North Paulding Robotics

North Paulding High School
300N Paulding Drive
Dallas, GA 30132

COMPANY MEMBERS

Anthony Robinson (12th grade)	CEO, Electrical Engineer
Jason Perez (12th grade)	Mechanical Engineer
Ben Skowronski (12th grade)	CFO, Mechanical Engineer
Jason Lees (11th grade)	Mechanical Engineer
Andy Griggs (11th grade)	Electrical Engineer
Toni Brozowski (10th grade)	Programmer
Drew Boles (10th grade)	Mechanical Engineer

Mentors: Geoff Gardener and Nicola Lees

TECHNICAL DOCUMENTATION

MATE World Championship 2021

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ABSTRACT

North Paulding Robotics was established in 2012 and currently has 7 company members ranging from 10th to 12th grade. To meet the individual needs of our clients, the company's members maintain a wide range of qualifications that allow them to be creative in their building of ROVs. The company strives to expand upon its knowledge and expertise with the goal of continuing to develop high-quality and reliable ROVs. Our company has developed a remotely operated vehicle (ROV) in response to a request for proposal from the MATE foundation. Our ROV is tailored to address the increasing concerns set out by the MATE foundation regarding the degradation of our world's waterways due to climate change, pollution, and unsustainable environmental practices. The compact, modular design of our company's ROV is well suited for global deployment with its unique features which allow it to efficiently remediate these issues. The ROV is equipped with a rotating manipulator that is highly maneuverable for efficient transformation of subsea landscapes, and an onboard control system allows for improved signal integrity. Additionally, complex software algorithms give the ROV partial autonomy which make it possible for demanding tasks to be quickly and accurately accomplished. The seamless integration of mechanical, electrical, and software engineering makes the ROV a compelling choice to complete the given tasks. This technical document describes the development process and design details that will make this ROV the best fit for tackling the current and future environmental concerns that may arise.

Figure 1. Company Members

DESIGN RATIONALE

North Paulding Robotics utilizes the iterative design process to develop a product that is both effective and reliable. We begin each year with an initial planning phase that lasts around two weeks. During this phase, the mission requirements provided by the Marine Advanced Technology Education Center (MATE) are analyzed, and the corresponding feature to complete each objective is determined and conceptualized. Our company considered last year's ROV, evaluating what worked and what did not. The company then brainstormed and discussed the new design, considering the size, weight, cost, complexity, safety, and ease of manufacturing the ROV in a timely manner for the requirements outlined in the request for proposal.

Once this is complete, a provisional budget and timeline are established which guide the iterative process and help determine the use of research and development costs during the design phase. Design teams, each specializing in an individual feature of the ROV, follow a four-step process of iterative design. During the analysis and design stage, each design team develops a prototype of their feature by considering the initial concept and their analysis from the last stage. The past analysis allows a more effective feature to be created from the first prototype, thus saving on costs. Once a prototype is created, it is assessed in the testing phase. The feature is then evaluated on its performance during testing and possible design improvements. If the design passes the team evaluation, it is reviewed by the entire company to determine how well the feature will coincide with the overall ROV and if its performance is acceptable.

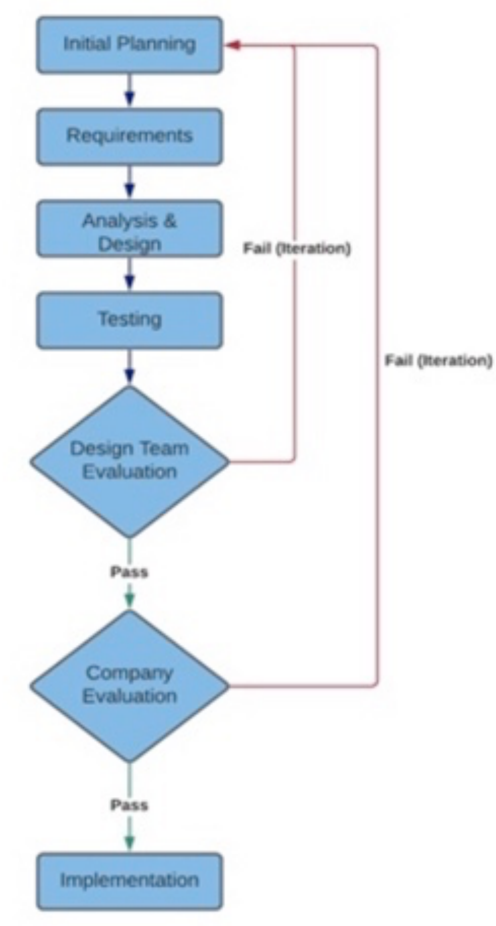

Figure 2: The iterative design process.

If the design passes company evaluation, a final product is created, and the feature is implemented to the ROV design. However, if the initial design fails one of these evaluations, the iterative design process is continued, starting again with the requirements phase, and continuing through each successive phase until the feature reaches another evaluation. This iterative process ensures that each feature is constantly evaluated and has passed rigorous standards of performance and reliability, leading to a final ROV that is, in turn, effective and reliable.

MECHANICAL COMPONENTS

FRAME

When designing the ROV frame, the company was presented with new opportunities that provided more flexibility in design through the improved access to 3D printing and Computer Numerical Control (CNC) machinery. A prototype of the frame was designed around the main components, such as the thrusters and onboard control box. It was vital that the onboard control box was positioned in the top half of the frame to ensure the center of mass was at the correct point on the ROV for maximum stability. Another necessary component consideration was the six T100 thrusters. The implementation of four horizontal thrusters allows the ROV to move forward, backward, and turn in place simultaneously. These thrusters are mounted at 45-degree angles on each corner of the frame and inset slightly to keep the frame compact in size. The additional two thrusters are centrally mounted on either side of the frame for stable, vertical thrust.

Figure 3: ROV frame

The design resulted in an agile and lightweight frame that utilized aluminum metal sheeting that was donated by Kennesaw State University (KSU). The CNC material was created with machined holes spaced at precise intervals for mounting and easy adjustments. Each component can easily be moved and switched allowing for reconfiguration of the frame when needed. The frame's dimensions measured 38 cm in length, 32 cm in width, and 20.5 cm in height with a weight of 1.36 kg without thrusters, tether, electronic housing, and payloads.

THRUSTERS

The proposal requested that the ROV be capable of maneuvering quickly and effectively in confined spaces. The company built an ROV that is equipped with six T100 Blue Robotics thrusters. This model of thruster was selected over the T200 model because it is $87.00 cheaper and draws 11.5 Amps less current. Each thruster measures11.3 cm in length with a diameter of 9.7 cm.

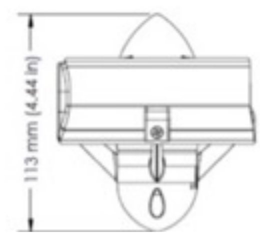

Figure 4: Thruster T100 side view

The thrusters operate at a maximum power of 150 W and can operate effectively at a depth range of 150 meters. Each thruster provides 9.4 N of thrusting power, and as the ROV is equipped with 6 thrusters, the company calculated the total thrust as:

Vertical thrust: 9.4 N * 2 thrusters * sin 90^o = 18.8 N

Horizontal thrust: 9.4 N *4 thrusters* sin 45^o = 26.59 N

Figure 5: Thruster shrouds front view

All 6 thrusters have protective shrouds and custom 3D printed thruster guards to enclose the propellers, ensure operator safety, and meet the safety MATE requirements.

TETHER

The ROV is equipped with a custom tether rather than a commercial tether due to the lower cost. The tether consists of two CAT 6e Ethernet cables, two 16-gauge wires (one main power, ground), and four camera wires. The cables are neatly bundled using a TechFlex braided sleeve, which can be coiled around the frame of the ROV, making transportation easy. The tether weighs 3.52 kg and has a total length of 15 meters which allows the ROV to maneuver with ease during the missions. Using evenly spaced flotation, the tether is kept neutrally buoyant so that it does not drag along the sea floor and threaten marine life. The tether is properly restrained at the control box and ROV side and is kept coiled when not in operation. During missions, a trained operator ensures that there is a proper length in the pool, there is no strain on the ROV, and any excess tether is coiled neatly where it is not a hazard to any team members.

Figure 6: ROV Tether

BUOYANCY

One of the benefits of having two onboard control boxes is that they serve as the main source of buoyancy. By having two airtight tubes spaced out on top of the ROV, the ROV will have a relatively flat source of buoyancy keeping it upright. Using Archimedes' principle, along with the measured volume of the ROV, the calculated buoyant force is 93.017 N. Since the ROV only weighs 86.044 N, an additional 7.0266 N of weight had to be added to make the ROV neutrally buoyant.

Figure 7: Lead weight added to baseplate neutral buoyancy.

Total ROV Volume	0.0096m^3
Density of Pool Water	992.72 kg/m^3
Total Buoyant Force of ROV	93.071N
Total Buoyant Force of Onboard Control Boxes	66.94N
ROV Weight	86.044N
Added Weight	7.0226N
Added Mass	717g

Table 1: Buoyancy calculations to determine how much weight needed to be added to ROV frame.

ELECTRICAL HOUSING AND SYSTEM

This year, instead of having one main onboard control system, the company decided to separate the control systems into two different waterproof housings. By using two control boxes, the overall height is reduced, and issues can be isolated to the control box in which they are housed. One housing holds the motor control system, while the other housing holds the servo control system. Both control systems consist of an Arduino mega running the atmega2560 8-bit microcontroller. This microcontroller is fast and reliable but also has a large selection of general-purpose input/output pins, or GPIO. Communication with the surface laptop is achieved with serial communication for a more reliable and stronger signal strength that is

Figure 8: Onboard electronic housing

converted to an ethernet cable when underwater. The company used Blue Robotics speed controllers for the T100 thrusters that use BLHeli ESC design with upgraded features and performance.

The two onboard control boxes house voltage regulators and bus bars with the voltage regulators dampening down the amperage to what the Arduino needs, so it does not overload. The onboard control box needs reliable and strong watertight enclosures for the electronics onboard, so the team opted to use two Blue Robotics 4-inch series watertight enclosure with 10 accessibility holes for the necessary wires to go through. Each tube measures 30 cm by 11 cm by 11 cm, and the inner diameter of the enclosure is 10.5 cm. Once the wires were fed through the vent hole, it was epoxied to prevent water leakage.

SURFACE CONTROL SYSTEM

The surface control system is comprised of three main subsystems: the control system, the camera system, and the communication system. The control system consists of two Logitech Extreme 3D Pro flight sticks which are used to pilot the ROV. With eleven buttons, a trigger, a hat switch, and three axes of movement, these highly customizable controllers are tailored to the preferences of the pilot. One joystick is customized to control the movement and camera angle of the ROV, and the other controls the manipulator. By using two joysticks, each pilot can focus on their specific task and complete the missions more efficiently. Pilot control is aided by the camera system which always displays the exact position and orientation of the ROV.

This system takes the camera inputs from the ROV itself and passes them through a camera multiplexer that can show up to four camera views at a single time. The output of the camera multiplexer is then connected via RCA to the monitor so that the pilots can view whichever camera angles are most useful at any given time. The camera system can also be connected to the communication system with an RCA to HDMI adapter for visual imaging tasks so that the laptop can interpret a single camera feed. This communication system consists of the laptop and the peripherals connected to a USB hub housed within the surface control system. The laptop reads the USB signal from the joysticks and converts this data with the surface code. It then communicates this data back through the USB hub and through the tether to the onboard Arduinos.

Each of the subsystems for the surface control system is neatly integrated into a singular surface control box. This control box takes one positive and ground wire and splits them with a bus bar to power everything within. All connections housed within the surface control box are properly secured to reduce the risk of pulled wires and electrical shorts. The control box also contains a power switch so that the entire ROV can be quickly powered off in case of emergency.

Figure 9: Surface control box

FUSE

To meet the safety requirements of the MATE competition, the company incorporated a 25 Amp fuse into the main power line. This small safety device will stop the ROV from working if the electric current exceeds the required amount, preventing fires, electrical shock, and damage to the main control box. The fuse is located 17 cm from the main point of connection to meet the safety requirements put forward by MATE.

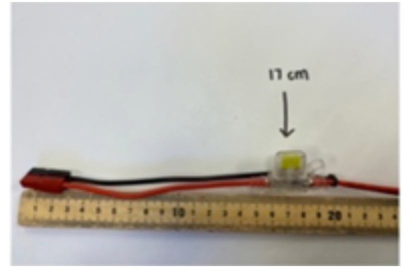

Figure 10: Fuse within 30cm of main power

SOFTWARE DESIGN

The software design to control the robot consists of two parts: the surface code and the onboard code. The surface code is written in the language of Python, and the onboard code is written in Arduino's wrapper of C++. The language of Python is responsible for the data conversion, transmission, and autonomous code as it was the easiest code to master and read, allowing it to be debugged with ease. Arduino's wrapper for C++ is used for its simplicity, as it can be used to receive, parse, and send data all onboard "The Whale".

It was also decided to run the surface code on a laptop rather than a smaller computer such as a Raspberry Pi. A laptop has an excess of computing power which equates to smoother movements, less chance for data corruption, and faster autonomous code runtimes. It also makes the use of the code impromptu to anyone familiar with computers.

The control scheme starts at two Logitech joysticks connected to the computer through an external USB hub. The joysticks chosen to allow many options to control the robot from buttons, switches, sliders, triggers, and joystick movement. The code starts by initializing the joysticks and its controls. The input from those buttons is then read and put into a and attached to respective functions that translates the data into data legible by Arduino. The new data set is then compiled into two-byte arrays as for its respective Arduino.

The path the data follows from the laptop is first to a USB hub, then split to two serial connections to two Arduinos, then loaded on the Arduinos is the onboard code. The onboard code then starts by receiving the respective byte array. The Arduino will then parse the received data and assign the values to the correct pins, which will be sent to the motors, servos, and modified servo. The Arduinos will finally send back the data it received back to the laptop, which will then print it in the terminal. This allows for isolation of problems such as data corruption, making debugging easier.

SYSTEM DECISIONS

BUILD VS BUY

This year, our strategy for construction of the ROV was customizing components to fit our vision for the ROV instead of attempting to bring together several different prebuilt components. A customized ROV also utilizes all the possible space available within the frame.

The custom fabricated ROV frame was milled from aluminum sheet using a CNC machine. The company chose to build the custom lightweight frame to fit the two onboard control boxes and 6 thrusters without sacrificing mounting space, something unavoidable had the company chosen a prebuilt frame.

Price differences arose with this change in the creative process. In previous years, a manipulator purchased from Blue Robotics would cost approximately $400.00. This year, our tailored fit 3D printed manipulator was considerably less, leaving funds available to invest in other components.

Not all the ROV's components are custom built. The company relied on some tried and tested products that are more practical to purchase than to build. The ROV's onboard control box was purchased from Blue Robotics and supports the ROV's entire electrical control system. The company decided to purchase components, such as servos and onboard electronics, as they were more reliable and cost-effective solutions than if the company attempted to build them instead.

NEW VS REUSED

Budget constraints were a driving component that determined if the company purchased or reused parts from previous years. The decision was made to only buy new parts if they were found cheaper than the cost to build or 3D print. The T100 thrusters and onboard control box housing were purchased from Blue Robotics since these components have been used in the past and are both reliable and cost-effective. The T100 thrusters were selected over the T200 thrusters because they were more cost-effective, utilized lower amperage, and offered the same performance as the T200 thrusters. The cost difference between the two was close to $100.00.

The company reused the surface control box, some onboard components, and cameras from last year as they were reliable, functioned correctly, helped minimize the expenditures, and saved on the budget.

MISSION SPECIFIC TOOLS

MANIPULATOR

Due to the relatively high number of tasks that require fine maneuvering of subsea items, such as the propagation of corals during the assigned missions, North Paulding Robotics opted to develop a manipulator that is both reliable and versatile.

To develop a reliable manipulator, the company designed a claw mechanism that uses mechanical processes to relieve stress from its driving components. The mechanical design of the claw consists of an acme threaded rod that screws a nut along its axis. The nut then links into a pin slot mechanism that controls the opening and closing of the gripper. By using a screw drive linear actuator, the claw can maintain its exact position even when no power is supplied because the nut cannot back drive. When combined with a Hitec hs-5646 wp servo, modified to rotate 360 degrees, the system becomes extremely reliable. Since the servo does not have to be powered at all times, the risk of overcurrent due to a servo having to constantly maintain position is eliminated. Another real-world application of the linear actuator-controlled claw mechanism is that in the unlikely case of temporary power loss, potential pollutants emitted from the ROV will not be reintroduced into the environment.

Besides being reliable, the manipulator is also versatile in its application. The specific shape of the gripper pads themselves, for example, are dictated by the mission specifications. Given that many of the required items to be manipulated are represented by ½ inch PVC, the team designed gripper pads that have a groove specifically designed to accommodate that material. Additionally, because the missions require a high amount of precision, the gripper pads have been attached to a 4-bar linkage for parallel open and close. This motion results in a more predictable closed position for the pilots which is essential for sponge sample collection.

One final feature of the North Paulding Robotics manipulator is its maneuverability. The claw mechanism has an additional 2 axis of freedom. A servo at the rear can rotate the entire assembly 90 degrees, allowing for the company to rotate the claw into a position where it can best complete the given task. Additionally, this whole system is mounted to a tilt mechanism which allows for an even greater positional accuracy to be achieved by the claw mechanism.

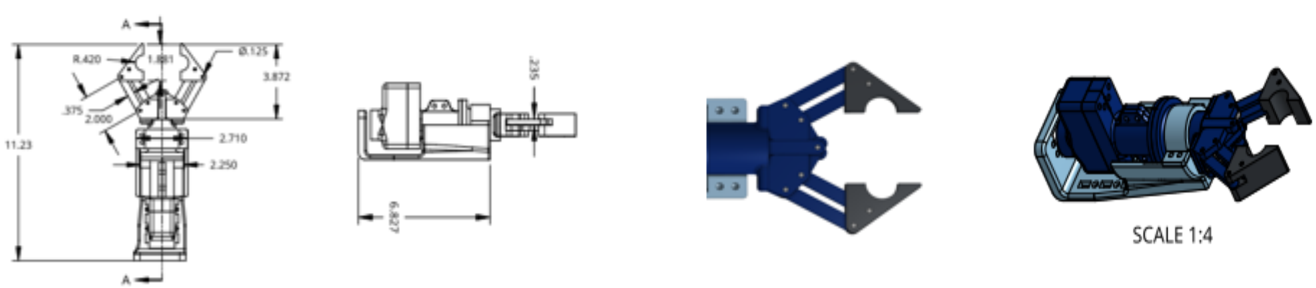

Figure 11: Pictures of the main manipulator with custom 3D printed parts.

During the mission, practices the pilots noticed that the threaded rod that opens and closes the claw would bind and detach itself from the motor. The motor would continue to spin, but the claw would not open or close. After attempting to troubleshoot, the company added washers to make a sleeve and keep the aligned and free from binding. In addition, the sleeve filled the gap enough to where there was no longer space for the shaft to become disconnected from the open/close motor.

Figure12: Backup arm

The company decided to avoid the loss pool practice time by having some members build a backup manipulator that could quickly be switched if problems occurred during a mission practice. The backup manipulator consisted of a purchased parallel gripper. The gripper has a maximum width of 7.1 cm and is designed to use a Savox servo 25T spline. The backup manipulator mounts to the same tilt mechanism as the original one, allowing the manipulators to be switched out easily poolside if needed.

MICRO ROV

One of the additional features the ROV is equipped with is a micro ROV which can be used to access smaller spaces that the original ROV cannot. In the product demonstration, the micro ROV “Little Buddy” will be used to autonomously retrieve a sediment sample from a drainpipe. The cylindrical structure of the micro ROV was chosen due to the constraint of the tunnel's diameter. The micro ROV has a diameter of 8.9 cm and a length of 25 cm; this size prevents the micro from turning sideways and becoming lodged in the tunnel.

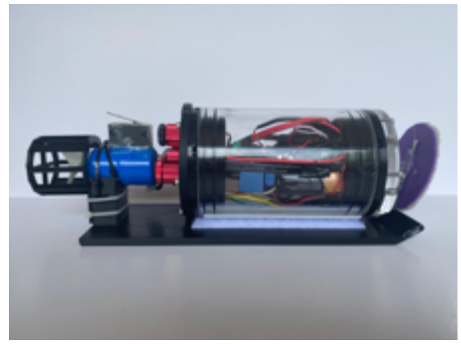

Figure 13: Micro ROV

The onboard housing is made from an acrylic watertight tube with 2 end caps. One end cap has 4 -10 mm holes allowing for mounting the switch and wires, and has a center hole, allowing the propeller to extend out. The propeller is covered by a custom 3D printed shroud to prevent damage to coral reef and operators. The end caps are equipped with a vent and plug. This vent allows any build-up of pressure to be released if it exceeds the outside pressure. The micro is powered by two 9V batteries securely mounted to the underside of the custom 3D printed electronic housing baseplate. A 5 Amp is installed within 5 cm of the battery's positive terminal, to meet the MATE safety guidelines. The housing contains two limit switches, a waterproof motor, and a quick On/Off switch located at the front. The On/Off switch allows our company to quickly cut the power to the Arduino and motor in case a problem occurs.

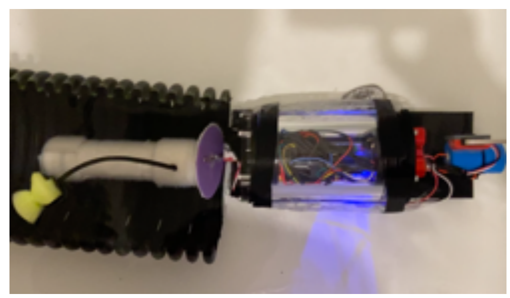

Figure 14: Test run of the micro retrieving the sediment sample

The micro ROV will be released by the main ROV, then will operate on its own, traveling down the pipe towards the sediment sample which it will attach to using Velcro. When the micro ROV touches the sample in the tube, it will trigger a pressure switch that will reverse the direction of the motor, bringing it out of the pipe along with the attached sediment sample and back to the main ROV. The main ROV will then bring the micro ROV and the sediment sample back to the surface.

PLASTIC RETRIEVAL DEVICE

The Plastic Retrieval Device was designed with two things in mind: quick attachment/removal and the prevention of plastic escape while underwater. The design incorporated a net that could be attached and detached, so its size would not impede on other missions. The payload itself is an oval-shaped rim with netting behind it to form our net and has two arms that extend from the bottom of the rim. Each arm has a peg underneath that fits into a custom-printed receiver made to perfectly match the shape of the peg. Once the pegs are in their respective receivers, a sliver of Velcro between the receivers and the arms ensures the payload will not detach from the ROV mid-mission. After the pilots have used the net to collect the plastic and descend underwater, the plastic attempts to float. However, due to our net being made of extremely loose material, the plastic pulls the net upwards and away from the mouth of the net itself. Without an escape from the net, the plastic is secured until the company retrieves the net from the ROV.

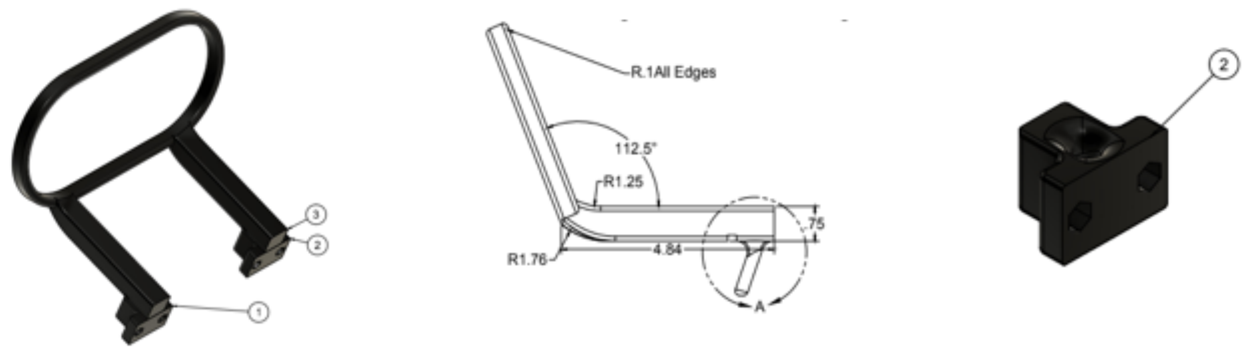

Figure 15: Plastic retrieval device mounting brackets and catchment

TRANSECT LINE AND MAPPING

Figure 16: Autonomous fly over of transect

To execute the task of the transect line, our company used the programming language Python and two different programmed operations. The first program oversaw controlling the robot itself and flying it over the designated area at a designated speed and height. The first function of this code is to control the horizontal movement of the ROV. This is completed by using a live camera feed and counting the number of times it passes a square. After a configurable number of times, the function will break. The second function of this program is to control the height of the robot. It does so by calculating the distance of the robot to the surface using the formula: F = (P x D)/ W, with F equaling the known focal width of the camera, P equaling the number of pixels of the measured object, W equaling a marker object of a certain width, and the solve-for variable, D, equals the distance of the camera to the surface. Depending on the value of this variable, the robot will go up or down to maintain a safe distance, allowing it to clear any high obstacles.

SUBWAY AUTONOMOUS STITCHING

North Paulding robotics has decided to also create a program that captures images of the Subway car and automatically stitch said images into the photomosaic. Completing this task automatically saves precious time during missions. The program, written in the language of Python, utilizes the library of OpenCV for every image operation performed. The program starts with the function needed to crop the captured images and utilizes the Joystick Class used for The Whale's movement. Immediately after the cropping function is made, the capture devices are declared. Then, using the pygame library and the joystick Class and a while not loop, images are taken of the subway by pressing joystick buttons and saved to a pre-created directory with predetermined file names. Only when all pictures are taken and another designated button is pressed, does the loop break. After the Loop breaks, an object is connected to each image file to be operated on. Each image then goes through the function of cropping. The cropping function starts by blurring the image, then converting it to grayscale. An adaptive threshold is then used to distinguish the white of the Subway and the white of the ocean floor. Using the augmented image, the largest contour is then located and then cropped to just that contour. Finally, the image is given back its color and saved as its own object. The new cropped photos are then resized depending on its size. The front and back of the Subway care are resized to 720:720, The sides and top are resized to 1440:720. The cropped and resized images are then stitched together into the photomosaic. The photomosaic is finally displayed in its own window.

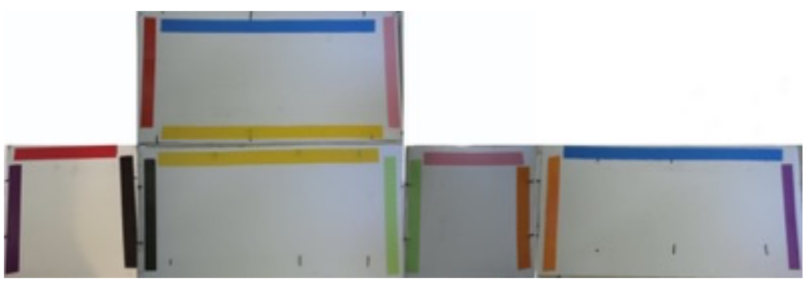

Figure 17: Photomosaic to show the Subway stitching

CORAL IMAGE REGONITION TOOL

A program was created that can automatically inspect the health of a coral compared to the previous year, measuring growth and damage. This code is integrated in the control code to allow the pilots to capture the image of the coral of today with a joystick button. After the new image is taken, it is put on top of an image of last year's image of the coral. The code will then locate the differences between the two images and the difference will be exported as its own image. This new image uses colored circles to distinguish

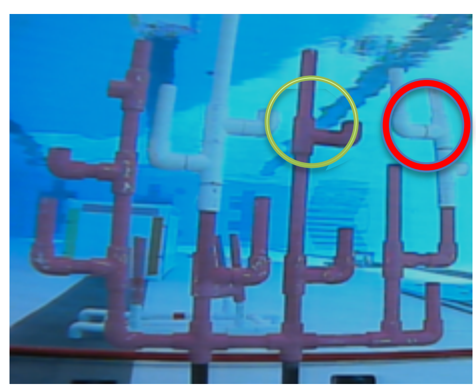

Figure 18: Coral colony image recognition

growth and death. The final image is then displayed on screen, new growth is indicated with a green circle, damaged coral with a yellow circle, bleaching with a red circle and recovering coral with a blue circle.

PIN REMOVAL TOOL

The pin removal tool was designed to pull and secure the pin from the ghost net. Removing the pin simulates the cutting of the rope and releasing the net to the surface. The ROV returns the pin and ghost net to the surface. To accomplish this task, a magnet was placed on the rear side of the manipulator claw within view of the side camera. The pilot will then maneuver the manipulator into position, allowing the peg and the magnet to make contact. The ROV will reverse, and the pin will be removed, releasing the ghost net. The manipulator is then free to secure the ghost net. During pool testing, this magnet system resulted in excessive electromagnetic interference (EMI). To resolve the issue, the team fabricated a new payload which places the magnets on an extension pole away from the ROV itself to avoid EMI.

Figure 19: Magnet attached to gripper for pin removal

Figure 20: Improved pin removal device.

SEABIN POWER CONNECTOR

The company is tasked with conducting maintenance of a deployed Seabin in open water. The ROV must disconnect the old power connector from the port of the Seabin. Once disconnected, the ROV must remove the old mesh catch bag and replace it with a new one. Lastly, the ROV must reinstall power to the Seabin by placing the custom power connector into the Seabin port. The LEDs on the power port will illuminate once power is restored successfully.

Figure 21: Pictures of Seabin power connector, transmitter side of inductive coupling power and tether wire to surface power supply

The custom built Seabin power connector was designed and constructed using 2-inch coupling and 2-inch PVC pipe measuring a length of 18 cm. A 2-inch to ½ inch reducing busher allows a T connector to be mounted, allowing a handle to be mounted to the top for a gripping point for the ROV. The transmitter side of the inductive coupling power connector is secured in a 2-inch knock out cap at the base of the 2-inch pipe. The device is waterproofed with slow curing epoxy. The transmitter side of the inductive coupling is attached to red and black wire 15 m in length that runs to the pool surface. Anderson connectors and fuse are attached to the end of the wire to comply with MATE 2021 safety guidelines. The power connector for the Seabin is powered from the surface using a 12V power source.

During the testing phase, the pilots observed that the power connector to the Seabin needed a few modifications. The tool was redesigned with 2-inch PVC pipe, a 2-inch to ½ -inch reducing brusher and a T connector. These modifications ensured that the new prototype was lighter, narrower, and easier for the manipulator to secure into the Seabin port.

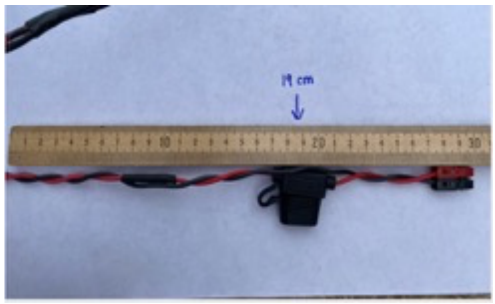

Figure 22: Modified Seabin power connector with fuse on the main power line

CAMERAS

This year, the specifications require that the ROV must disconnect the power to a Seabin, retrieve and replace a catch mesh bag, remove floating debris from the surface, remove a ghost net, determine the health of the coral colony, remove coral fragments, collect samples of sponge species, fly a transect line over a coral reef, and create a photomosaic of a submerged subway car. To accommodate the proposal and complete the tasks effectively, the company decided that the ROV needed to be equipped with four underwater waterproof fish-finder color cameras with built-in lights. The camera extension cable length is 50 m long. The camera incorporated a light source of 12 high-power bright white led lights. The cameras offer a field of view angle of 92 degrees. The camera's dimensions are 2.5 cm in diameter and 5 cm in length. The operating temperature of the cameras is -20C-60 degrees, allowing the cameras to operate in cold temperatures.

One camera was mounted to a DDT500 tilt system with a built-in Savox-1210SG waterproof servo placed on the front of the ROV. The tilt mechanism allows the camera to move up and down with a rotation of 150 degrees that optimizes the front view of the ROV for the retrieval of the plastic pollution and for allowing full view of the manipulator.

The remaining cameras were mounted by using mounting brackets in specific spots on the frame to help monitor the payloads and to assist in the completion of each task. In addition to the main front camera, an extra camera is positioned at a 45-degree angle to the front that shows the claw and its contents when it is rotated to a vertical position, giving the pilot a different angle when the manipulator is rotated during a mission. The third camera is mounted to the frame and assists with the visual imaging task, allowing images to be captured and stitched together during the subway autonomous mission. The final camera is integrated underneath the ROV to show an orthographic image of the pool bottom for other visual imaging tasks, including flying the transect line and mapping points of interest on a coral reef.

The main control box houses a camera multiplexer system which allows our pilots to see multiple camera angles at the same time on a single monitor. The CCTV multiplexer box has a maximum of four input camera signals and one output signal and has multiple viewing modes and combinations. Therefore, the pilots of our ROV can switch between these viewing modes to focus on one camera or view multiple camera angles at once in whichever format they choose.

Figure 23: Baseplate camera for viewing transect line

Figure 24: Main camera mounted on tilt mechanism

Figure 25: Video splitter, allowing multiple cameras to be viewed on one monitor

MUSSEL QUADRANT TOOL

The mussel quadrant tool is designed to be placed on the mussel bed and allow the number of mussels in the quadrant to be counted. The tool was designed with one aspect in mind: weight. The company wanted the tool to be lightweight and easy to maneuver for the ROV during the mission. The first prototype made from ½ inch PVC with a U-bolt hook worked during the mission practices, however, the team felt that they could modify it to be easier to take down and retrieve during the mission. The final design, a quadrant measuring 50 cm by 50 cm and weighing 181 g, was constructed from lightweight aluminum tube and held together at the corners by 3D custom printed connectors. The tool was placed in the manipulator and could be easily guided down to the mussel bed for the accurate count to be made. The pilot will then report the count to the CEO who will then calculate the total amount of water filtered by the mussel bed in one hour.

Figure 26 First prototype of mussel quadrant

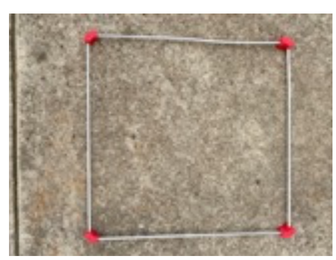

Figure 27: Final design mussel quadrant

SAFETY

COMPANY SAFETY AND PHILOSOPHY

All team members are taught that safety is a key feature in our company's success. The team is committed to the MATE published safety guidelines and upholding the highest standards of safety. Creating this safer work environment requires a commitment from all levels of our company's workforce. The team emphasizes the importance of safe working practices among our employees by engaging them directly from the ground up. To accomplish this goal, they have created a company safety committee where committee members are trained to identify hazards and unsafe work practices, prevent accidents by removing any known obstacles, and evaluate the company's ongoing efforts to achieve an accident and injury-free workplace. The safety officer is tasked with updating the Job Safety Analysis (JSA) and Safety Checklist documents throughout the year as our employees work, design, and test the ROV (Table 2).

PROCEDURE	CHECK
Eye and ear protection worn when operating power tools	
No loose clothing is worn, long hair tied back when working with machinery or moving parts on the ROV	
No open-toed shoes	
Operation of machinery is under adult supervision and only if the member has been trained on how to operate the machine.	
Rubber gloves and dust masks/ respirators when sanding or handling chemicals	
All company members will follow workshop rules – no horseplay in the workshop	
Training is mandated before members can operate new machinery	

Table 2: Construction checklist

LAB PROTOCOLS

The company ensures and maintains clean working environments by returning tools to their respective areas, removing any tripping hazards from the floor, and organizing tools and equipment to eliminate clutter. These are just some of the many safety precautions that are initiated by the employees to ensure a healthy workplace. A Job Safety Analysis (JSA) provides the stepping-stones for members to follow, identifies potential hazards before starting the task, and recommends the safest way for the task to be completed. The safety coordinator documented any changes to the forms during the manufacturing procedures. The North Paulding Robotics safety handbook was readily accessible for review and training throughout the build year.

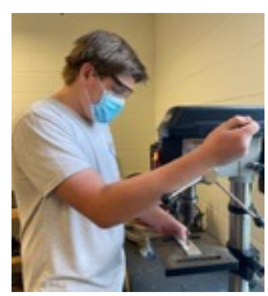

Figure 28: Drilling with proper safety protocol

During the build and design of the ROV, company members are required to wear appropriate clothing when working in the workshop area. Inappropriate clothing includes open-toed shoes and loose-fitting attire. While working with chemicals, such as adhesives, company members are required to wear gloves and safety goggles. In addition, safe working practice dictates that our personnel should not work alone when dealing with power tools. Company members are required to have an adult present when working with any large machinery. Lastly, all members are expected to conduct themselves professionally; misbehavior is not permitted in the ROV work area.

TRAINING

Training is an important tool for informing workers and managers about workplace hazards and controls, so they can work more safely and be more productive. Training incorporates awareness and understanding of workplace hazards and how to identify, report, and control them. Also, specialized training is offered when work involves unique hazards or the introduction of new machinery. One aspect of North Paulding robotics is the peer-to-peer training that is given to the new employees. Veteran members teach new members and mentor them while they are learning to operate machinery and techniques such as soldering. All employees are subject to training at the beginning of the build year to refresh safety protocol and use of new tools. The company emphasizes that the program can only work when everyone involved feels comfortable discussing concerns, making suggestions, and reporting injuries, incidents, and hazards. In doing so, the company can be successful moving forward knowing that safety is their number one concern.

VEHICLE SAFETY PROCEDURES

The company designed the ROV for rapid deployment and simple operation without sacrificing quality and versatility. To accomplish this, the company integrated special safety features to keep the crew, work environment, and ROV safe during operation and testing. At the start of every year, North Paulding Robotics develops a plan for the ROV that is compliant with the MATE safety handbook. The ROV frame does not have sharp edges that could cause injury during the deployment and transportation of the ROV. The ROV thrusters are housed within the aluminum frame. This prevents objects from contacting the propellers, ensuring the safety of the thrusters and the surrounding marine environment. Safety labels are placed on the surrounding casing of the thrusters, indicating that the moving propellers could cause harm.

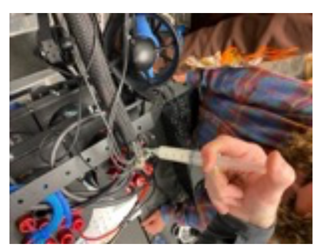

Figure 29: Safety measures implemented on ROV include no sharp edges, danger labels on thrusters, tether restraint and epoxying wires for watertight seal.

The control box is clearly labeled to prevent wires from being switched or connected incorrectly. The clear canisters housing the onboard electronics allow for easy detection of water leakage during the operation of the ROV. All cables inside the frame are secured away from the moving propellers. A fuse is attached to prevent the ROV from exceeding the maximum operation value of 25 amps. All connections are waterproofed with liquid tape. The

Figure 30: Safety measures implemented for surface components include warning labels to prevent water damage

control system is constructed from watertight 6-inch acrylic tubes with watertight end caps. The ROV is free from any chemical substances or pollutants that may affect or harm the marine environment.

OPERATION AND SAFETY CHECKLIST

All Members operating the ROV are required to follow the safety checklist before the deployment and operation of the ROV to ensure the safety of the company and the robot. A visual inspection of the ROV's electronics and hardware will be conducted before operation to ensure that any potential issues can be addressed before the ROV is in the water. In addition, a deck command list will be maintained by the company during testing within the pool to ensure the safety of the crew members and to minimize the potential damage to the ROV (Appendix A).

LOGISTICS

COMPANY STRUCTURE AND TEAMWORK

North Paulding Robotics showed exceptional teamwork throughout the building process and the preparation for the competition. At the beginning of the year, the company was split into four different segments (Frame, Micro ROV, Code, and Manipulator) to work on key parts of the ROV. This allowed the company to finish the designated jobs at a much higher level of efficiency.

Company members were assigned roles based on their understanding of the tasks, as well as the strengths, skill-level, experience, and interests of each company member. These members were then organized under division leaders with one division leader responsible for each segment. The division leaders collaborated, voiced their concerns, and informed the CEO of any potential delays or changes in the build to ensure a successful construction of the ROV.

BUDGET AND PROJECT COSTING

Our company proposed a budget for vehicle development after reviewing the requirements for the 2021 MATE competition and the expenses incurred from previous builds. The company pledged $5,000.00 for vehicle development and $2,500.00 for operating expenses, including travel and accommodation. Actual vehicle development costs totaled $4,166.00 and operating expenses totaled $2,279.00. The company stayed on budget with a remaining balance of $155.00.

The team is a self-funded program that relies on fees, donations, and fundraisers. The company works with a limited income, and expenditures are closely monitored. Employees track all purchases through quick books, scanning all receipts and packing slips to keep track of all expenditures. The budget and costing sheets can be found in Tables 3 and 4.

Operating Income 2020-2021		
Fees	Company member's fees ($175 per company members, total 12 members)	$2,100.00
Donations	Donations/ STEM Days/ Fundraising	$3,000.00
Carryover	Funds carried over from 2019-2020 build year	$1,500.00
	Total operating income	$6,600.00
Operating costs 2020-2021		
Travel	Hotel costs, transport, food for 7 members	$2,079.00
Registration fees	MATE registration fee	$200.00
	Total operating costs	$2,279.00
	Balance	$4321.00

Table 3: Operating income and costs for 2020-2021 ROV build.

Component	Item	Description	Type	Amount	Quantity	Running Total
Frame	1/8 Aluminum metal	KSU donation	Purchased	$200.00	1	$2000.00
	CNC Framing parts	KSU loaned machine time	Donated	$150.00	1	$0.00
	Nuts and bolts		Purchased	$30.00	1	$30.00
Thrusters	T100 Thrusters	2 up/down, 4 forward/reverse	Purchased	$200.00	4	$800.00
	3D Printed Guards	Guards to protect propellers	Printed	$30.00	4	$120.00
	Screws	Screws for mounting	Purchased	$30.00	1	$30.00
Arm	Savox Servo	Turning and tilt mechanism	Purchased	$81.99	6	$491.94
	Brackets	Sliding mechanism for arm	Purchased	$104.95	1	$104.95
Tether	Tech Flex covering	Encloses and protects tether wires	Purchased	$14.79	1	$14.79
	Conductor wire	16 meters 16 AWG 2 – wire	Purchased	$19.99	1	$19.99
	CAT 6 cable	16 meters	Purchased	$47.99	1	$47.99
	Ethernet cable	100ft	Purchased	$56.99	1	$56.99
Housing	Cast Acrylic Tube 4inch	2 housing for electrical components	Purchased	$90.00	2	$180.00
	Aluminum End Cap	13 holes, 6 inches, seals the caps	Purchased	$44.00	4	$176.00
	O-Ring Flange	6 Inches diameter, waterproofing	Purchased	$59.00	2	$118.00
	Cable Penetrator	Tether input	Purchased	$4.00	4	$16.00
	Molex connectors	Detachable tether	Purchased	$9.75	100	$9.75
	Relay module	Jbtek 4 channel DC 5V	Purchased	$6.99	4	$27.99
	TP link 5-port Switch		Reused	$9.95	1	$0.00
	Arduino stackable header kit		Purchased	$5.70	1	5.70
	Shelving house	28 Mounts for onboard box	Purchased	$6.00	1	$6.00
	DROK mini voltage converter		Purchased	$18.86	4	$75.44
Box	Silver case	Housing for components	Purchased	$54.99	1	$54.99
	On/off switch		Reused	$21.99	1	$0.00
	Laptop	Coding	Purchased	3200.00	1	$300.00
Cameras	Cameras	High-definition cameras	Purchased	$79.00	4	$316.00
	Tilting Mounting Bracket	Servo City Tilt camera	Purchased	$24.99	1	$24.99
	Video Quad Splitter		Reused	$50.49	1	$50.49
	Savox servo		Purchased	$89.00	1	$89.00
Buoyancy	Paint		Purchased	$8.00	1	$8.00
	High Subsea Foam		Purchased	$139.00	1	$139.00
	Washers and bolts for attachment		Purchased	$35.00	1	$35.00
Control	Logitech 3D Pro Flight Stick	Control the ROV	Reused	$72.50	2	$145.00
	Computer Monitor	View from 4 cameras	Reused	$298.00	1	$298.00
Micro ROV	3D printed housing base	House electronics	Purchased	$29.99	1	29.99
	motors	12 V brushless motor	Purchased	$24.99	2	$24.99
	Arduino Board		Purchased	$22.00	1	$22.00
	Switch		Purchased	$14.00	2	$24.00
	9V batteries		Purchased	$7.00	1	$7.00
	Electronic housing and components		Donated	197.00	1	0.00
Payloads	Ping Pong Retrieving Mechanism	3 D printed	Printed	$29.99	1	$29.99
	Seabin power connector	PVC connectors	Reused	$20.00	1	0.00
	Magnet for test peg	3 D printed and magnet	Reused	0.00	1	0.00
					Total Project Cost	$4166.00

Table 4: project costing and sheet for 2020-2021 ROV build

TROUBLESHOOTING AND TESTING TECHNIQUES

Testing and troubleshooting are an integral key step to the iterative design process outlined in the company's design rationale. Each feature of the ROV is constantly evaluated for both performance and reliability to ensure these traits are carried forward to the main ROV. For example, if the manipulator is designed to assist with planting an ox bile injection device to cull an outbreak of Crown of Thorn Sea stars, it will be evaluated on how well it can grab and plant the devices as well as how reliably it can perform the task over several trials. Possible improvements are then analyzed and may result in another iteration of the design if performance (such as the speed at which the manipulator can grab an injection device) or reliability (example: improving the rigidity of manipulator linkages so they do not break under the stress of multiple mission runs) can be improved.

The testing process of North Paulding Robotics is deeply rooted within the iterative design process and is greatly effective for improving already working designs. However, features almost never work on the first design, and combining features on the main ROV often results in problems spanning multiple discipline areas. When troubleshooting, the first step taken is to gather everyone relevant to the issue at hand. If the problem is within a singular feature, the design team who created it will gather to resolve issues. If the problem is between multiple features of the ROV, the relevant design teams will gather together to offer their expertise on the problem. After everyone is present, the issue is isolated. For example, if pressing the control joystick forward is expected to activate all motors, but the front right motor is not spinning, the exact motor will be isolated as not working. This allows the programming team to check the area of code pertaining to that specific motor and the electrical team to check the wiring to the front right motor rather than all of the wiring. Usually, a simple check reveals the problem, and the issue is quickly resolved. Sometimes, multiple changes could fix the problem. When troubleshooting, the company is careful to change only one thing at a time. This helps identify and converge on exactly what change works and eliminates any confusion about what is contributing to the issue. This process of troubleshooting combined with the rigorous testing dictated by iterative design ensures that North Paulding Robotics can efficiently bring the best product possible to market while reacting quickly to any issues along the way.

Figure 31: Team member troubleshooting code

OUTREACH

In response to the COVID 2019 crisis, the company was eager to use our unique skills and capabilities to support our local communities. The company focused on two initiatives:

- Building hands-free hand sanitizer dispensers for our local schools
- Printing ear guards to distribute to local hospitals and health care workers

Figure 32: Hand sanitizing stations

In total, North Paulding Robotics built 56 hand sanitizing stations for teachers at Sammy McClure Middle School and Shelton Elementary school to assist in the efforts allowing students to return to school safely. The stations were constructed from ½ inch and 1-inch PVC pipes and connectors, spray painted our school colors, and included our robotics logo. They were distributed and placed in the classrooms during the first week of school. Each device took 2 hours to build, glue, and paint.

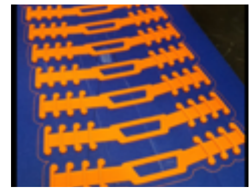

Figure 33: 3D printed ear guards

Watching the news and the outcry from our essential workers, nursing staff, and doctors, the company became familiarized with the personal discomfort that the long-term use of face masks had on individuals. The masks were irritating the skin behind the ears over time. The company leveraged an open-source design and started 3D printing the ear guards to distribute to local hospitals and health care workers. The ear guards were printed using 3D filament that the team had on hand. In total, more than 900 were distributed to local hospitals including, WellStar Paulding Hospital, Kennestone Hospital, Children's Healthcare of Atlanta Urgent Care, and the Harbin clinic. In response to social media requests, ear guards were also distributed to caring individuals out of state for their own small healthcare teams.

It was extremely rewarding to know that we could contribute in some small way to aid our community and essential workers during this unprecedented crisis.

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North Paulding Robotics would like to recognize several sponsors and individuals for their continuous support and help throughout the year.

• MATE Center and Gray's Reef National Sanctuary for creating the 2021 missions and organizing the competitions.

• Huge shout out to our **GOLD Level Team Sponsors** for helping us raise the funds needed to go to the 2021 MATE World Championships.

• Governors Towne Club for allowing us the use of their pool to practice for the event.

• Evans structural Engineering, EY, Pearson Packaging Systems, Quality Cuts Landscaping, Factory automation systems, Remax Unlimited, Proshine and Think GA Homes for their generous donations towards our program.

• Mr. Gardener and Mrs. Lees for the continuous help and support throughout the year.

• MATE sponsors (Marine Technology Society, Marine Technology Society ROV Committee, National Oceanic and Atmospheric Administration (NOAA), National Science Foundation (NSF), Oceaneering, Marine Technology Society, Ballad Health, TVA, Teledyne Marine, Department of Environment and Conservation, Martin Klein, Eastman Foundation, bioPure, and Motorola Solutions Foundation.

• Longhorn Steakhouse, Southland Greenhouse, and the Dallas Rotary Club for allowing us to host multiple fundraising events.

• SolidWorks for free student license software.

• Glen Lewis and Michael Lees, former team members, for their assistance and guidance with training for our new members.

APPENDIX A- OPERATIONS SAFETY CHECKLIST

PROCEDURE	CHECK
PRE-POWER CHECKS	
ALL team members are wearing correct attire when poolside.	
Operational area is clear of obstructions	
Check to make sure ROV power is off before conducting safety checks	
Check fuse is in place and operational	
All components of ROV are secured in place (tether, arm, cameras)	
ROV and tether are free of sharp edges	
ROV thruster shrouds are in place and secure	
Manipulator is secure and can move freely	
All tether and cable connections are secured and waterproofed	
Onboard control boxes are secure and end caps are securely fastened	
Call out "Safe"	
PRE-WATER CHECKS	
Connect tether and power cables to power box	
Call out "Power On" "Hands Clear"	
Check operation of cameras and video feed	
Check movement of manipulator and tilt camera	
Call out "ROV in"	
IN-WATER CHECKS	
Test up and down thrusters	
Test forward and backward thrusters	
ROV OUT CHECKS	
Wait for ROV to return to the surface	
Call out "Power off"	
Remove the ROV from the pool, facing the manipulator away from the pool edge.	
Place ROV on pool deck	
Retrieve and place tether neatly to one side	

APPENDIX B – SID MICRO ROV AND SEABIN POWER CONNECTOR

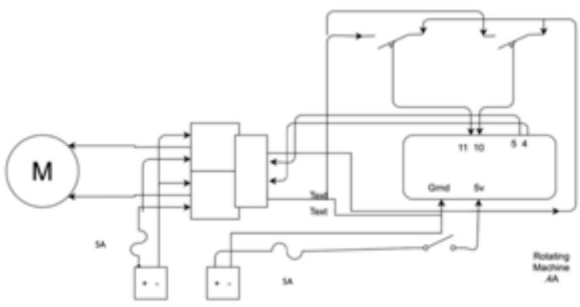


Figure 39: Micro ROV SID

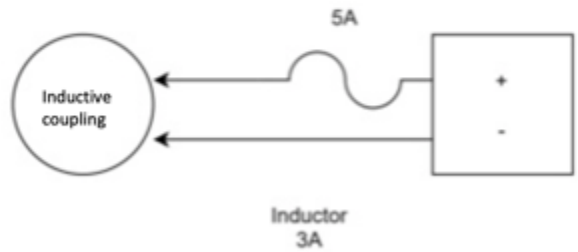
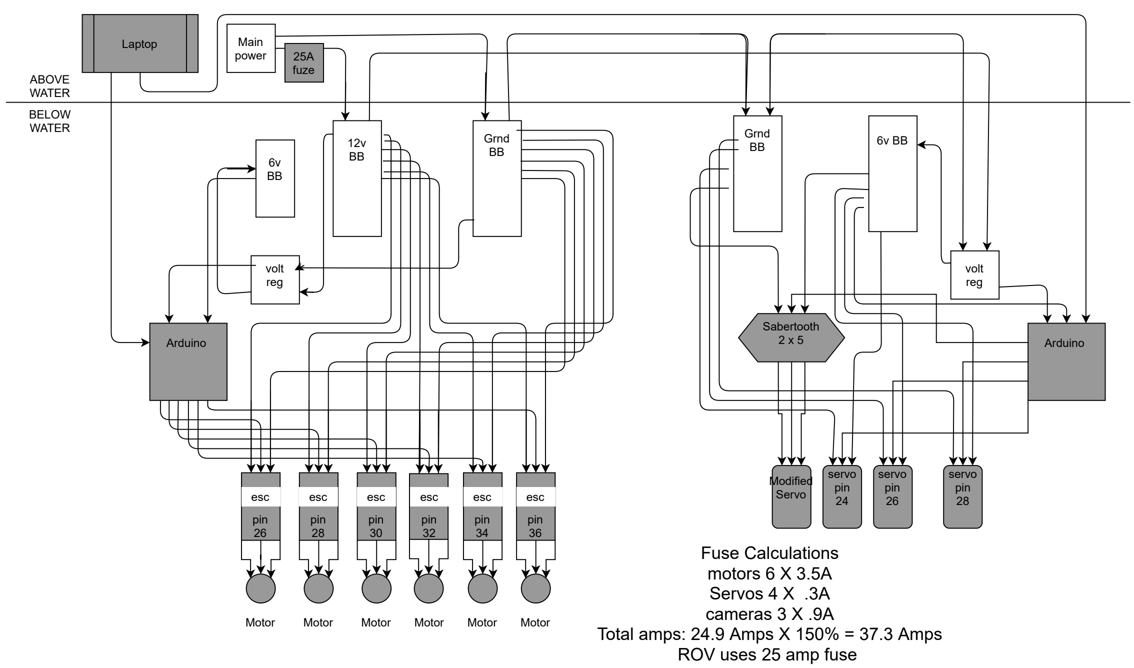


Figure 40. Seabin Power connector SID

APPENDIX C – SID MAIN ROV



APPENDIX D - FLOW CHART