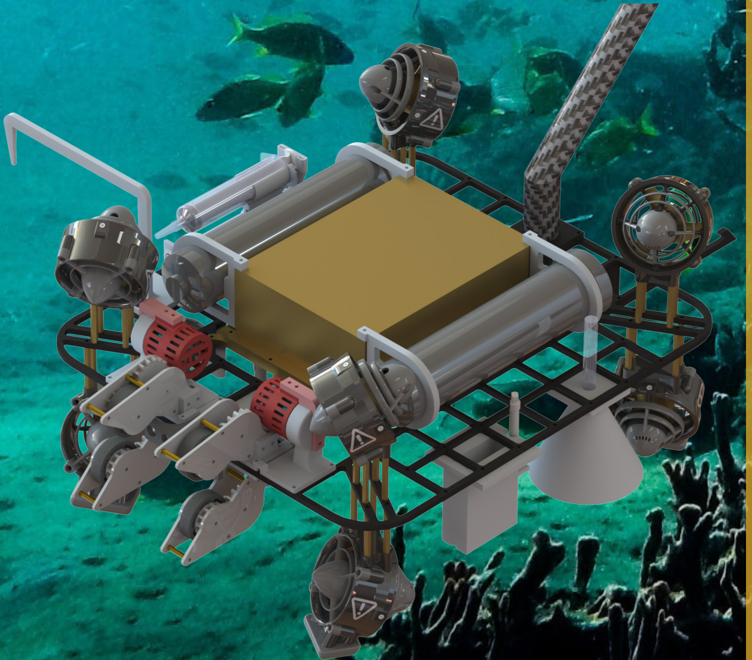
Purdue
ROV

2023 Technical Doumentation

Creating marine technology to protect the environment and enable our green energy future

PURDUE UNIVERSITY
West Lafayette, IN USA

ROV
Iso-Squid



COMPANY EMPLOYEES

NAME	POSITION
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Benjamin Tapp	Sponsorship Coordinator
Corina Capuano	Mechanical Department Lead
Bryce Sasser	Electrical Department Co-Lead
Rachel Livesay	Electrical Department Co-Lead
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I. INTRODUCTION

Abstract

In order to meet the needs of the global community, Proven Robotics presents the Remotely Operated Underwater Vehicle (ROV) Sub-Optimal – a polished vehicle capable of performing crucial tasks in the renewable energy and preservation of the Antarctic. ROV Sub-Optimal is capable of collecting morts from the sea's surface to its floor, deploying a vertical profiling float, inspecting offshore fish pens, and much more. The 40-person company has endeavored over the last year to develop and refine ROV Sub-Optimal.

Proven Robotics is divided into four departments: Mechanical, Electrical, Software, and Administrative. Cross-disciplinary project groups focus on separate vehicle subsystems to improve integration and coordinate over the company's combined 14,000 work hours. Given the difficult nature of the past year, Proven Robotics was especially cognizant of the need for safety protocol, enhanced flexible scheduling, and tighter budget constraints throughout the design process.

ROV Sub-Optimal is taking on measured technical risks from a consistent foundation of past vehicles to make substantial strides in reliability, development flexibility, and overall capability. Building on previous experience, the company implemented high-performance and reliable platforms like Robotic Operating System (ROS) and Controller Area Network (CAN) to produce a more robust vehicle. In other areas, the ambition and failure of prior vehicles inspired a retreat to the basics, exemplified by the simplicity and reliability of the Power Box. The following technical document discusses the design rationale and process used to create ROV Sub-Optimal.

Fig. 1- Team Photos

II. Safety

A. Safety Philosophy

Safety is the highest priority for Purdue ROV. A safe work environment does more than prevent workplace injuries; it improves employee comfort, productivity, and enjoyment. The safety of all employees, bystanders, and equipment is examined in each action taken or product used. All employees are trained before using heavy machinery, heating elements, and chemicals. New employees are mentored and supervised by more experienced employees to ensure their work is safe.

Fig. 2 - Bench Grinder with Safety Precautions

B. Safety Standards

Purdue ROV uses multiple safety procedures which every employee follows when working on ROV Iso-Squid. Personal protective equipment (PPE) is available to every employee in the workspace. This includes eye protection, dust masks, face masks, eyewash stations, shower stations, first aid kits, and fire extinguishers. Employees are mandated to use safety glasses when operating the drill press, band saw, or other power tools. Employees are also required to wear a dust mask if working with fiberglass. Purdue ROV's workspace is located on the Purdue University campus, giving safe access to all employees. This workspace is also regularly inspected by the school for proper adherence to the school's safety regulations In the event that an employee works in another environment with different safety standards, such as an on-campus machine shop, the stricter set of the two safety standards are followed.

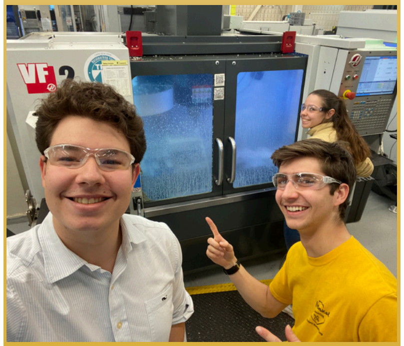


Fig. 3 - Machining with Proper PPE

C. Safety Features

ROV Iso-Squid has numerous safety features. First, the tether has both a master fuse for the device and a strain relief cord. Secondly, sharp edges are minimized on the metallic parts both via manual hand-reaming as well as anodization. Next, each time ROV Iso-Squid is deployed, the safety checklist (see Appendix) is followed to ensure all employees, bystanders, and the vehicle are kept safe during operation.

Additionally, Iso-Squid's custom thruster ducts integrate ingress protection features. They satisfy IP20, blocking objects larger than 12.5 mm and simultaneously minimizing the reduction in water flow. The shrouds are 3D-printed in-house and mounted via heat-set inserts and screws.

Finally, the vehicle's software gives the pilot information on its system so they can determine if the ROV is functioning correctly before it is deployed into the water. After correct operation is established, the pilot instructs two poolside employees to deploy the ROV. Data on the thrusters and other systems are continuously updated on the pilot's screen, so the pilot can shut off the ROV if anything becomes unsafe.

Fig. 4 - Pre-reamed frame with burrs attached

III. Mechanical Design Rationale

A. Mechanical Overview

The Mechanical Department prioritized size reduction and versatility in the design of ROV Iso-Squid. Additionally, more emphasis was placed on creative solutions to problems such as the Rolly Claw. Throughout the design process, the department conducted rigorous design reviews, constantly improving each component and streamlining the electrical and software integration. Every part was designed and iterated upon in SOLIDWORKS, validated through a combination of 3D-printed prototypes and FEA, and tested extensively – both in pool tests and in the company's pressure-testing chamber.

The ROV is designed and tested to handle depths well in excess of 20 meters. It is primarily constructed of anodized aluminum, but also utilizes 3D-printed parts to create tools that can be easily updated and reprinted to further adapt the ROV as needed for different missions. The final ROV is smaller than previous designs and is very lightweight, providing ample room for additional tools if necessary. These efforts have produced a robust and reliable ROV that excels at the tasks required of it and can be adapted to new objectives and requirements.

B. Frame

The frame was designed to serve as a universal mounting system for all of the individual subsystems of the ROV. The main priorities for the frame are to enable easy mounting for diverse subsystems and provide vehicle rigidity while remaining as light as possible.

We decided on a single frame plate, to cut weight from previous designs. While two plates would seem to provide more mounting, it obstructed access and reduced the total useful volume for mission tool mounting. To make mounting simple, we chose a universal 2" square grid. The overall frame footprint was designed to fit in a suitcase, making air transport possible (since the design was completed before the championship location was announced). The frame was laser-cut from a single sheet of 0.25" thick aluminum based on our previous experience. In SolidWorks, an FEA drop test from three feet was utilized to simulate the strength of the frame. It was found that the maximum stress on the part was less than one-half of the yield strength, which validated our weight-saving reduction in rib thickness.

C. Thruster Layout

The layout of the stable resulting in no work needed to maintain the ROV orientation. Due to uncertainty in mass and exact position of CoM and CoB, the design is for a very small stability Moving from static analysis into dynamic analysis introduces hydrodynamic forces also known as drag. In motion, the various forces all create torques about the vehicle's center of mass. Thrusters

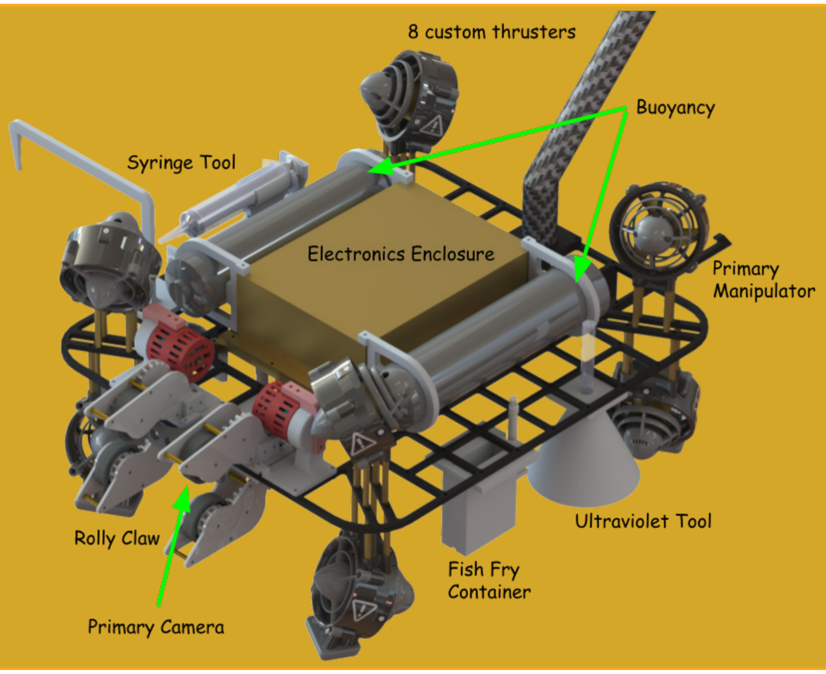


Fig. 5 - Mechanical schematic detailing the location of several key components of the ROV

forces are a function of thruster layout and commanded force, buoyancy

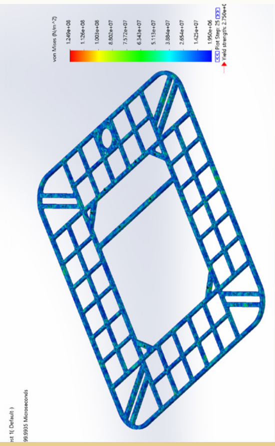


Fig. 6 - *Finite Element Analysis of Frame*

D. Power Box

The Power Box is the heart of the ROV, housing our custom circuit boards which convert and distribute power and send signals to all subsystems. Continuing from our success with previous billet-machined boxes, this year's Power Box again houses both power and logic electronics thanks to improved board design and cameras. The Power Box is CNC milled out of a single block of 6061-T6 aluminum. This allows for direct integration of o-ring grooves and requires minimal manual post-processing. The enclosure seals to a custom-manufactured lid via a face seal using a 1/8" x-profile o-ring and has a vacuum port to test the seal. Hydrostatic finite element analysis (FEA) was performed to determine the minimum wall thickness needed to prevent failure due to water pressure at a depth of 10m with a factor of safety of 2.0.

The biggest change in our design was to flip the Power Box upside down meaning that the electrical system sits on top of a flat Carrier Plate. The Carrier Plate supports all electronics and includes all waterproof connections. This greatly improves access to the electronics which were previously hard to maintain due to the narrow space surrounding the electronics and old Power Box. It also greatly simplifies manufacturing since the Power Box no longer has tapped holes on many faces and instead, the Carrier Plate has all connections in a single direction.

The combined Power Box and Carrier Plate connect to the tether and provide support for connections to 12 brushless DC motors (BLDCs) including 8 thrusters, the pneumatic enclosure, as well as multiple USB cameras via Binder ports. There are additional ports for further expansion to new capabilities and flexibility in arrangement.

Fig. 7 - Frame Prototype fitting in Luggage

E. Pneumatic Enclosure

Four of Iso-Squid's tools are powered by pneumatics. An air compressor provides 40 psi through the tether into a manifold with four solenoid valves. Each time a cylinder moves, the compressed air is routed back through the tether and vented to the atmosphere, which provides a higher pressure differential than venting to water at depth. The manifold and the lid seal together to protect the valves; both are 3D printed with SLA resin. The fittings are threaded into aluminum inserts, which are bonded with epoxy and SLA resin to the manifold. The valves are SMC's SY3140-6LZ providing highly responsive tools with less than 250 ms of downtime.

Resin 3D printing was chosen because it could produce geometry that is un-manufacturable with other processes: smooth, compact curves that minimize losses and size. Also, it produces water-tight parts, has a low cost, and has high machinability, making post-processing easy. After extensive market research, Siraya Blu was chosen over other resins for its low linear shrinkage making it easier to work with. Its final tensile strength allowed for thinner walls in the manifold and thus more compact routing. Despite these benefits, it was critical to design around the main drawback of SLA resin: shrinkage threading, shrinkage, and warping. SLA resin cannot be threaded well, and its long-term shrinkage causes press-fit inserts to fail. An oversized hole was printed and superglue was utilized to attach the inserts instead. Print warpage was reduced by adding extra material to be machined off leading to a smooth sealing surface.

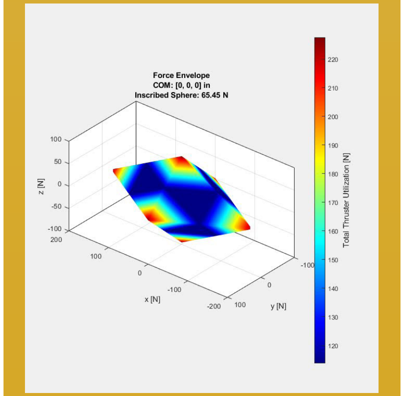


Fig. 8 - Thruster Envelope from MATLAB

F. Buoyancy

Achieving a net-neutrally buoyant ROV has long been a design requirement for Proven Robotics. First, the tether supplying power to the ROV includes a continuous foam run that was calibrated to ensure neutral buoyancy. This year, the company achieved net-neutral buoyancy with the use of our old Modular Foam Shells, which are 3D-printed shells filled with expanding foam. These allow for fine-tuning relative to our inclusion of two unpressurized tanks as buoyancy. These tanks were great since they were easy to design around and were more buoyant per unit volume reducing the bulk of the overall vehicle.

Approximately 1 kgf of buoyancy was added in addition to the unpressurized tanks. Using modular foam allows for easy adjustment of the stability of the ROV. Slight movements forward and backward of the foam control the passive angle that the ROV comes to in the water. Modular foam enables quick adjustments.

G. Cameras

The wide-angle cameras, exploreHD 2.0 Underwater ROV/AUV USB Camera, are mounted to the frame using custom designed 3D printed mounts. There are multiple versions of the mount for downward facing cameras and front facing cameras. These mounts allow for easy insertion and removal of the cameras which allows for a large variety of camera positions to be set up and swapped to depending on pilot preferences. Currently, there is one downward facing camera which aids in positioning for the eDNA water sample task. Then, there is one camera mounted on the Rolly Claw for positioning to grab PVC props. Finally, the last camera is mounted at an angle pointed at the Primary Manipulator for optimal view for grabbing props such as the heavy lift container.

H. Basestation

The base station was created to ensure creating a stable connection between the vehicle, control laptop, and network is quick and reliable. This custom box houses a network router with room for a laptop and its charger. In addition, it features a compartment to carry safety glasses and various small equipment the company might need. This station remains largely unchanged from the previous year though some of the electronics have been replaced due to malfunctions.

I. Tether

The tether acts as an umbilical to ROV Iso-Squid from the base station, transmitting all the data and power required. The main priority was to upgrade the tether to last for the next few years as the old tether was starting to degrade and due to the use of different connectors to the Power Box. 48V is transmitted from the base station to the Anderson Power connector through a heavy duty power cable to the ROV's Power Box. Data is transmitted through ethernet which was originally an unshielded CAT5 cable but was replaced with a shielded CAT6 cable. This was due to EMI interference underwater leading to the unshielded cable dropping signal the moment the ROV was submerged. These decisions were made in collaboration with electrical leadership along the way to ensure proper compatibility. Mechanically wise, the main concern was ensuring that the tether was neutrally buoyant to reduce impact on the ROV. The amount and thickness of the foam in order to balance out the weight of the other materials was measured and calculated in Excel. However due to manufacturing tolerances, the foam was less buoyant than specified leading to a slightly negatively buoyant tether.

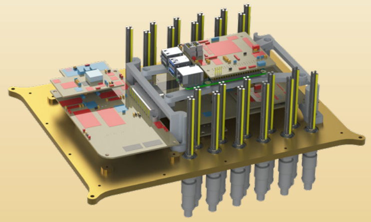


Fig. 9 - Carrier Plate with Electronics Stack

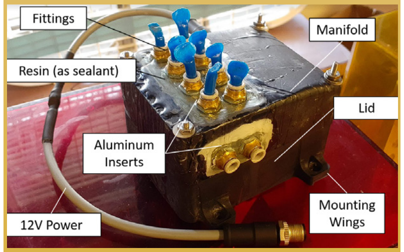


Fig. 10 - Labeled diagram of Pneumatic Enclosure

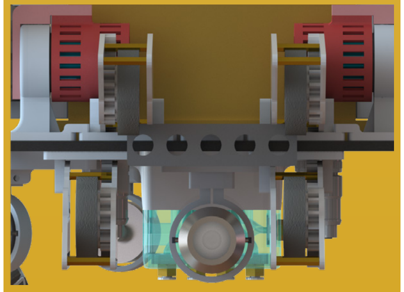


Fig. 11 - Camera for Rolly Claw

IV. Mission Tools Rationale

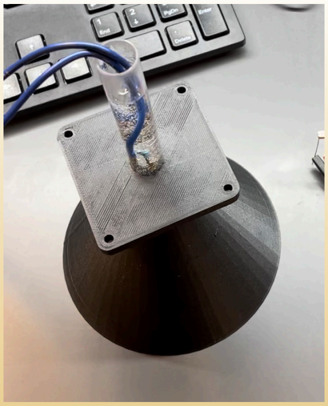


Fig. 12 - UV Tool

A. Ultraviolet (UV) Tool

The UV Coral Light tool is built to meet the requirements of task 2.3 in a way that is simple for the ROV pilot to execute. The main concern in the design of this tool was the simplicity of its operation when in use. Initially, the design was inspired by both the MATE prop building manual (specifically the power connector LEDs) and the flythrough video. A cone is incorpated around the LED assembly in order to increase the acquitision zone. This LED is in turn connected to the Power Box. As for materials, the cone itself is 3D printed, and the light was thrown together using a plastic test tube, clear epoxy, a white LED, a 150Ω resistor, and wiring as needed. All components except for the epoxy and test tubes were sourced in-house.

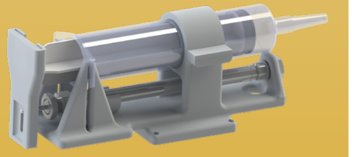


Fig. 13 - Syringe Tool

B. Syringe Tool

This tool serves to complete Task 2.2, which involves extracting a water sample from a bucket with a syringe. A new 4" pneumatic cylinder was purchased to actuate the afore-mentioned syringe. This tool was rapidly prototyped utilizing SolidWorks and 3D printed parts. The tool was initially designed to hang off the side of the frame of the ROV and have the syringe tip inserting into the bucket. However, due to spacing issues between the ROV and the bucket and difficulty performing this operation during testing, the tool was re-designed. A 3D printed port mounted onto the ROV frame that would interface with the side of the bucket was attached, increasing the acquisition zone. Additionally, tubing was attached to the end of the syringe so that the heavy weight of the parts could be offloaded to the ROV while a separate proboscis could be attached to insert into the bucket. Tests were conducted and this proved as a viable solution to the task.

C. Variable Buoyancy

The variable buoyancy system has the task of providing extra buoyancy so the ROV can perform the heavy lift task. The priority was to ensure the lift bag fills in a reasonable amount of time and does not compromise the movement of the ROV. A pool float was chosen after extensive market research due to its cost-effectiveness and suitable size. Additionally, grommets were already in place which could be used to quickly attach and detach the lift bag via carabiners. In order to inflate the lift bag quickly, we attached pressure accumulators to the ROV as we discovered that most of the pressure loss happened inside the tether during testing.

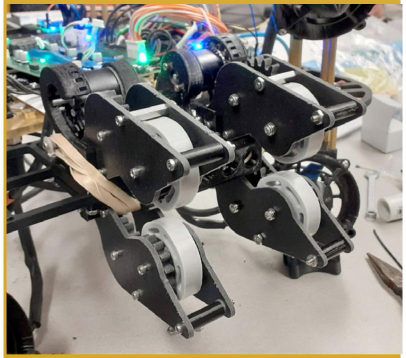


Fig. 14 - Rolly Claw

D. Rolly Claw

The Rolly Claw was designed in order to intake PVC of various sizes (with a range of ~0.5") with increased efficiency and an increased acquisition zone versus the Primary Manipulator of the previous years. The main priorities of the design were to collect PVC props as quickly as possible with a high tolerance to the relative positioning of prop and the ROV, as well as holding the props firmly. The entire system is mounted onto the front of the ROV. The system is constructed utilizing UHMW plates, UHMW gears, rubber flex wheels, rubber bands, 3-D printed PETG, nylon spaces, nylon washers, and 6-32 nuts and bolts.

When deciding on what motors to use, we ended up utilizing the M200s over the M100s, as the pads on the M100s kept tearing off, making them unreliable. We decided to use UHMW as the main material for construction since it is positively buoyant (reducing the need for buoyancy on the vehicle) and due to its high abrasion resistance. The rubber compliant wheels allowed for a grippy intake and flexibility to intake various sizes of PVC.

E. Fry Fish Container

The tool is designed to hold 3 Northern Redbelly Dace and transport them to a new habitat, where they need to acclimate to their new environment before being released. The main priority was to ensure quick release of the fishes while maintaining adequate space such that they would not get stuck. The fishes are contained within a 3D printed box with a lid made out of corrugated plastic and permanent mesh on the other end. The fishes are released with actuation of the pneumatic cylinder which pulls on the corrugated which exerts enough force to surpass the magnet latch's closing force and thus opens the lid. Most of these components were reused from previous year's tools though the enclosure went through multiple iterations to ensure proper lid operation while allowing enough room for the fishes to be released without getting stuck.

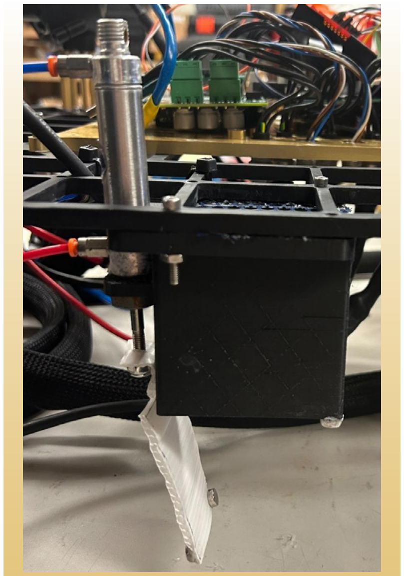


Fig. 15 - Fry Fish

F. Primary Manipulator

The Primary Manipulator is designed to pick up props with loops attached such as the diseased coral tent as well as the heavy lift container. The Primary Manipulator replaces the four-jaw design with a single aluminum hook and a locking top jaw. This allows for a larger acquisition zone as the pilot can simply drive into loops with a small hook and then lock the part in with the actuated jaw. This decision was in part driven by the new heavy lift task but also due to the inclusion of the secondary Rolly Claw which allowed this tool to be custom-designed for the props that the Rolly Claw could not handle.

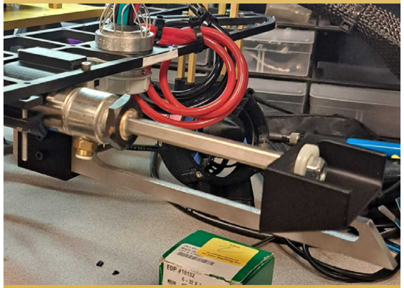


Fig. 16 - Primary Manipulator

G. Vertical Profiling Float

The vertical-profiling float serves as a float that is capable of completing two vertical profiles after being deployed by the ROV. It utilizes a buoyancy engine to control the displacement of seawater and thus control the vertical height of the float. This buoyancy engine consists of a syringe actuated by the linear actuator controlled through an H-bridge by the Arduino Nano. In combination with neutrally buoyancy calibration at the 70mL mark of the syringe, this leads to sinkage when the syringe is retracted and flotation when the syringe is extended. Onboard the float also contains a RTC module which keeps track of the current UTC to be sent to the base station controller via a radio module. This module uses the LoRa protocol to send data on the 915.0 MHz radio channel per federal regulations for unlicensed radio usage.

Using the knowledge gained from last year's float, I wanted to create a smaller, more robust, and elegant solution. This solution replaced the unreliable float bag powered by compressed air with a syringe driven by a repeatable linear actuator inspired by the CityU Underwater Robotics Team's float from 2022. In addition, a more reliable enclosure utilizing O-ring seals replaced PVC tubes with screw-on caps. Concern arose about how long the new float would take to rise/sink. However, a Python script estimated the time to surface to be 20 seconds in a 6-meter-deep pool which eased our concerns and thus we proceeded with the build. After numerous challenges including epoxy leaks, broken parts from drops, and incorrect 3D print tolerances, the float was finished.

Fig. 17 - Vertical Profiling Float

V. Electrical Design Rationale

A. Electrical Overview

The electronics in ROV Iso-Squid utilize a fourth-generation architecture that builds upon the electronics designed for the previous competition. It includes improvements to accommodate a single-enclosure robot, such as minimizing the overall stack size. The power box, which houses all the electronics, receives power and transmits/receives signals through the tether, which is plugged into the bottom of the power box. The tether consists of the 48VDC power line, supplied from the surface control box that converts AC power from a wall outlet to DC power, and the shielded CAT 6 Ethernet cable. The Ethernet cable provides noise immunity from the marine environment and high bandwidth for three low-latency camera streams.

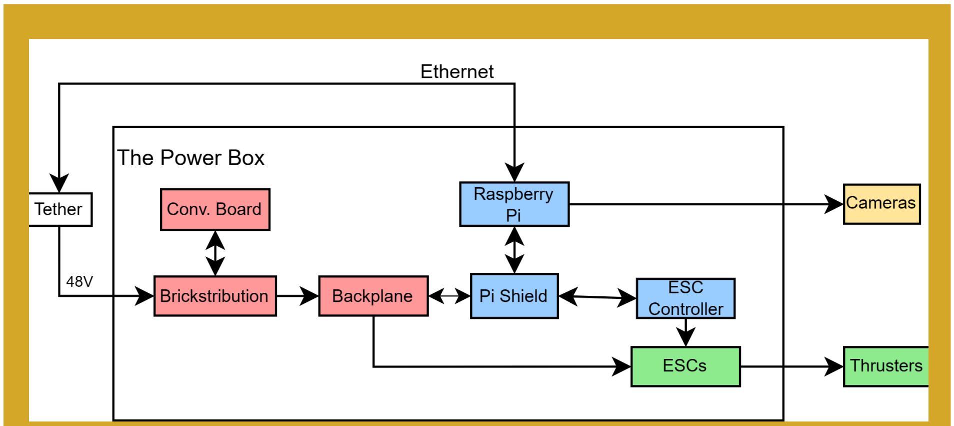


Fig. 18 - Simplified SID

Specifically, the 48VDC power inside the tether is delivered through two 2.05-mm diameter marine-grade wires with an in-line 25A fuse. For input/output signals, the ROV, primarily the cameras and thrusters, is controlled from a surface base station that consists of the pilot's computer, monitor, and gamepad.

The electronic stack of the ROV Iso-Squid is housed inside the Power Box. It mainly consists of seven boards interconnected through power connectors: Brickstribution (with one Power Brick), Backplane, Power Conversion, ESC controller, ESC adapters (with three ESCs), and Pi Shield (with Raspberry Pi 4). The stack is divided into two vertical sub-stacks to provide accessibility to boards that are frequently removed or programmed during development. The Brickstribution board serves as the power distribution and protection circuit board, adapting to one power brick module that converts 48VDC to 12VDC with a power capacity of 1300W. The Power Conversion board, positioned on top of the Brickstribution, receives 12V and converts it to 5.2V and 3.3V for the logic electronics. The power lines, including isolated 12VDC for thrusters, logic 12V, 5.2V, and 3.3V, are then routed to the Backplane board to interface with the ESC Controller, ESC Adapters, and Pi Shield. The ESC Controller operates under a Nucleo32 board to communicate with the Pi Shield through the SPI protocol and output PWM signals to the ESC Adapters. The three ESC Adapters connect directly to the panel mounts under the Backplane to power the three ESCs (Lumenier Mini Razor). Lastly, the Pi Shield is an adapter board for the Raspberry Pi 4, providing 5.2V power and header pins for other external tools. The Pi 4 is directly connected to the Ethernet cable to control thrusters, sensors, and camera feeds.

All printed circuit boards were designed and assembled in-house by the Purdue ROV Electrical Department using EAGLE, except for the Raspberry Pi, ESCs, solenoid latches, and three exploreHD 2.0 Underwater ROV/AUV USB Cameras.

B. Brickstribution

TThe Brickstribution board serves five main purposes: housing the Power Brick module to convert the tether's 48V (32A) to 12V (110A), supplying 12V to both Power Conversion & Backplane, and distributing 5.2V & 3.3V from Power Conversion to Backplane. It connects to the tether via Phoenix terminal blocks, Backplane via MOLEX connector, and Power Conversion via single-row header sockets. Design priorities are optimizing board layout for space reduction and heat dissipation, removing outdated circuits, protecting the Power Brick, placing effective vias for current flow, and selecting compact yet suitable components. Design considerations are selecting decoupling capacitors as well as inductors with low magnetic flux leakage.

C. Power Conversion Board

The Power Conversion board converts 12V power input from Brickstribution to 5.2V (3A) via buck converter and 3.3V (1A) via linear regulator for other logic electronics. It is positioned on top of Brickstribution through single-row header pins. The design priorities are minimizing board size, converting precisely to desired output voltages, and matching Brickstribution's position. Design considerations include choosing the LM2679SX-ADJ buck converter, calculating components' values to output precisely at 5.2V, and optimizing conversion through board layout.

D. Backplane

The Backplane board routes signal and power for multiple boards: Brickstribution, Pi Shield, ESC Controller, ESC Adapters, and Solenoids. Design priorities are transmitting Brickstribution's power lines, length tuning of CAN Bus signals, separating power traces from logic traces, and increasing debugging tools such as LED indication. Design considerations are removing features such as MUX, programming signals, and robot arms implementation while also housing the BJT transistor arrays to take in Pi 4's GPIO signals and convert them to Solenoid signals.

E. ESC Controller and Adapter Boards

The ESC Controller board serves as communication between the Raspberry Pi and the Lumenier ESCs. It is powered with 3.3V from the underneath Backplane via 2x6 header pins. Initially, it receives signals on the CAN Bus signals from the Pi and translates them to 12 PWM outputs for the ESCs. Design priorities are optimizing the function of the onboard STM32 chip and ensuring clear CAN Bus protocol to the Pi Shield. Design considerations are length-tuning of CAN Bus signals, assigning the correct pinouts of the STM32 chip, and communication to the Pi. However, through several debugging on the CAN Bus and iteration of board design, the ESC Controller is changed to an adapter board of the Nucleo32 board to communicate with the Pi 4 via SPI protocol and output 10 PWM outputs to the ESCs.

The ESC Adapter board takes in 12V power from Backplane, houses the Lumenier ESC, and connects the ESC to thrusters. It is positioned underneath Backplane as it connects to both Backplane and Thruster via a power socket strip. Design priorities are utilizing the limited space available and optimizing power delivery to the ESC. After multiple design considerations, the thrusters' wires are soldered directly onboard as the connectors are removed.

F. Raspberry Pi and Pi Shield

The Raspberry Pi 4, the strongest commercially available Pi, is the onboard computer of the ROV, plugging underneath the Pi Shield. With the flexibility to program, the Pi processes code & commands to control the ROV, provides feedback information to the surface, and provides camera feeds for the pilot. The Pi is plugged in with two ExploreHD 2.0 Underwater Cameras via USB 3.0 and tether's ethernet cable. Specifically, the tether protocol to control the ROV operates in the Pi's server through ethernet signals from the Pi in the Power Box to a router which then connects to a surface computer.

The Pi Shield board provides 5.2V & 3.3V powers from Backplane to the Raspberry Pi, connects the depth sensor to the Pi, controls the Solenoids, and transmits the CAN Bus Signals to ESC Controller. It facilitates communication protocols including Inter-Integrated Circuit (I2C) and Serial Peripheral Interface (SPI). Furthermore, it delivers four Pi's GPIO

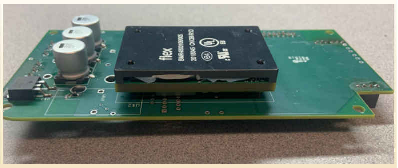


Fig. 19 - Power bricks


Fig. 20 - Backplane (bottom) and Conversion (top)

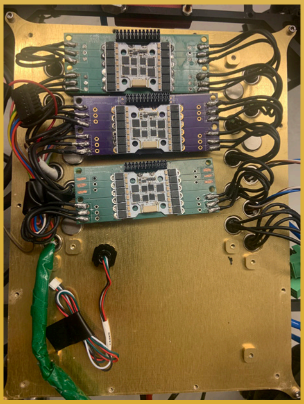


Fig. 21- Lumenier 4in1 ESC and adapter board

Fig. 22- ESC controller board

signals to control the solenoids to Backplane which positions underneath. Design priorities are simplifying the CAN Bus circuit, ensuring the proper functionality of the CAN Bus signal through the CAN Transceiver/Controller IC, and ensuring sensor testability. After further design considerations, the Pi Shield no longer utilizes CAN Bus but instead SPI communication to ESC Controller.

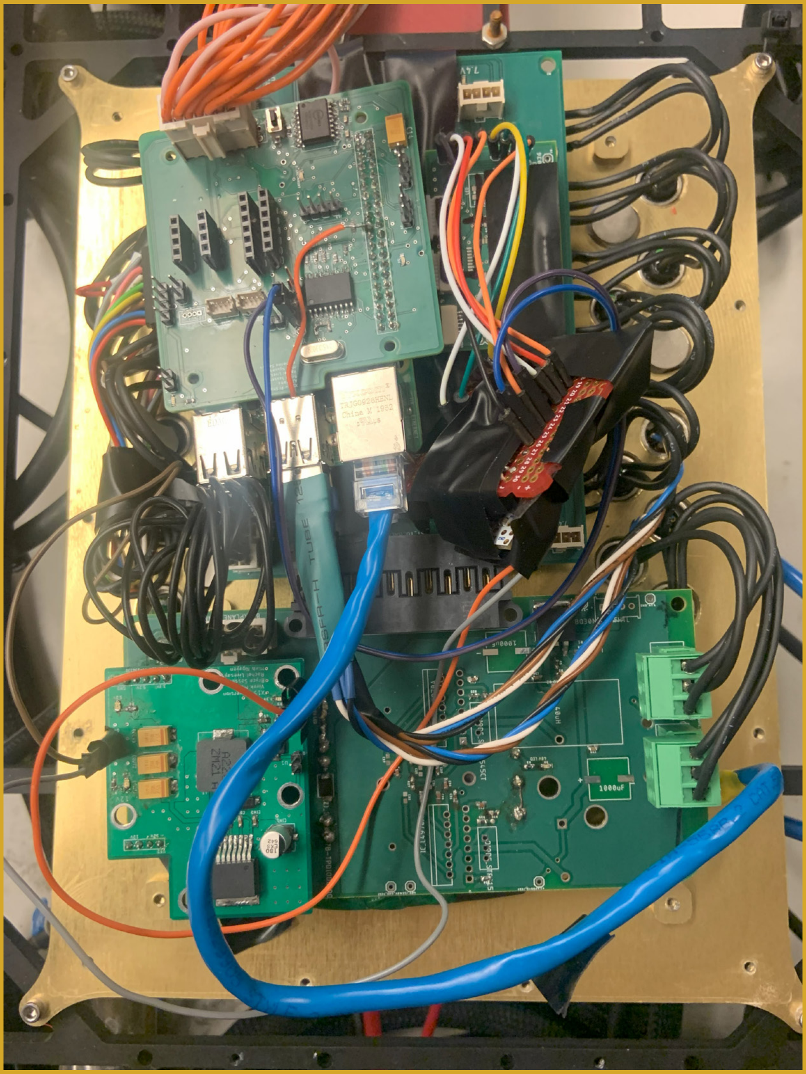


Fig. 23 - Full power electronics stack

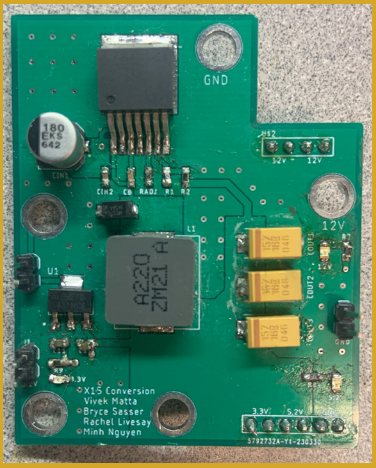


Fig. 24 - Power Conversion

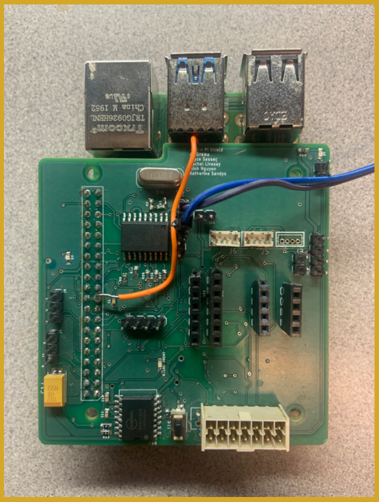


Fig. 25 - Pi Shield

VI. Software Design Rationale

A. Software Overview

Proven Robotics designed ROV X15's software stack intending to simplify data pipelines while still maintaining a modular and reliable framework. To achieve this goal, the software department underwent several design changes from previous years. First, the software department restructured the X15 software stack, using a ROS2 (Robotic Operating System) framework instead of ROS1. ROS2 provides several optimizations and improvements over ROS1, permitting more responsive ROV performance. Next, the software team streamlined our embedded communication by switching from the CAN protocol to the SPI protocol, which better fit our use case. Finally, X15's software stack was tailored to handle the unique tasks in this year's product demonstration.

Operationally, the X15 software team stressed individual ownership of projects, following industry coding standards, and maintaining clean documentation. X15 software followed proper version control techniques using GitHub, adding features into new branches, and performing code reviews before they are merged into the main development branch. Additionally, this year, Proven Robotics began maintaining documentation on BookStack, ensuring everything is kept in a centralized location. Finally, every meeting began with a stand-up, where the software team discussed what each member was working on, whether the team faced any blockers, as well as the short-term timeline for development.

B. Software Architecture

The X15 software stack was redesigned within a ROS (Robotic Operating System) network to streamline data pipelines and improve efficiency. ROS is a tool that handles IPC (inter-process communication) across a network of processes. A ROS network consists of Nodes, Topics, and Messages. Nodes are the separate processes within the system, such as thrust control or solenoid monitoring. These Nodes can publish "Messages" to a certain topic that other nodes can subscribe to and receive the "messages". The modular structure of ROS allowed the team to develop all components of the software simultaneously without relying on prior processes to be complete, giving a greater degree of freedom in the development process.

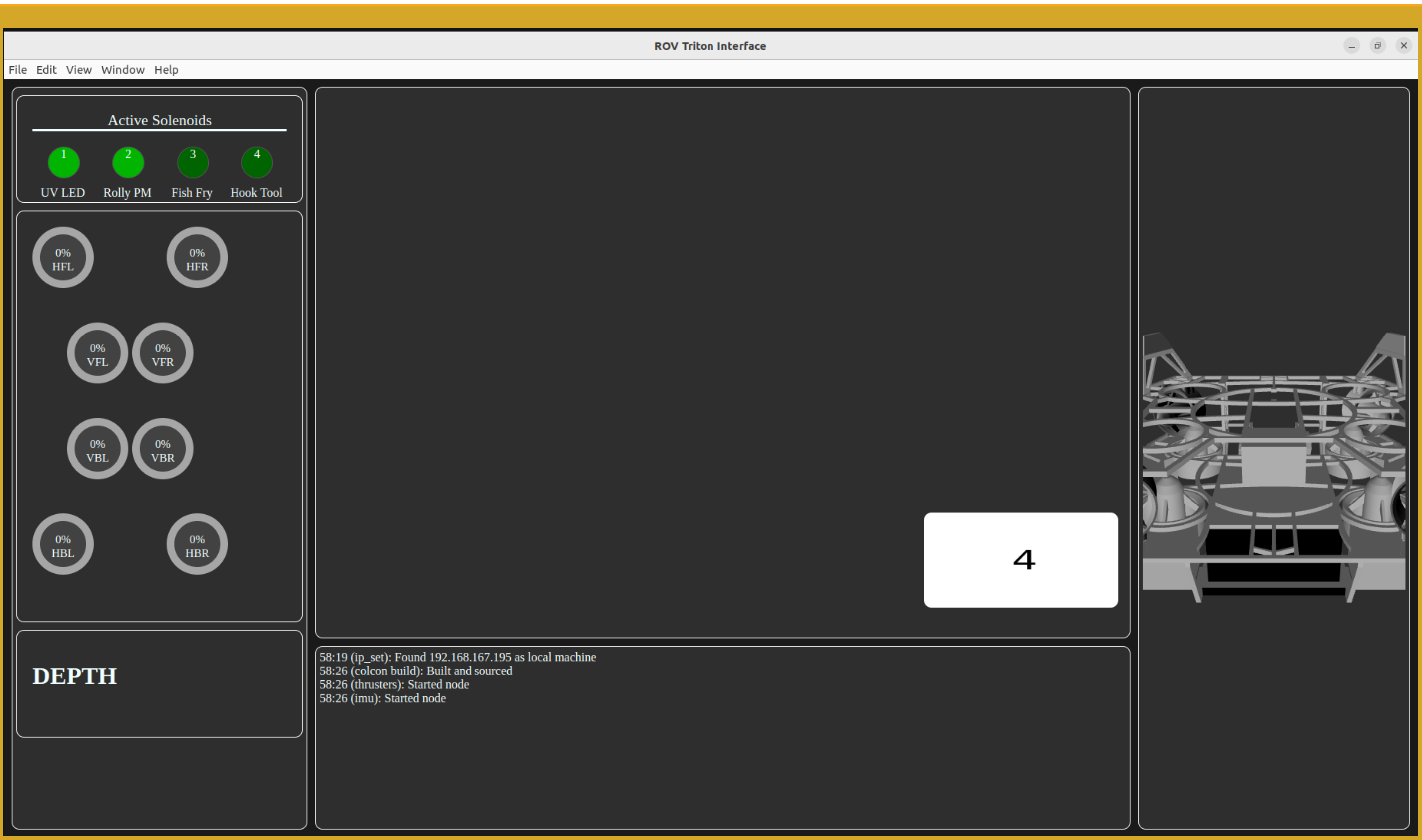
X15 migrated from ROS1 Noetic, used in X14, to ROS2 humble, which involved a complete rewrite of our core codebase. We undertook this design challenge for three reasons. First, beginning from scratch gave us the freedom to make larger architectural changes, re-evaluate design decisions, and improve efficiency and organization. Second, it ensured that our software kept up with the latest stable LTS version of Ubuntu (22.04). Finally, this allowed X15 to benefit from the improved efficiency and new features of ROS2, such as multi-threaded execution on multicore processors and superior real-time processing.

The X15 software stack is divided into two logical blocks: X15-Core, the software that runs on the Raspberry Pi inside the ROV, and X15-Surface, the software which runs on the surface laptop. The X15-Core ROS network manages thrusters mapping and the Raspberry Pi's hardware peripherals including I2C sensors, GPIO tools, and SPI communication. X15-Core also streams the cameras to the surface station and handles all of the Pi's peripheral interfaces. X15 Surface, on the other hand, receives the camera streams, publishes the desired velocity from the controller, and runs the user interface. These two blocks are physically connected by an ethernet cable within the tether, and the blocks communicate by transmitting ROS topics across a UDP bridge.

C. Embedded Communication

The Raspberry Pi relies on a variety of communication protocols to interface with the electronics inside the ROV. The embedded level of X15-Core is responsible for the embedded communication and managing a variety of tasks including driving thrusters, signaling solenoids, and receiving sensor data.

One of the most significant design changes made this year was using SPI instead of CAN to communicate with the ESC controller, the microcontroller that drives the thrusters. The Raspberry Pi transmits a series of bytes to the ESC controller across the SPI bus. Each byte represents the thrust effort of one thruster. The ESC controller then uses the values of these bytes to drive the PWM signals to the ESCs.



```
58:19 (ip_set): Found 192.168.167.195 as local machine
58:26 (colcon build): Built and sourced
58:26 (thrusters): Started node
58:26 (imu): Started node
```

Fig. 26 - Pilot Interface display showing adjustable thruster controls

The software department decided to forgo the CAN bus in favor of SPI because the CAN bus is designed for communication between several, peer-to-peer nodes on one network, this year's electrical stack requires only a single master, the Raspberry Pi, and a single slave, ESC-controller. SPI offered simpler integration and better performance than CAN, and better fit X15's intended use case.

The X15 ROV also relies on several I2C sensors, connected to the Raspberry Pi, to gather information on the ROV's positional state. Specifically, the ROV uses an IMU, which provides data on the ROV's current acceleration and orientation, and a pressure sensor used to calculate the ROV's depth. Using several open-source Python libraries, the sensor data is read from the I2C bus and then published to a ROS topic, where it can then be accessed by the frontend user interface, or used for mission tasks such as the CV coral detection.

Finally, the pilot must be able to trigger solenoid-based tools. The X15 Software stack contains ROS nodes that control the tools' solenoids on the ROV. A node in X15-Surface subscribes to the tools topic from the gamepad (xbox controller) as an array of four bytes intended to control the four solenoids. A ROS node then reads the array and triggers GPIO pins on the Raspberry Pi using an external Python library. These pins trigger the solenoids of different tools on the ROV.

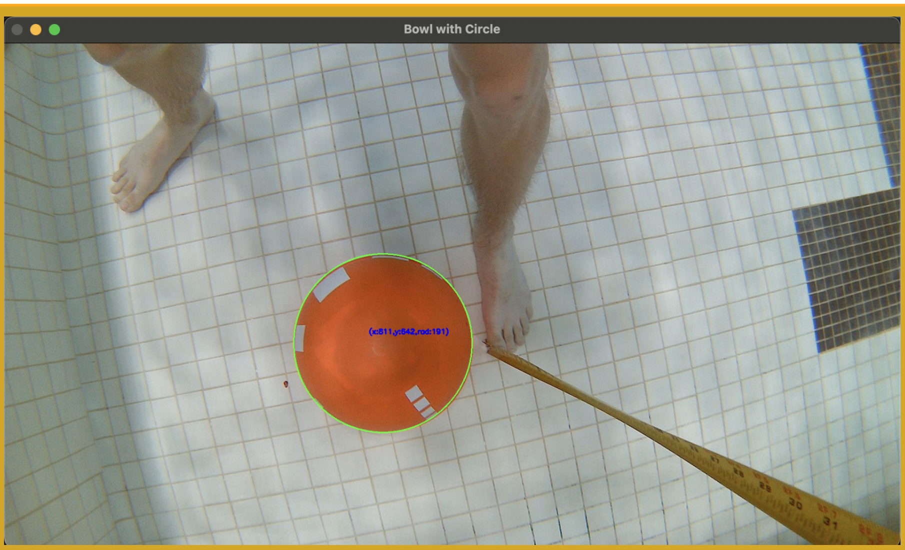


Fig. 27 - View of a Comera with Computer Vision

D. Propulsion and Control

X15 is driven using open-loop control where the pilot sends movement commands using a gamepad (xbox controller). A process listens for gamepad events, and based on the controller state, publishes a desired velocity vector for the ROV. The velocity vector contains the desired translational movement, relative to the ROV's center of mass, as well as the desired roll, pitch, and yaw. This vector passes through the thrust mapper, which performs a linear transformation using a Moore-Penrose pseudo-inverse matrix, to determine the required thrust effort from each thruster to achieve the desired velocity. Finally, the thrust effort is transmitted to the ESC controller, which drives the thrusters.

This open-loop control algorithm provides the pilot with six degrees of freedom for complex maneuvering. Additionally, the pilot has the option to select between three thrust envelopes: fine, standard, and coarse. Fine limits the thrust envelope, for precise movements, the standard has a larger, but still limited thrust envelope, and coarse unlocks the ROV's full thrust envelope, but is not conducive for precise actions.

Finally, the team prototyped a depth PID loop using information from the depth sensor. This feature would allow the pilot to lock the ROV at a constant depth if desired, such that if a value of 5 meters was inputted, the algorithm would produce thrust values that would hold the ROV constant at 5 meters. This could be very helpful for tasks that require the ROV to be held at one point. Work will continue to be done on this feature and will hopefully be implemented in a future ROV.

E. Pilot Interface

The X15 surface station consists of two monitors, one containing the surface UI, and the second displaying the ROV's camera streams. The software team found that this setup allowed the largest possible camera windows, and provided the best pilot experience.

X15's electron UI (user interface) builds off of previous years, adding new features and tailoring it for this year's ROV. This UI was designed in-house using Electron, ReactJs, and TypeScript. The application communicates to the ROV by spawning ROS nodes on the ROV's ROS network. These ROS nodes perform a variety of tasks such as writing IMU and depth sensor data to the UI, as well as publishing velocity commands based on controller input.

This year, the software department focused on providing the pilot with additional ROV state information on the UI, including indicators for solenoid actuation and thruster power, as well as information on the ROV's state such as a depth indicator. Finally, a console log was used to display diagnostic information and error messages to the pilot.

X15 used GStreamer to stream the cameras on the ROV camera to the surface station. GStreamer is an open-source multimedia framework that is generally used to construct video streaming pipelines. The video stream begins with a source camera, which puts the video through a series of transformations, such as resizing or format conversions. The data is then compressed in preparation for it to be sent over the network. This leads the stream to be sent to a network sink that transmits to a specific IP address. This IP address is then able to make a data processing pipeline to convert the stream to the specific format needed.

E. Computer Vision

The Proven Robotics software department developed a custom CV pipeline to tackle the coral computer vision task in this year's product demonstration. The task required the ROV to autonomously determine the height and diameter of a bowl simulating coral, find the size of infected areas on the coral, and finally, generate a 3D model of the object. To locate the coral bowl from the camera stream, the CV pipeline uses HoughCircle to find the edge of the bowl. We eliminate extra circles generated by HoughCircles by discarding generated circles that do not make sense, such as those that congregate in the corner of the camera stream and have arcs that lie beyond the frame of the video stream. This design lies on the assumption that the pilot of the ROV will maintain the coral bowl in the center of the video frame. Based on the depth sensor's readings (h1 and h2) and the size of the bowl relative to the video size, we're able to calculate the diameter of the coral bowl by comparing the change in depth relative to the change in bowl size in the video frame.

Finally, the 3D photogrammetry is completed through a three-step pipeline. We first use openMVG to generate a point and dense cloud. This is fed into openMVS to create the surface of the coral and enhance its texture. Finally, we call the Blender API to display the fully-rendered and rotatable coral bowl.

VII. Logistics

A. Company Organization

Purdue ROV utilized the organizational structure from the previous year due to its proven effectiveness. The three technical departments: Mechanical, Electrical, and Software were maintained. With the exception of Software, all departments have two leads which aid in covering the many branches of technical knowledge and administrative skills needed. The leads report directly to the CEO. Six interdisciplinary project groups were employed to focus on six major subsystems of the company: Frame and Buoyancy, Tools and Pneumatics, Electronic Boards, R&D Electronics & Embedded, ROS, and Front end. Several groups have designated heads, while others report to the department technical lead. These groups fostered communication around key areas of the ROV that require complex integration.

B. Project Management

Purdue ROV's design cycle is split into four stages: training, design, manufacturing, and testing. During the training phase, new employees are recruited and trained in applicable areas of SolidWorks CAD, Eagle, Embedded C, Python, Web Development, GrabCAD, and proper GitHub use for their department. Returning employees may revisit their training to expand their knowledge or help lead it and pass on the experience they've gained. Training sessions are also recorded for those who can not make the meeting.

At the start of the year, the CEO and technical leads made Gantt Charts for a visual organization of deadlines (See Appendix C). This visualization of deadlines aided employees in understanding when tasks needed to be started and completed, as well as what tasks had to be done first. Technical leads also made SIDs and architecture decisions that set the tone for ROV Sub-Optimal. Purdue ROV completed most of the design before mission specifications were released but allowed ample room to adjust for mission-specific needs. In the early design phase, group discussions were held with example sketches and low-fidelity prototypes to brainstorm and select design plans. Each week the company held a planning meeting remotely to discuss progress and high-level details. In addition, the company conducted two full-company meetings each week with flexibility for in-person or virtual attendance. Employees collaborated during scheduled meeting times and put in additional effort outside these times to finish designs. As designs progressed, higher fidelity prototypes were made and test PCBs were ordered. Several design reviews, including a formal, comprehensive one with alumni, were conducted to ensure optimal designs and minimal hurdles and delays. After the design phase, all of the designs were verified and ready for manufacturing.

During the manufacturing phase, all components for the ROV were fabricated and assembled. Employees worked together to ensure that all tools and waterproof enclosures were machined or 3D printed, the frame was waterjet-cut, circuit boards were populated, and software was developed and tested. The company prioritized mission-critical components, but all components had scheduled times to be manufactured or completed. After a component was completed, it was tested in isolation before introduction to the system in the air to ensure functionality before deployment in the water. If tests failed, the component would either be modified or redesigned depending on the severity of the issue. Once all critical components passed individual testing, the ROV was assembled and fully tested. Separately, non-critical tools and software features were integrated and tested upon their completion.

Full-system tests began promptly when the ROV was pilotable. As tool iterations were completed, they were integrated, tested, and refined. Simultaneously, the buoyancy system was adjusted to account for the impact each new tool had on the ROV. The piloting software was also tweaked to pilot preferences and vehicle mechanics. The planned mission path was also adjusted based on ROV performance and how many points tasks were worth.

C. Project Costing and Budget

Purdue ROV creates its yearly budget based on a combination of previous years' budgets, projected incomes, and projected future expenses. These expenses include the cost of producing ROV Iso-Squid and the costs of attending the competition. The Mechanical, Electrical, Software, and Administrative

Departments each have their own budget. Overspending in any department must be accounted for by cutting back on the spending in other departments or by raising additional funds. The budget category for ROV Construction with the largest changes from prior years was the electrical budget. An overall increase of $1750 in the electrical budget enabled the allocation of more money towards boards, miscellaneous components, and prototyping. Purdue ROV pays for flights and lodging for as many employees to attend the competition as the budget allows, rewarding them for their hard work throughout the year. This represents the largest portion of the company's total budget but has not increased from the previous year. The company receives income from various grants from Purdue University organizations along with sponsorships and in-kind donations from other companies. These donations include physical hardware, software, and discounts on purchases. Any surplus the company has after the competition is utilized to fund future improvements for the company, including upgrading equipment for the workspace, R&D for projects such as robotic arm, and new manufacturing processes such as welding or metal printing the Power Box.

Budget

Purdue ROV's 2023 Budget

Budget Category	Item and Description	Type	Amount	Total Amount	Budget Allocated
Electrical: Boards	PCB Fabrication	Purchased	$605.26	$605.26	$800.00
Electrical: Cameras	ExploreHD Camera	Purchased	$285.90	$367.40	$500.00
	Nano Pi Duos	Purchased	$81.50		
Electrical: Components	Power Bricks	Purchased	$279.71	$1,170.94	$1,500.00
	STM Nucleos	Purchased	$103.70		
	Lumenier ESCs	Purchased	$256.76		
	SMD Components	Purchased	$479.43		
	Vertical Profiling Float Materials	Purchased	$51.34		
Electrical: Equipment	None	Purchased	$0.00	$0.00	$250.00
Electrical: Prototyping	Test parts and boards	Purchased	$115.69	$115.69	$600.00
Mechanical: Connectors	New Tether Materials and Binder Connectors	Purchased	$1,146.81	$1,146.81	$800.00
Mechanical: Equipment	Thruster Test Stand Materials	Purchased	$54.42	$1,217.78	$800.00
	Pressure Test Vessel	Purchased	$367.81		
	Resin Printer Components	Purchased	$180.98		
	COM/COB Scale	Purchased	$438.79		
	Misc. hand tools	Purchased	$175.78		
Mechanical: Materials	Aluminum and Polycarbonate Stock	Purchased	$425.69	$1,963.16	$2,250.00
	Buoyancy (Foam and tanks)	Purchased	$112.65		
	3D printer filament, resin, epoxy	Purchased	$176.15		
	Parts for tools (Screws, bolts, epoxy, etc.)	Purchased	$772.37		
	Pneumatic Enclosure Parts	Purchased	$269.06		
	Prop Parts (PVC, corrugated plastic, etc.)	Purchased	$207.24		
Mechanical: R&D	Robotic Arm Parts	Purchased	$511.47	$511.47	$1,000.00
Mechanical: Thrusters	Blue Robotics T200s and other parts	Purchased	$1,694.55	$1,694.55	$1,200.00
Total Expenses for ROV Construction				$8,793.06	$9,700.00
General: Competition and Lodging	Hotels, registrations	Estimated	$3,475.00	$3,475.00	$5,000.00
General: Travel	Gas, flights, etc.	Estimated	$1,500.00	$1,500.00	$3,000.00
General: Apperal	T shirts and polos for the team	Estimated	$900.00	$900.00	$1,100.00
General: Other	Miscellaneous purchases	Estimated	$120.00	$120.00	$650.00
Total Expenses for Competing				$14,788.06	$19,450.00
Income	CAT	Cash	$500.00	$500.00	$500.00
	4PCB	Cash	$500.00	$500.00	$500.00
	Purdue Polytechnic Institute	Cash	$2,000.00	$2,000.00	$2,000.00
	Purdue ECE	Cash	$3,000.00	$3,000.00	$4,000.00
	PESC	Cash	$1,000.00	$1,000.00	$1,000.00
	Grant Geyer	Cash	$2,000.00	$2,000.00	$2,000.00
	Purdue ME	Cash	$0.00	$0.00	$1,000.00
	Purdue Provost Office	Cash	$0.00	$0.00	$6,000.00
Total Cash Income for 2020-2021				$9,000.00	$17,000.00
Donations and Discounts	Binder USA	Discount	$135.00	$	N/A
	Advanced Circuits	Discount	$500.00		
	Digikey	Discount	$68.00		
	Colors	In Kind	$200.00		
Total Expenses				$14,788.06	$19,450.00
Total Cash Income				$9,000.00	$17,000.00
Net Balance				-$5,788.06	-$2,450.00
Next Year Investment				-$5,788.06	-$2,450.00

VIII. Conclusion

A. Testing and Troubleshooting

Considerations were made during the design phase of the ROV to reduce the testing workload. This included mechanical simulations of components with Finite Element Analysis (FEA), integration of CADDed components into one assembly, and inclusion of test points on electrical boards. Another technique utilized was rapid prototyping with parts such as the frame with low-fidelity prototypes determining the desired grid size to minimize interference during assembly.

During the manufacturing phase, components were tested before integration into ROV Iso-Squid. For instance, the electrical boards were continuity tested after soldering to ensure proper solder joints. Mechanical components each had their unique tests such as the pneumatic enclosure which had its components tested, then assembled and re-tested. The solenoids were each manually fired, the enclosure was leak tested with a vacuum, connectors were continuity tested and then the whole assembly was tested to 100 psi per the safety guidelines. Once the individual components were functional, they were integrated into the ROV on land and tested before deployment underwater.

Troubleshooting the electronics was a major challenge this year, specifically the three debugging phases on the CAN Bus communication from the Raspberry Pi to the ESC Controller board, spanning 2 long months. The initial design is diagnosed to be unsolvable through datasheets, coding, oscilloscope monitoring, and alumni with the following errors: using the incompatible CAN Transceiver/Controller IC on Pi Shield and the incorrect CAN termination. The second method is replacing the ESC Controller board with a PCA9685 I2C module; however, the communication between Pi and the module is often disrupted when running the thrusters. The last method finally works with reviving the ESC Controller board by using the Nucleo32 board as the Pi can communicate to the board through SPI and control the thruster smoothly.

Before deployment in the water, the Safety Checklist (see Appendix) is checked for student safety and a multi-minute dunk test is performed before powering the vehicle. Initial pool tests were used to adjust control, piloting, and buoyancy; collect computer vision footage, and test tool prototypes in isolation. Subsequent pool tests were used to practice extended portions of the mission run and gauge task difficulty and time.

B. Challenges

A major challenge the company faced this year was the effective handling of setbacks. For instance, the ESC controller issues that plagued the spring semester singlehandedly prevented pool tests for two months. This was mostly a scheduling issue as we started board integration late into the spring semester but also a shortage of experienced members to aid in troubleshooting. Then, when the ESC controller was finally fixed, there were more issues such as the unshielded ethernet cable dropping signal in the water due to excessive EMI. The excessive focus placed on the ESC controller caused other electrical issues to not be diagnosed. A similar situation occurred with the Pneumatics Enclosure.

The organizational structure where the burden of both technical leadership and administrative leadership was placed on the captain and by extension the leads was also a challenge. Due to a large number of new members and a shortage of experienced members, administrative work was deprioritized in favor of technical leadership. This caused issues with inadequate scheduling leading to the aforementioned issues but also led to technical issues such as the electronic stack not fitting in the Power Box causing a last-minute redesign of a board. While we did end up with a functional ROV, it was a much more arduous journey than it should have been.

C. Lessons Learned and Skills Gained

All All Purdue ROV employees learned valuable technical skills both from their departments and from those they collaborated with. A large portion of skills development came from workshops held throughout the semester by the company. The Mechanical Department held workshops for SolidWorks, 3D printing, CAM, and machining. The Electrical Department held workshops for Eagle, Soldering, and Embedded C. The Software Department held workshops for Git, ROS, and Linux. Employees had the opportunity to develop soft skills including presenting, communicating, and technical writing techniques. Design reviews held throughout the year allowed employees to present their work and receive feedback from current employees and alumni. Written documentation is a critical aspect of work done for the ROV; employees document their design rationale, strengths, and improvements of a component.

Due to the aforementioned challenges, the company learned that making the team captain the CEO and CTO leads to issues. This is due to the CEO being immersed in the day-to-day technical struggles and losing sight of the bigger picture leading to the schedule not being adhered to. Additionally, the lack of experienced members to take up the slack when setbacks occurred was a critical setback. More emphasis should have been placed on retaining members and accepting new members in the previous years.

D. Future Improvements

Software: The software department plans to use X15 as a foundation for future improvements. First, the software team plans to implement additional closed-loop control, including perfecting the closed-loop depth control prototyped this year. Additionally, we plan to redesign the surface station user interface and rethink the pilot controls for ease of use and productization.

Electrical: The electrical department will focus on enhancing the power brick's performance, integration of ESCs signals on the Backplane, and multiple communications from the Pi to the ESC Controller. The department will also continue the current R&D projects including custom ESC to replace the Lumenier ESCs and Custom USB/Port Hub to support more devices.

Mechanical: The mechanical department plans on continuing its pursuit of R&D projects that failed to enter production due to various issues such as a multi-DOF robotic arm and welded Power Box. The department also plans to optimize the hydrodynamics based on simulation results in addition to further development of our new tool types, specifically our wheeled

E. Reflections

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

> *Although I had heard about Purdue's ROV team before, it wasn't until I attended the IEEE callout that I could learn about the team and see the dedication and innovation that went into creating the ROV. What most attracted me to the team was the connection I saw between the members at the callout and how passionate each of them was about the ROV and their role on the team. I was quickly adopted into the team and given a suitable role for my skill set. I loved how every member of the team was always willing to teach and guide me along the way as I completed my assigned tasks. I have been fortunate enough to not only grow close to my team but also build an amazing alumni network. Throughout this year, I have not only learned about engineering and robotics but also teamwork and professionalism. ROV has brought me an incredible amount of knowledge over the past year and I can't wait to see how much more I can learn in the next three.*- Raygan Bingham (Mechanical Department, New Member)
>
> *I consider the ROV club to be some of the most important education I've received at Purdue. I joined just after my freshman year and I feel like I pretty much knew nothing. ROV is where I learned how to solder. It's where I learned how to design a PCB from nothing. And it's where I learned how to troubleshoot with the tools available. This club taught me most of the practical skills I have with electrical systems. I was surprised when I was made the lead of the electrical team because I felt out of my depth, but I learned how to organize and how to lead, and I have ROV to thank for that. There has been no single activity that better prepared me for professional work than ROV* - Bryce Sasser (Electrical Team Lead)

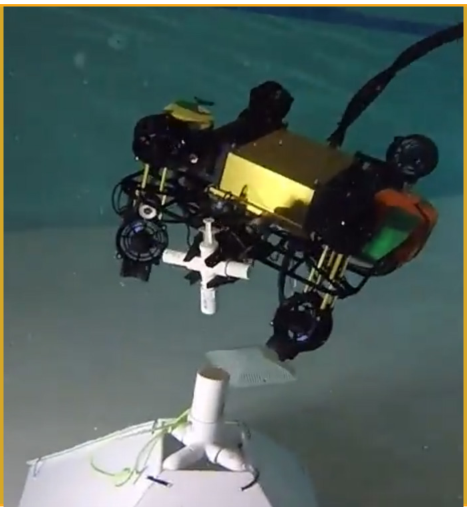


Fig. 28 - ROV Sub-Optimal during pool test

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,

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

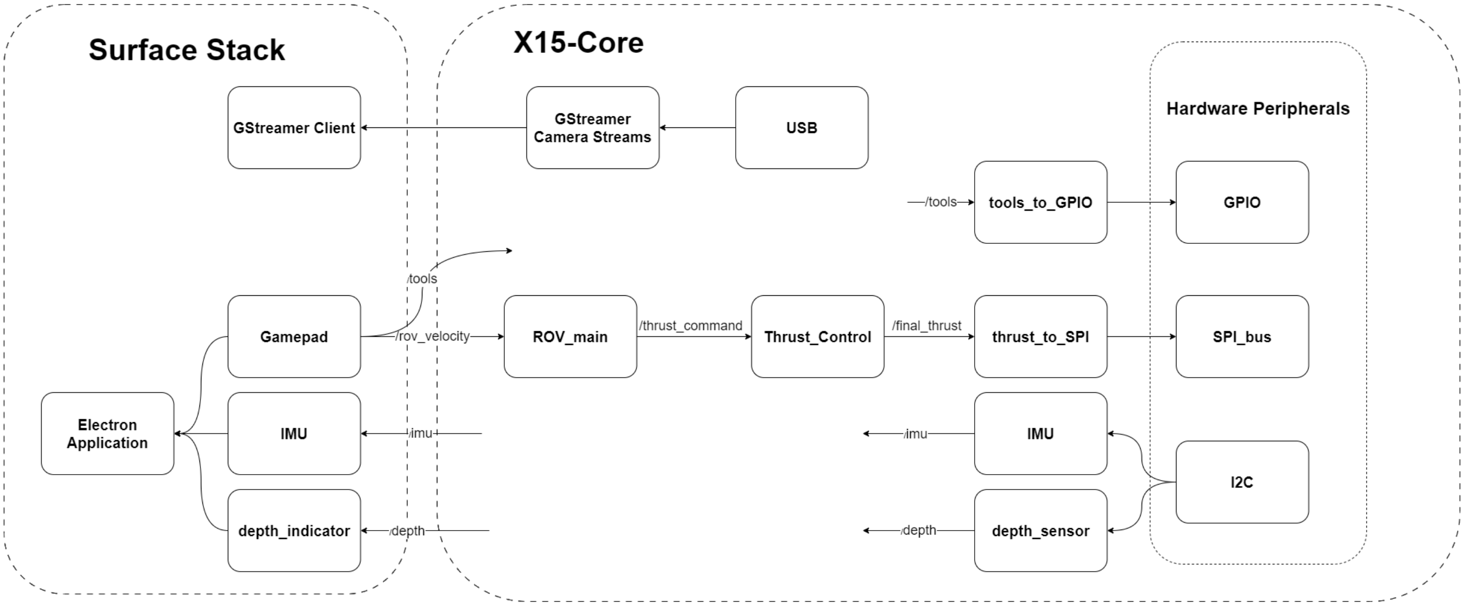
Lost Communication
- ☐ Steps attempted in order. Mission resumes when one succeeds.
- ☐ Co-pilot checks tether and laptop connections on the surface
- ☐ Pilot attempts to reset the BattleStation
- ☐ Co-pilot cycles the power supply
- ☐ If nothing succeeds, the mission stops
  - ☐ Co-pilot turns power 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

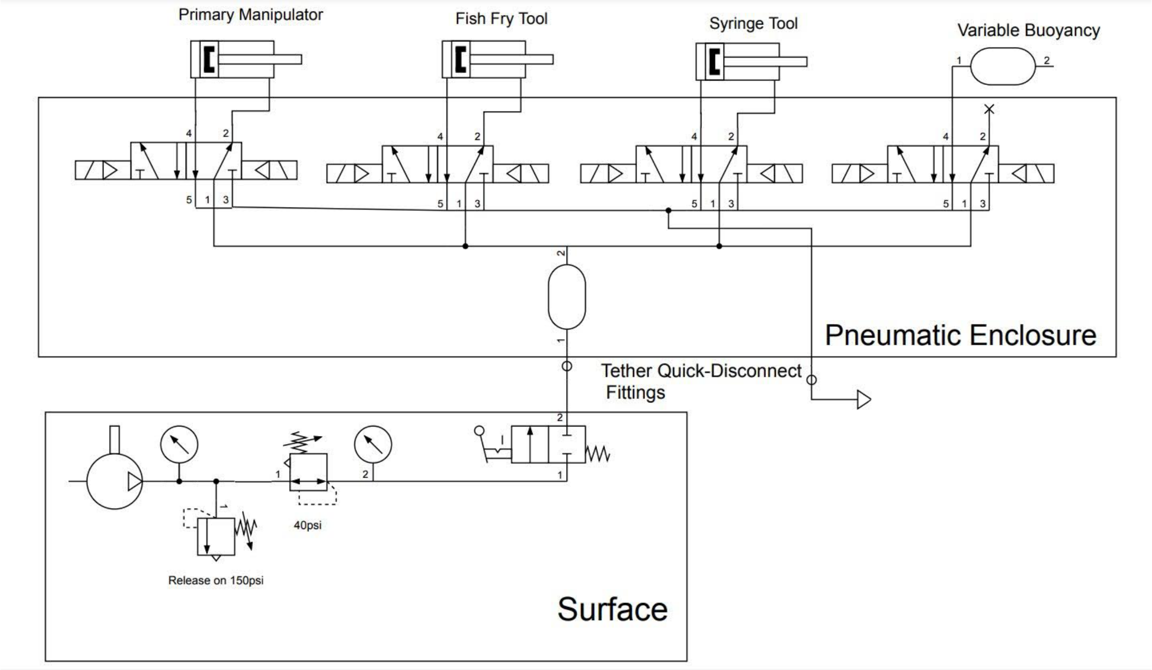
Demobilization
- ☐ Co-pilot turns power supply off and calls out, “Power off”
- ☐ Deployment members do a quick visual inspection for leaks or damage on ROV
- ☐ Pilot stops BattleStation and powers off laptop
- ☐ Anderson connectors of tether are removed from power supply
- ☐ Turn off air compressor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

B. System Interconnect Diagrams

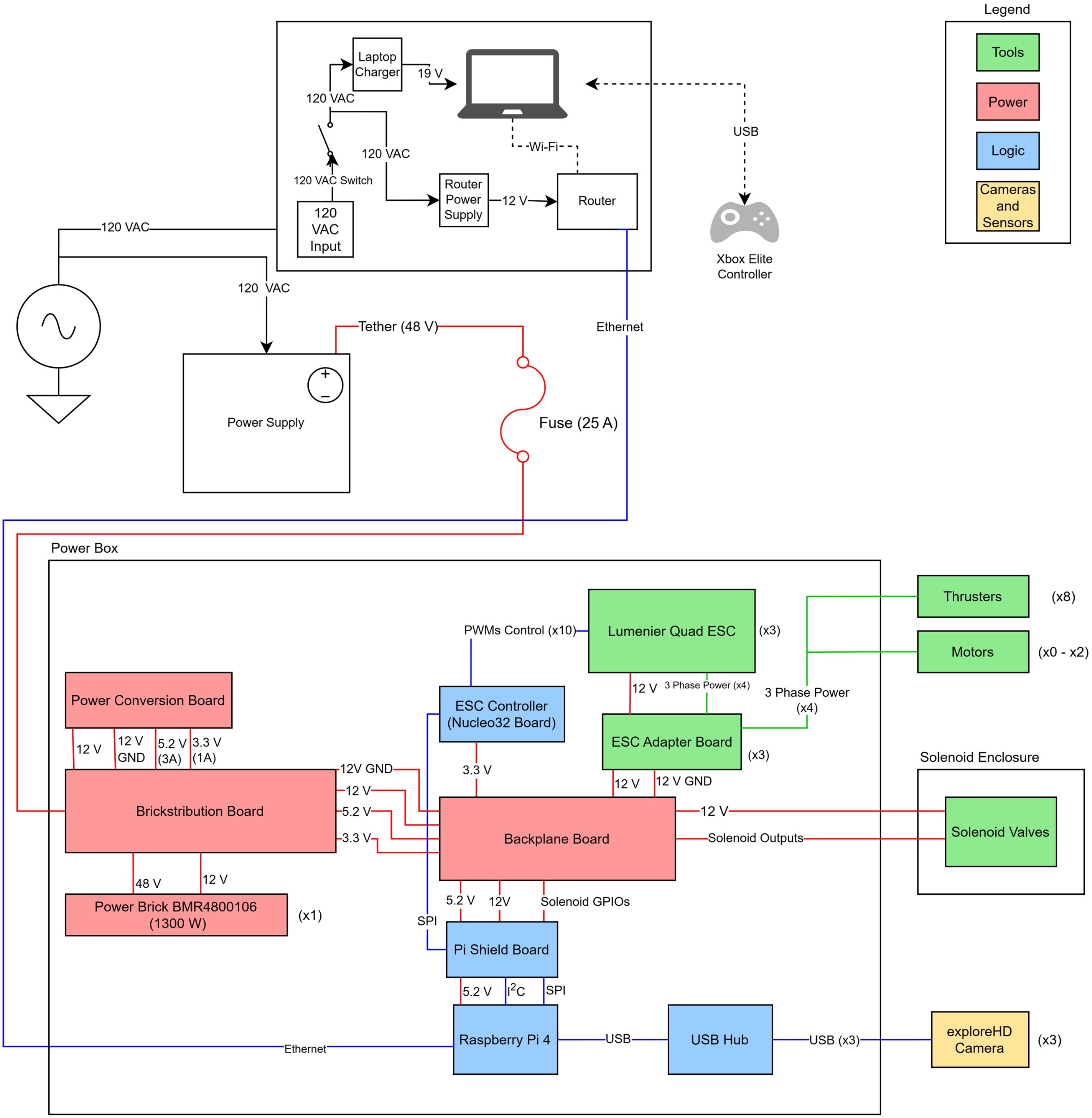
Software Flowchart



Fluid Power System Interconnect Diagram



Electrical Systems Interconnect Diagram

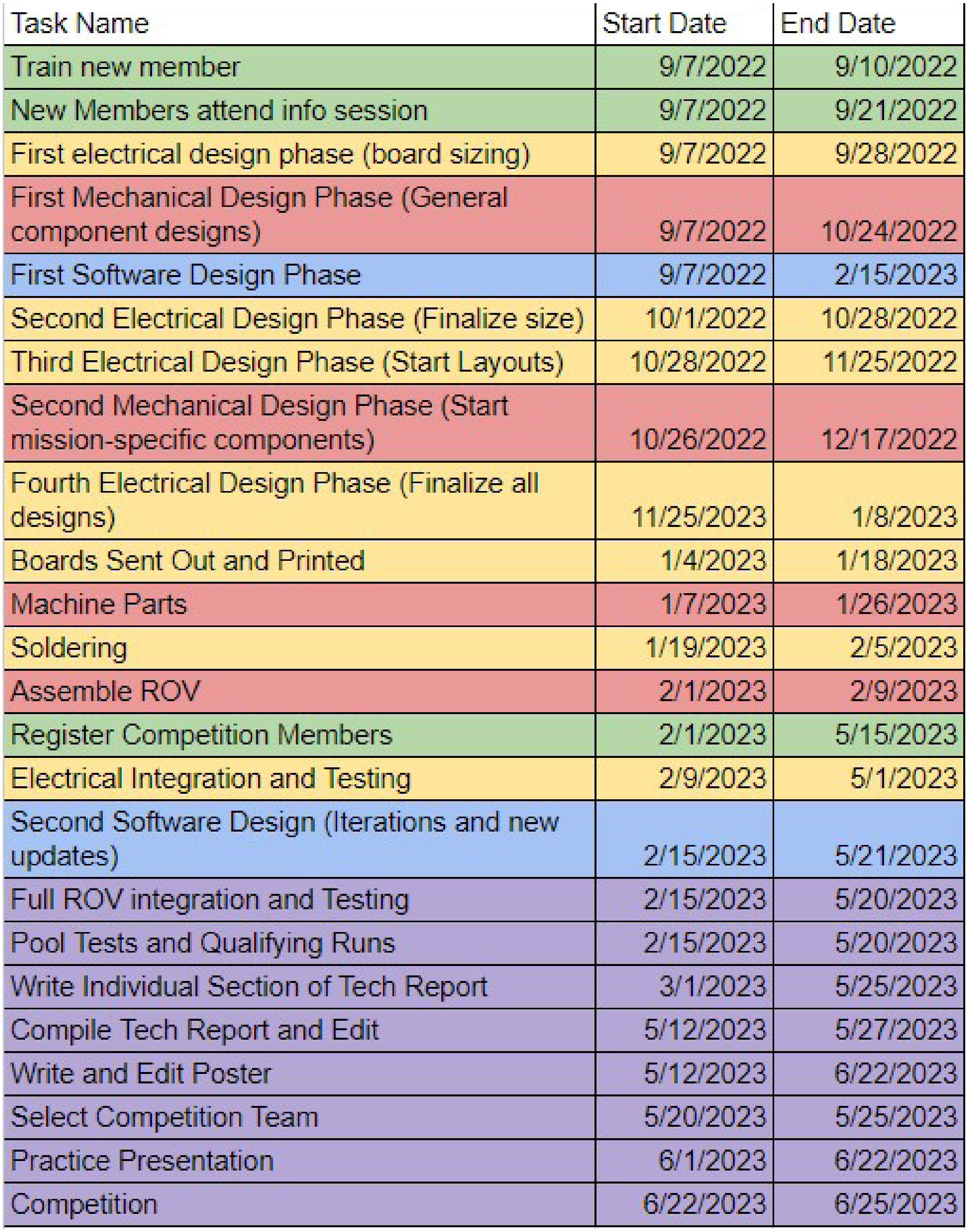


Tether Fuse Calculations:

8 x Thrusters @ 120 W
1 x Raspberry Pi w/ Camera @ 5 W
3 x exploreHD Camera @ 2 W
12 V-5 V Buck Converter (loss) @ 2.8 W
5 V-3.3 V Linear Regulator (loss) @ 0.51 W
1 x 48 V-12 V Buck Converters (loss) @ 50 W
Total Power: 1024.31 W

Current = 1024.31 W / 48 V = 21.34 A
21.34 A * 150% = 32 > 25 A
So 25 A fuse is used

C. Task List for Gantt Chart



Task Name	Start Date	End Date
Train new member	9/7/2022	9/10/2022
New Members attend info session	9/7/2022	9/21/2022
First electrical design phase (board sizing)	9/7/2022	9/28/2022
First Mechanical Design Phase (General component designs)	9/7/2022	10/24/2022
First Software Design Phase	9/7/2022	2/15/2023
Second Electrical Design Phase (Finalize size)	10/1/2022	10/28/2022
Third Electrical Design Phase (Start Layouts)	10/28/2022	11/25/2022
Second Mechanical Design Phase (Start mission-specific components)	10/26/2022	12/17/2022
Fourth Electrical Design Phase (Finalize all designs)	11/25/2023	1/8/2023
Boards Sent Out and Printed	1/4/2023	1/18/2023
Machine Parts	1/7/2023	1/26/2023
Soldering	1/19/2023	2/5/2023
Assemble ROV	2/1/2023	2/9/2023
Register Competition Members	2/1/2023	5/15/2023
Electrical Integration and Testing	2/9/2023	5/1/2023
Second Software Design (Iterations and new updates)	2/15/2023	5/21/2023
Full ROV integration and Testing	2/15/2023	5/20/2023
Pool Tests and Qualifying Runs	2/15/2023	5/20/2023
Write Individual Section of Tech Report	3/1/2023	5/25/2023
Compile Tech Report and Edit	5/12/2023	5/27/2023
Write and Edit Poster	5/12/2023	6/22/2023
Select Competition Team	5/20/2023	5/25/2023
Practice Presentation	6/1/2023	6/22/2023
Competition	6/22/2023	6/25/2023

-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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Proven Robotics Thanks

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
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Purdue Cordova Recreation Center and Hampton Inn for their provision of pools for testing
Micheal Hayashi

E. References

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