PROVEN ROBOTICS

PURDUE ROV

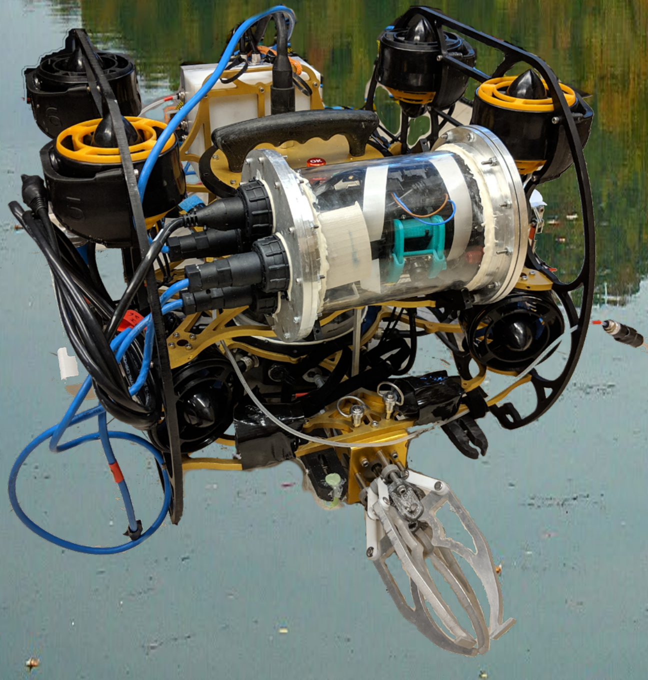
2019 Technical Documentation

Innovations for Inshore: ROV Operations in Rivers, Lakes, and Dams

PURDUE UNIVERSITY
West Lafayette, IN USA

ROV *Remora*

Remotely Exploring Marine Organisms and Recovering Artifacts



COMPANY EMPLOYEES

NAME	POSITION
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Jason King	Electrical Department Lead
Jonathan Kline	Mechanical Department Lead (Fall)
Tyler Stagge	Mechanical Department Lead (Spring)
Ben Maxfield	Software Department Co-Lead
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Cynthia Zatlokowicz	Power and Enclosures Head
Grant Geyer	Sensors and Cameras Head
Jacob Bobson	Logic and Enclosures Head
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I. INTRODUCTION

Abstract

Proven Robotics developed a Remotely Operated underwater Vehicle (ROV) that satisfies the request for proposals from Eastman Chemical Company. The vehicle can complete a wide range of tasks in a variety of inland waterways. These tasks include inspecting and repairing a dam, determining the size and weight of a Civil War cannon, returning it to the surface, and repopulating lakes and streams with fish. The 54-person company worked tirelessly throughout the year to produce ROV *Remora*, one of the most technologically advanced ROVs in company history. This ROV is designed, built, and tested in-house to ensure it can complete every mission.

Proven Robotics is broken down into four departments: Mechanical, Electrical, Software, and Administrative. Each focuses on their respective areas within the company. Cross-disciplinary project groups were utilized to focus on separate vehicle system, to improve communication between departments, and to coordinate over 7,000 work-hours put into ROV *Remora*. Safety, scheduling, and budget constraints were taken into account throughout the year. Multiple iterations of each mission tool were designed and tested to ensure that each one could successfully complete its task.

Improved robustness of ROV *Remora* was the key design consideration for the year. Several new features were introduced to achieve this, including Ethernet cameras and Controller Area Network (CAN) for communications. A new electronics architecture reduces noise for the Raspberry Pi, and a new electronics enclosure design increases serviceability to boards and waterproof connectors.

The following technical document discusses the design rationale and process used to create ROV *Remora*.

Fig. 1 - Proven Robotics 2019 Team

II. Safety

A. Safety Philosophy

Safety is of the utmost importance at Proven Robotics. Providing a safe work environment not only helps prevent workplace injuries, but also improves employee comfort and productivity. The safety of all employees, bystanders, and equipment is considered whenever an action is taken or a product is used. All employees must be trained before using heavy machinery, chemicals, or heating elements. New employees are mentored by more experienced employees to ensure they are working in a safe manner.

Fig. 2 - Employee using a rotary tool in the lab

B. Safety Standards

Proven Robotics has several safety procedures that every employee must follow when working on ROV *Remora*. Personal protective equipment (PPE) is available to every employee in the workspace. This includes eye protection, dust masks, eye wash stations, shower stations, first aid kits, and fire extinguishers. Employees are required to use safety glasses when operating the drill press, the band saw, or other power tools. Employees are also required to wear a dust mask if working with fiberglass. Proven Robotics' workspace is located on Purdue University's campus, providing safe access to all employees. In the event that an employee must work in another environment with different safety standards, such as an on campus machine shop, the stricter set of the two safety standards is followed (Ref 11).

Fig. 3 - New employees learning safe soldering practices

C. Safety Features

There are several safety features built into ROV *Remora*. These include a master fuse on the tether, a strain relief cord for the tether, smooth rounded frame pieces, and a pressure relief on the solenoid enclosures. Any time the vehicle is deployed, a safety checklist (See Appendix) is used to ensure all employees and bystanders are kept safe when the vehicle is running, and that the vehicle is kept safe.

Another safety feature on the ROV is protective shrouds on all thrusters. They were designed to sufficiently block objects larger than 12.5 mm while minimizing the reduced water flow to the thrusters. The shrouds are 3D-printed in-house and use a series of rings to accomplish this. The front shrouds attach using snap fit connectors, while the back shrouds use a friction fit.

Fig. 4 - Shroud on the back of a Blue Robotics T200 thruster

The ROV's software gives the pilot information on its systems so they can determine whether the vehicle is working properly before it is placed in the water. Once it has been determined that the ROV is working properly, the pilot instructs two poolside workers to deploy the ROV. Information about the thrusters and other systems is continuously updated on the pilot's screen, and if anything becomes unsafe, the pilot can quickly shut down the ROV. Any unexpected loss of communication will also shut down the ROV, which puts it into a safe mode shutting off all thrusters.

III. Mechanical Design Rationale

A. Mechanical Overview

In the development of ROV *Remora* the Mechanical Department focused on robustness and end-user ease of use, while still achieving the strictest size and weight requirements. All CAD files and drawings were generated using SOLIDWORKS, and stored and version-controlled using GrabCAD Workbench. To ensure continual progress, communication, and integration, periodic design reviews were held to discuss, iterate, and refine all designs and manufacturing plans. Mock-ups and early prototypes for many components were 3D-printed to test basic functionality and fit while final prototypes were manufactured using both CNC and manual mills and lathes, water-jet cutters, and laser cutters. The design of the vehicle as a whole was largely dictated by the use of eight thrusters and four electronics enclosure designs – all of which were pressure tested in water to a minimum of 200 kPa, ensuring a factor of safety of at least 4 at maximum competition depth. Every mechanical component was custom designed and built by Proven Robotics employees to ensure ROV is optimally designed for this mission. The final vehicle and tether has a mass of 15.51 kg and final dimensions of 42.27 cm x 47.17 cm x 37.64 cm.

B. Frame

ROV frame consists of two vertical side plates, two horizontal plates, and one vertical back plate. These are all connected using hybrid mortise and tenon joints, and secured using bolts. The joints carry stress between the two plates, and the bolts hold them securely in place. Similar to the past two ROVs, the vertical thrusters are placed part way through the vertical side plates, with their line of action coplanar to them oriented vertically. This design optimizes the overall vehicle size and the amount of usable room between the side plates. The frame is made from 6061-T6 aluminum to reduce mass and cost while retaining structural integrity (Ref 1).

The first step in the frame design was to place all waterproof enclosures and tools. When all locations are finalized and attachment points are finalized, sections of the frame plates are removed to reduce mass. Employees used finite element analysis to determine which members are critical for structural integrity, and only those are kept. Overall, about 75% of the mass from the frame plates was removed. The plates were accurately cut using a waterjet, and finished with a colored anodized layer to reduce corrosion and improve visual appeal. The final frame has a mass of 2.16 kg.

C. Power Tube

This vehicle's electrical enclosures were designed to address the two primary issues with its predecessor's Integrated Electronics Tube: electrical noise in the control system and the accessibility of waterproof connectors. To mitigate the electrical noise issue, the Mechanical Department separated the power and logic electrical boards into two separate tubes. The Power Tube receives power from the tether via a SubConn connector in its top end cap. The Power Conversion, Power Distribution,

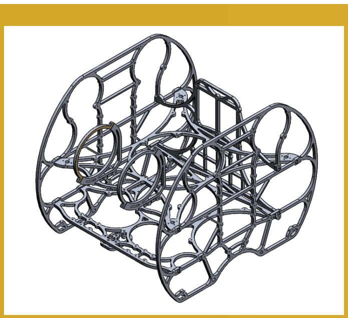


Fig. 5 - CAD of complete frame

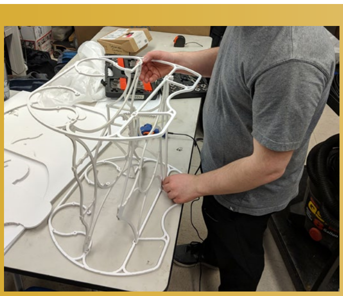


Fig. 6 - A company employee working with a foam board mock-up

Fig. 7 - Final Frame

and ESC Boards are all secured to a mechanical scaffold, removable as a single unit along with this end cap, which, being aluminum, also serves as the primary heat sink. These boards plug into a single Backplane Routing Board, mounted via stress-absorbing springs to the Connector Base at the bottom of the tube. Power is then routed to all thrusters and other enclosures via easily accessible cables positioned radially about the tube.

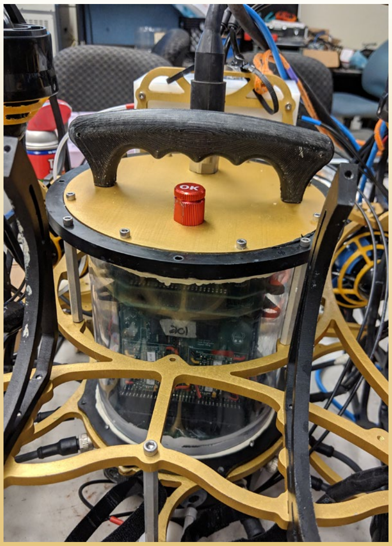


Fig. 8 - Power Tube inside the frame

The Connector Base was machined out of aluminum round stock using a 5 axis CNC mill. The top and bottom flanges and end cap are also machined out of aluminum using a 3 axis CNC mill. A polycarbonate tube is adhered via epoxy to the flanges, which use laser-cut Buna-N gaskets to form a face seal with the Connector Base and end cap. These seals have been found in years past to be the simplest to implement, given its customizability and large tolerances. The bottom flange screws directly into the frame, and the top flange attaches using standoffs.

D. Logic Enclosure

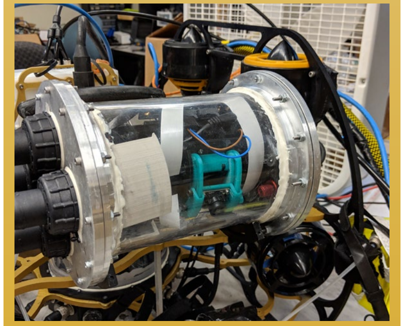


Fig. 9 - Final logic enclosure on ROV Remora

The Logic Enclosure is designed primarily to house the electronics that control the ROV. As will be discussed in the Electrical Design Rationale these electronics include a Raspberry Pi, a Pi Shield, and an Ethernet switch. To avoid electrical noise issues experienced by previous vehicles, dedicated waterproof Ethernet connectors, produced by Samtec, were used. Both the switch and these connectors are quite large – resulting in a large tube in exchange for better signal integrity. A Pi Camera is attached to the Raspberry Pi to give the pilot a forward view. All the electronics are mounted to a sled inside the polycarbonate tube. Flanges are attached to both ends of the tube, and form a face seal with the end caps using gaskets quite similar to the power tube. The flanges and end caps were turned and milled out of aluminum stock. Four Ethernet connectors are embedded in one end cap: the Binders required to power the tube, as well as a vacuum plug, and the temperature and pressure sensors are embedded in the other.

E. Pneumatics and Solenoids

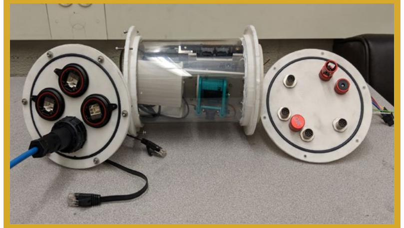


Fig. 10 - Initial version of logic enclosure showing connector and sensor placement

ROV *Remora* utilizes a pneumatic fluid power system to actuate its tools. This was done to reduce the number of electronic speed controls (ESCs) on the ROV, and to improve tool function. An air line bring pressurized air down from the surface and an exhaust line returns air to the surface. The exhaust line isn't strictly necessary, but reduces the head loss of the system having to vent into the ambient water, improving tool functionality. These two lines are routed inside of a custom manufactured manifold block that also functions as the lid to its watertight enclosure. All of the routing to the 5-port solenoids as well as the external fittings for tools are designed into the main manifold, reducing the complexity of the other components of the enclosure. That enclosure is comprised of that manifold base, a high density polyethylene (HDPE) box, and is sealed with a laser cut Buna-N gasket. The solenoids as well as the electronics to control them are housed within this watertight enclosure. This setup allows for individual control of all eight output ports used to control mission tools. Transitioning to a fluid power system for tools provides many more options in terms of what kinds of mechanisms could be employed to solve mission tasks.

F. Cameras

ROV *Remora* uses three cameras to aid the pilot in navigating and completing mission tasks. The primary camera is mounted on a servo inside the logic enclosure, giving the pilot the ability to adjust the camera to the ideal orientation for the current task. A linkage mechanism allows the camera to move 180º without distorting the field of view. An additional two external cameras are used to view the Grout and Trout tool and Cannon Shell Marker when these tools are in use. A third camera and enclosure are used for the Micro-ROV. These cameras are attached to the frame using a universal mounting system that can be attached anywhere along the frame. Two balls on the mount give the camera three angular degrees of freedom. Each camera enclosure includes a bottom and top sub-assembly. In the bottom assembly, the camera is fixtured to the camera end cap using four standoffs and a 3D-printed mounting plate. The camera end cap has three holes for waterproof cable penetrators, which provide camera power, ethernet connection, and pressure testing capabilities. A 3D-printed ring is used to increase the surface area between the tube and disk to increase the strength of the epoxy seal. The camera flange seats an X profile o-ring in its bottom that is used to create a waterproof face seal against the end cap when the enclosure is assembled. When not in use, 3D-printed camera covers screw on to protect the cameras' viewports.

G. Buoyancy and Ballast

To ensure vehicle stability and ease of control, the department added a foam buoyancy system and ballast to the ROV. These moved the center of mass (CoM) and center of buoyancy (CoB) to the center of the ROV, with the CoB directly above the CoM. This orientation makes the ROV stable and is ideal for piloting. Employees used SOLIDWORKS models to calculate the CoM and CoB without foam, and calculated how much foam was needed to stabilize the ROV. Several parts were then machined out of HCP 30 foam and attached to the ROV. This foam was selected because of its high hydraulic crush point of 3000 kPa (Ref 4).

H. Basestation and Tether

The Basestation is Proven Robotics' surface control station. The company decided to reuse the previous year's Basestation and focus design efforts on other technical innovations. One of these innovations is a neutrally buoyant tether. This was designed to improve handling of the ROV by calculating the density of the tether and placing foam along the wires at specific intervals. The tether attaches directly to the ROV with paracord acting as strain relief. The paracord, which is shorter than the wires, is connected to both the ROV and a surface mount. The paracord, Category 6 cable, two 2.05-mm marine-grade power cables, pneumatics lines, and foam are all fed through a snakeskin wrap.

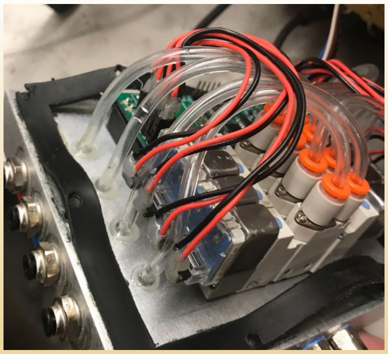


Fig. 11 - Solenoids inside the enclosure

Fig. 12 - Secondary camera housing

Fig. 13 - Universal Mounting System

IV. Mission Tools Rationale

A. Primary Manipulator

The primary manipulator (PM) on ROV *Remora* is an adapted version of the previous year's PM – a "quad-pincer" that allows firm grasps of horizontal and vertical pipes with only one degree of freedom. It uses a similar end effector design, but updates the actuation mechanism to use pneumatic power. This prevents the tool from jamming, a recurring issue from the past few years. It can actuate faster than the electromechanical PM could, and can apply a constant gripping force without constant electrical power.

The end effectors are cut out of 6.35-mm aluminum stock for strength and durability. The PM is attached to the frame using a simple quick release mechanism, where the entire assembly slides on and off the frame. This was done to reduce the ROV's size and the keep the pneumatics lines attached to the PM.

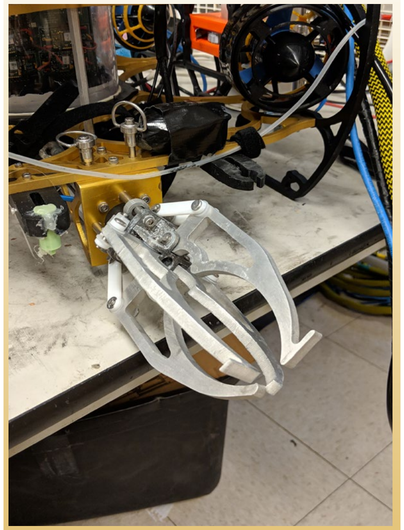


Fig. 14 - Primary Manipulator attached to the ROV

B. Grout and Trout

Proven Robotics decided to design a single tool to complete both the Trout and the Grout task. The Mechanical Department developed two different designs: the Grout/Trout tool that specializes in self alignment and the Grouter tool which maintains neutral buoyancy even when filled with rocks. Both tools have a central cylinder that holds both the grout and trout props, and a pneumatic cylinder that opens a bottom flap. The Grout/Trout tool has a cone on the bottom to align around the grout cup, making it easier for the pilot to accomplish this task. Based on the geometry of the cylinder, the bottom flap is different for the grout and trout and has to be manually changed on the surface. The Grouter tool used a MATLAB script to calculate the volume of the cylinder needed to have the same weight in water when filled with rocks and air compared to when it's filled with water. A gasket on the bottom and an additional top flap seal the cylinder when the pneumatics are actuated, and let water flow when unactuated. This balance makes it easier for the pilot to control the ROV when transporting the grout.

Fig. 15 - Grout/Trout Tool

C. Cannon Shell Marker

The Cannon Shell Marker tool is designed to drop different colored markers to differentiate between exploded and unexploded cannon shells. The tool has a dual action pneumatic cylinder on the side which is attached to a two bar linkage. The linkage translates the dual action cylinder's linear motion to rotary motion. The opposite end of this linkage is attached to a dispensing cylinder, called the dropper, that is directly below the colored markers. This mechanism creates two states for the tool: retrieving new markers and dispensing markers. When pressurized, the mechanism dispenses a marker with minimal outward motion while underwater allowing the ROV to dispense markers very near the desired location. The body of the tool, the dropper, and the two linkages are 3D-printed parts. The pneumatic cylinder is attached to a standoff on

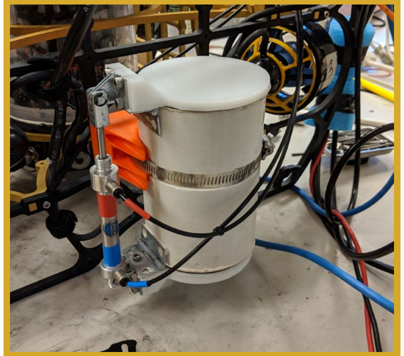


Fig. 16 - Grouter

the tool body with a 5⁄8" - 18 nut. The linkages are connected with a flathead M5 machine screw and M5 bolt. The flathead machine screw was selected to reduce friction between the linkage and the tool body. The linkage is connected to the dispensing cylinder with a 6/32" screw and corresponding threaded insert. The threaded insert was selected to provide a rigid connection between the linkage and the dropper by permanently melting the insert into the dropper.

Fig. 17 - Cannon Shell Marker tool

D. Micro-ROV

The Micro-ROV is a smaller, projectile-like vehicle deployed from the primary ROV for the purpose of inspecting pipes. It was designed to be as simple as possible – from both a functional and developmental standpoint. The Micro-ROV uses an adapted version of the existing Camera Enclosure, attached to the front of a Blue Robotics T200 thruster, and powered via a copper-wire tether from the main ROV. Its body consists of two nearly identical plastic shells that secure the camera and thruster in place, route the tether cables, and allow the flow of water through large intakes. These parts were 3D-printed out of PET-G and fastened to one another using cap screws and heat-set threaded inserts. This design results in a simple, balanced, easy-to-manufacture design, and a smooth exterior profile, allowing the vehicle to slide without hindrance through the required 152-mm Corex pipe without the complexity of control surfaces or thrust vectoring.

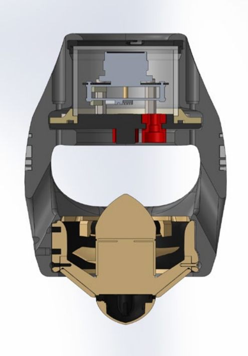


Fig. 18 - Cross Section of the Micro-ROV

Fig. 19 - Isometric view of the Micro-ROV

E. Mantis Claw and Lift Bag

The Mantis Claw is a simple, gravity-operated claw designed to pick up objects the PM cannot. When pushed onto an object, the end effectors are pushed out then fall back underneath the object. The weight of the object pushing down on the end effectors prevents the object from falling out. This tool is used to retrieve the cannon, and is attached to a PVC scaffold along with a lift bag. This mechanism is mechanically independent of the ROV, and is held with the PM. A separate pneumatics line inflates the bag, which causes the entire mechanism to return to the surface.

Research and testing conducted by Proven Robotics determined that commercial lift bags were readily available and more reliable than any of the evaluated in-house options. Therefore, an open-bottom lift bag from Carter Lift Bag, Inc. was chosen (Ref 3). The selected CB-25 lift bag supplies a lift of 111.21 N when fully inflated and has dimensions of 38.1 cm x 50.8 cm. The lift bag must be able to be stored on the ROV, so this relatively small size was desirable. A small PVC pipe ring keeps the lift bag compact until the pneumatic line fills the bag with air. Once filled with air the valve at the end of the pneumatic line ensures water does not backfill into the pneumatic line.

Fig. 20 - Mantis Claw and Lift Bag Assembly

Fig. 21 - Progression of the Mantis Claw pick up the cannon

V. Electrical Design Rationale

A. Electrical Overview

ROV *Remora* electronics are designed for compact size and reliability. The ROV is controlled from the surface using a laptop computer and gaming controller, and is powered by a 48-V supply. Control data is sent directly from the laptop's Ethernet port to the ROV's Logic Enclosure using a Category 6 cable, where it connects to the onboard Raspberry Pi through a compact Ethernet switch. Category 6 cable is used because it provides high data throughput for the Ethernet cameras on the ROV, while maintaining data integrity through the cable's natural noise immunity. 48 V is delivered to the ROV's Power Tube using two 2.05-mm diameter marine-grade wires with an in-line 25-A fuse.

The Power Tube houses two Power Bricks Boards (PBBs), the Power Distribution Board (PDB), Power Conversion Board (PCB), three Electronic Speed Controller boards (ESCs), and a Backplane Routing Board. These are placed in a vertical stack in the order previously specified with the PBBs at the top of the stack. 48 V enters the Power Tube and is converted to 12 V by the Power Brick boards. The Power Distribution board then routes the 12-V power bus to the Power Conversion board which produces 5 V using a buck regulator circuit, and 3 V using a linear regulator from the 5-V power bus. These power buses are then routed to the ESC board and in turn routed to the Backplane Routing Board. The Backplane Routing Board routes all signals to the thrusters, Micro-ROV, Solenoid Enclosure, and Logic Enclosure, and motorized tools.

The Logic Enclosure contains the Raspberry Pi, the Pi Shield board, the Raspberry Pi Camera, and the on-board Ethernet switch. The Raspberry Pi Shield contains connections for 5 V, I^{2}C for connections to sensors, and Controller Area Network (CAN) bus for connections to the other boards in the electronics system. The Pi connects to the Pi Shield board through header pins and provides the processing capabilities of ROV *Remora*. The Ethernet switch provides connections to the Raspberry Pi, the two Ethernet cameras present on ROV *Remora*, and the Micro-ROV.

The Solenoid Enclosure houses the Solenoid Control Board which communicates with the Raspberry Pi through the CAN bus. A boost converter increases the voltage from 12 V to 24 V. The four solenoids are controlled by a MOSFET on the Solenoid Control Board, which direct the flow of pressurized air in the pneumatics system. All circuit boards with the exception of the Raspberry Pi, ESCs, solenoid latches, and Ethernet switch were designed by the department using EAGLE and populated in-house.

B. Power Bricks Board

The Power Bricks Board serves as a mount for the power bricks. The bricks receive the 48-V supply from the tether and use a buck converter to provide a 12-V power bus. The board allows the bricks to be broken out using connectors and attached to other boards. ROV *Remora* uses a different brand of bricks, produced by Delta. ROV *Remora* uses two quarter bricks instead of four eighth bricks used on previous ROVs to save space. These bricks also require less supporting circuitry than previous years, only requiring three bulk capacitors across the 48-V input. In the design of the boards, the bricks' documentation suggested a mirrored pinout from the physical design. This was discovered after the boards were tested and the boards did not work properly. A correct, mirrored revision

Fig. 22 - Full power electronics stack

of the board was quickly ordered. The bricks can provide up to 600 W of power each, sourcing up to 50 A each. The bricks are heat sunk to end cap of the Power Tube in order to prevent the electronics from overheating.

C. Power Distribution Board

The Power Distribution Board receives 48 V from the tether and sends it through a reverse voltage protection circuit. It then goes through an on/off circuit which prevents damage to the bricks by allowing the bricks to all turn on simultaneously once the voltage exceeds 36 V when the bricks are in a parallel configuration. This configuration also allows for load sharing. Then the 48 V is sent to the power bricks and two separate 12-V lines are sent back where they are tied together with two OR-ing diodes. This 12 V is then distributed to the Power Conversion Board.

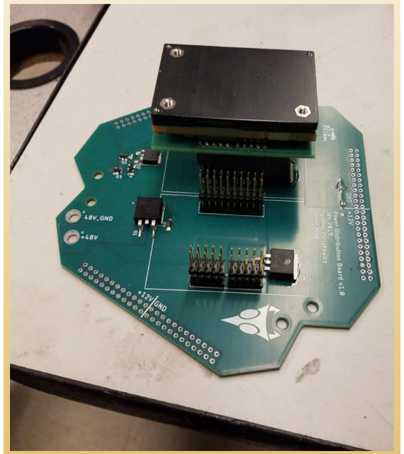


Fig. 23 - Power Distribution Board with power bricks

D. Power Conversion Board

The Power Conversion Board receives 12 V from the Power Distribution Board and outputs 12 V, 5 V, and 3.3 V to the ESC Board. The board uses two switching buck regulators to convert 12 V to two separate 5-V lines while reducing noise to maintain a stable signal used for the Raspberry Pi and Ethernet hub. It uses a linear regulation to convert the second 5-V line to 3.3 V, for a more stable 3.3-V supply for microcontrollers.. Both the 5-V regulator and the 3.3-V regulator requires supporting circuitry for the regulators to work. Two separate lines of 12-to-5 V and 12-to-5-to-3.3 V were designed for precautionary reasons so that the 5-V line would not interfere with the 3.3-V output. A snub circuit of capacitors as well as a split inductance were implemented into the circuit to reduce noise. After testing, the split inductance created additional noise, so the circuit was reverted to the original single inductor design.

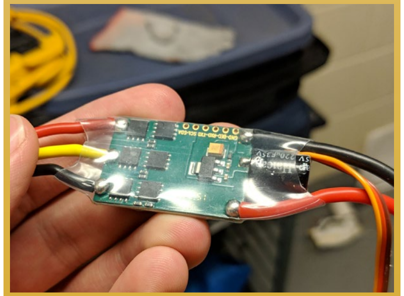


Fig. 24- Commercial ESC

E. Electronic Speed Controller (ESC) Boards

Each of the three ESC Boards is responsible for powering four ESCs, which actuate the eight thrusters. This board works by receiving 12 V, 5 V, and 3.3 V from the Power Distribution Board. The current draw of the ESCs is monitored using an INA4181A4 current sensor and shunt resistor. The 12-V input directly powers the individual ESCs and the 3.3-V input is used to power all other active components, including the onboard STM32 microcontroller, TCAN337D CAN transceiver, and the INA4181A4 current sensor. The 5 V are passed directly to Backplane Routing Board. There are a total of eight thrusters on the ROV *Remora* and one on the Micro-ROV and therefore only nine of the total twelve ESCs onboard the ROV are used. The inclusion of the three additional ESCs are a failsafe if an individual ESC fails or if motors are needed for mission tools. ESCs are chosen as they provide high efficiency control over the brushless DC motors.

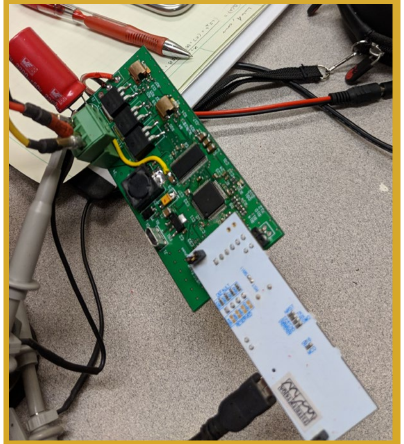


Fig. 25- Proven Robotics-designed ESC

G. Blue Robotics T200 Thrusters and Custom ESCs

ROV *Remora* uses Blue Robotics T200 thrusters, which have been used on the past three ROVs. These thrusters are both low cost and small, while still providing high power and reliability, as seen in past years. At the beginning of this year, the company decided to design custom

ESCs. Designing custom ESCs, rather than buying them like the company has in the past, provided a unique learning opportunity for employees to get a deeper understanding of embedded hardware. Making the ESCs in-house also allows for greater customizability versus simply buying ESCs as the controller components could be easily broken out, and peripheral components could be more easily added. One key advantage is that custom controllers make it easier to monitor the current draw from each thruster. The custom ESCs were developed for ROV *Remora* and will be implemented on next year's ROV.

G. Raspberry Pi and Pi Shield

The department continued to use a Raspberry Pi 3 Model B+ for ROV control, as software employees can easily interface with it. The Pi Shield board mounts the Raspberry Pi and communicates with different sensors on the ROV through a variety of interfaces. The Pi Shield receives 5 V from the Power Distribution Board through the Connector Base which is used to power the Raspberry Pi. The Pi Shield routes many of the sensors that ROV *Remora* uses to the Raspberry Pi, namely the inertial measurement unit (IMU), the depth sensor, the temperature sensor, and the pH sensor. All sensors communicate with the Raspberry Pi over I^{2}C and are powered by a 3.3-V linear regulator on the Pi Shield board. The board has a CAN transceiver for communication and control of the ESCs and tools.

H. Backplane Routing Board

The Backplane Routing Board receives 5 V and 12 V from the ESC boards. The board routes 5 V and CAN bus to the logic enclosure, 12 V and CAN bus to the solenoid enclosure, CAN bus to the ESC boards. ESC boards are connected via large board-to-board connectors.

I. Ethernet Cameras

This year Proven Robotics decided to use Ethernet cameras for the ROV. These cameras were chosen because they have better signal integrity than previous year's USB Cameras. One issue the department faced last year was the Pi not having enough throughput to connect to all four USB cameras at the same time. The three Ethernet cameras connect via a five-port Ethernet switch, with one port going to the surface and one port going to the Raspberry Pi.

J. Sensors

ROV *Remora* is equipped with four different external sensors: pH, temperature, pressure, and IMU. The pH and temperature are used to complete tasks during the product demonstration. The pressure and IMU help the pilot orient the ROV in the pool. All four sensors connect to the Raspberry Pi over I^{2}C.

Fig. 26 - Ethernet Camera

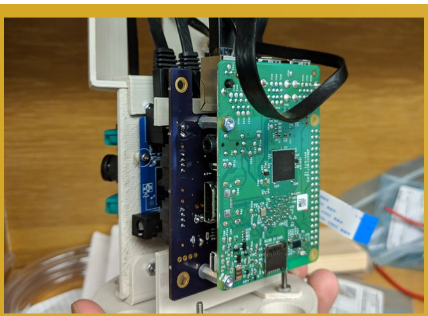


Fig. 27 - Ethernet Switch, Raspberry Pi, and Pi Shield

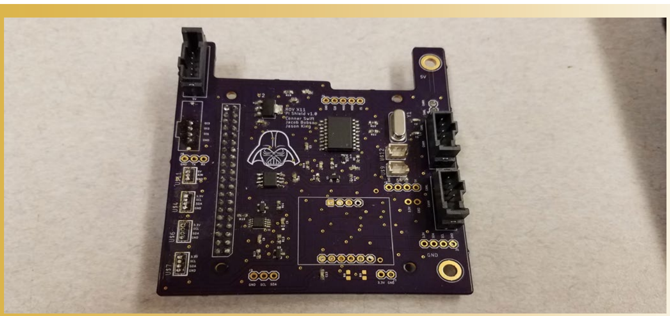


Fig. 28 - Pi Shield

VI. Software Design Rationale

A. Software Overview

Proven Robotics aims to make the software structure of the ROV more flexible, dynamic, and testable from year to year. This year, with the help of the ROS middleware, this goal has been realized further. The design is now more modular and unit-based than ever, with the system able to be broken down into independently functioning nodes that contain integrating diagnosis tools, automatic connection and routing, and reduced failure propagation. From this the Software Department has seen the main development cycle become drastically reduced in complexity.

While a client-server model is still in place between the pilot's driving interface and the main control software, ROS and ReactJS have become the two main environments for the Proven Robotics software. A server run by one of the ROS nodes allows for communication between the Electron application hosting the web development environment for ReactJS and the main ROS application. This allows both ends to exercise their strengths separately, with an agreed mode of communication between them to permit cohesive updates of controls and sensory information through the full system. Furthermore, ROS simplifies the issue of communication from the BattleStation down to the Raspberry Pi on the ROV itself, handling Ethernet communication automatically within its internal environment after setting the addresses of the two systems up as environment variables, during the launch process.

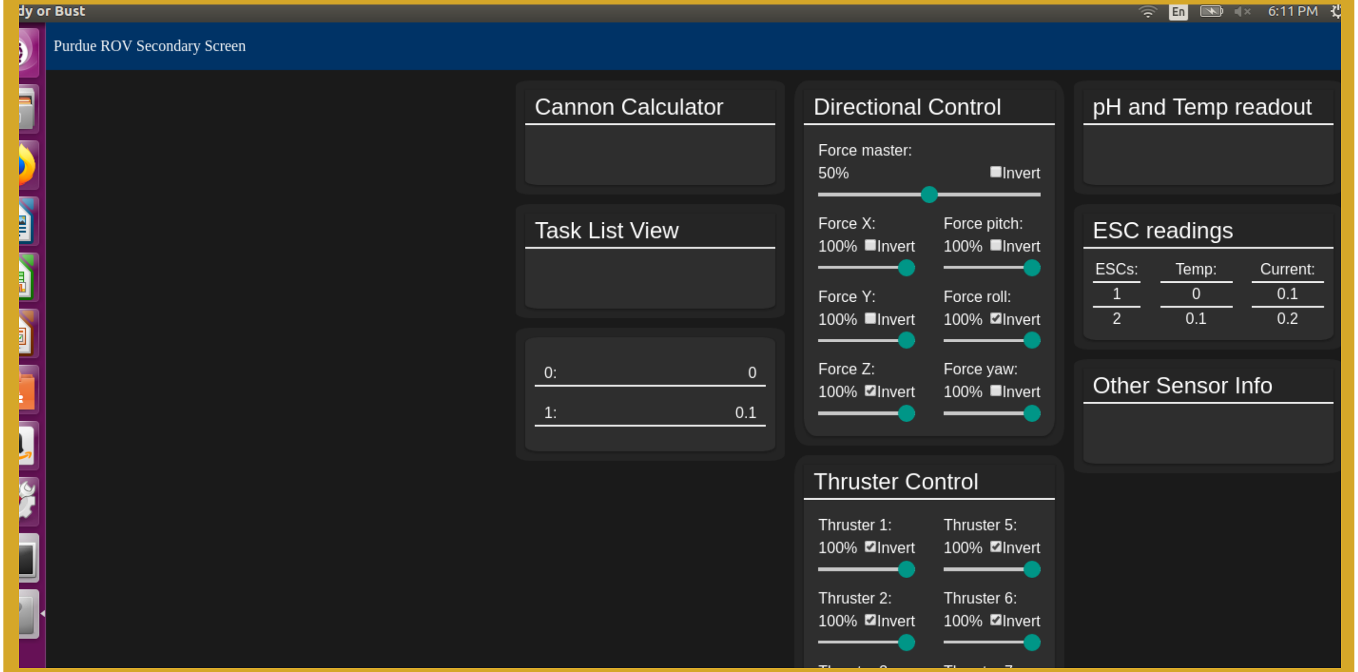
B. BattleStation

The BattleStation includes everything on the surface that the driver and co-pilot interface with, containing both the physical equipment needed for the mission, as well as the software to interface with the ROV. For the pilot, the status of an Xbox Elite controller is read and interpreted into driver controls for the ROV. The driving display was developed modularly using the ReactJS framework within an Electron environment, while communication with the ROV itself was achieved by implementing a web-based interface in a ROS node, described in more detail in the ROS section below.

This year, both ROS and ReactJS give the Software Department the power to make modular and reusable components, though the pilot UI capitalizes on the previously written ReactJS code moreso than newly written ROS code. The components are intended to assist in the completion of the pilot's tasks, as they provide critical information — anything from checking proper controller registration, to a 15-minute mission timer.

Another major focus of the BattleStation is the camera display, as it's essential for the driver to actively see the surroundings of the ROV during operation. The BattleStation was given the ability to switch between these feeds during drive time, to modularly allow for one or more cameras. The BattleStation also has an extra-wide screen, in addition to the laptop's screen, to allow for a display of extra camera angles, sensor readouts, or power scaling tools, without cramming the viewspace for any particular piece. Any camera can be viewed from either the laptop screen or the external one, without losing space for the informational displays for the driver.

Additional components range from pure informational aids like control scaling and sensory readouts, to more dynamic assistance like the task checklist, or the detected line graph: once the data has been read in and relayed to the BattleStation, the component enables the driver to generate a graph showing what grid the line was discovered in, and the observed length of the line. This and other components allow for the driver to focus on their mission goals and not worry about calculation or analyzation details.



0: 0

1: 0.1

Force master: 50% ☐Invert

Force X: 100% ☐Invert

Force pitch: 100% ☐Invert

Force Y: 100% ☐Invert

Force roll: 100% ☑Invert

Force Z: 100% ☑Invert

Force yaw: 100% ☐Invert

ESCs:	Temp:	Current:
1	0	0.1
2	0.1	0.2

Thruster 1: 100% ☑Invert

Thruster 5: 100% ☑Invert

Thruster 2: 100% ☑Invert

Thruster 6: 100% ☑Invert

Fig. 29 - BattleStation display showing adjustable thruster controls

C. Robot Operating System (ROS)

The Robot Operating System (ROS) is a middleware that allows for easy communication between processes running on one or multiple computers. Proven Robotics is using ROS specifically for its easy interprocess communication, modularity, and debugging/logging support. Proven Robotics' implementation of ROS is organized into a tiered map of subsystem programs (ROS nodes) which are all independently testable and communicate with each other through ROS's interprocess communication system (ROS topics).

The system's first tier starts on the surface computer and is called the mux-demuxer (named due to its similarities to Simulink's muxing and demuxing of multiple signals into one or multiple signals) as it aggregates ROS topic information from many other ROS subsystems and relays the data to the Battlestation. In reverse, Battlestation commands in the form of JSON packets are split by the mux-demuxer into the individual ROS topics so the subsystems only receive data intended for themselves. The second tier contains control and sensor programs which receive commands from the mux-demuxer returning calculations to the surface as well as feeding lower tiers instructions intended for hardware interaction. And the third tier contains all hardware interfacing programs. These interpret instructions from higher tiers into hardware protocols and vice versa.

D. Embedded Communication

Embedded communication on the ROV is handled via the CAN protocol. This provides a high level of noise immunity at a high data rate. The Raspberry Pi communicates on the CAN bus using drivers built into the Raspbian Operating System for the MCP2515 SPI controlled CAN controller. Each STM32F0 microcontroller on the ROV has custom firmware written in C which receives the CAN messages and then performs the appropriate action based on the message received. This allows the pilot to control the embedded portion of the ROV efficiently through a custom built API, tailored to the tasks set forth by the mission.

E. Movement Control

The ROV is controllable in 6 degrees of freedom: forward and back, left and right, up and down, roll, pitch, and yaw. However, the ROV is physically moved by 8 thrusters: four aligned vertically and four aligned horizontally and offset by 20º into the ROV from the side frame plates. The direction the ROV should move is given by the pilot in the aforementioned 6 directions and needs to be mapped to power given to each of the 8 thrusters. The input direction values range from -1 to 1, and the desired output array for the thrusters is an array of length 8 that should range from -1 to 1. The values of the input direction vector correspond to the desired direction of ROV movement, while the values of the thruster array correspond to the pulse width modulation (PWM) output of each thruster, and therefore power output. The movement control algorithm is set up so that directional inputs are interpreted as a force vector on the ROV, which is then converted to individual forces from each thruster to create the same overall force on the ROV. This process is achieved through a thruster mapping algorithm, which uses the center of mass and thruster position and direction to calculate the appropriate thruster force values, then converting these to power values.

Several safety features were built into the movement system as well. A thrust limiter calculates the estimated power usage of a force vector on the whole power system as well as the power usage by a single thruster. If either would overload the circuitry, the algorithm proportionally scales down the power of all thrusters to be within power thresholds; because the power and thrust of the thrusters do not have a linear relationship with PWM input, it was necessary to scale the forces of the thrusters instead of the PWM to preserve the desired movement direction of the ROV. Ramping is included in the movement system to prevent current spikes in the power system and prevent internal damage to thrusters when switching directions. This was implemented by decreasing the maximum difference in PWM input to thrusters between two outputs from the thrust mapping algorithm. Finally, a watchdog system was also implemented to ensure that if communication was cut for an extended period of time between the ROV and the surface, the thrusters would be shut down. Special care was put into ensuring that the desired direction of the pilot and stabilization system would be preserved within the movement system while also maintaining a high standard of safety.

F. Computer Vision

Proven Robotics' computer vision system is operated on the surface and uses ROS's topic synchronization system to transport an image from the ROV up to a surface computer where the image is processed. The four image recognition programs are run independently as ROS nodes and utilize OpenCV to process the image. Each node subscribes to the image from the ROV and outputs onto its own ROS topics. The output topics are subscribed to by the mux-demuxer which forwards the results to the battlestation where they can be displayed.

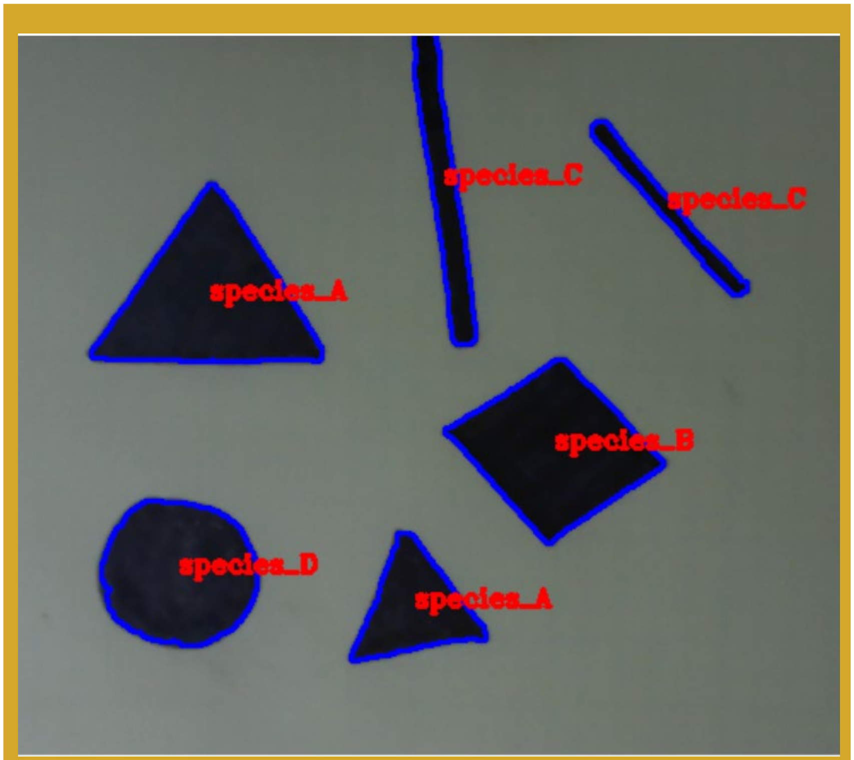


Fig. 30 - Computer vision program identifying the benthic species

VII. Logistics

A. Company Organization

Proven Robotics retained the organizational structure it has used over the past three years. There are three technical departments: Mechanical, Electrical, and Software, which focus on their respective technical areas of the ROV. The Electrical and Mechanical Departments are led by a single technical lead, while the Software Department has two co-leads. All four leads report directly to the Administrative Department and CEO, and work with employees to foster their technical learning and work. The company continues to use a five project group structure this year with some slight changes to the systems they work on: Surface and Frame, Logic and Enclosures, Power and Enclosures, Sensors and Cameras, and Tools and Thrusters. These groups allow employees to be evenly distributed across all necessary tasks to ensure that every project has an appropriate level of attention, and that every person has an appropriate task to work on.

B. Project Management

Proven Robotics' design cycle is divided into four stages: training, designing, manufacturing, and testing. During the training phase, new employees are recruited and trained in a combination of: SOLIDWORKS design, EAGLE design, Python, JavaScript, web development, and proper Github practices, depending on the their department. Returning employees take part in this training to improve or expand their knowledge of these programs or to teach new employees.

In the beginning of the year, the CEO makes a Gantt Chart to organize deadlines in a visual manner (See Appendix). This makes it easy for employees to understand when all tasks have to be done. Proven Robotics starts the design phase before mission specifications are released, and therefore only designs general components such as the frame, electronics enclosures, cameras, and the Primary Manipulator. These designs can all be modified after the mission specifications are released. Once they are, mission tools are designed and all components finalized. There are two general meetings throughout the week, and one additional leadership meeting each week. Employees collaborate during scheduled meeting times and put in additional effort outside these times to finish designs. A thorough design review process is used to ensure that nothing is overlooked. First, the entire company brainstorms solutions to every mission task using the “Think, Pair, Share” method. This process involves individual employees brainstorming solutions to a specific mission task, then discussing these solutions in a small group and combining similar ideas. The entire company discusses these ideas and is able to get a diverse set of solutions. Next, all mechanical parts are modeled in SOLIDWORKS and all PCBs in EAGLE to maximize each design's functionality and manufacturability. The company then holds a design review where leadership, current employees, former employees, and other Purdue students review every design. After all designs have been thoroughly vetted, the company moves to the manufacturing phase.

In the manufacturing phase, all components for the ROV are built. Employees work together to ensure that all tools and waterproof enclosures are machined, the frame is waterjet-cut, circuit boards are populated, and software is developed. Mission critical components are given priority, such as waterproof enclosures, but all components have scheduled times to be manufactured. When a component is finished, it is thoroughly tested to ensure it can work as designed. If it fails testing, it is either fixed if the issue is small or redesigned and rebuilt if the issue is severe enough. Once all critical components have passed individual testing, the ROV is assembled and fully tested. Non-critical tools are added as they are finished.

C. Project Costing and Budget

Proven Robotics creates its yearly budget based off previous years’ budgets and projected incomes and expenses. These expenses include the cost of producing ROV *Remora* and the costs of attending competition. The budget categories for ROV Construction with the largest changes from the prior year's are: Mechanical: Materials which decreased $1,000, Mechanical: Thrusters which decreased $700, and Electrical: Components which increased $500. The budget decreases for thrusters and materials are due to expected discounts and the increase for components was due to the development of custom ESC boards. Proven Robotics pays for flights and lodging for as many employees to attend competition as the budget allows, rewarding them for their hard work throughout the year. The company receives income from various grants from Purdue University organizations along with sponsorships from companies and discounts on purchases. A $6,000 donation from the Office of the Provost and a $1,000 donation from the Purdue Engineering Student Council came in April, after most of the ROV purchases were already made. As such, the company will have a surplus for the year after the competition. This will go into future improvements for the team, including equipment for the workspace and research and development for custom ESCs. The Mechanical, Electrical, and Administrative Departments have their own budget, and if they overspend on any category they must account for it by cutting back on others or raising additional funds.

Budget

Proven Robotics’ 2018 Budget (USD)					
Budget Category	Item and Description	Type	Amount	Total Amount	Budget Allocated
Electrical: Boards	PCB Printing (Power Boards, Camera Board, etc.)	Purchased	$669.12	$669.12	$750.00
Electrical: Components*	Buck Regulator Parts (Power Bricks and Discrete Components)	Purchased	$332.22		
	Components for Board Population	Purchased	$2045.67		
	Tether Creation Material (Wires, Ethernet Cable, etc.)	Purchased	$293.99		
	Basic Electrical Supplies (Wires, banana plugs, fuses, etc.)	Purchased	$23.09		
	Ethernet Cameras	Purchased	$105.04		
	Motors (for tools)	Purchased	$210.00	$3,010.01	$3,600.00
Electrical: Equipment	Basic Equipment (Wire strippers, extension cords, etc.)	Purchased	$122.65		
	Power Supplies (for testing circuits)	Purchased	$18.95	$141.60	$750.00
Electrical: Prototyping	Cameras	Purchased	$72.49		
	Test Boards and Parts	Purchased	$554.23	$626.72	$750.00
Mechanical: Connectors	Connectors (Binder, Subconn, etc.)	Purchased	$1085.53	$1085.53	$250.00
Mechanical: Equipment	Tap Sets and Tap Extractors	Purchased	$18.99		
	Experimental Equipment (Hand Pump, Toaster Oven)	Purchased	$0.00		
	Miscellaneous Equipment (Hex set, calipers, etc.)	Purchased	$118.46	$137.45	$1,100.00
Mechanical: Machining	Miscellaneous (3D-printing filament, band saw blade, etc.)	Purchased	$467.43	$467.43	$1,000.00
Mechanical: Materials	Buoyant Foam (enough for next three years)	Purchased	$0.00		
	Stock materials (aluminum and polycarbonate)	Purchased	$56.55		
	Parts for tools (Screws, bolts, epoxy, etc.)	Purchased	$26.01		
	Basestation parts (Pelican case, snake skin, etc.)	Purchased	$293.99		
	Prop Parts (PVC, rocks, corrugated pipes, etc.)	Purchased	$22.30	$398.85	$3,000.00
Mechanical: Prototyping	Raw materials (Polycarbonate, HDPE, etc.)	Purchased	$105.85	$273.26	$500.00
Mechanical: Thrusters	Blue Robotics T200 Thrusters and ESCs	Purchased	$1,225.80	$1,128.76	$1,300.00
Total Expenses for ROV Construction				$7,938.73	$13,000.00
Lodging & Travel	Hotels	Purchased	$4,367.16		
	Flights	Purchased	$8,000.00		
	Gas for travel throughout the year	Purchased	$72.79		
	Gas for competition (estimated)	Purchased	$650.00	$13,089.16	$13,250.00
Team Apparel	T-Shirts and Polos	Purchased	$788.92	$788.92	$1,250.00
Miscellaneous Costs	Poster Printing and Supplies	Purchased	$200.00		
	MATE Registration Fee and Fluids Power Quiz	Purchased	$415.00	$415.00	$2,500.00
Total Expenses for Travel, Lodging, Team Apparel and Miscellaneous Costs				$14,293.08	$17,000.00
Cash Income	Purdue Office of the Provost	Cash	$6,000.00		
	Boeing	Cash	$5,000.00		
	Purdue Engineering Student Council	Cash	$4,000.00		
	Northrop Grumman	Cash	$3,000.00		
	Purdue School of Electrical and Computer Engineering	Cash	$3,000.00		
	College of Engineering	Cash	$1,000.00		
	Kleppinger Family & Northrop Match	Cash	$1,000.00		
	ExxonMobil	Cash	$1,000.00		
	IEEE Central Indiana Section (CIS_IEEE)	Cash	$500.00		
	Carry-Over	Cash	$4,605.81	$29,105.81	$30,000.00
Total Cash Income for 2017 Build Year				$29,105.81	$30,000.00
Donations and Discounts	Blue Robotics	Discount	$500.00		
	Binder USA	Discount	$62.92		
	Dassault Systèmes	Donated	$5000.00		
	Advanced Circuits	Discount	$500.00	$6,062.92	N/A
Total Expenses				($22,231.81)	-
Total Cash Income				$6,874	-
Net Balance				$6,874	-
Next Year Investment				$6,874	-

VIII. Conclusion

A. Testing and Troubleshooting

Full system testing of the ROV occurs after the design and building phases, and is critical in producing a functional vehicle. Tools are tested to make sure they function as designed, and all boards are checked for continuity and functionality. Initial functionality testing is performed out of water to ensure that the thrusters run in the correct direction before any pool tests are performed. If anything doesn't work as expected, Proven Robotics employees will use technical documentation and lab testing to determine the source of the issue. Once functionality testing is completed, the ROV is brought to a local pool for a full systems test and to practice mission runs. Before the ROV is put in the water, the Safety Checklist from the Appendix is used to make sure everyone present is safe. At the pool, a dunk test is performed before powering is connected to make sure all enclosures are still waterproof after transportation. Initial pool tests are used to fine tune thrust mapping to ensure the ROV runs smoothly. Subsequent pool time is used to practice mission tasks.

B. Challenges

Proven Robotics faced many challenges throughout the year; one of the biggest being changes to leadership. Four of the five project group heads were new to their roles, and one of the two software co-leads was new. These new leaders had to adjust to their new positions while on a tight schedule to finish the ROV by the middle of March. They learned through guidance from department leads, the CEO, and alumni how to best perform their duties. An end of semester review determined where they were succeeding and where they need to improve. Ultimately, everyone was able to figure out how best to work in their new positions and guided the employees under them to finish the ROV.

One of the biggest technical challenge the company faced this year was getting the Logic Enclosure fully waterproof. In an effort to save weight on this component, the end caps and flanges were machined from HDPE plastic. When testing the enclosure, the end caps would buckle under pressure preventing a waterproof seal from being formed. Both end caps had to be remade from aluminum to improve durability. With further testing, it was determined that the epoxy that held the flanges to the polycarbonate tube did not stick to the HDPE enough to fully seal, and those had to be re-machined out of aluminum as well. Once both of these pieces were finished, the enclosure finally sealed. The other major technical issue was getting CAN to work reliably. The initial issue was determined to be caused by the electrical system and some of the boards had to be reprinted. Once the hardware was changed, the Software Department had to limit the amount of information sent over CAN by only sending updated thruster values when they changed by a large enough amount. With both of these changes implemented, the communication system runs smoothly. These two issues delayed full vehicle testing until late in the year, so there was limited time to fully test the ROV. Even with all these setbacks, the company was able to qualify for international competition.

C. Lessons Learned and Skills Gained

All Proven Robotics employees learn technical skills relevant to their respective departments. Employees of the Mechanical Department learn how to use SOLIDWORKS for part design and how to make parts easily manufacturable. By making all parts in-house, employees have the opportunity to learn how to use CAM pathing, and how to operate CNC mills, CNC lathes, manual mills, manual lathes, waterjets, and a variety of hand tools. Employees of the Electrical Department learn how to make circuit board schematics, how to make layouts using EAGLE, and how to hand populate their circuit boards. Employees of the Software Department learn how to develop their own code for a client-server architecture. Employees from all departments learn how to test their designs to make sure they work as intended.

In addition to technical skills, each employee learns a variety of soft skills. These include time management and communication. Every employee is on a strict deadline and must complete their projects on time. Since every project is connected, any small delay can cascade through the entire company and cause major issues. These issues can be mitigated through clear and prompt communication between employees, and leadership assigning people to tasks that are tailored to their abilities. During weekly meetings, department leads and project group heads talk with employees to see how their work is progressing. Weekly leadership meetings allow the department leads to get a better understanding of how each project group is progressing, and what needs to be done to meet project deadlines. These discussions help the company meet their goals in a timely manner, and they encourage all employees to develop communication skills with people outside their technical department.

D. Future Improvements

A long term design improvement that began this year and will be implemented next year is custom ESCs. Employees began work on custom ESC code in the fall and got a working version in the spring. PCB designs will be finalized this summer. When the design is integrated into the ROV, the company will have better control over the thrusters, communication, and current monitoring. Furthermore, the company will have a more fundamental knowledges of the ESCs and be able to write software tailored for the ROV.

The company struggled some with the testing and integration of ROV *Remora* due to delays in development and cascading technical issues. The company did not begin testing until halfway through the spring semester, and employees continued to find and solve issues until the end of the semester. The delays the company had were created when employees focused on a single critical issue instead of working on all projects. In the future, Proven Robotics will devote more leadership and organization toward seeing that all work on the ROV progresses, not just the most critical component.

E. Reflections

Purdue IEEE ROV has participated in the MATE Center competition for ten years now. Each year individuals share their experiences and pass on their knowledge.

> *My first year on the Purdue ROV team was truly an incredible experience unlike any that I have ever experienced. Not only is the team really smart and amazingly capable, but they are also incredibly friendly and welcoming. The members are always incredibly patient, and create amazing learning experiences that enable me to propel myself further into my own education. The skills that I have learned from the team have not only allowed me to better understand my classes, but gave me useful abilities that can be used for my professional life, such as designing a PCB, soldering components onto a board, and coding a microcontroller, each more interesting than the last. Joining ROV is one of the best decisions that I have made during my freshman year.*
>
> - Justin Zhang (Electrical Department, New Member)

> *Joining the ROV team my freshman year was the best decision of my college life. It is amazing how much I learned from the team, both technically and professionally. My first two years on the mechanical team gave me the opportunity to learn how to design products using CAD and manufacture them myself; something I wouldn't have learned until senior design. Along with the technical knowledge I got from the team, I learned how to work with people outside my field to achieve the common goal of building a new ROV every year. This is something I'll take with me everywhere I go in life. Along the way, I made some of the best friends I had in college. I loved my time on the team, and look forward to the next chapter of my life.*
>
> -Alex Ruffino (CEO, Graduating Senior)

IX. Appendix

A. Safety Checklist

Pre-Power
- ☐ Clear the area of any obstructions
- ☐ Verify power supply is “OFF”
- ☐ Connect tether to ROV
- ☐ Connect Anderson connectors of tether to power supply
- ☐ Pressurize air compressor to 275.79 kPa
- ☐ Attach pressurized air line to pneumatics enclosure
- ☐ Check ROV
  - ☐ Check Power Tube seals
  - ☐ Check Manipulator and other mission tools

Power Up
- ☐ Pilot boots up laptop and starts BattleStation
- ☐ Pilot calls team to attention
- ☐ Co-pilot calls out, “Power on,” and moves power supply switch to “ON”
- ☐ ROV deployment members verify ROV electronic status lights
- ☐ ROV enters water under control of deployment members
- ☐ Deployment members check for signs of leaks (e.g. bubbles)
  - ☐ If leaks occur, go to Failed Bubble Check
  - ☐ Otherwise, continue Power Up sequence
- ☐ Deployment members ensure that ROV remains stationary in water
- ☐ ROV is neutrally buoyant
- ☐ ROV is balanced in all directions
- ☐ ROV deployment members release any air pockets and shout “ROV ready”
- ☐ Pilot arms ROV and starts thruster test
- ☐ Deployment members adjust cameras to achieve desired viewing angles
- ☐ Continue to Launch procedures if no issues arise

Failed Bubble Check
- ☐ If many bubbles spotted during mission, the pilot quickly surfaces the vehicle
- ☐ Co-pilot turns power supply off and calls out, “Power off”
- ☐ Deployment members retrieve ROV
- ☐ Inspect ROV and troubleshoot
- ☐ If time remains after problems addressed, then return to Power Up sequence

Launch
- ☐ Pilot calls for launch of the ROV and starts timer
- ☐ ROV deployment members let go of ROV and shout, “ROV released”
- ☐ Mission tasks begin
- ☐ Go to Failed Bubble Check or Lost Communication if either problem occurs during the mission
- ☐ Continue to ROV Retrieval if mission completed

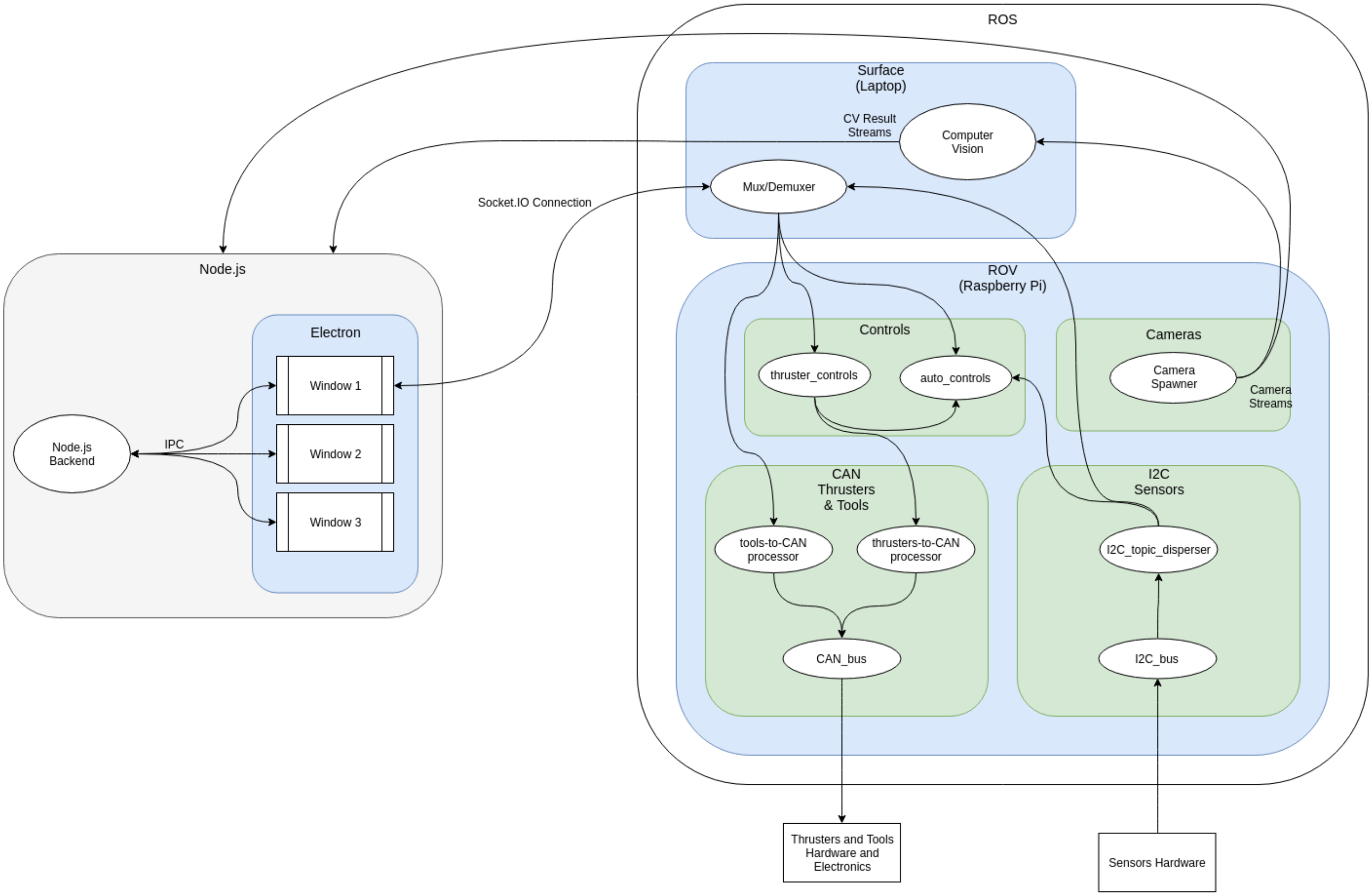
Lost Communication
- ☐ Steps attempted in order. Mission resumes when one succeeds.
- ☐ Co-pilot checks tether and laptop connections on the surface
- ☐ Pilot attempts to reset the BattleStation
- ☐ Co-pilot cycles the power supply
- ☐ If nothing succeeds, the mission stops
  - ☐ Co-pilot turns power supply off and calls out, “Power off”
  - ☐ Deployment team pulls ROV to surface

ROV Retrieval
- ☐ Pilot informs deployment members that ROV needs retrieval
- ☐ An ROV deployment member’s arms enter the water up to the elbows
- ☐ The ROV deployment member pulls the ROV up from water after making contact
- ☐ Deployment team yells, “ROV retrieved”
- ☐ Pilot stops timer

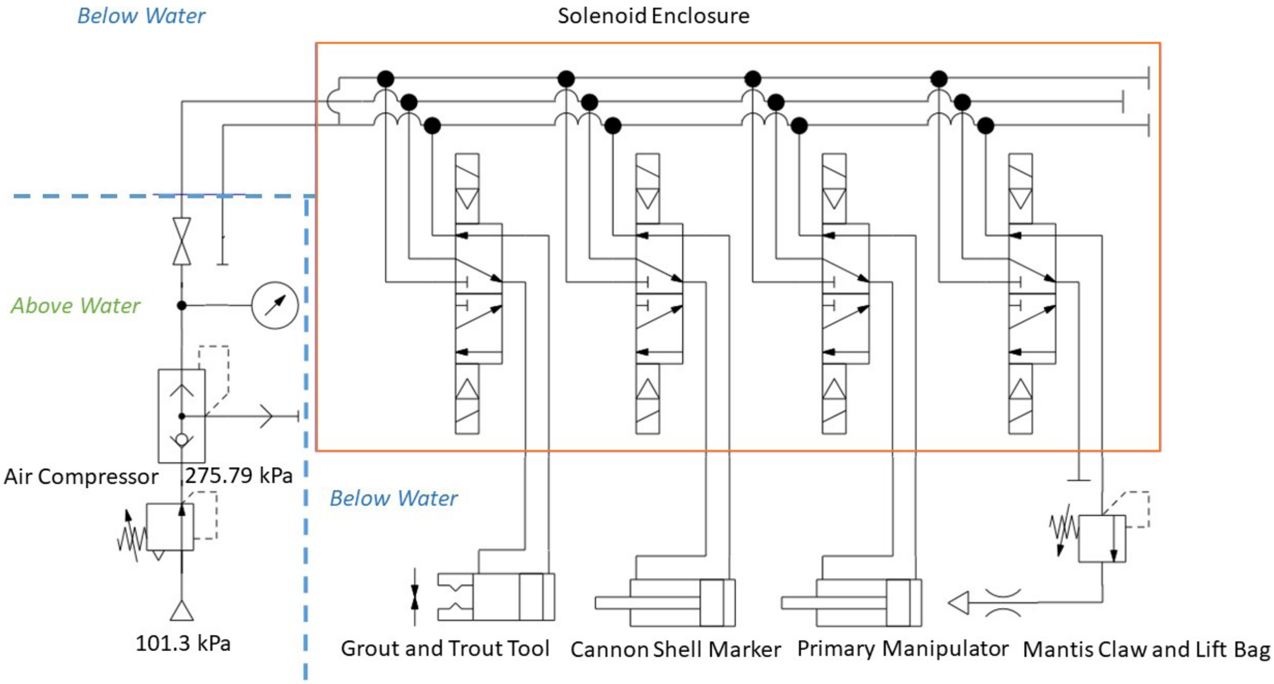
Demobilization
- ☐ Co-pilot turns power supply off and calls out, “Power off”
- ☐ Deployment members do a quick visual inspection for leaks or damage on ROV
- ☐ Pilot stops BattleStation and powers off laptop
- ☐ Anderson connectors of tether are removed from power supply
- ☐ Turn off air compressor and vent line
- ☐ Remove air line from pneumatics enclosure
- ☐ Camera monitor and laptop are shut down and packed up
- ☐ Team vacates the area

B. System Interconnect Diagrams

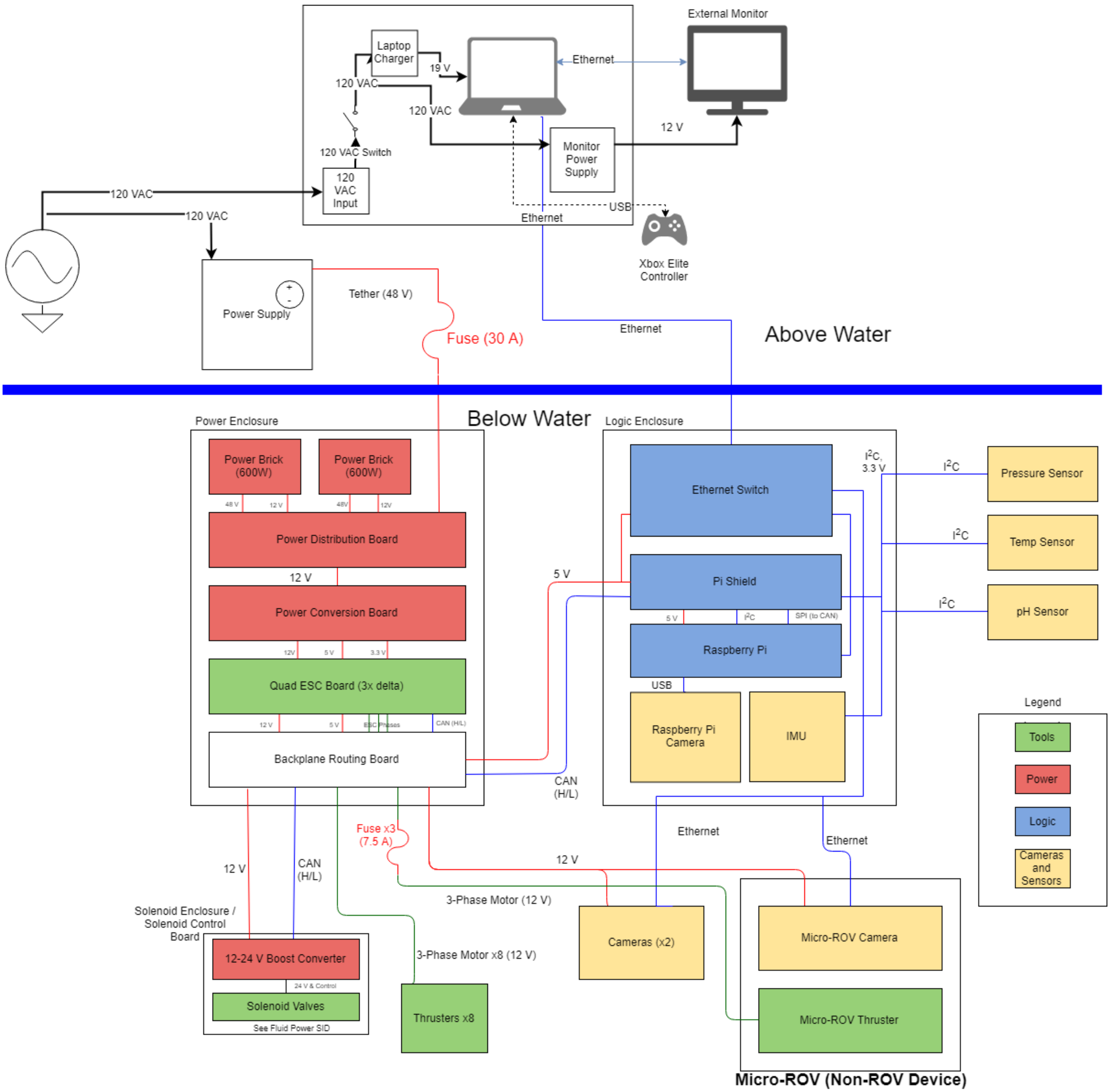
Software Flowchart



Fluid Power System Interconnect Diagram



Electrical Systems Interconnect Diagram



Main Tether Fuse Calculations:

8 x Thrusters @ 120 W
Raspberry Pi w/ Camera @ 10 W
3 Secondary Cameras (12 V * 0.3 A) * 3 = 10.8 W
Ethernet Switch @ 6 W
12 V-5 V buck converters (loss) @ 2.8 W
5 V-3.3 V linear regulators (loss) @ 0.52 W
48 V-12 V buck converters (loss) @ 66 W
Total: 1056.12 W

Current = 1056.12 W / 48 V = 22 A
Current * 1.5 > 30 A,
so a 30 A fuse is used

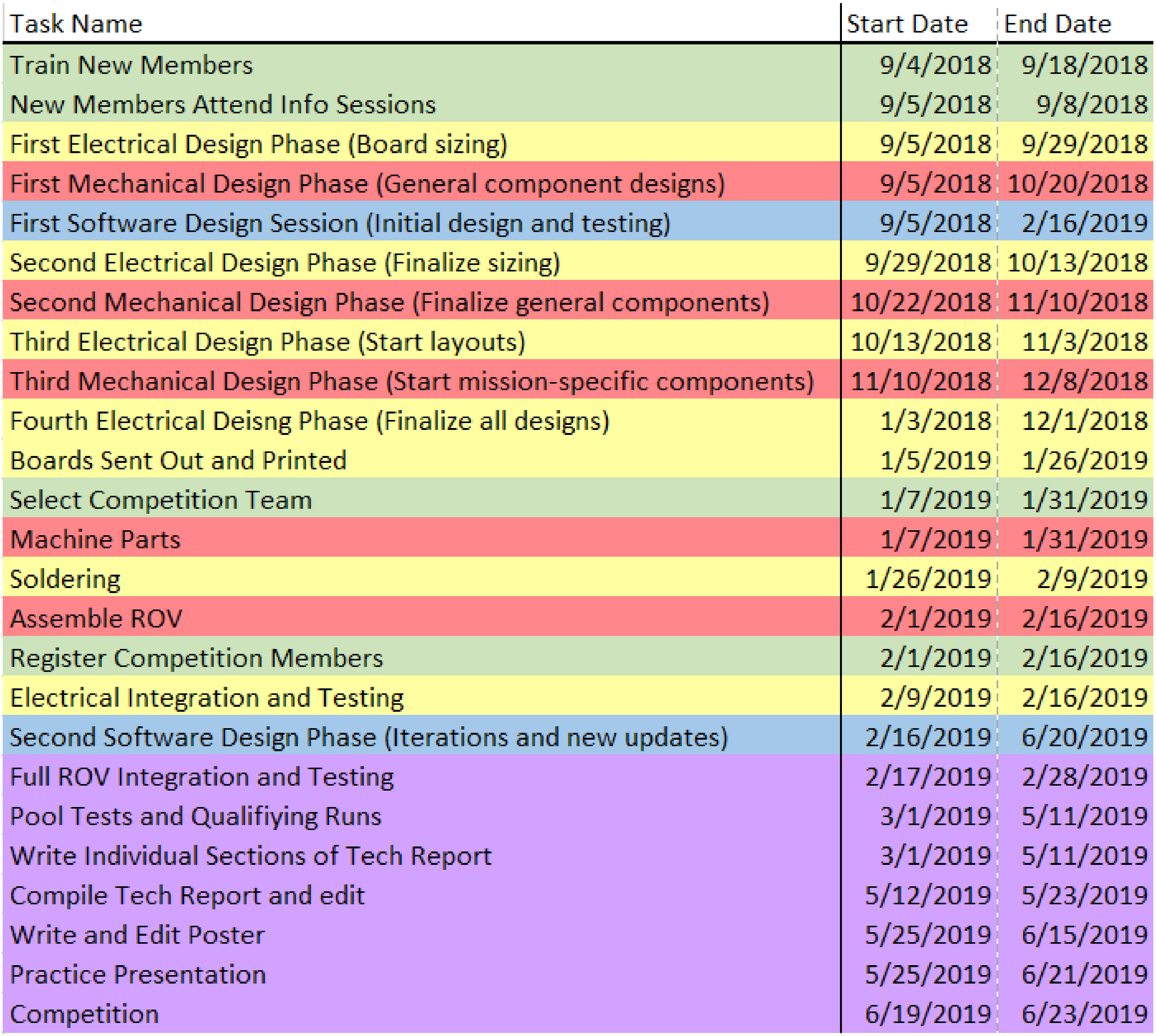
Micro-ROV Camera Fuse:

The maximum current draw of the camera is 0.3 A. With a factor of 1.5, a 0.45 A fuse is low enough to be omitted

Micro-ROV Thruster Fuse:

120 W thruster @ 12 V = 10 A.
10 A * 1.5 (overcurrent factor) = 15 A max.
Using 3 phases 5 A per phase / 0.707 (rms of sine wave) = 7.07 A.
The next largest fuse size is 7.5 A.

C. Task List for Gantt Chart



Task Name	Start Date	End Date
Train New Members	9/4/2018	9/18/2018
New Members Attend Info Sessions	9/5/2018	9/8/2018
First Electrical Design Phase (Board sizing)	9/5/2018	9/29/2018
First Mechanical Design Phase (General component designs)	9/5/2018	10/20/2018
First Software Design Session (Initial design and testing)	9/5/2018	2/16/2019
Second Electrical Design Phase (Finalize sizing)	9/29/2018	10/13/2018
Second Mechanical Design Phase (Finalize general components)	10/22/2018	11/10/2018
Third Electrical Design Phase (Start layouts)	10/13/2018	11/3/2018
Third Mechanical Design Phase (Start mission-specific components)	11/10/2018	12/8/2018
Fourth Electrical Deisng Phase (Finalize all designs)	1/3/2018	12/1/2018
Boards Sent Out and Printed	1/5/2019	1/26/2019
Select Competition Team	1/7/2019	1/31/2019
Machine Parts	1/7/2019	1/31/2019
Soldering	1/26/2019	2/9/2019
Assemble ROV	2/1/2019	2/16/2019
Register Competition Members	2/1/2019	2/16/2019
Electrical Integration and Testing	2/9/2019	2/16/2019
Second Software Design Phase (Iterations and new updates)	2/16/2019	6/20/2019
Full ROV Integration and Testing	2/17/2019	2/28/2019
Pool Tests and Qualifiying Runs	3/1/2019	5/11/2019
Write Individual Sections of Tech Report	3/1/2019	5/11/2019
Compile Tech Report and edit	5/12/2019	5/23/2019
Write and Edit Poster	5/25/2019	6/15/2019
Practice Presentation	5/25/2019	6/21/2019
Competition	6/19/2019	6/23/2019

-Green tasks are Administrative Department tasks
-Red tasks are Mechanical Department tasks
-Yellow tasks are Electrical Department tasks
-Blue tasks are Software Department tasks
-Purple tasks are full company tasks

D. Acknowledgments

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The Kleppinger Family
Parents and Family for advice and support
MATE Center for providing us this opportunity
Volunteers and Judges at the MATE Competition
Company alumni for their support throughout the year
All our employees for their hard work throughout the year
Purdue IEEE Student Branch for being a great parent organization
Launch Apartments and Four Points by Sheraton for their pool use

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