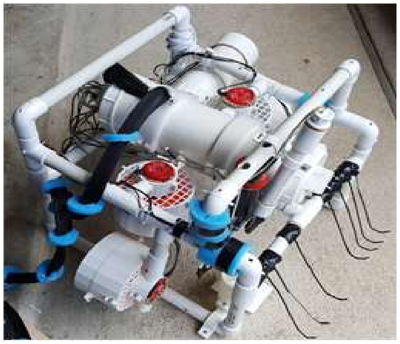
The second phase, made up of the EHT, motors, and a cradle-like frame, provided the foundation for our current robot. After the release of the product demonstration tasks, modifications were made as to best fit our purposes. The final result of these modifications was the third phase, our current ROV.

2.1- Original ROV Shape



2.2- The Second Phase

2.3- The Final Robot



Frame Design

Structured around simplicity and cost effectiveness, we constructed a simple rectangular frame made out of 3/4" PVC pipe. We decided to use PVC because it is easy to assemble—as our ideas for our ROV evolves, our frame would need to as well. Another aspect to our choice of PVC is because the sizes of the tubes are common and consistent, and we have access to 3D modelling software and 3D printers. Thus, any custom attachments we would need for propellers or design considerations could be easily designed other to be compatible with the PVC pipes we are using.

The frame is structured in order to be compatible with our electronics housing tube, or EHT. The EHT sits on the middle strip of the frame and is mostly contained within the frame. The EHT is secured to the frame using 3D printed clamps sized to fit inside 3/4" PVC joints and to clamp around the housing tube. One of these clamps was also designed to have a smaller clamp on the upper side of it for the tether to be routed through, offering strain relief on the tether and routing the tether upwards to prevent the tether from interfering with the maneuverability of the ROV.

As we improved our ROV, we were able to condense the electronics inside the EHT, shortening the board they were mounted on. This allowed us to also shorten the both the EHT and the entire frame, offering the ROV more maneuverability.

Electronics Housing Tube Design

Electronics Housing Tube design: We tested several different forms of electronics housing before deciding to use the current design. Our primary focus for the housing was verifying that it was consistently waterproof at pressure, something that our first several designs failed at. Eventually we decided to use a tube of 4" PVC pipe. The caps on either end could be removed to access the inside, where our electronics were mounted on a wooden board. The reason we chose this design is because it is very easy to effectively waterproof the pipe and PVC pipe is very cost-effective.

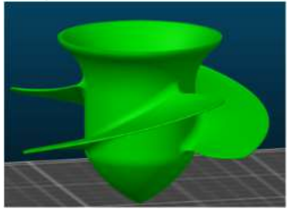
Motors

The motors are mounted onto the PVC frame with PLA 3D-printed adapters. These adapters partly enclose the motor in plastic and have plates that interface with our propeller shrouds. The motors themselves are repurposed bilge pumps. We chose these as our motors primarily because they are already waterproof, so we would not have to spend time trying to effectively waterproof generic motors.

Propellers

Our propellers are 3D printed out of ABS plastic. They are designed to fit over our motor housings (metal cases that attach to the motors' drive shafts). Because we as a team have no previous experience with propeller design, we went through a lot of trial and error in the design of the propeller and the size/pitch/etc. of the blades. Eventually, we settled on the current design because it gave the most thrust for efficiency of the designs we tested.

Figure 2.4- Propeller



Control Box

For our on-shore control box, we repurposed the outdoor electronics box we had originally tried to use as our underwater electronics housing. We built a wooden mount on the inside of the box for our control joysticks and sliders to attach to, with a hole in the mount through which wires are routed. Beneath the wooden mount, all of the control/power wires are safely contained. The tether wires that connect to the controls are routed through holes we drilled in the side of the box and are secured using conduit wire. All of the wires from the tether go through these clamps so they have strain relief.

Figure 2.5- Control Box

Claw/Hooks

Our ROV employs a custom made claw grabber system that functions using an additional bilge pump motor. The claw is designed to be used for both grabbing any objects that a simple hook could not hold as well as to operate a mechanism to release both the trout and rocks in the product demonstration. Several hooks made of coat hangers are mounted on the front of the ROV. We chose coat hangers as our material because they are cheap, easy to manipulate into the optimal shape, and are strong enough to pick up most of the objects in the product demonstration.

Build vs. Buy

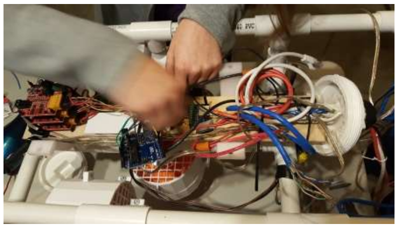
Frame

Build: PVC is very easy to work with in constructing a simple frame, so we decided it would be best to use it and make our own frame.

EHT

Build: We decided to try to make our Electronics Housing Tube ourselves; we knew we could effectively waterproof PVC, so we waterproofed a large tube for all of our electronics. This way, we would not have to spend much money on acquiring an EHT.

Figure 2. 6- Working on the EHT



Propellers

Build: We decided to build our propellers because we needed a very specific size and shape in order for it to be compatible with our motors, and we had access to 3D printers and modelling software.

Control Box

Build: We used an outdoor weatherproof electronics box as container; we built a mount on the inside of the box for controllers, drilled holes for them and for wiring to enter (and exit) the box; and installed clamps in the wire holes so the wires could be clamped down for strain relief.

Cameras

For our two primary cameras, we decided to buy inexpensive car backup cameras and build waterproof housings out of PVC pipe. We needed to have additional electronics kept with our third camera that has more utility (screenshotting, identifying shapes, etc.), so we used a slightly larger PVC tube and mounted the electronics on a wooden board, much like we did in our EHT.

Claw/Hooks

Build: A member of our team had the resources necessary to build a functioning claw, so we decided it would be best to make one and use another bilge pump motor to operate it.

New vs. Reused

As this is our company’s first season, we had nothing to reuse.

Electrical Documentation

Motors

The thrusters of the ROV are controlled by two joysticks and a slider in the onshore control box. The two joysticks control the left and right motors while the slider controls both vertical motors. We decided to use two vertical motors to increase our speed and power while ascending and descending in the water, which is necessary when carrying objects such as the screen for the trash rack. The slider allows the pilot to set the thrust to a desired point without needing a constant and steady hand, freeing up the pilot to maneuver and operate the claw. The analogue signal is sent from the joysticks and to the Electronics Housing Tube (EHT) on the ROV. In the EHT an Arduino translates the analogue signal and passes the "message" to the motor controller via a Pulse Wave Modulator (PWM). The PWM creates an effect similar to changing the voltage but does so by releasing energy at set intervals. The modulating factor is how long it releases energy during these intervals, ranging from the interval to no energy released. Aside from the PWM wire. The motor controller then dictates the flow of energy to the motors, which are two 500 gallon/hour (gph) motors for horizontal movement and two 1100 gph motors for vertical movement.

Claw

The claw on the ROV is operated by a third joystick in the onshore control box. Otherwise, the motor for the claw is operated the same as the thrusters. Refer to the mechanical section for more detail on the claw.

Cameras

Our ROV contains three backup cameras: one facing forward, a second facing the claw, and a third on the right side. Each camera is housed inside a PVC tube with one end sealed similarly to the electronics housing tube, a screw cap sealed with epoxy, but the other end terminates with a clear acrylic pane. These panes were measured and cut to fit each tube and are held in place and sealed by PVC glue. The RCA cables connect to the fore and aft cameras while the side camera, housed with the Raspberry Pi, sends its information through the ethernet cable. The first and second cameras send composite video, an analogue signal, with no drastic lag. However, the third camera runs the video through the RaspberryPi's program before sending it to the surface, creating a notable lag. This issue was solved by creating a feature in the code to allow the RaspberryPi operator to replay the video if the ROV already passed a point of interest. The Power to the cameras is routed off the main power cable. All wire connections on the ROV are first soldered, then sealed in epoxy and heat-shrink, ensuring a solid connection and preventing any exposed connections. The front camera allows us to monitor the claw, dropper, and rake; the rear camera gives us a clear view of the tether and more awareness when reversing; and the side camera allows us to

Figure 2. 7- Full ROV Setup

come alongside an object to observe it, rather than running straight into it. The side camera in particular is planned to be used while inspecting the foundation of the dam and, when it is adjusted to face downwards, to make use of the image recognition software to examine the benthic species under the rock.

Tether

The tether consists of two 10 AWG cables for power and ground, five communication cables, three RCA cables for video, and one ethernet cable for the Raspberry Pi. Each related group of wires is tied together at regular intervals to keep them orderly, and all wires are wrapped in a nylon shroud to prevent tangling. Over the course of testing, we discovered that our previous cables created too stiff of a tether, making maneuvering the ROV difficult. To solve this, we perused a variety of cables in search of something more flexible, finally settling on our current wires which contain more strands with a smaller diameter.

By housing electronics in the ROV we: reduced the size of the tether, increased the power of the motors, and decreased the potential for mixed signals caused by unshielded wires in close proximity over a long distance. Running wires for power and information from shore to each motor would result in a tether that restricts the mobility of the ROV, and the length of the tether would also result in noticeable drops in voltage, which may prevent any actions underwater. By placing the Arduino and motor controller inside the ROV, all of these issues are avoided.

The rear end cap of the electronics housing tube links the power and control wires from shore to the contents of the tube. The cap screws on and off to allow easy access to the contents and contains a seal that the crew checks before and after placing the ROV in the water. The entry for the wires required an orifice to thread the cables, but also a waterproof seal. To accomplish this, epoxy was poured in and around the wires, once inserted, and held in place by a mold to fully seal the end cap.

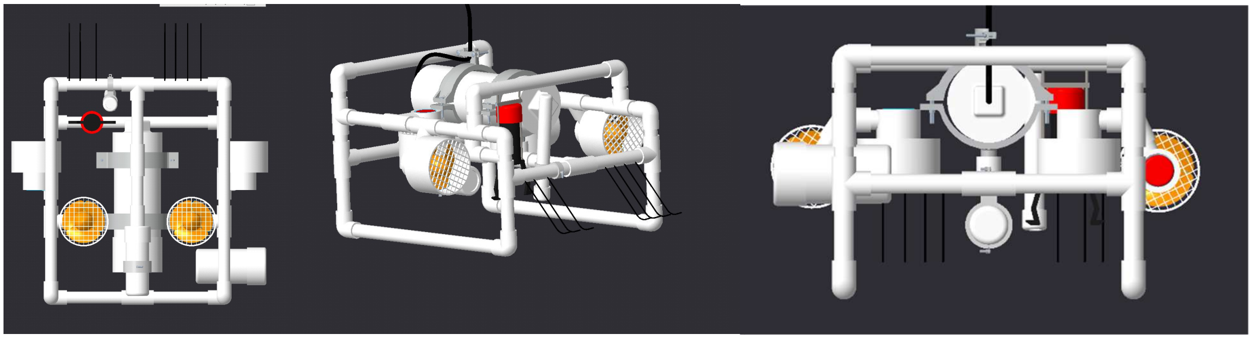


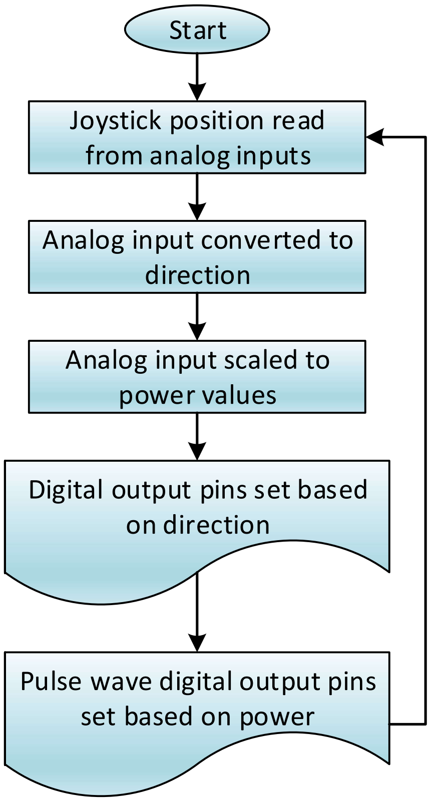
Figure 2.9- 3D Renderings of "For Pete's Sake"

Software

Our motors are controlled via an Arduino, which converts the joystick inputs to analog signals for an on-board motor controller. The program on the Arduino was made from scratch, which allowed us to fine-tune the curve functions that map the joystick positions to power settings for the motors.

The side camera and temperature sensor on the ROV are connected to a Raspberry Pi, from which they send their data through a Transmission Control Protocol (TCP) socket to the on-shore laptop via a custom Python script. From there, we can view the temperature fluctuations, take snapshots, and run image recognition with the help of another script. All of this is accomplished through the versatile Pygame library, which enables us to grab the image from the camera and receive, display, and overlay text on it from the laptop.

Figure 2.10 Arduino Motor Control



The image recognition is done using OpenCV functions grabContours and approxPolyDP, which get closed curves from a greyscaled, blurred, thresholded version of the image, then approximate the curve to get a shape. For the International Competition we added the ability to replay recorded frames to find the best frame to use for image recognition. One of the hardest challenges we faced during the programming was integrating the OpenCV image recognition with the Pygame image data we received. The solution we chose saves the image as a file, opens it in OpenCV and detects the shapes, converts the color data using cvtColor, rotates the color data into a Pygame format, then copies the result back into a Pygame image. The end result is a live temperature overlaying our camera feed.

The diagrams on the follow page provide flowchart for the programs on the Raspberry PI for getting the images from the camera and the temperature and the program on the laptop for displaying the temperature, viewing the video, replaying video, measuring the crack and doing image recognition.

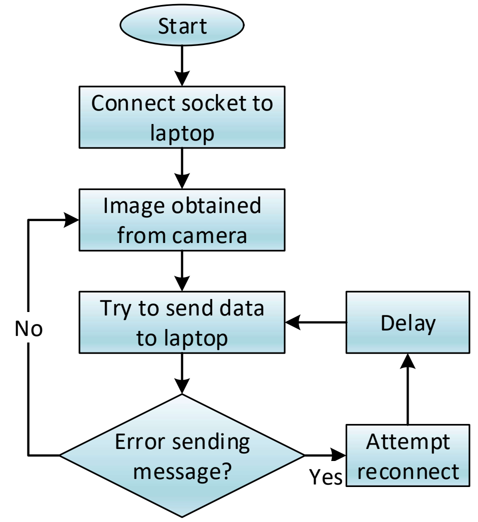


Figure 2.11- Image on the Raspberry PI

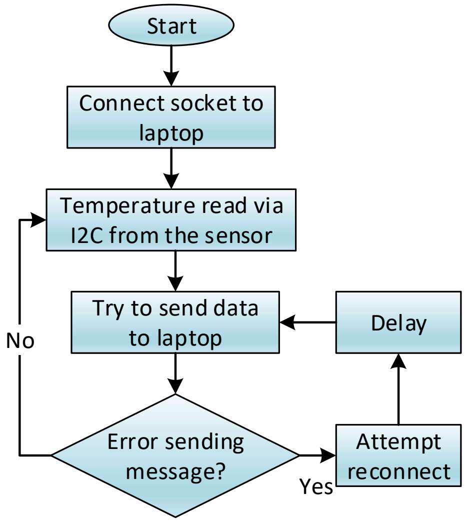


Figure 2.12- Temperature on the Raspberry Pi

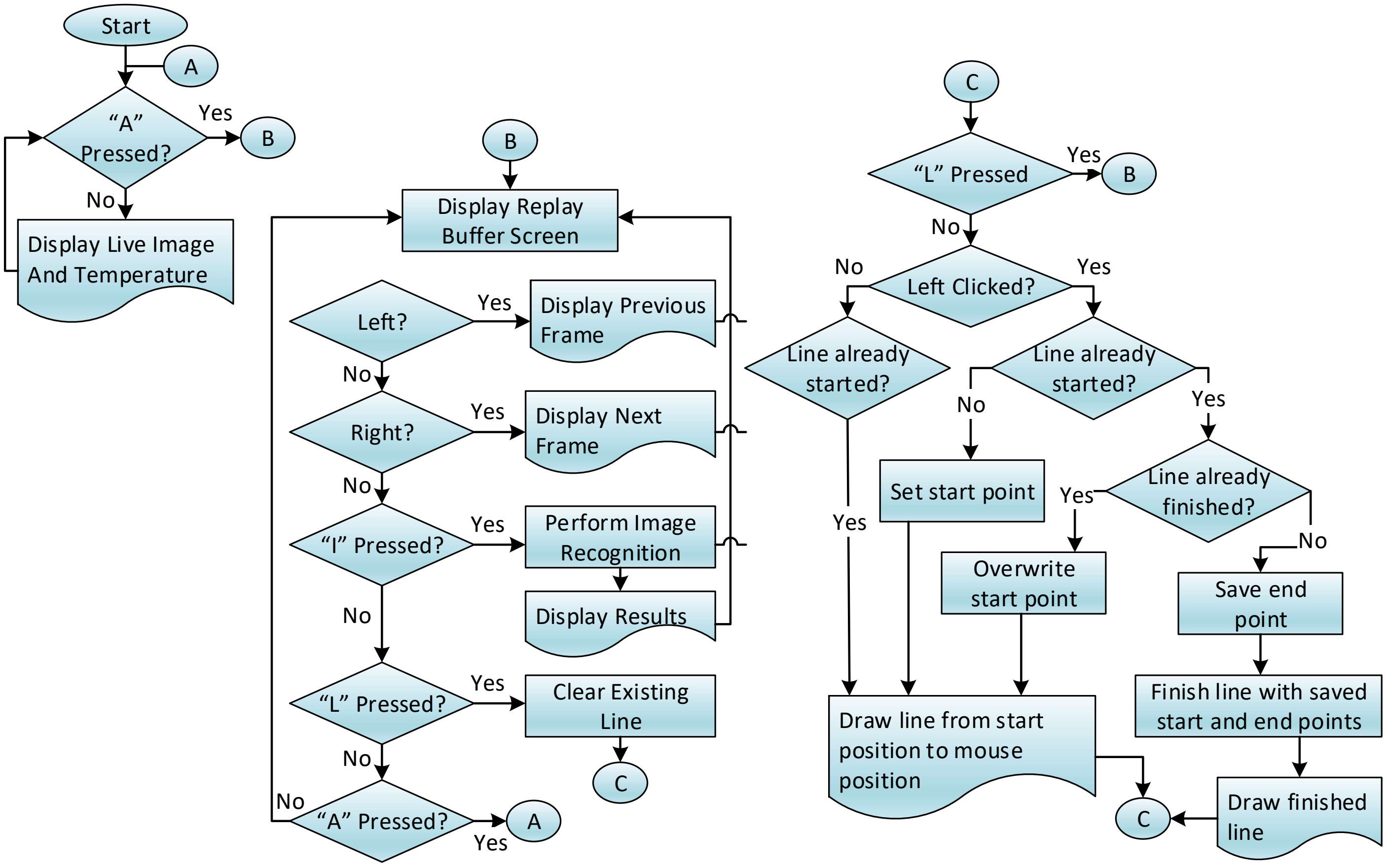


Figure 2.13- Display Module on Laptop

Image Recognition Documenation

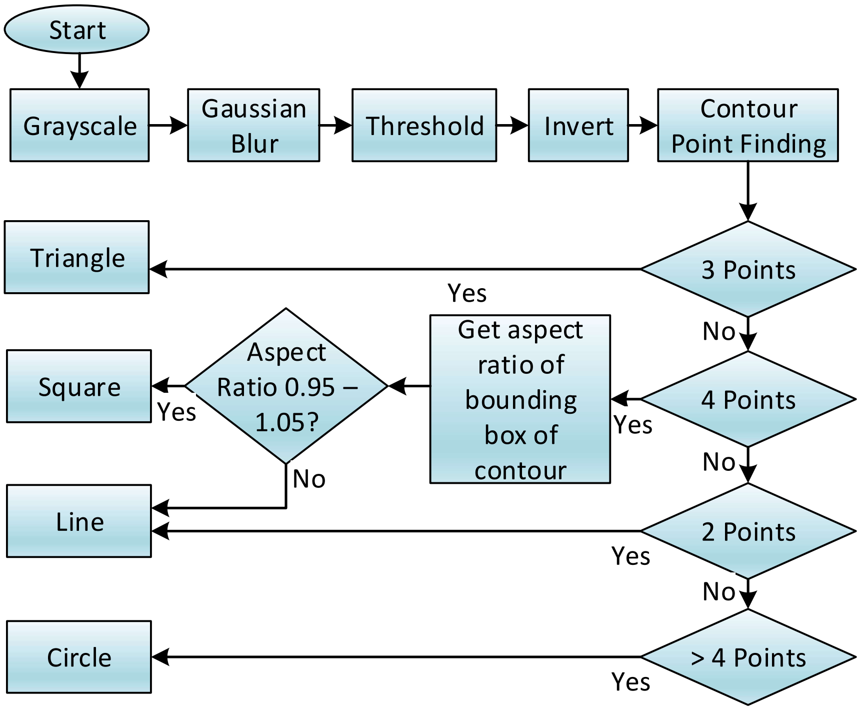
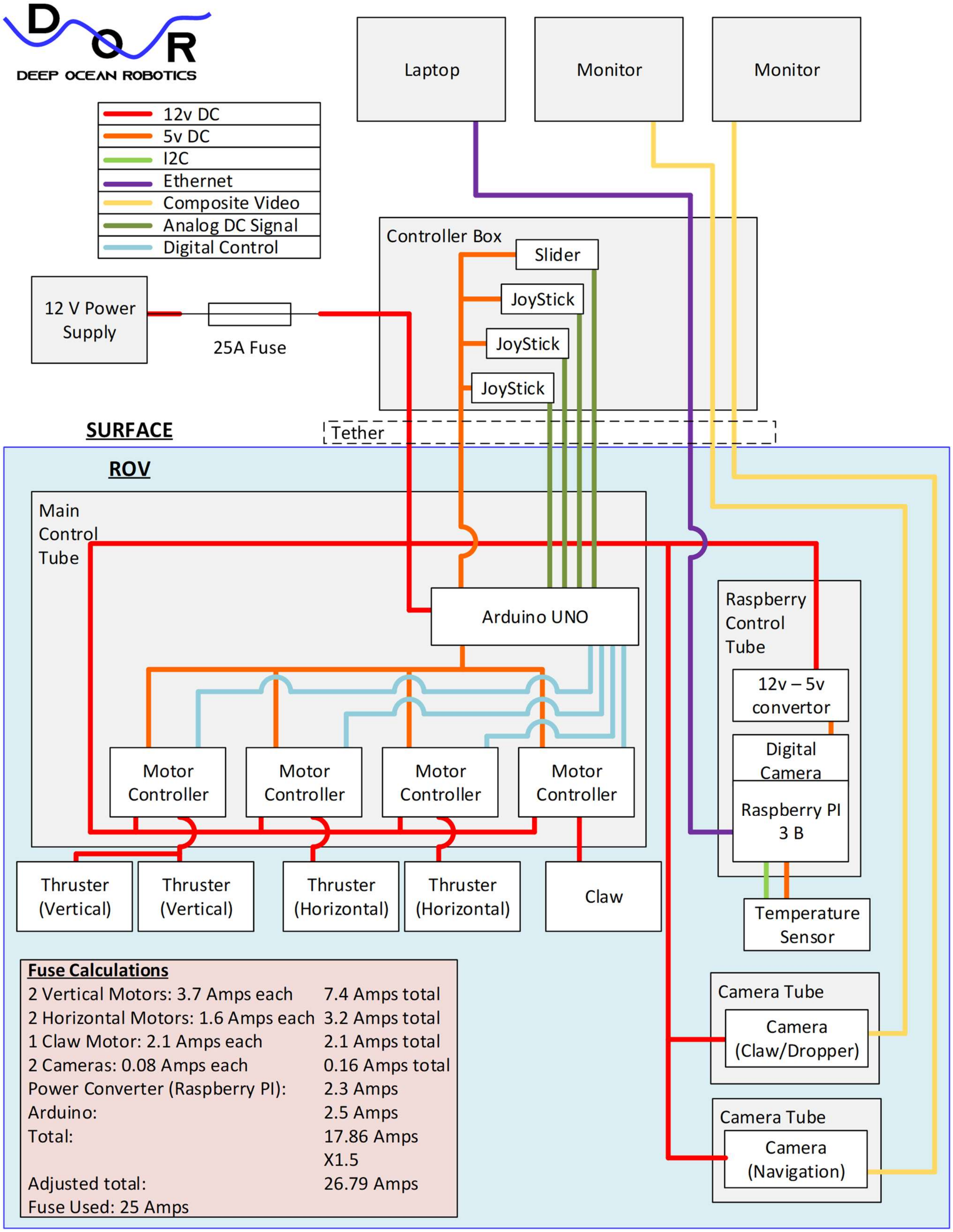


Figure 2.14 Image Recognition Diagram

Once the image is selected the following steps perform the image recognition:

- **Greyscale** applies a threshold to the image to discard all white intensity levels over or under the given range and converts the image to black and white.
- **Gaussian Blur** blurs the image using a 5x5 filter to make shape detection more accurate.
- **Threshold Discards** all intensity data outside the set range.
- **Invert** inverts the black and white values using a bitwise not filter. This is the equivalent of setting each pixel value to 255-current pixel value, assuming 255 is the maximum intensity of a pixel.
- **Contour Point Finding** represents all of the code required to iterate over each contour and save the necessary values for shape detection (get the points).
- **Checking** for the number of points is a combination of an if statement and some contour functions from OpenCV.
- **Get Aspect Ratio** is done by getting the bounding rectangle of the contour using an OpenCV function and computing the aspect ratio from that.
- **Aspect Ratio 0.95 – 1.05** Determine if 4 points is square or rectangle/line.
- **Triangle, Line, Circle, and Rectangle** represent the code used to add one to the number of triangles, lines, circles, and rectangles respectively.

System Interconnection Diagram (SID)



Fuse Calculations

2 Vertical Motors: 3.7 Amps each	7.4 Amps total
2 Horizontal Motors: 1.6 Amps each	3.2 Amps total
1 Claw Motor: 2.1 Amps each	2.1 Amps total
2 Cameras: 0.08 Amps each	0.16 Amps total
Power Converter (Raspberry PI):	2.3 Amps
Arduino:	2.5 Amps
Total:	17.86 Amps
	X1.5
Adjusted total:	26.79 Amps
Fuse Used: 25 Amps	

Critical Analysis: Testing

Method for Testing Complete Vehicle

When testing our ROV, our team follows a specific procedure.

1. **Gathering Necessary Equipment**

   This involves gathering everything necessary for piloting and testing the ROV. This includes the monitors for the ROV cameras, the product demonstration props we use for testing, the ROV itself, and other such equipment.

2. **Carrying Equipment to Testing Area**

   After gathering all the equipment, we carry it to the testing area.

3. **Setting Up and Enabling Electronics**

   The ROV's onshore electronics are set up; this includes arranging and plugging in the monitors, connecting the power supply to the ROV, etc. Once this is complete, we switch on the power to verify that everything is working.

4. **Placing the ROV in the Water**

   If the electronics are working as intended, we then set the ROV in the water to begin testing. If the electronics are malfunctioning, we attempt to troubleshoot and solve the issue.

5. **Arranging Demonstration Props**

   Our replica props of items in the product demonstration are placed around the testing area to serve as objectives for the testing.

6. **Beginning Testing**

   Once the demonstration props are in place, our pilot begins the test and attempts to complete the mock challenges around the pool.

7. **Returning the ROV**

   Once the testing is complete, the pilot maneuvers the ROV back to the edge of the pool, where the power is cut before we remove the ROV from the water.

8. **Packing Up**

   At this time, we once again gather our equipment and return it to the working area.

9. **Considering Improvements**

   The final step in our procedure is considering as a team any improvements or changes we should make to the ROV.

Troubleshooting Strategies

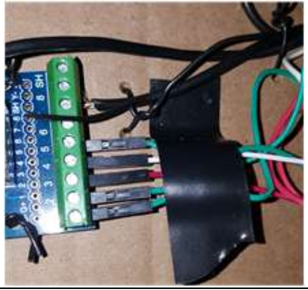
Throughout the course of the year, our team has experienced a lot of issues with our ROV. While it could be frustrating, it also provided valuable experience with troubleshooting issues.

The first and most important step we found for troubleshooting is to identify the exact problem. This is done by evaluating all the possible sources of the issue and testing each of them to find which one is causing the issue. The method for this varies between each situation, but in cases of seemingly bad wiring it often involves tracing the trouble-wire along its path and searching for loose or faulty wiring.

The next step is to find a solution. In some cases, the solution is as easy as rewiring something or simply reconnecting a wire, but on occasion the solution is significantly less clear and requires more thought. In those cases, we as a team would discuss possible solutions and would decide on what we thought the best solution would be. After this decision, we would employ the solution and see if it fixed the problem. If it did, we continued to work on the ROV, but if not, we tried the next best solution, and so on.

By troubleshooting in this way, we were able to effectively both identify and eliminate issues and were also able to do so as a team.

Figure 3.1- Wiring Prototype



Prototyping and Testing

Our first step when testing a prototype part on our ROV is to integrate it onto the ROV. In very early stages, this often involved utilizing tape to secure the part to the frame for initial testing, though our methods of securing these parts did improve. Most importantly, we want to make sure the part is where we ultimately want it to be so that the testing phase can be more effective. Also, this will let us know if we want the part to be moved before we permanently integrate it.

After temporarily integrating the prototype onto the frame of the ROV, we test the part on land before moving to the testing pool. We do this to ensure that our wiring or mounting is not faulty and to make sure that the part is working as intended. If the on-shore test is successful, we gather our equipment and move to the testing area. Once the ROV is in the water, we test the part again initially to verify that it is working, and then begin whatever task we intend for the part to do.

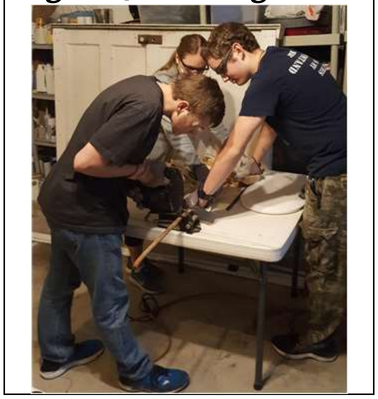
Once the testing phase is complete, we discuss as a group what could be done to improve the part. We make any improvements we decide on and then proceed to more effectively mount the part onto the ROV.

By employing this method, we are able to effectively test and improve additions to our ROV.

Challenges/Lessons Learned

This season, we encountered quite a few challenges in building and testing our ROV. For a while, two of our camera cases were not fully waterproof, and took in water when we would practice. We traced this problem to the sealant we had been using, and so we looked around a bit more and found another sealant that lent itself more to our purpose. After drying out and resealing the cameras with the new adhesive, the problem was solved and the cases no longer leaked in the pool. Another challenge was securing the neutral buoyancy of For Pete's Sake. When adding or repositioning the cameras, our robot's neutral buoyancy would be greatly affected, even to the point of practically turning over in the water. To fix this, we cut small rods of rebar at different lengths and placed them inside the PVC frame to level out the robot. If a side sank too much, we would secure sections of closed cell polyethylene foam to the frame until neutral buoyancy was restored. The most recent challenge was a leak in our Raspberry Pi case. During a test run in the pool, a team member noticed that the lens had water on the inside of it, and after further investigation, we found that a wire had been cut and left unsealed. The water coming in through this wire could have damaged the Raspberry Pi and the camera within the case. However, the problem was found and the wire sealed before anything was affected.

Figure 4.1- Cutting Rebar

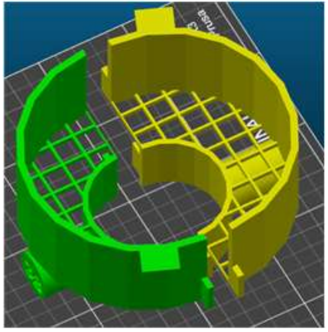


Future Improvements

Looking back at this season, we realize that we have learned much, and are forming plans for the future based on those lessons. Thanks to those lessons, we have been enabled to enter next season with a more determined and realistic budget. This will help to decrease confusion between members and will act as a guideline for decision-making. We also plan on experimenting more with neutral buoyancy so the amount of adjustments needed after modifications will be minimized. We will continue to learn and improve our robot as our tests require.

Safety

Figure 6.1- Motor Shrouds



During testing and operation of the ROV there are many steps that can be dangerous, but we have taken steps to reduce or eliminate these risks. During testing and operation, the major risks are tripping and/or falling into pool, hand or foot injury, shock hazard, and neck injury and/or hair damage. To reduce tripping, we make sure all cords or wires are visible, and if they are being carried, cables are never dragged on the ground. In case of an accident and someone falls into the pool no one ever goes to the pool alone and there are rescue implements accessible. To reduce hand or foot injury we have two or more people carry the ROV, round out all sharp edges, and equipped the motors with shrouds. To eliminate shock hazards, we sealed all wire connections inside of control tube. To keep long hair from getting wrapped in motors or stepped on, causing neck strain or injury, we make sure it is always tied back.

During construction and maintenance, risks include tripping, hand or foot injury, eye damage or fume inhalation, neck injury and/or hair damage, shock hazards, and electronics damage. To minimize tripping hazards, we keep cords out of walking space and pick up any fallen or dropped objects when we see them. To reduce hand or foot injury we make sure everyone wears gloves when handling sharp or hot objects, and when using glue; we also stress that everyone wears close-toed shoes to every meeting. To lessen the risk of eye damage we make sure that everyone wears safety glasses if within the reach of debris. To protect against fume inhalation, we use glue and\or paint outside, and to further protect we do all construction/ maintenance in an open garage with fans. To eliminate risk of long hair getting stuck in power tools or glue, long hair is always tied back. To prevent electric shock, we make sure that everyone is clear before we turn the power on; we also turn the power off if anyone needs to work on the electronics. To protect against damage to the electronics we installed a fuse in case of a problem. We have summarized these risk prevention steps on Job Safety Analysis (JSA) forms in the appendix, categorizing each into these two groups, operation/testing and construction/maintenance.

Finances

Budget

This being our first year, we had no idea how much this project would cost. Our mentor compiled a general list of things we expected to need during the year; and he and the president found pricing for the items, mostly through Amazon. After the list was finished, it was presented to the parents of the eight potential members.

Item	**Unit Cost**	**Quantity**	**Extended with tax**
Raspberry PI 3B+	$ 55.00	1	$ 59.40
Raspberry PI Camera	$ 30.00	1	$ 32.40
3 MD10C Motor Controllers	$ 17.80	3	$ 57.67
Ethernet cable (50ft)	$ 12.99	2	$ 28.06
HDMI Cable (50ft)	$ 30.00	1	$ 32.40
Sliders	$ 13.00	4	$ 56.16
Ethernet Breakout	$ 6.00	2	$ 12.96
Composite Video Cable	$ 20.00	2	$ 43.20
12v - 5v Convertor	$ 10.00	2	$ 21.60
Composite Video Camera	$ 50.00	2	$ 108.00
PVC	$ 75.00	1	$ 81.00
Marine Epoxy	$ 10.00	1	$ 10.80
Entry Fee	$ 200.00	1	$ 200.00
Shirts	$ 20.00	10	$ 216.00
USB Camera	$ -	1	$ -
Arduino Uno	$ -	1	$ -
Soldering Kit	$ 60.00	1	$ 64.80
Misc Parts, spares, replacements	$ 175.00	1	$ 175.00
Total			**$ 1,199.45**
Initial Team Fee	**$ 150.00**	**8**	**$ 1,200.00**

Actual Cost

Below is the summary of the cost. We exceeded the original budget by about $808. The main difference between the estimate and the actual cost was the equipment, such as the power supply, unused motors, and tools. In going to internationals, we got a second set of shirts, and due to a team member making them, we totaled two sets for the expected cost of one.

Cost Summary	**$ 2007.99**
ROV Build	$ 845.37
PVC –Consumed, Unused, Props	$ 112.35
Supplies (Tape, Clamps, Wire, Electrical, Solder)	$ 74.97
Equipment	$ 457.76
Shirts	$ 217.54
MATE Entry Fees	$ 300.00

Details of the cost summarized above are shown in the Appendix.

On the next page is a summary of the income. Two of the original company members did not continue with us for the season, so that set us back $300 from the original estimate. Since our team is not funded by a school, members donated additional funds throughout the year to make up the difference. UTSI International donated the cost of the shirts in exchange for advertising their company on the back. The grabber was built and payed for by a member using their family's machine shop. One of the president's robotics laptops was used.

Income

Income		**$ 2007.99**
Company Dues	6 @ $150	$ 900.00
Member Donation	Cash	$ 890.45
UTSI International - Shirts	Cash	**$ 217.54**
Member Donation	Grabber Materials	

Appendix: Acknowledgements and Recognition

OpenCV - Image Recognition Documentation and Example
https://www.pyimagesearch.com/2016/02/08/opencv-shape-detection/

Riverstone, Nanjing Institute of Technology, China- Technical Documentation Image Recognition Document Example
https://www.marinetech.org/files/marine/files/ROV%20Competition/2019%20competition/Missions/Explorer_E05_China_Nanjing%20Institute%20of%20Technology_IR_909.pdf

Circuit Basics - Connect Raspberry PI to Latop
http://www.circuitbasics.com/how-to-connect-to-a-raspberry-pi-directly-with-an-ethernet-cable/

How to Mechatronics - Arduino DC Motor Control Tutorial – L298N | PWM | H-Bridge
https://howtomechatronics.com/tutorials/arduino/arduino-dc-motor-control-tutorial-l298n-pwm-h-bridge/

Nova Underwater Technologies - Job Safety Assessment Example
https://www.marinetech.org/files/marine/files/ROV%20Competition/2019%20competition/Safety/Halifax%20Robotics_Nova%20Underwater%20Technologies_JSA_2017.pdf

Home Built ROV's – Bilge pump to Thruster Conversion & Water Proofing Techniques
http://www.homebuiltrovs.com/

Shirt Donation – UTSI International Corporation
Pool for Testing – Pete and Phyllis Finn
MATE – Marine Advance Technology Education

Mentors

Matthew Steakley
Corbett Freeman
Ed Vandenberg

Appendix: Cost Details

Total ROV		**$ 845.37**
Amazon	1100 GPH Bilge Pump	$ 59.99
Amazon	12v - 5v Power Convertor	$ 13.01
Home Depot	2 - Lexan Sheets	$ 9.96
Blackburn Marine	2 500 GPH Bilge Pump	$ 67.98
Marine Trading Post	2 Bilge Pumps 1100 GPH	$ 97.41
Amazon	Dual 10A Motor Controller	$ 26.10
Micro Center	3D Filament	$ 34.98
Amazon	50' 10 guage wire	$ 38.95
Amazon	50' Cable Sleeving	$ 27.50
Amazon	2 - 50' CAT6 Ethernet Cable	$ 19.98
Amazon	Arduino Uno	$ 20.69
Amazon	Arduino Wires	$ 6.98
Amazon	Backup Camera (2)	$ 33.98
Amazon	Dual Motor Contoller	$ 18.99
Home Depot	Electric box	$ 12.13
SparkFun	Ethernet Breakouts (2)	$ 12.00
EPO	Fuses, Power Poles, Fuse Holder, etc.	$ 28.45
Fry's	Hardware	$ 3.78
Home Depot	Hardware	$ 14.16
Lowe's	Hardware	$ 6.46
Amazon	JoySticks	$ 8.89
Lowe's	Marine Epoxy	$ 29.88
Home Depot	Marine Sealant	$ 14.97
Home Depot/Lowes	PVC and Lexan	$ 49.12
Lowe's	PVC Cement	$ 5.52
Fry's	Raspberry PI 3 B+	$ 38.10
Amazon	Raspberry PI Night Vision Camera	$ 21.78
Fry's	Resistors	$ 6.97
Amazon	Right Angle USB cable	$ 14.00
SparkFun	Slider	$ 2.60
Home Depot	Strain Releif Clamps - 5 pack	$ 3.14
Fry's	USB Cable and Heat Shrink	$ 6.98
Amazon	Waterproof Temperature Sensors (5)	$ 11.88
Lowe's	Wire	$ 11.40
Home Depot	Wire	$ 45.38
Lowe's	Wire and connectors	$ 18.08
Home Depot	Wire Lock Pins	$ 3.20

PVC - Consumed, Unused, Props		**$ 112.35**
Lowe's	PVC	$ 5.31
Lowe's	PVC	$ 6.43
Lowe's	PVC	$ 6.31
Home Depot	PVC	$ 13.56
Lowe's	PVC	$ 2.86
Lowe's	PVC	$ 11.98
Home Depot	PVC	$ 15.04
Home Depot	PVC	$ 6.27
Home Depot	PVC	$ 11.18
Home Depot	PVC	$ 16.54
Lowe's	PVC	$ 32.81
Home Depot	PVC	$ 28.40
Home Depot & Lowe's	Less PVC and Lexan on ROV	$ (49.12)

Supplies (Tape, Clamps, Wire, Electrical, Solder)		**$ 74.97**
Lowe's	Tape	$ 20.93
Home Depot	Tape	$ 4.27
Lowe's	Clamps	$ 3.16
Lowe's	Wire/Electrical	$ 36.14
Harbor Freight	Solder	$ 10.47

Equipment		**$ 457.76**
Frys	Calipers	$ 9.99
Lowe's	Wire stripper	$ 8.80
EPO	Switch for Power Supply	$ 9.95
Amazon	Power Supply	$ 27.99
Amazon	Digital Clamp Meter	$ 29.97
Fry's	Soldering Iron	$ 64.80
Amazon	Digital Video Capture Converter	$ 10.29
Amazon	Relay (4)	$ 5.49
Lowe's	Marine Epoxy	$ 19.92
Amazon	Ethernet Coupler	$ 9.39
Amazon	50' 10 Guage Wire	$ 38.95
Amazon	50' and 15' CAT6 Ethernet Cables	$ 15.87
Lowe's	50' CAT5E Cable	$ 18.48
Amazon	Arduino	$ 18.98
SparkFun	3 - L298N Motor Controllers	$ 44.94
Donated	2 360-GPH Bilge Pump	$ 63.96
Amazon	Bilge Pump 1100 GPH	$ 59.99

Shirts		**$ 217.54**
WalMart	Shirts	$ 173.54
Joann's	Embroidery Supplies	$ 44.00

MATE	**Entry Fees**	**$ 300.00**

Appendix: Job Safety Assessments

JOB: ROV Testing/Operation

TEAM MEMBERS: Jacob Blanchard, James Blaine, Lily McDonald, Nathaniel Kinonen, Olivia Freeman, Shawn Steakley

No.	Task Description	Steps	Potential Risks	Risk Minimization Efforts	Overseeing Members
1	Set Up	A. Carrying ROV To Pool	a. Tripping b. Mild Hand Injury c. Mild Toe Injury	Keeping wires and tether above foot level Rounding out all sharp edges Having 2 or more people carry the ROV	Jacob, James, Lily, Nathaniel, Olivia, Shawn
		B. Electronics Connected	a. Shock Hazard b. Hand Injury	Checking that everyone is clear Motor shrouds	Jacob, James, and Shawn
		C. Placing ROV in Pool	a. Falling in Pool b. Hand Injury	Rescue implements accessible, no one by pool alone, no one in pool, and cell phone Motor shrouds/ rounded edges	Jacob, James, Lily, Nathaniel, Olivia, Shawn
2	Drive Time	A. Tether Management	a. Tripping	Tether team keeps tether above foot level	Olivia and Lily
		B. Controls/ Electronics	a. Shock Hazard b. Trip Power Supply c. Hair Tied in Motors	Wire connections sealed inside box Fuse installed Long hair is tied back or tucked in shirt	Jacob, James, Lily, Nathaniel, Olivia, Shawn
3	Pack Up	A. Taking ROV Out of Pool	a. Falling in Pool b. Hand Injury	Rescue implements, no one alone, cell phones Motor shrouds/ rounded edges	Jacob, James, Lily, Nathaniel, Olivia, Shawn
		B. Carrying ROV Back	a. Tripping b. Mild Hand Injury c. Mild Toe Injury	Keeping wires and tether above foot level Rounding out all sharp edges Having 2 or more people carry the ROV	Jacob, James, Lily, Nathaniel, Olivia, Shawn

Appendix: Job Safety Assessments

JOB: ROV Construction/ Maintenance

TEAM MEMBERS: Jacob Blanchard, James Blaine, Lily McDonald, Nathaniel Kinonen, Olivia Freeman, Shawn Steakley

No.	Task Description	Steps	Potential Risks	Risk Minimization Efforts	Overseeing Members
1	Power Tools	A. Set Up	a. Tripping b. Hand Injury c. Toe Injury	Keeping cords out of walking space Wearing gloves for sharp blades or tools Wearing close toed shoes when working	Jacob, James, Lily, Nathaniel, Olivia, Shawn
		B. Turning on Equipment	a. Hand Injury b. Eye Injury c. Neck Injury/Cutting	Checking that everyone is clear Wearing safety glasses while operating tools Long hair is tied back or tucked in shirt	Jacob, James, Lily, Nathaniel, Olivia, Shawn
		C. Cleaning Up	a. Tripping	Picking up dropped items	Jacob, James, Lily, Nathaniel, Olivia, Shawn
2	Programing	A. Set Up	a. Tripping	Keeping cords out of walking space	Jacob, James, Lily, Nathaniel, Olivia, Shawn
		B. Electronics	a. Shock Hazard b. Trip Power Supply c. Burning Components	Checking that everyone is clear before testing Fuse installed Paying attention to the 20 volt vs 5 volt wires	Jacob, James, Lily, Nathaniel, Olivia, Shawn
3	Adhesives	A. Before Gluing	a. Mild Hand Injury b. Long Hair in Glue c. Fumes	Wearing plastic gloves Long hair is tied back or tucked in shirt Air circulation through open garage door	Jacob, James, Lily, Nathaniel, Olivia, Shawn
		B. After Gluing	a. Water Leaks Through	Testing seal before placing in electronics	Jacob, James, Lily, Nathaniel, Olivia, Shawn
4	Soldering	A. Using Iron	a. Burn Hazard b. Fumes	Using gloves if at risk of touching the iron Air circulation through open garage door	Jacob, James, Lily, Nathaniel, Olivia, Shawn