PROVEN ROBOTICS

2022 Technical Doumentation

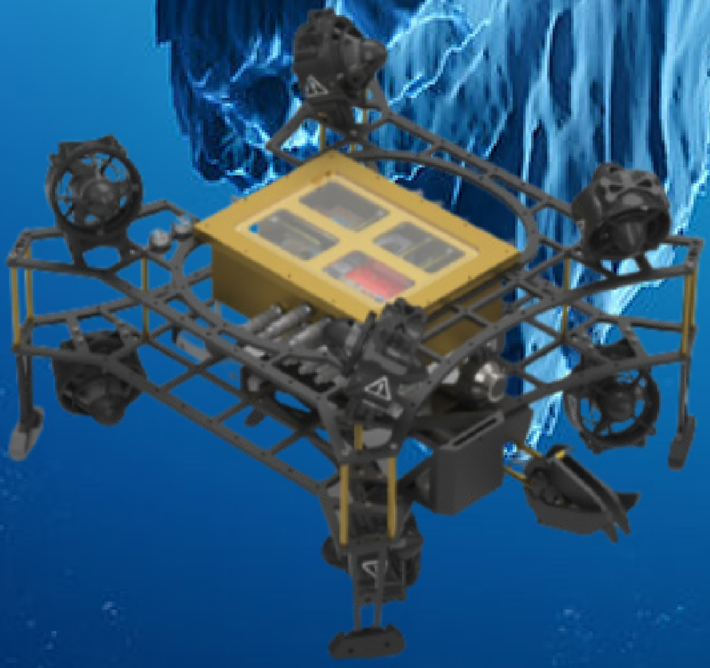
Protecting the Antarctic below and above

PURDUE UNIVERSITY

West Lafayette, IN USA

ROV

Sub-Optimal



COMPANY EMPLOYEES

NAME	POSITION
Katherine Sandys	Chief Executive Officer
Jonathan Heidegger	Pilot / Software Department Co-Lead
Corina Capuano	Mechanical Department Co-Lead
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Erin Park	Electrical Board Head
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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 Proven Robotics. 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.

B. Safety Standards

Proven Robotics uses multiple safety procedures which every employee follows when working on ROV Sub-Optimal. 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. During the Covid-19 pandemic times, masks were worn at all times in the workspace and other meeting places to prevent disease transmission. 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. Proven Robotics' workspace is located on the Purdue University campus, giving safe access to all employees. 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 is followed (Ref 11).

C. Safety Features

ROV Sub-Optimal has numerous safety features. The tether has both a master fuse for the device and a strain relief cord. The frame is an X-pattern with no sharp edges. Each time ROV Sub-Optimal is deployed, the safety checklist (see Appendix) is followed to ensure all employees, bystanders, and the vehicle are kept safe during operation. Sub-Optimal'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 mount via heat-set inserts and screws.

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. 2 - The Company's Pressure Testing Chamber During Testing of the Power Box Outside

Fig. 3 - Frame and Primary Enclosure Pre-anodization

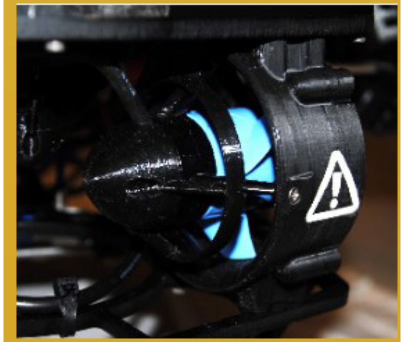


Fig. 4 - A Thruster, Featuring Custom-Printed Ducts with Integrated Safety Shrouds and Warning Placard

III. Mechanical Design Rationale

A. Mechanical Overview

The Mechanical Department prioritized weight reduction and versatility in the design of ROV Sub-Optimal. Additionally, based on previous years pilot feedback, the thrusters were re-oriented in order to provide the pilot with more maneuverability. Throughout the design process, the department conducted rigorous design reviews, constantly improving each component and streamlining the electrical 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 pervious designes 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

ROV Sub-Optimal's frame design carefully incorporates a balance of weight saving, center of mass placement, tool and thruster mounting, and usability features (including handles and electrical connection accessibility). The frame was constructed using 6061 aluminum plates connected with mortise-and-tenon joints. The plates were designed utilizing a basic grid template to create standardized mounting capabilities for tools. FEA was utilized to optimize the thickness and depth of the plates to ensure maximum impact resistance while maintaining a lightweight construction. Proven Robotics also introduced a completely new thruster layout, consisting of eight thrusters mounted with 30 degree pitch and 20 degree yaw rather than the four vertical and four horizontal thruster layout utilized in years past. This new layout prioritizes forward motion while maintaining the same maneuverability of the previous layout. Additionally, the frame was designed to accommodate an infinitely adjustable vertical height for the power box while still maintaining electrical connection accessibility.

C. Thruster Layout

The layout of the thrusters is a critical design decision that drives vehicle architecture and defines maneuverability, the primary function of the ROV. The primary factors when controlling underwater vehicles are Buoyancy and Stability. The goal of ROV design has been to build a vehicle that is neutrally buoyant thus the vehicle exerts no work to maintain depth. This is accomplished through CAD displacement and weight calculations as well as trimmable ballast. Stability is a product of

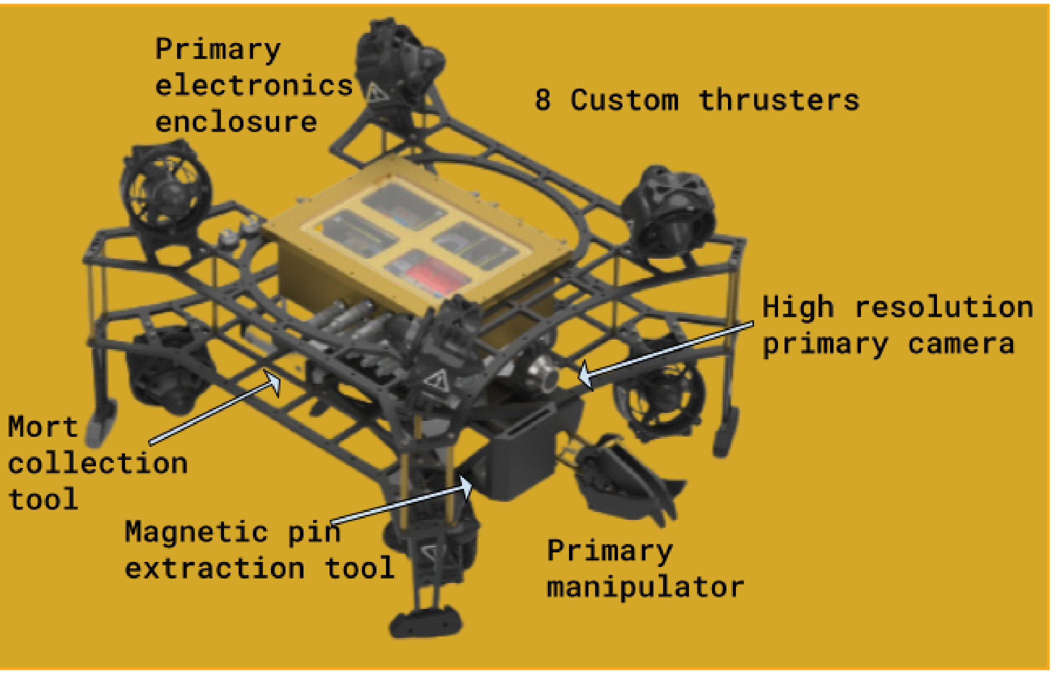


Fig. 5 - Mechanical Schematic Detailing the Location of Several Key Components of the ROV

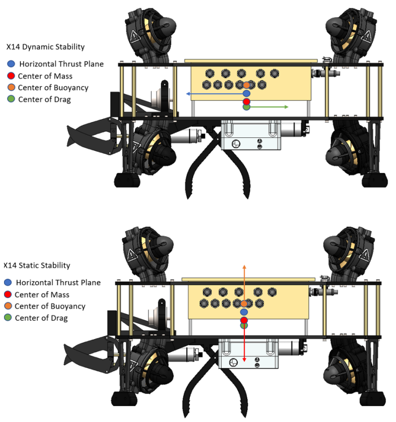


Fig. 6 - Static and Dynamic Stability Analysis

buoyancy and mass distribution. Historically, the company has an emphasis on building a stable ROV with the CoM (Center of Mass) well below the CoB (Center of Buoyancy). However, when the CoM and CoB are collocated the ROV is marginally 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 forces are a function of thruster layout and commanded force, buoyancy a function of ROV orientation, and drag a function of orientation and velocity. These sum together resulting in a vehicle torque and force vector. Lowering unintended torques caused by thrusters and buoyancy to the vehicle improves its dynamic stability.

A unique thruster configuration and vehicle layout was designed with the goals of neutral buoyancy, marginally static stability and positive forward dynamic stability. This resulted in a very symmetric vehicle to colocate effective thrust point, effective drag point, and CoM. Symmetry breaking is required to provide control effort in all three principal moments. The thrusters are also biased to maximize forward thrust as pitch and yaw moment. This configuration also allows for effective lateral translation (strafe) at the expense of vertical thrust and roll moment.

Optimized thruster angle selection was enabled by use of a simulation tool developed in MatLab that plots the maximum simultaneous thrust and moment envelopes of the vehicle. With these optimized angles, Sub-Optimal achieves agility in dynamic operations and surfaces quickly by reorienting the forward direction of the vehicle toward the edge of the pool. This takes advantage of the most power, least drag, and passive dynamic stability

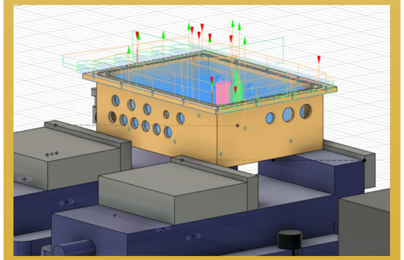


Fig. 7 - Tool Path to Manufacture the Power Box

D. Power Box

The Power Box is the heart and brain of the ROV; housing custom circuit boards which convert and disseminate power to the various enclosures, tools, thruster electronic speed controllers (ESCs), and the main Raspberry Pi. The Power Box receives power and pilot commands through the Bulgin and waterproof Ethernet connectors, respectively. The Power Box supports connections to 12 brushless DC motors (BLDCs) including 8 thrusters as well as multiple USB cameras via M12A electrical connection ports. The Power Box also connects to the pneumatics enclosure and a depth sensor. Even with this set of connections the ROV still has multiple additional ports available. This provides design flexibility and allows forward compatibility to incorporate more cameras or tools as required. The rectangular form of the box is well-suited to rectangular PCBs, which provide ample space for experimenting with board orientation, cable routing methods, or new boards as needed.

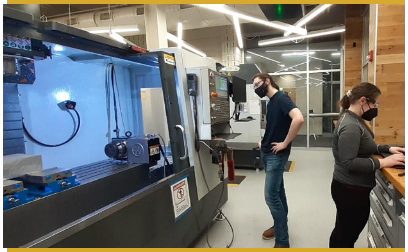


Fig. 8 - Manufacturing of the Power Box

The box is milled using computer numerical control (CNC) out of a single block of 6061-T6 aluminum. The computer aided manufacturing (CAM) design process went through five major iterations in order to create an efficient workflow while still running the machines at conservative feed and speed rates, reducing the wear on the machine and the risk associated with machining. The resulting CAM used 6 separate set-ups for each of the sides of the box. A 5 axis operation was considered, however due to the weight of the starting material it was deemed unsafe to use the fixturing available to the company. The major issue when milling the power box came in how deep the box is. The tools available to the company were not able to fully reach the depth of the box and would end up crashing into the walls. To mitigate this, raised portions around the internal bottom edges of the box were designed such that the

maximum amount of material can be safely removed.
Additionally, computer analysis allowed for further optimization to maximize internal volume while minimizing weight. Unlike welded construction, potential leaks are limited to the lid seal and connector seals. The enclosure seals to a custom manufactured lid via a face seal using 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 10 meters depth. Final box dimensions were selected including the factor of safety of 2.5 to yield from international competition pool depth and accounting for constraints due to required fastener wall thickness. The reduction in wall thickness allowed a decrease in the weight by over one pound compared to last year’s power box.

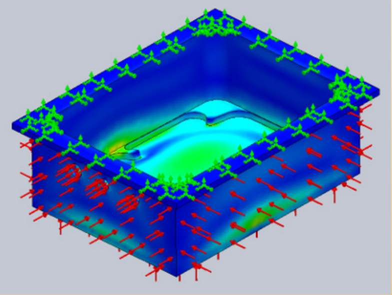


Fig. 9 - Finite Element Analysis of the Power Box

E. Solenoid Enclosure

Two of ROV Sub-Optimal’s mission tools are powered by pneumatic cylinders. An air compressor on the surface provides 275 kPa through the tether to a manifold. This manifold mounts four solenoids, which allows for design flexibility should more tools be needed. Each time a cylinder cycles, the exhaust is routed back through the manifold, through a second line in the tether, and vented to the atmosphere, resulting in a higher working pressure differential than if it was vented into the water at depth.This manifold is integrated into the Solenoid Enclosure, which protects the solenoids and their electronics from the ingress of water. The enclosure’s base and lid are both 3D-printed out of engineering-grade impact-resistant resin using stereolithography (polymer filament-based 3D-printing methods cannot produce pressure-tight parts). This approach saved weight and manufacturing time and enabled compact and efficient “spaghetti" channels that would be unmanufacturable by traditional means. The pressure inlet, exhaust, and tool I/O lines all interface via press-fit push-to-connect fittings that were selected to avoid small, delicate threads in resin. The solenoids themselves are model SY3140-6LZ from SMC, with an effective area of 5.4mm^2 and a Cv of 0.3. Combined with the manifold’s loss-minimizing design, these enable the tools to cycle on the order of 5 Hz – a marked improvement over prior versions that ensures highly responsive controls.

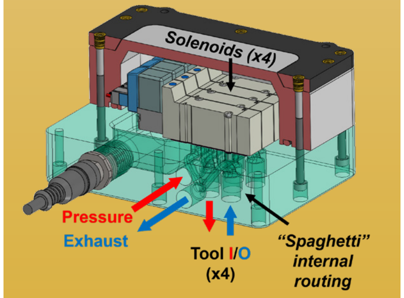


Fig. 10 - Partial Section View of the Solenoid Enclosure

F. Buoyancy and Ballast

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 experimentation into Modular Foam Shells, which are 3D printed shells filled with expanding foam. Previous foam and ballast systems were milled from a single piece of high-density, closed cell foam, which was a wasteful and time-consuming process.The new modular foam system allowed the company to create highly-accurate, modifiable competition foam, as well as calibration foam.Disks of foam were created at different net buoyancies, and were attached poolside as needed based on the equipped tools and enclosures.

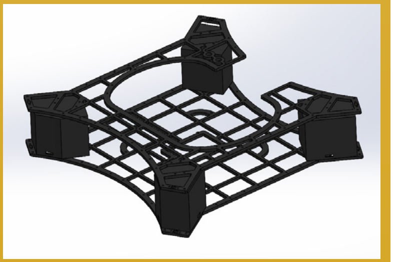


Fig. 11 - Foam on the ROV

Competition foam for Sub-Optimal was designed to be primarily located between the frame plates at the four corners to ensure stability. Approximately 3 kfg of buoyancy was located in these four pieces, which was the majority of foam needed for the ROV. They are attached to the frame using easy release clips purchased from McMaster-Carr. The competition foam also includes a secondary system of two removable segments on the sides for modular configuration of buoyancy adding an addition 800 gram force of buoyancy. A ballast system of iron washers on the ROV’s feet was also designed to allow for trimming the total buoyancy and shifting the CoB. The final foam design provides 3.3 kgf of

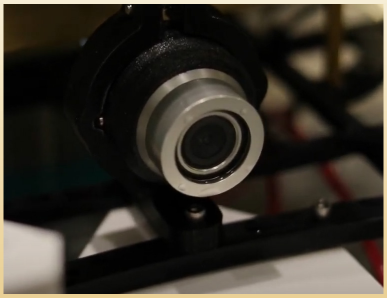


Fig. 12 - Wide Angle Camera

G. Cameras

The two wide-angle cameras, exploreHD 2.0 Underwater ROV/AUV USB Camera, are mounted to the frame using custom designed 3D printed mounts. There are two versions of the mount, one for the forward facing camera and one for the downward facing camera. These mounts allow for easy insertion and removal of the cameras as the 3d print remains flexible enough to ease the removal process. Additionally, there is one borescope camera that can be attached in any location using zip ties in order to allow for extra camera views and quick adjustments as needed.

H. Base Station

To ensure setting up stable connection between the vehicle, control laptop, and network quickly and reliably, a custom box to house a network router, laptop charger, and place to mount the laptop was created. In addition, it features a compartment to carry safety glasses and various small equipment the company might need.

Previously, the base station was significantly larger than the ROV itself. This year, many of the components were compacted into smaller spaces. As a result, the station was designed to be handled by one person and only house the bare necessities. MDF is used on the interior of the base station case to ensure the case was light enough to easily carry.

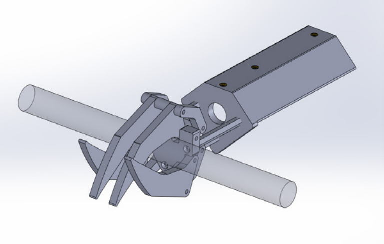


Fig. 13 - Primary Manipulator

IV. Mission Tools Rationale

A. Primary & Auxilary Manipulators

ROV Sub-Optimal has a pneumatically actuated primary manipulator (PM) located on the front of the vehicle to pick up and precisely transport mission props such as the inter-array power cable, the buoyancy module, and the seagrass. This year, the team opted for a vertical claw design compared to the previously used “quad pincer” design as a majority of the tasks this year involve horizontal pipes. While sacrificing the ability to grasp vertical pipes, the new design allows the manipulator to have a larger acquisition area and to better grasp the mission props. The mechanism remains simple with only one degree of freedom but uses a stationary end hub to make it easier for the pilot to align the claw with the props.

The primary manipulator was constructed from 3D printed PLA parts to allow for rapid iteration and well-tuned fits. The PM is attached to the frame with a 3D printed mount that uses threaded inserts to minimize the space the mechanism takes up and to allow for convenient replacement.

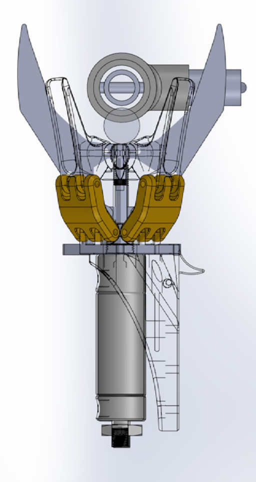


Fig. 14 - Old vs New Primary Manipulator

B. Magnet Tool

The magnet tool was created with the goal of removing the pin holding the ghost net in place. Inside the magnet tool are 6 strong magnets in a 3x2 formation. The use of magnets instead of a conventional mechanical grip was chosen in order to allow for a wider area of acquisition, making the task easier on the pilots. The tool is mounted to the frame to the right of the wide-angle camera and just within the frame of view. The placement of the tool took into consideration the locations of the Primary Manipulator, wide angle camera, and waterflow as a result of the thrusters. The design, made out of printed PLA, has a thin wall to allow strong magnetic attraction between the tool itself and the metal pin that is to be removed. It is far enough away from the primary manipulator so as to not interfere with any other items that may be held in the primary manipulator during the duration of the competition. The placement also ensures that a significant portion of the camera's view remains unobstructed.

C.Mort Tool

The Mort Tool was created to reliably retrieve a Mort (weighted rubber fish) from the bottom of the pool, and deposit it at a target location. The tool was designed with a downward-facing claw, allowing for the ROV to continue operating upright with optimal maneuverability, instead of pitching the ROV downwards to complete the task using its forward-facing primary manipulator. It was also designed to be compatible with a 1-inch stroke length pneumatic cylinder and to fit in the space between the bottom frame of the ROV and the pool. The tool is mounted to the frame of the ROV using threaded fasteners. The mort tool is designed to be 3D printed in PLA, which allowed for rapid prototyping and quick iterative trial and improvements of the tool.

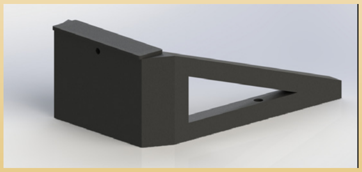


Fig. 15 - Magnet Tool

D. 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 is composed of 3 separate modules. Firstly is the pressure accumulator that powers the system. Secondly is the pneumatic control system composed of the solenoids and bladder. This system controls the pressurized airflow to and from the bladder. The bladder's volume varies, which modulates the buoyancy of the buoy. The last module is the electrical housing, which controls the solenoid actuation timing.

Our design approach focused on rapid prototyping and testing for the development and construction of the float. To accelerate the design process we used standard parts like PVC piping that could be locally sourced. We also developed a basic python program that helped us determine the movement of the float given a few parameters like mass and volume. This program aided us in estimating the time to surface of 1 second in a 6-meter pool given a 2.5% increase in volume. This program proved the viability of our design before any physical testing. After the initial prototype took only 3 seconds to surface, we became confident in our design approach. With this newfound confidence, prototypes started construction.

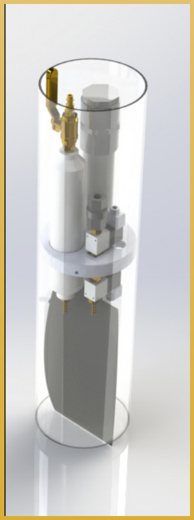


Fig. 16 - Vertical Profiling Float

These prototypes failed on many occasions, which helped us locate issues before the competition. One such issue was that our solenoids began to leak over time when the accumulator was pressurized at 40 psi. This proved to be a fundamental issue with the product thus the issue was bypassed by replacing the solenoids and purchasing a larger accumulator. Another issue was that the decreased hydrostatic pressure at the surface of the pool led to the bladder not deflating fully. Removal of the check valve to reduce barriers proved moderately successful. Together with the additional pressurized air volume provided by the larger accumulator and modification of the float buoyancy, this issue was resolved. In the end, our rapid failures and resulting solutions culminated in a successful test, and the fundamental design was finalized. We then turned our focus toward creating a proper housing and mounting system for the float.

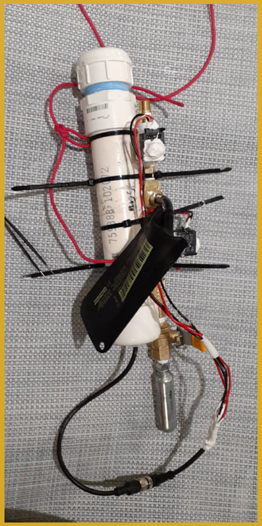


Fig. 17 - Vertical Profiling Float Initial Design

V. Electrical Design Rationale

A. Electrical Overview

The electronics in ROV Sub-Optimal are a third-generation architecture that iterates upon the electronics designed for the previous competition with improvements to accommodate a single-enclosure robot. The ROV is controlled from a surface base station consisting of the pilot's computer, monitor, and gamepad. The tether's electrical connection is composed of an Ethernet cable and the 48-V power lines, both of which plug into the rear of the power box. A Category 6 Ethernet cable is used to provide noise immunity and high bandwidth for three low latency camera streams. 48 V is delivered to the power box using two 2.05-mm diameter marine-grade wires with an in-line 30-A fuse.

The electronics are all housed inside the Power Box. This includes two Power Bricks Boards, the Distribution Board, the Power Conversion Board, the Backplane Board, three electronic speed controller (ESC) Controller Boards, three ESC Adapter Boards, the Raspberry Pi, and the Pi Shield. The boards are split into two vertical stacks to provide accessibility to boards that are frequently removed or programmed during development. The Power Bricks Boards produce a nominal 12 V for the thrusters and solenoids, and the Power Conversion Board produces both a nominal 5 V and 3.3 V for logic electronics. The power and logic signals from these boards are routed through the Distribution Board to the Backplane, which interfaces to the remaining PCBs: the ESC Controllers, ESC Adapters, and Pi Shield. The ESC Adapters connect directly to panel mounts to send power to the thrusters.

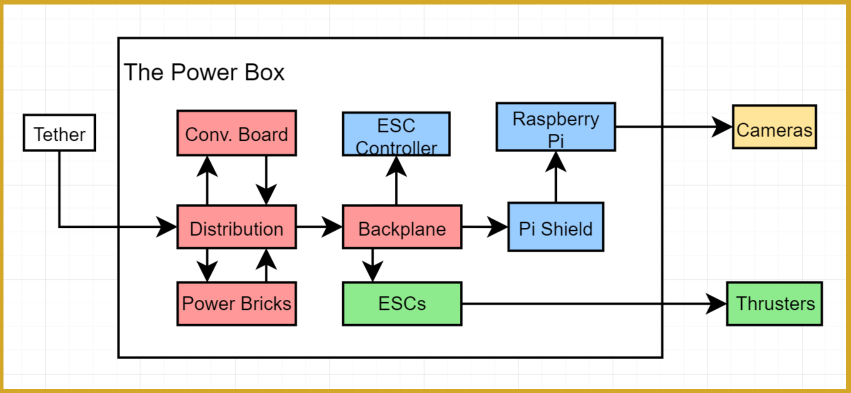


Fig. 18 - Simplified SID

The Ethernet cable goes directly to the Raspberry Pi for control, sensors, and camera feeds. The Raspberry Pi is supplied with 5 V produced by the Power Conversion board. The Pi Shield also communicates with the ESC Controller Boards with the reliable Controller Area Network (CAN) bus. All printed circuit boards were designed and populated in-house by the Proven Robotics Electrical Department using EAGLE excluding the Raspberry Pi, ESCs, solenoid latches, and two exploreHD 2.0 Underwater ROV/AUV USB Camera and one borescope.

B. Power Bricks Board

The Power Bricks Board is used to convert power from an input of 48 V at 12 A to 12 V at 50 A. The board takes its input from the Distribution Board and passes the power to the bricks where it is converted to 12 V and then returned to the board along with data lines for the Power Management Bus (PMBus) protocol. These signals are then sent back to the Distribution Board. The main change for this generation is the new connector which allows the board to be smaller and simpler. There are two Power Bricks Boards that work in tandem to provide 12 V at a total of 100 A.

C. Power Distribution Board

As the name suggests, this board takes input from the tether and distributes the power to the other boards on the stack. It connects to the tether where it receives 48V, the Backplane Board, the Power Conversion Board, and both Power Bricks Boards. The Power Bricks Boards are sent 48V and return 12 V and PMBus signals. The Power Conversion Board receives 12 V and outputs 3.3 V and a nominal 5 V. The Backplane is sent two 12-V lines: one solely to power the thrusters, and another to trigger solenoid valves. These are kept separate to isolate back-emf and noise generated by each of the intended loads. In order to make the routing easier, the top half of the board was used for 48 V and the bottom half for 12 V.

D. Power Conversion Board

The X14 Power Conversion Board is positioned on top of the X14 Power Distribution board where it receives a nominal 12 V, stably converts to two signals, and sends it back to the Distribution board. The Power Conversion first nominally outputs 5.2 V at 5 A using a buck converter, then outputs exactly 3.3 V at 1 A using a linear regulator.

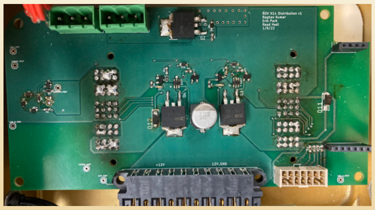


Fig. 19 - Power Bricks

E. Backplane

The Backplane routes signals throughout the ROV, it receives 12 V, 5 V, and 3.3 V from the Distribution Board. It then sends those power rails along with other signals such as the PMBus lines from the Bricks Boards and the CAN bus to the ESC Adapters, the ESC controllers, and the Pi Shield. To ensure enough current for the ESCs, 12-AWG wire was soldered directly to the board for the 12-V line. Due to a lack of space in the power box, the solenoid board and its respective signals were condensed to the Pi-Shield.

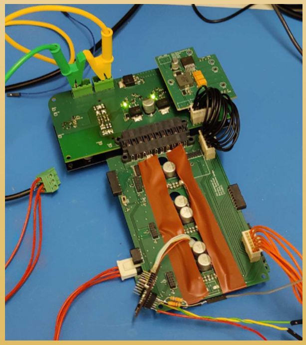


Fig. 20 - Backplane (bottom) and Distribution (top)

G. ESC Controller and Adapter Boards

The Quad ESC Controller Board connects the Backplane and Raspberry Pi to the Lumenier Quad ESC on the adapter board. The STM controls the PWM sent to the ESC, and communicates via Universal asynchronous receiver-transmitter (UART). This year, there are additional test points added to make debugging the PWM signals easier.

The Quad ESC Adapter Board connects the Lumenier ESCs to the backplane for input power and the thrusters they drive. The Lumenier ESCs allow for simple, compact design in the Power Box. The board makes use of bulk capacitors placed on the Backplane Board to provide current to the thrusters on startup.

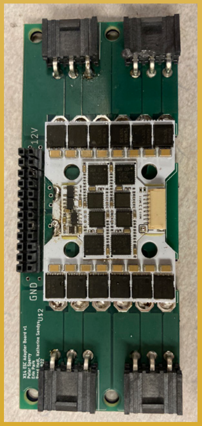


Fig. 21- Lumenier 4 in 1 ESC and Adapter Board

G. Raspberry Pi and Pi Shield

The Pi-Shield both powers the Raspberry Pi and connects the depth sensor on the ROV to the Raspberry Pi. The solenoid board from last year has also been moved to the Pi-Shield, so the shield also hosts a BJT array to control them. The Pi-Shield receives 3.3-V and 5-V power signals from the Backplane and sends the CAN Bus and Solenoid Control signals back to it. The Shield sends the Raspberry Pi 5V power, and communicates with Inter-Integrated Circuit (I2C) and Serial Peripheral Interface (SPI). Additionally, the Raspberry Pi sends 4 GPIO signals to the BJT array to control the solenoids. During the design of the board, priority went to ensuring the functionality of the CANBus.

The Raspberry Pi is the computer on board the vehicle; it is located in the power box. The Pi runs the process that allows for the vehicle to be controlled, provide feedback and information to the surface and provide camera feeds for the pilot. Both of the exploreHD 2.0 Underwater ROV/AUV USB Camera are directly plugged into the Pi's USB ports. The company is using one Raspberry Pi 4, the newest and best pi available. The use of the Raspberry Pi is due to the large flexibility to program and design around.

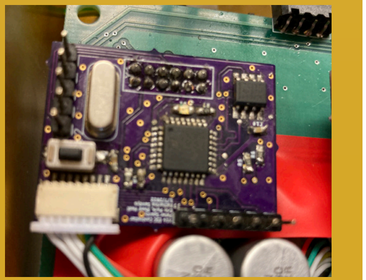


Fig. 22- ESC Controller Board

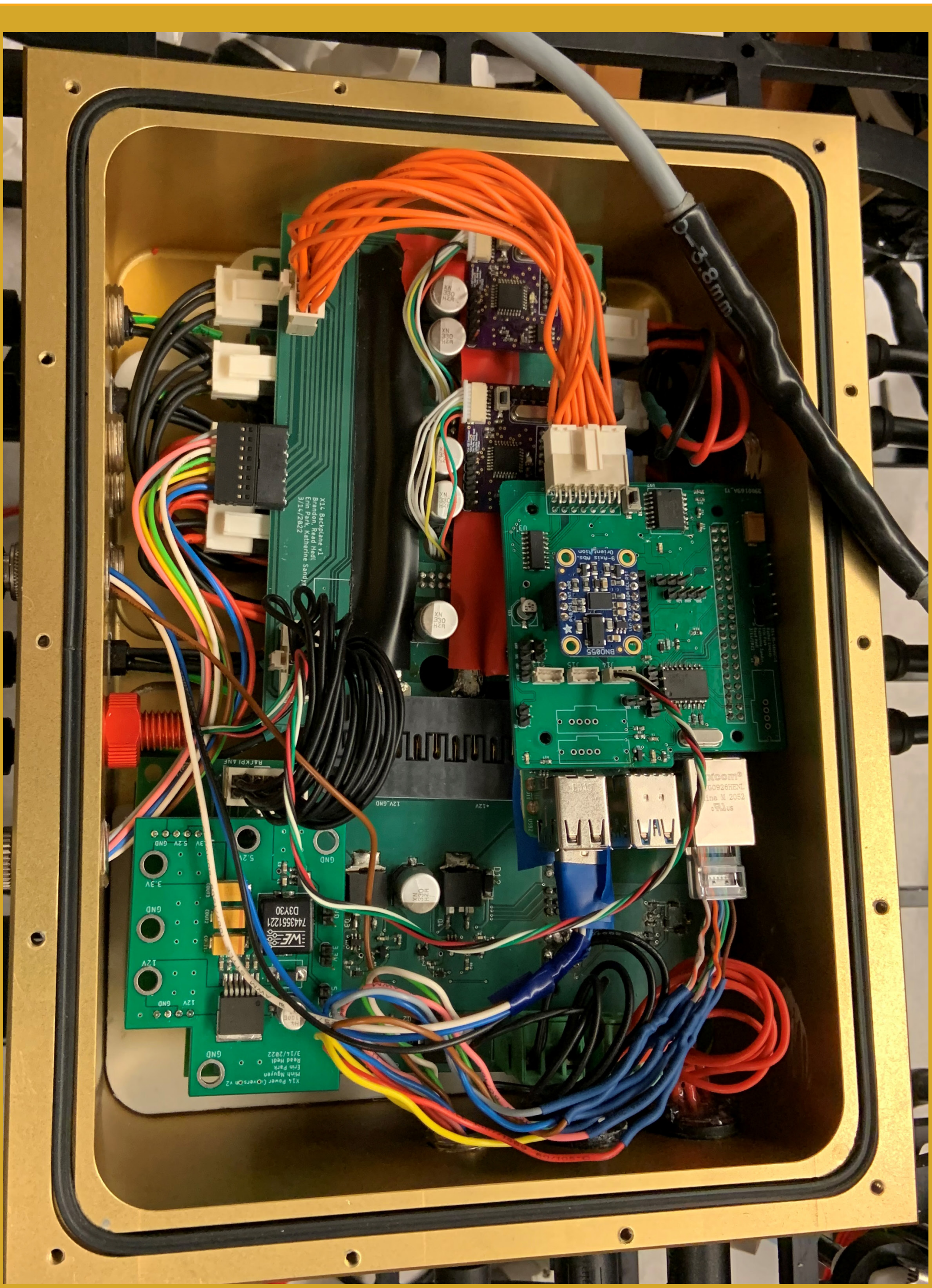


Fig. 23 - Full Electronics Stack

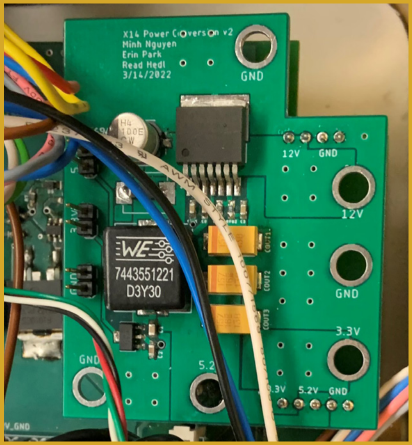


Fig. 24 - Power Conversion

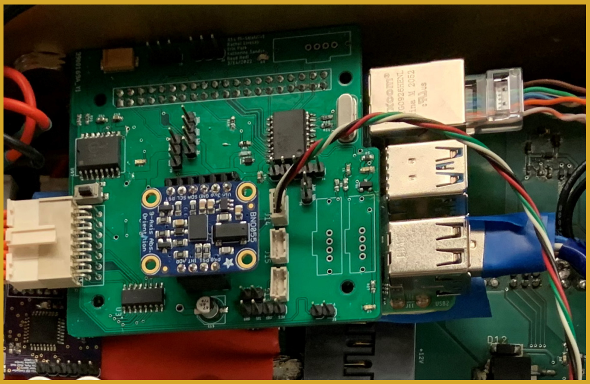


Fig. 25 - Pi Shield

VI. Software Design Rationale

A. Software Overview

Proven Robotics has designed the ROV X14 core software to be modular and reliable.This year's software builds on the solid foundations and institutional knowledge of the company's previous ROVs. The software department utilizes a unified ROS (Robot Operating System) network from Pilot Interface through to control hardware on the ROV. This aids in achieving the goals of modularity and flexibility through defined standard interfaces. The software department can more fully utilize its employees working as teams to develop independent modules that integrate predictably into the full system.

The key strides taken by the software department include both technical growth and project management. This year the software department sought to increase the accountability and visibility of tasks through use of industry standard atlassian suite. Jira integrated directly with the source control in github that clearly tracked each employee's responsibilities and progress in the current sprint. The software department operated in a 2 week sprint capped off by a pool test verifying the software development on production hardware. In addition to Jira task tracking, Confluence also was used to document institution knowledge and aid in new employee onboarding.

To keep up with Linux LTS (long term support) versions the development environments were upgraded to 20.1 with another upgrade from ROS Melodic to ROS noetic. This required a custom build for Raspbian, the native raspberry pi operating system.

B. Front End

Overview: ROV Sub-Optimal’s Frontend Pilot Interface is a native desktop application created using Electron, ReactJS, and Typescript. This application is used to connect and relay controls to the ROV from the pilot, monitor incoming sensor data, modify thrust settings and receive diagnostic information during a dive. ReactJS enables each component to be designed with a specific purpose, facilitating increased code reuse and the modular development of many different features. Typescript’s type safety allows errors to be detected during compile-time instead of while the program is running. For the purpose of piloting an ROV where minimizing runtime errors is critical, Typescript provides a clear advantage over Javascript.

Gamepad Connection: ROV Suboptimal’s frontend interface supports the use of a commercial gamepad for pilot control.

Thruster Tweaker: ROV Suboptimal’s thruster tweaker (in the left column of the interface) provides the pilot with detailed control over the responsiveness of the ROV’s thrusters. The power of thrust in each of the cardinal and rotational directions may be modified manually to respond to different conditions.

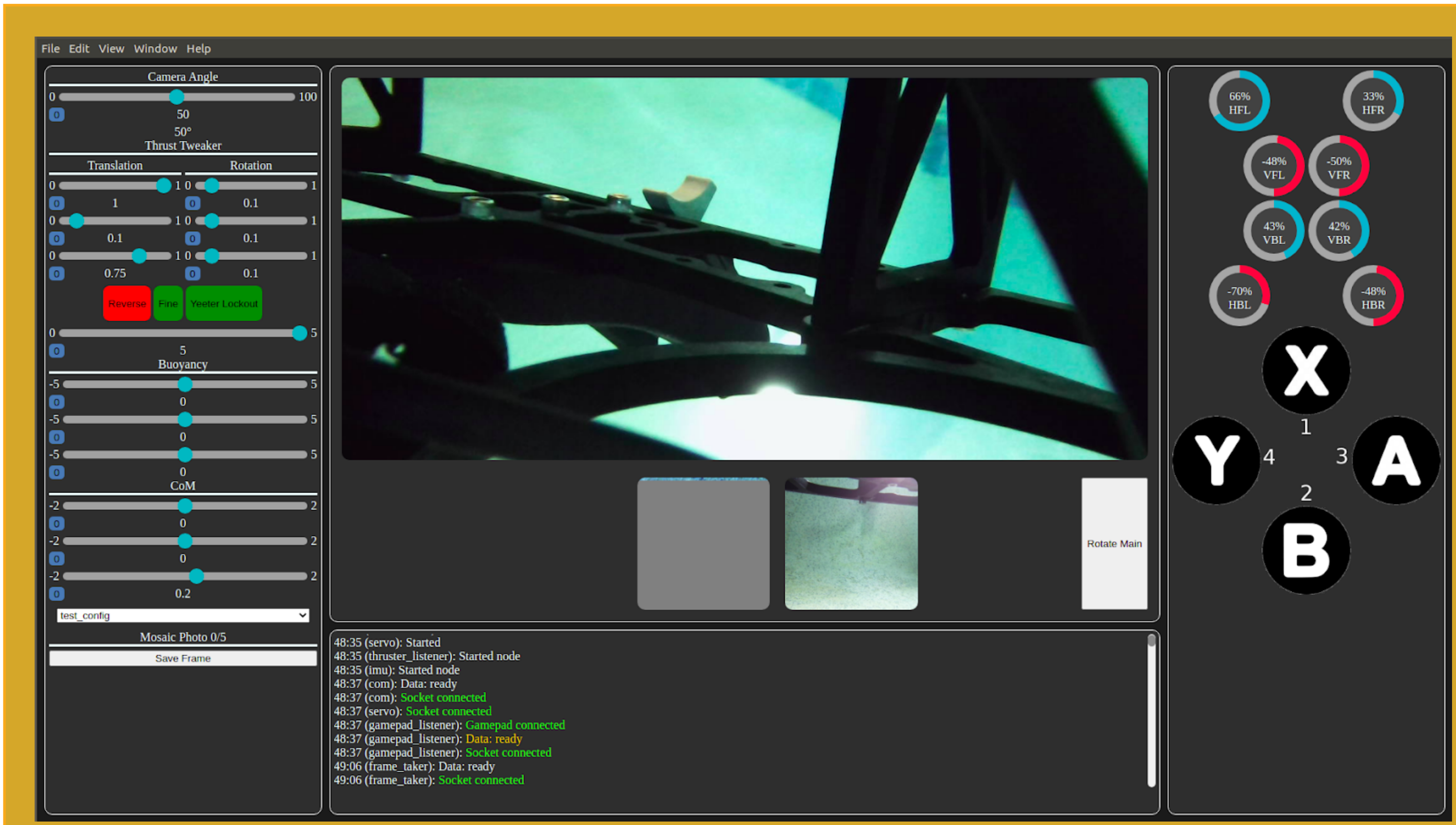
Buoyancy and Center of Mass (COM): While the ROV alone maintains a consistent buoyancy and mass distribution, lifting and moving objects can result in changes to the overall distribution. The Center of Mass and Buoyancy Sliders allow a pilot to adjust the center of buoyancy and center of mass used by the thrust mapper during a dive. While picking up an object, these sliders may be adjusted to accommodate for the changes to these values. A configuration for the thrusters may be saved and reloaded at any time, allowing the pilot to anticipate changes in mass or buoyancy and load a new configuration accordingly.

Console Log: The console log provides live information about the state of the ROS backend, allowing the pilot to verify that systems are running smoothly. The Console Log also outputs messages that would be displayed on a terminal running the ROS core, allowing this information to be relayed to the pilot without needing multiple windows. Making this information more readily available allows the pilot to focus on controlling the drone without needing to consult an external interface.

Thruster Power Display: The thruster power display shows the current power in each thruster relative to its maximum capacity. This information is retrieved from the ROV through an interface with ROS, ensuring that it is a reliable indicator of the messages that have been received by the thrusters.

C. 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 map of subsystem programs modules (ROS nodes)



```
48:35 (servo): Started
48:35 (thruster_listener): Started node
48:35 (imu): Started node
48:37 (com): Data: ready
48:37 (com): Socket connected
48:37 (servo): Socket connected
48:37 (gamepad_listener): Gamepad connected
48:37 (gamepad_listener): Data: ready
48:37 (gamepad_listener): Socket connected
49:06 (frame_taker): Data: ready
49:06 (frame_taker): Socket connected
```

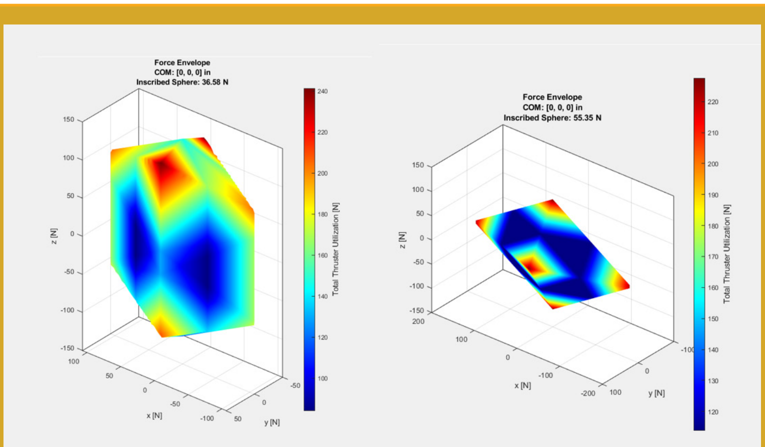
Fig. 26 - Pilot Interface Display Showing Adjustable Thruster Controls

which are all independently testable and communicate with each other through ROS's interprocess communication system (ROS topics).

The strengths of ROS lie also in the community of third party libraries and packages that are supported. These robust packages allow the software department to focus innovation in areas that are unique to the ROV and the current challenges while leveraging the existing community to solve known problems. These packages such as tf, pid, and dynamic reconfigure, serve to increase flexibility and capabilities of the department and ROV.

D. Embedded

The software system communicates through a variety of hardware interfaces to the embedded systems and sensors. The primary control of the vehicle uses the CAN bus protocol to communicate thrust value information to the motor controllers. The system continues to use CAN because of the flexibility it allows in adding and removing devices from the bus and its robust library support. The Raspberry Pi is configured such that the CAN bus appears as a network interface to which the software can easily interface with sending and receiving packets.



X13 Envelope

X14 Envelope

Fig. 27 - Visual Representation of the Thrust Envelope

To support the vehicle's mission a suite of standard sensors was equipped to the vehicle enabling the vehicle to sense its position and orientation in the water. A depth sensor and IMU both communicate through the I2C protocol that is natively supported by the raspberry pi hardware. The software department leverages commercial libraries to build custom wrapper interfaces that provide extra functionality for the specific applications. These sensor readings then are integrated directly into ROS for other nodes to utilize using standard message classes. These standard message classes allow for sensor data to also be used by 3rd party libraries and packages.

Controlling the pneumatic solenoids and thus the tools was an area that saw increased development. Building off the design last year, the electrical interface was determined to stay the same using a parallel binary bus to indicate requested solenoid state. This decision reduced the electrical complexity of the system and processing requirements for the pneumatics board. A prototype converter board was built to convert an I2C packet into the parallel binary bus however after further development it was determined that the raspberry pi GPIO (General Purpose Input Output) could drive the bus sufficiently which reduced the complexity of the system. This direct drive model created an easier to maintain and simpler solution while maintaining the needed control for solenoids.

E. Propulsion and Control

This year the movement control and thrust configuration took a technical risk to migrate from the historic thrust configuration the company has used for the past several vehicles. This year after a trade study analysis of COTS ROVs a number of new thruster configurations were proposed and modeled in Matlab to better evaluate the thrust envelopes of these configurations. The thrust envelope of a thruster configuration is the group of all thrust vectors that are achievable given a fixed thruster configuration. From this analysis it was decided to go forward with the current thruster design because of its symmetry and increased control authority for translation.

This then required a new software model which was developed from previous years foundations. The control system enables the pilot to take advantage of the full six degrees of freedom of the vehicle. The main control interface is received as a six dimensional force vector and moment representing the translation in x,y,z and roll, pitch, yaw. This could be from the frontend joystick or an autonomous closed loop controller. Next, using the location of the vehicle's center of mass and the location and direction of its thrusters, a matrix is assembled that maps from thruster forces to net force and net moment. Since that is a transformation from an 8-dimensional space to a 6-dimensional space, the Moore-Penrose pseudo-inverse is used to generate a usable inverse mapping.
Another key step in controlling the thrusters was generating a custom lookup for thrust given the custom electronics power delivery. A thrust test stand was assembled that allowed for an extended cable to be attached to the vehicle and control a thruster generating an conversion from ESC control percent into calibrated thrust output in water. This enables the controller to use more accurate units given the custom hardware configuration than the provided Blue Robotics Thruster Data using different ESC and power delivery.

Whenever the pilot wishes to maintain a constant depth, a PID (Proportional Integral Derivative) controller is used in conjunction with the ROV's Blue Robotics depth sensor to control the ROV's depth. The frontend pilot interface can quickly enable or disable the PID controller whenever the pilot wishes to use it. Additionally, the proportional, integral, and derivative constants can be optimized using ROS's dynamic reconfigure package. PID control is an effective tool for constant depth control because, when properly tuned, it can apply precise thrust controls to maintain the desired depth.The IMU was moved this year to aid in the initial calibration by aligning the primary Z axis with the force of gravity. The IMU then gives absolute orientation combining its internal sensors that is reported to the control system allowing for closed loop control upon the orientation of the vehicle.

F. Computer Vision

Proven Robotics followed previous iterations by using OpenCV with Python as the primary tool for performing computer-vision related tasks. OpenCV provides a number of advantages in ease of use and processing video that make it a valuable tool, and its integration with ROS makes it suitable for continued use. Additional Python libraries such as NumPy and scikit-learn were used for further computations required for using the inputs to pilot the ROV.

In addition to using OpenCV and Python libraries, the software department used a deep learning approach for the task of identifying the morts in segments of real video. This year marks the first time that Proven Robotics used Plainsight for image labeling and dataset creation. This platform allows the dataset to be shared among many collaborators, and allows image annotations to be reviewed by other members. Using over 500 labeled underwater images, the YOLOv3 multi-object detection model was retrained to identify and count both live and deceased fish in images taken from the cameras of underwater ROVs.

VII. Logistics

A. Company Organization

Proven Robotics shifted the organizational structure developed over the past several years to better fit the leadership of the company and the shifting boundaries of projects. The company continued to operate with three technical departments: Mechanical, Electrical, and Software, which focus on the technical areas of the ROV. 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

Proven Robotics' 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.

At the start of the year, the CEO and technical leads made Gantt Charts to organize deadlines in a visual manner for the company (See Appendix C). This aided employees in understanding when tasks needed to be completed or initiated, and what tasks are prerequisites to others. Technical leads also made SIDs and architecture decisions that set the tone for ROV Sub-Optimal. Proven Robotics nearly completed the design phase before mission specifications were released, but allowed ample room to adjust for mission-specific needs. In the early design phase, sketching and low-fidelity prototypes were used to communicate new ideas. Each week the company held a planning meeting remotely to discuss progress and high-level details, in addition to two full-company meetings. The full company meetings allowed flexibility in the way they were attended, either 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. At the conclusion of the design phase, all designs had been vetted and were 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. Mission critical components are given priority, but all components had scheduled times to be manufactured or completed. When a component was finished, it was tested in isolation before introduction to the system in the air to ensure it can work as designed before deployment in the water. If it failed tests put in place by the company, it was either fixed or redesigned and iterated upon depending upon the issues. Once all critical components had passed individual testing, the ROV was assembled and fully tested. Non-critical tools and software features were added as they were finished.

Full system tests begin promptly when a pilot-able vehicle is established. Tools are added incrementally and refined as they are completed, tested, and revised. Buoyancy is also adjusted as tools are added and other elements changed. Piloting software is improved too to adjust to preferences and the mechanics of the vehicle. As the competition approaches, the success ratio and completion time is measured for tasks to prioritize them for a high-scoring mission run.

C. Project Costing and Budget

Proven Robotics creates its yearly budget based off of previous years' budgets and projected incomes and expenses. These expenses include the cost of producing ROV Sub-Optimal and the costs of attending the competition. 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. The budget categories for ROV Construction with the largest changes from the prior year's are the mechanical and electrical budgets. The mechanical budget increase the funds allocated towards materials and manufacturing, which allows the company to have more design freedom in using novel materials and methods. The electrical budget increased the money allocated towards cameras, which increased to $750, in order to prototype with different options and purchase higher quality cameras. Proven Robotics pays for flights and lodging for many employees to attend the 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. If the company has a surplus for the year before after the competition; this will go into future improvements for the company, including equipment for the workspace, increasing prototyping, and research and development for custom ESCs and thrusters.

Budget

Proven Robotics' 2022 Budget

Budget Category	Item and Description	Amount	Total Amount	Budget
Electrical: Boards	PCB Fabrication	$166.67	$166.68	$350
Electrical: Cameras	ExploreHD 2.0 Camera	$513.78	$513.78	$400
Electrical: Components	Power Bricks	$415.78	$1218.82	$1600
	ESCs	$290.71		
	SMD components and board connectors	$375.13		
	Wires, cables, heatshrink, etc.	$69.25		
	Raspberry Pis, IMU, etc.	$67.95		
Electrical: Equipment	Multimeters, power supplies	$134.23	$134.24	$500
Electrical: Prototyping	Test parts and boards	$41.72	$41.72	$600
Mechanical: Connectors	Binders, Cable Penetrators	$1202.14	$1202.14	$800
Mechanical: Equipment	Elegoo resin printer and curing station	$901.25	$901.25	$700
Mechanical: Materials	Aluminum and Polycarbonate Stock	$662.01	$1575.04	$1750
	Expanding foam	$62.84		
	3D printer filament, resin, epoxy	$63.98		
	Parts for tools (Screws, bolts, epoxy, etc.)	$477.63		
	Vertical Profiling Float	$195.39		
	Prop Parts (PVC, corrugated plastic, etc.)	$113.19		
Mechanical: Prototyping	Test prints and enclosures, etc	$476.12	$476.12	$1500
Mechanical: Thrusters	Blue Robotics T200s and other parts	$56.53	$56.54	$1200
Total Expenses for ROV Construction			$6,286.33	$7,650
General: Competition and Lodging	Hotels, registrations	$4976	$4977	$5000
General: Travel	Gas, flights, etc.	$3500	$3501	$8250
General: Apparel	T shirts and polos for the team	$896	$897	$1300
General: Other	Miscellaneous purchases	-	-	$650
Total Expenses for Competing			$9,375	$15,200
Income	Boeing		$5000	$5000
	ECE		$4000	$4000
	INSGC		$3000	$3000
	PESC		$1750	$2000
	IEEE R4		$1000	$1000
	Mechanical Engineering department		$1000	$1000
	Advanced Circuits		$500	$500
	CAT		$500	$500
	Milwaukee Tool and Grant		$400	$0
	MATE		$100	$100
Total Cash Income for 2020-2021			$9,375	$15,200
Donations and Discount	Colors	In Kind		
	Waterjet Cutting of Indiana	In Kind		
Total Expenses			$15658.31	$24600
Total Income			$17250	$17100
Net Balance			$1591.69	$-7500
Next Year Investment			$1591.69	

VIII. Conclusion

A. Testing and Troubleshooting

Due to the competition being canceled two years prior, many members of the company were used to a two year design cycle. Now, with just one year, the company had to move faster through the design cycle and make quick decisions and iterations. The company also operated with COVID-19. Protocols present for safety and peace of mind of all members. Despite both these challenges, the company was able to innovate and improve upon many aspects of the ROV's design . Moving to a one box system instead of two and having a new frame and thruster design impacted all three design departments and provided new challenges the company had to work through. For the first several months of the design cycle, the software department was testing and improving the ROV Triton architecture from 2021. To get ROV Sub-Optimal foundations in working order boards were continuity and functionality checked, and seals were pressure tested before the complete vehicle was assembled. The functionality of cameras, thrusters, and tools were confirmed on land before deployment in the water. When a component malfunctions, Proven Robotics employees use technical documentation, experience, and lab testing to discover the cause and resolve the issue. When the ROV is completely functional, it is brought to a pool to practice mission tasks. During development, greater emphasis was placed on testing in isolation such as using load resistors, recorded video footage, or a brushless motor test box. This aided in later troubleshooting as test setups could find if something had malfunctioned or if a change had negative side effects.

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 are used to adjust control, piloting, and buoyancy; to collect computer vision footage, and to test tool prototypes in isolation. Subsequent pool tests are used to practice extended portions of the mission run and gauge task difficulty and time.

B. Challenges

Proven Robotics faced many challenges over the past season, the greatest of which being COVID-19. During the Fall and Spring semester, the company had employees in person and online. Prior to the pandemic all meetings were held in person but due to restrictions and if people had been exposed, the company utilized Discord to host meetings remotely. This did hinder development, especially when things needed to be done in person but specific people were unable to come in. The company transitioned to a mixed development style system, where the functions that did not need to have the ROV insight were completed online.

There was also the issue of a massive supply shortage due to the pandemic , which affected the availability of many electrical components and also increased the cost of many materials. The company had to try its best in order and think of things ahead of time to try and negate time loss as much as possible. Going from two to one enclosure to hold the electronics proved to be a difficult but possible task for the electrical department. This change impacted both software and mechanical. On the side of the machine it meant that more space was able to be used for tools and less for enclosures. On the software side, it meant that they only had raspberry pi on board, compared to the two from the previous year, and they had to combat this with code that ran more efficiently.

C. Lessons Learned and Skills Gained

All Proven Robotics employees learned valuable technical skills both from their own departments and from those they have collaborated with. A large portion of skills development comes from workshops held throughout the semester held 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 have the opportunity to develop soft skills including presenting, communicating, and technical writing techniques. Design reviews held throughout the year give employees an opportunity to present their work and receive feedback from current employees and alumni. Written documentation is an important aspect of work done for the ROV; employees document their design rationale, strengths, and improvements of a component.

Due to the effects of the pandemic on the supply chain, the company had to be forward thinking. The company tried to anticipate future needs and order items ahead of time, while also taking into consideration the possibility that there could be increased expenses due to unneeded items. As the pandemic is still ongoing, the company ensured a safe working environment for all, improving organizational standards by utilizing time logs to ensure that the workspace was not overcrowded. Health standards were also improved through increased sanitation and cleanliness practices.

D. Future Improvements

Software: T he software department looks towards the future of increasing closed loop control options for pilots and autonomous actions. This requires building off the work done this last year to develop accurate models of the thrusters and thruster configuration to build a dynamics model for the ROV.
Electrical: The electrical department is currently designing custom electronic speed controllers (ESCs) to replace the Lumenier ESCs currently in use. Custom ESCs would allow for flexibility in both board size and placement. The department is also looking into custom thrusters to replace the Blue Robotics M200. The project involves waterproofing a brushless motor, designing a propeller and measuring thrust produced by a design.
Mechanical: In future years, the mechanical department plans on creating a more integrated and module foam system; a module foam system can be designed in tandem with the frame in order to ensure seamless integration. The department will continue its exploration into custom thrusters.

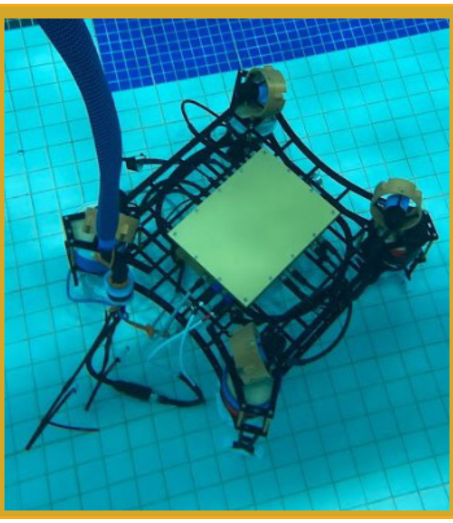
E. Reflections

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.

> *After reading about Thommy Thompson and his discovery of the SS Central American last semester, I developed a strong interest in ROVs and underwater exploration. After a quick Google search, I found the Purdue ROV team and I decided to join. I hoped to learn more about underwater robotics and get the chance to apply some of the concepts I had been learning about in school. During my time with the club, I helped create a reel tool and the vertical profiling float used in the 2022 competition. The team is a wonderful collection of smart, driven people with a wide variety of technical backgrounds and expertise. If I ever had a question, team members would be happy to answer questions at length. There is a sense of innovation and creativity within the team that is very inspiring to me. My experience with the club has been very rewarding these past 2 semesters and I look forward to next year.*
>
> - Uly Hennelly (Mechanical Department, New Member)

> *I joined the IEEE ROV team at Purdue in my second semester of my freshman year looking to build off the hands-on engineering experiences that I had enjoyed in High School. This team has exposed me to more engineering concepts and lessons than any of my individual classes could. This is because the nature of the challenge of synthesizing a complex design working cross discipline in a collaborative setting was something more akin to a senior design. I was able to gain those experiences through all four years and reflecting back am a better engineer because of the lessons learned, sometimes the hard way, with the ROV team. This team builds leaders in each of its technical fields and consistently has helped challenge my views and require me to learn and adapt to form the engineer I am becoming. As I look forward to the next chapter after Purdue I can say with certainty that the lessons and relationships I built on this team will be influential in where I go!*
>
> - Jonathan Heidegger (Software Department Co-Lead, Graduating Senior)

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

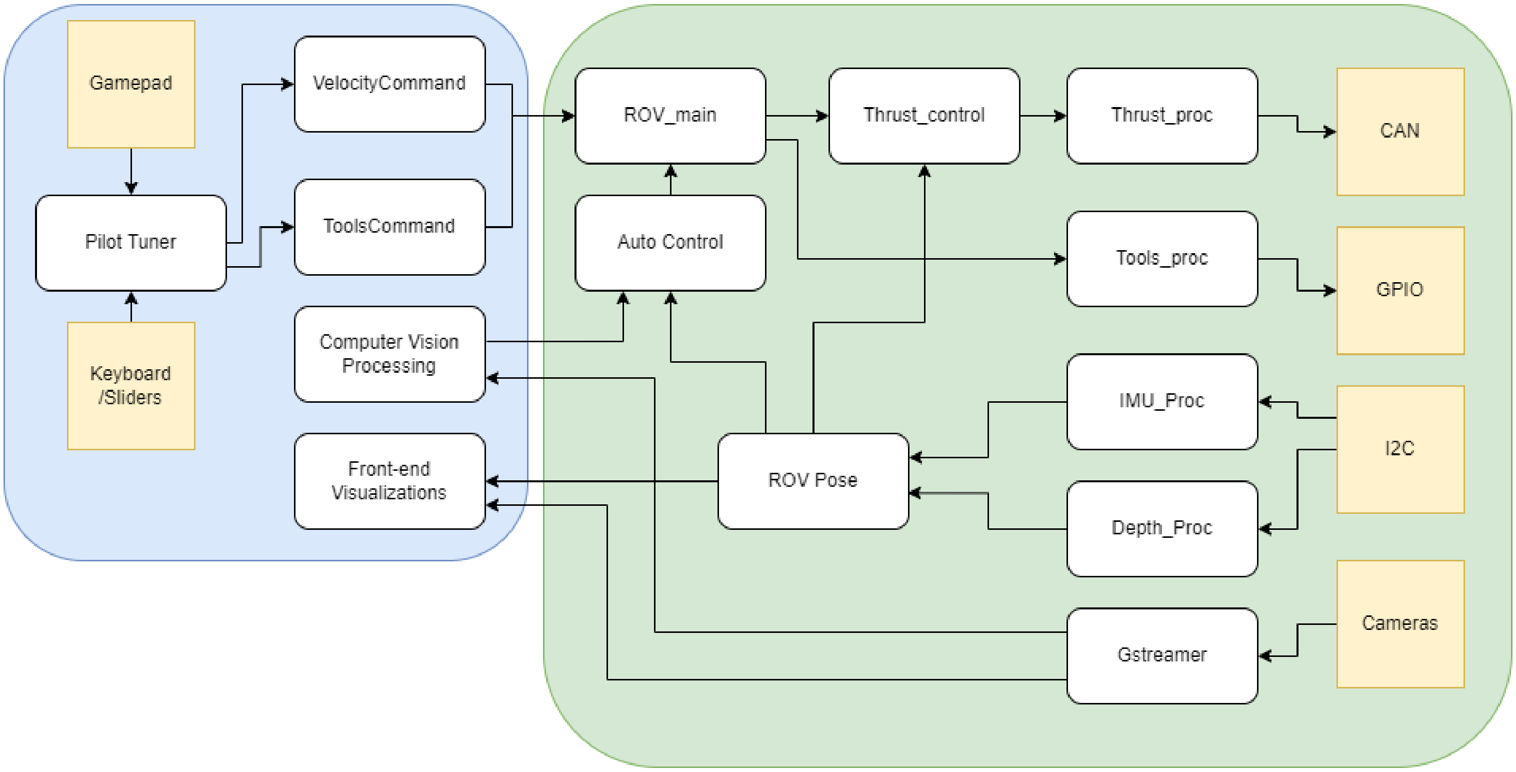
Lost Communication
- ☐ Steps attempted in order. Mission resumes when one succeeds.
- ☐ Co-pilot checks tether and laptop connections on the surface
- ☐ Pilot attempts to reset the BattleStation
- ☐ Co-pilot cycles the power supply
- ☐ If nothing succeeds, the mission stops
  - ☐ Co-pilot turns power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

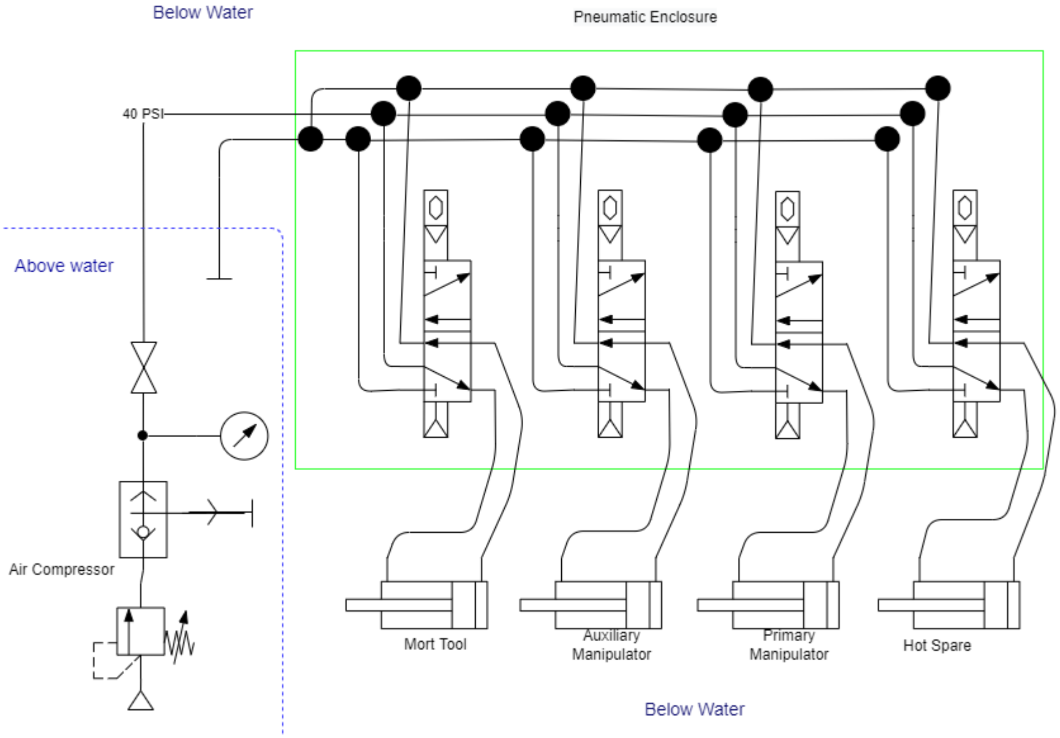
Demobilization
- ☐ Co-pilot turns power supply off and calls out, "Power off"
- ☐ Deployment members do a quick visual inspection for leaks or damage on ROV
- ☐ Pilot stops BattleStation and powers off laptop
- ☐ Anderson connectors of tether are removed from power supply
- ☐ Turn off air compressor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

B. System Interconnect Diagrams

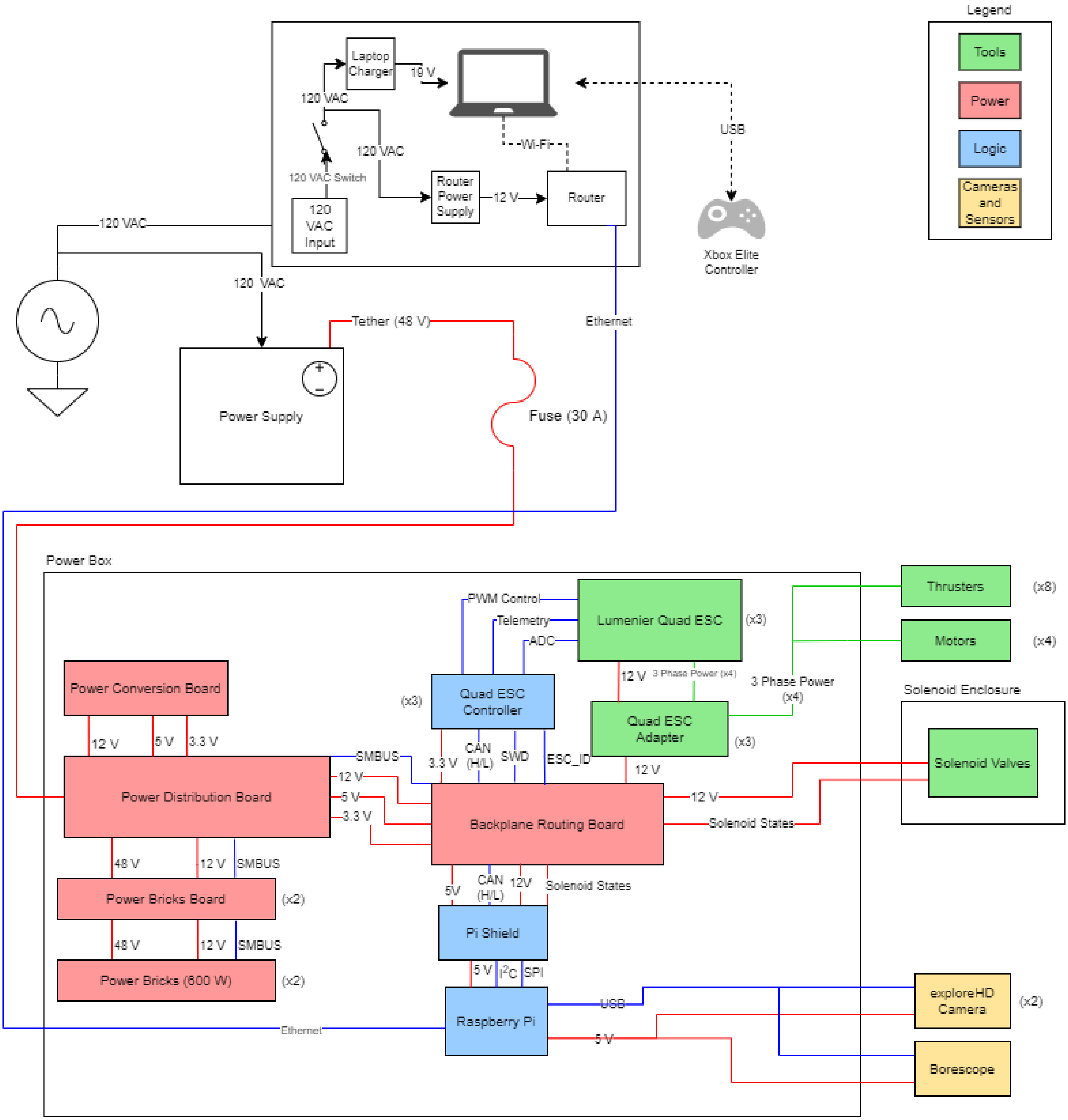
Software Flowchart



Fluid Power System Interconnect Diagram



Electrical Systems Interconnect Diagram

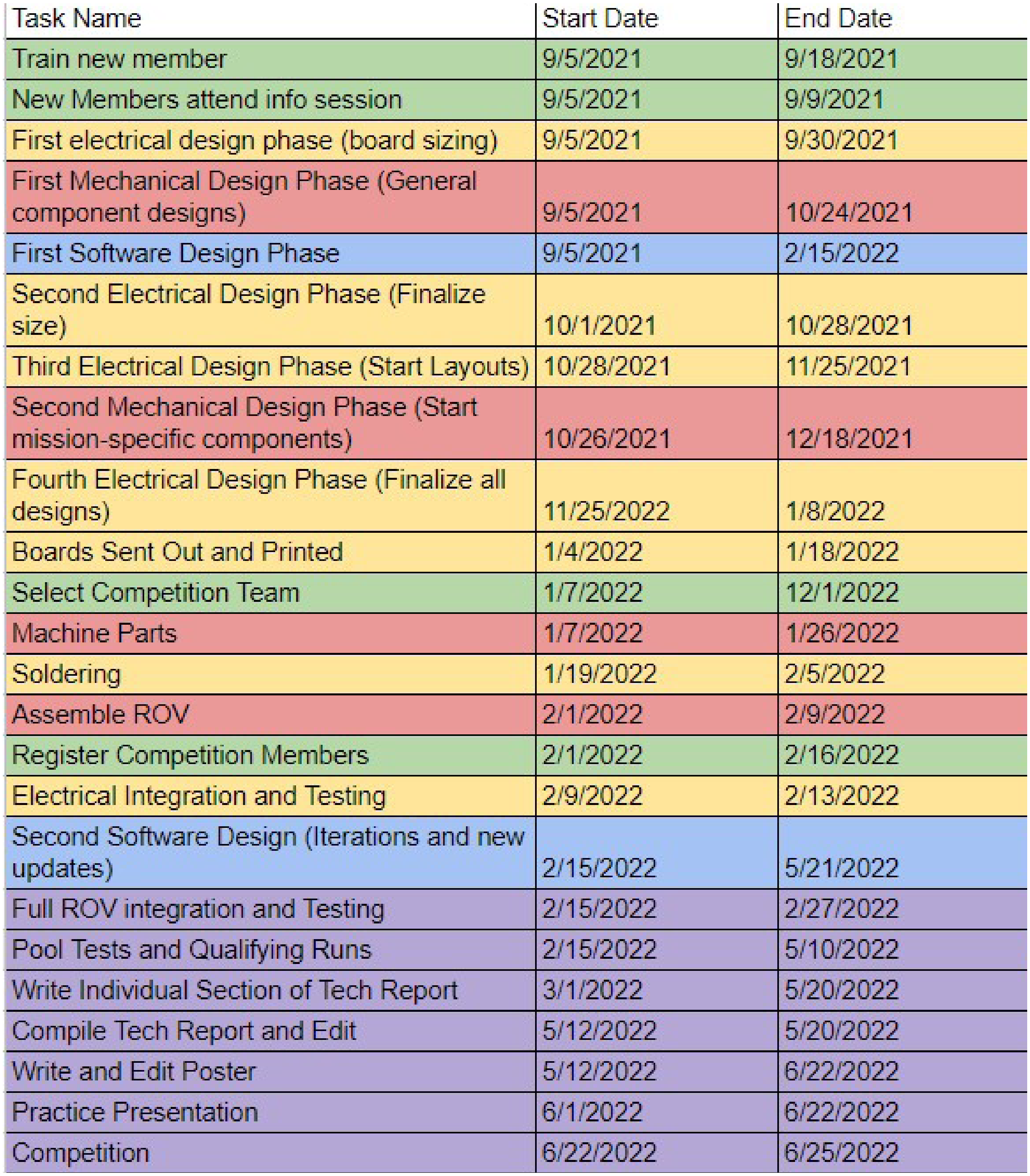


Tether Fuse Calculations:

8 x Thrusters @ 120 W
1 x Raspberry Pi w/ Camera @ 5 W
2 x exploreHD Camera @ 2 W
1 x Borescope @ 0.5 W
12 V-5 V Buck Converter (loss) @ 2.8 W
5 V-3.3 V Linear Regulator (loss) @ 0.51 W
2 x 48 V-12 V Buck Converters (loss) @ 35 W
Total Power: 1042.81 W

Current = 1042.81 W / 48 V = 21.7 A
Current * 1.5 > 30 A
so a 30 A fuse is used

C. Task List for Gantt Chart



Task Name	Start Date	End Date
Train new member	9/5/2021	9/18/2021
New Members attend info session	9/5/2021	9/9/2021
First electrical design phase (board sizing)	9/5/2021	9/30/2021
First Mechanical Design Phase (General component designs)	9/5/2021	10/24/2021
First Software Design Phase	9/5/2021	2/15/2022
Second Electrical Design Phase (Finalize size)	10/1/2021	10/28/2021
Third Electrical Design Phase (Start Layouts)	10/28/2021	11/25/2021
Second Mechanical Design Phase (Start mission-specific components)	10/26/2021	12/18/2021
Fourth Electrical Design Phase (Finalize all designs)	11/25/2022	1/8/2022
Boards Sent Out and Printed	1/4/2022	1/18/2022
Select Competition Team	1/7/2022	12/1/2022
Machine Parts	1/7/2022	1/26/2022
Soldering	1/19/2022	2/5/2022
Assemble ROV	2/1/2022	2/9/2022
Register Competition Members	2/1/2022	2/16/2022
Electrical Integration and Testing	2/9/2022	2/13/2022
Second Software Design (Iterations and new updates)	2/15/2022	5/21/2022
Full ROV integration and Testing	2/15/2022	2/27/2022
Pool Tests and Qualifying Runs	2/15/2022	5/10/2022
Write Individual Section of Tech Report	3/1/2022	5/20/2022
Compile Tech Report and Edit	5/12/2022	5/20/2022
Write and Edit Poster	5/12/2022	6/22/2022
Practice Presentation	6/1/2022	6/22/2022
Competition	6/22/2022	6/25/2022

-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
All our employees for their hard work throughout the year
Purdue IEEE Student Branch for being a great parent organization
Purdue and Hampton Inn for their pool use

E. References

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