PROVEN ROBOTICS

PURDUE ROV

2021 Technical Doumentation

Mitigating the effects of pollution and climate change in water ways

PURDUE UNIVERSITY

West Lafayette, IN USA

ROV Triton

COMPANY EMPLOYEES

NAME	POSITION
Grant Geyer	Chief Executive Officer / Electrical Dpmt. Co-Lead
Joseph Navarra	Mechanical Department Co-Lead
Aidan Molnar	Mechanical Department Co-Lead
Scott Hotchkiss	Research and Development Lead / Electrical Dpmt. Co-Lead
Read Hedl	Power Head
Katherine Sandys	Logic Head
Ryan Pearson	Electrical Design Advisor
Conner Swift	Embedded Head
Eric Sibley	Software Department Co-Lead
Jonathan Heidegger	Software Department Co-Lead
Ivan Kouzmine	Pilot / Front End Head
Sebastian Gruenwald	Sponsorship Coordinator
Logan Grissom	Electrical Department
Erin Park	Electrical Department
Rachel Livesay	Electrical Department
Bryce Sasser	Electrical Department
Kaitlyn Yu	Electrical Department
Sam Kovnar	Electrical Department
Chris Laszlo	Mechanical Department
Rafay Imran	Mechanical Department
David Ho	Mechanical Department
Abhignan Saravana	Mechanical Department
Nathan Fei	Mechanical Department
Angelo Guarnero	Mechanical Department
Hanna Hatfield	Mechanical Department
Matt Koeske	Mechanical Department
Peter Salisbury	Mechanical Department
Corina Capuano	Mechanical Department
Cyrus Xu	Mechanical Department
Aaradhya Jajoo	Mechanical Department
Carrie Li	Software Department
Jason Bleasdell	Software Department
Zachary Neel	Software Department
Hunter Haglid	Software Department
Mentors:	Tyler Stagge, Michael Hayashi

2020 Graduates: Cynthia Zatlokowicz, Jacob Bobson, Alex Wilson, Logan Walters, Melchor De La Garza, Tyler Stagge

Table of Contents

I. INTRODUCTION

Abstract

In order to meet the needs of the global community, Proven Robotics presents the Remotely Operated Underwater Vehicle (ROV) Triton – a reliable and polished vehicle capable of performing crucial tasks in the restoration and protection of our oceans, coral reefs, and inland waterways. ROV Triton is capable of collecting debris from the sea's surface to its floor, assess and improve aquatic wildlife health, retrieve hard to reach samples, and much more. The 35 person company has endeavoured over the last two years to develop and refine ROV Triton, making it the longest developed ROV in company history.

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 team's combined 14,000 work hours. Given the tumultuous nature of the past two years, Proven Robotics was especially cognizant of the need for enhanced safety protocol, flexible scheduling, and tighter budget constraints throughout the design process.

ROV Triton is more technologically conservative than past vehicles, reckoning with hard-learned lessons while making 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 brutal simplicity and reliability of the Power Box. The following technical document discusses the design rationale and process used to create ROV Triton.

Fig. 1- Team Photo

II. Safety

A. Safety Philosophy

Safety is the highest priority for Proven Robotics. A safe work environment does more than preventing 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 - The company's pressure testing chamber, undergoing pre-pressurization inspection by Napkin the cat

B. Safety Standards

Proven Robotics uses multiple safety procedures which every employee follows when working on ROV Triton. Personal protective equipment (PPE) is available to every employee in the workspace. This includes eye protection, dust masks, face masks, eye wash stations, shower stations, first aid kits, and fire extinguishers. During the Covid-19 pandemic, 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).

Fig. 3 - Water-Jetting a frame plate

C. Safety Features

ROV Triton has numerous safety features. The tether has both a master fuse for the device and a strain relief cord. The frame is rounded with no sharp edges. Each time ROV Triton is deployed, the safety checklist (see Appendix) is followed to ensure all employees and bystanders and vehicle are kept safe during operation.

Triton's custom thruster ducts integrate ingress protection features. They satisfy IP20, blocking objects larger than 12.5 mm and simultaneously minimizes the reduction in water flow. The shrouds are 3D-printed in-house. The shrouds and pieces mount via heatset 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 instruct 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 - A horizontal thruster, featuring custom-printed ducts with integrated safety shrouds and warning placard

III. Mechanical Design Rationale

A. Mechanical Overview

In the development of ROV Triton, the Mechanical Department prioritized simplicity, reliability, and development flexibility. 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 fits into a 64cm sphere, and weighs only 13 kg, fitting within the smallest size and weight class, 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.

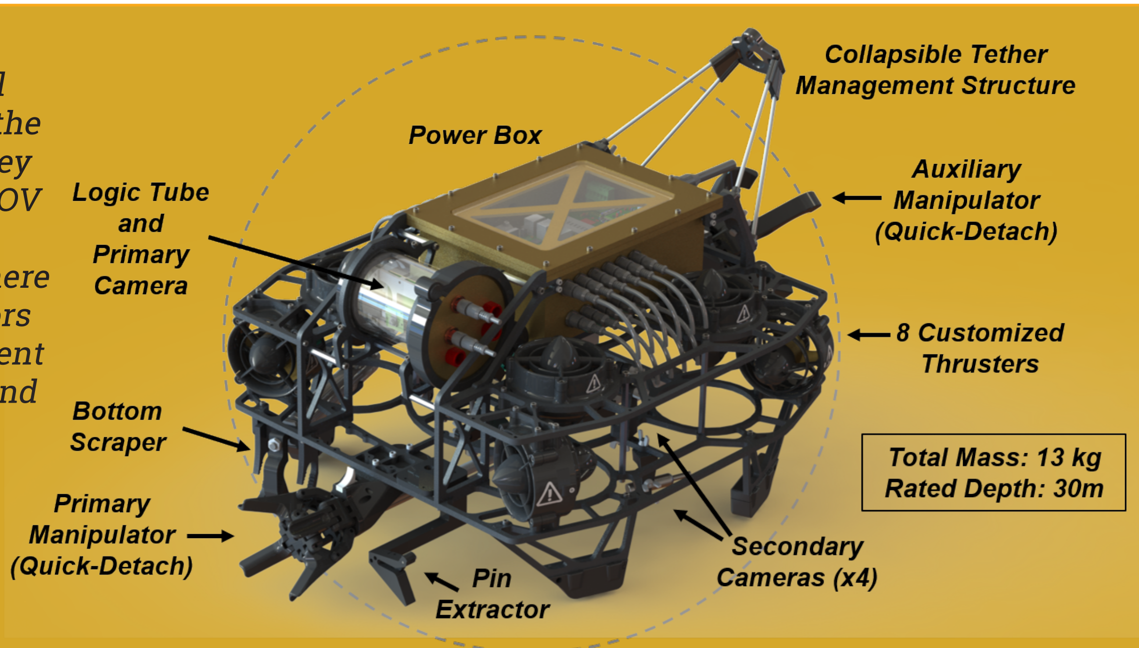
B. Frame

The vehicle's frame is sturdy and well considered – an excellent design, balancing competing interests and incorporating all the small, quality-of-life features demanded by years of hard-earned lessons. It continues in Proven Robotics' long tradition of water-jet 6061 aluminum plates, assembled with standoffs and mortise-and-tenon joints. The electronics enclosures and mission tools are carefully placed to keep the vehicle's center of mass (COM) as close as possible to the center of the horizontal thruster configuration, with the center of buoyancy (COB) several centimeters above the COM. This ensures passive stability and optimal control. The ROV has eight thrusters – four vertical and four horizontal. They are modified Blue Robotics T200's, using the stock motor core and propeller, but with 3D-printed ducts and nacelles; these parts are based on the originals but altered so as to integrate the required ingress protection features (IP20) and improve the mounting geometry. This enabled smooth integration into the frame. The placement of mission tools and cameras were also integral to the frame's design, ensuring the pilot has excellent views of the tools, the props, and the targets.

Finally, the frame has a slew of quality-of-life features. Handles are integrated into the main plates and wrapped with 3D-printed shrouds. The aluminum feet are protected by 3D-printed "shoes" that reduce friction with the bottom of the pool and serve as a replaceable wear item. The tether is managed by a collapsible structure in the rear that prevents it from interfering with the Auxiliary Manipulator and relieves strain from the cables. Lastly, the electronics–in particular those in the Power Box–are as accessible as possible.

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

It fits in the 64cm sphere with the manipulators and tether management structure detached and stowed



C. Logic Tube

The Logic Tube houses the control electronics: the Raspberry Pi, the Pi Shield, and the primary camera. The previous vehicle's Logic Enclosure suffered from several major issues: it was difficult to access, hard to seal reliably, and bulky. With these considerations in mind, instead of using screws, a tapered endcap and flange allow a nylon quick-clamp to compress the O-ring. This design allows for sealing and unsealing the enclosure quickly, reliably, and without tools.

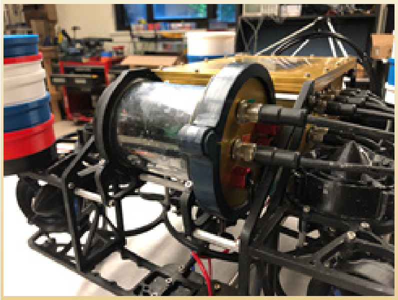


Fig. 6 - The Logic Tube

The endcap features two 8-pin Binders and three cable penetrators that allow for power and communication with a small area footprint on the endcap, reducing the overall size of the enclosure. A 3D-printed scaffold secures the electronics to the endcap. In addition, the enclosure holds a servo-mounted camera that can be angled by the pilot to increase its effective vertical field of view. The main body of the tube was cut from polycarbonate and epoxied to the flange. CNC-milling was used to machine the endcap and flange. A polycarbonate disk was used to seal the opposite end of the tube with epoxy.

D. Power Box

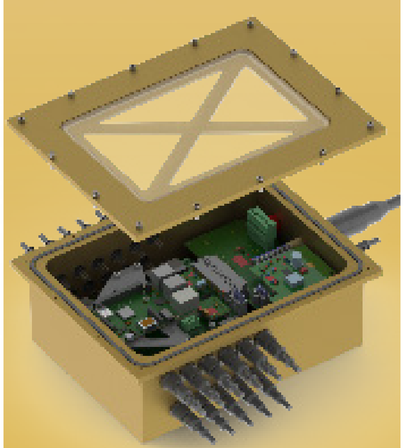


Fig. 7 - The Power Box

The Power Box is the heart of the ROV, housing a myriad of custom circuit boards to convert and disseminate power to the various enclosures, tools, and thruster electronic speed controllers (ESCs). The Power Box receives power and pilot commands through the SubConn and the Ethernet connector, and distributes them through up to 22 Binder ports. The current design of the ROV only utilizes 18 of the available ports, providing additional ports for design flexibility and forward-compatibility, should more cameras or tools be required. In contrast to previous tube-based designs, the large, rectangular Power Box provides advantages in manufacturability, thermal properties, and design flexibility. The box is milled out of a single block of 6061-T6 aluminum. Unlike welded construction, potential leaks are limited to the lid seal. The enclosure seals to a custom manufactured lid via a face seal using 3.175 mm x-profile o-ring, and has a vacuum port to test the seal. The lid includes a polycarbonate window for visual access to the internals without the need to fully reseal the lid each time.

The rectangular form factor is very conductive to the rectangular PCBs, which provides ample space for experimenting with board orientation, cable routing methods, or new boards as needed. The Power Box also has excellent heat dissipation, where parts that heat-sink directly to the enclosure through thermal paste are able to efficiently dissipate heat via the large outer surface of the box that is directly exposed to water. Within the Power Box, a 3D-printed scaffold secures the boards. 3D-printing provided critical flexibility, enabling redesign and smooth integration when the original 2020 electrical system and all the PCBs therein were revised. Finally, placement of the enclosure at the top of the vehicle allows for easy access to the electronics.

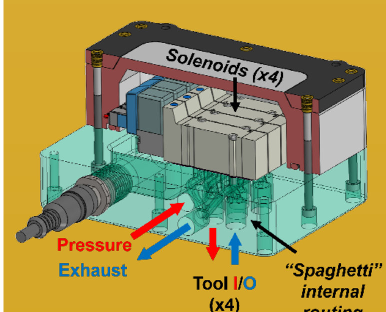


Fig. 8 - Partial section view of the Solenoid Enclosure

E. Solenoid Enclosure

Four of ROV Triton'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 individually control the Primary Manipulator, Auxiliary Manipulator, Pin Extractor, and Bottom Scraper. Each time a cylinder cycles, the exhaust is routed back through the manifold, through a second line in the tether, and vented to 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 5.4mm2 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. 9 - An USB camera in its adjustable mount

F. Secondary Cameras

An array of secondary cameras provides the pilot with crucial views of mission tools and props. In previous years, Proven Robotics has custom-designed and manufactured camera enclosures, but these were labor-intensive, bulky, and difficult to mount. ROV Triton instead uses off-the-shelf waterproof USB borescopes, greatly simplifying the secondary camera system. Each mounts to the frame with a 3D-printed bracket, adjustable without tools on two-axes, enabling pool-side modifications to get the desired view.One secondary camera under the ROV has a straight-down view for the computer vision tasks. The remaining four cameras provide views of the Primary Manipulator, Auxiliary Manipulator, Pin Extractor, Bottom Scraper, and Sediment Sample Retrieval Tool. Together, they give the pilot excellent awareness of the environment and the vehicle's tools.

Fig. 10 - A stack of calibration foam disks

G. Buoyancy and Ballast

The buoyancy system has two goals: provide additional displacement to make the vehicle net-neutral, and ensure ROV is stable and level – the optimal condition for pilot control.The company achieved net-neutral buoyancy with modular 3D-printed shells filled with an expanding polyurethane foam. Previous foam systems were milled from a single piece of high-density, closed-cell foam, which was time-consuming, expensive, and not conducive to iteration. The new modular system was quicker and easier to tune.

The first step of this approach was to produce an assortment of "calibration" parts – threaded, stackable disks of foam in units of 1, 1.5, and 2.5 N. This allowed the buoyancy to be tuned poolside and adjusted throughout development as hardware was added. With the required amount and distribution of buoyancy determined, the final foam was designed and produced. This final foam was made in 13 segments using the same method as the calibration foam. Sections are removable for easy access to mission-critical components, and the total buoyancy is modifiable by replacing individual segments of the shell. In order to make fine adjustments, ballast was integrated into the 3D-printed "shoes." This ballast consists of segments of 9.5mm steel rod, secured with a wing-nut for easy access. The final foam design provides 33.8 N of net buoyancy, and the shoes provide up to 2.4 N of net ballast.

Fig. 11 - The initial COM and COB, along with the tuned COB and COM

IV. Mission Tools Rationale

Fig. 12 - The quick-detachable Primary and Auxiliary Manipulators

A. Primary & Auxilary Manipulators

ROV Triton has a Primary Manipulator (PM) located on the front of the vehicle and a nearly-identical Auxiliary Manipulator (AM) located on the rear. Together, they represent the fourth generation of the proven “quad-pincer” – a simple, reliable, and multipurpose manipulator design, capable of grabbing both vertical and horizontal pipes. They can both be used to outplant coral, cull sea stars, and replace the seabin power connector. The AM’s placement and end effectors are specialized to also collect sponges, replace the Seabin catch bag, and constrain the vehicle for pipe inspection. The PM, meanwhile, is placed next to the Pin Extraction Tool to facilitate retrieval of the ghost net.

Both manipulators are driven by pneumatic cylinders, providing 75 N of clamping force. They mount to the vehicle using a rotary quick-release with a captive latch for compact storage and convenient replacement. Nearly all parts are 3D-printed in PET-G, selected for its strength and impact resistance. 3D printing allowed for rapid iteration, well-tuned fit, and pilot ease-of-use.

Fig. 13 - Bottom Scraper Tool

B. Bottom Scraper

The bottom scraper tool is intended to remove plastic debris from the bottom of the pool, specifically, the ½” PVC samples velcroed to zip-lock bags. The tool uses a claw attached to a non-rotating, pneumatic cylinder to trap debris in two tapered claws. To have a usable camera view, the tool was built into the one of the ROV’s feet.

The width of the fixed claws were iterated upon so the grip tapers from a free fit to a friction fit on the debris. The fixed claws also elastically deform as the pneumatic cylinder forces the debris into a cavity that was not initially wide enough for it to fit in. As the pneumatic cylinder opens and the claw relaxes, angled teeth hold the debris in place. This allows for the tool to hold one piece of debris in place while the pneumatic cylinder opens to grab another. Thus, both pieces of debris can be grabbed without surfacing.

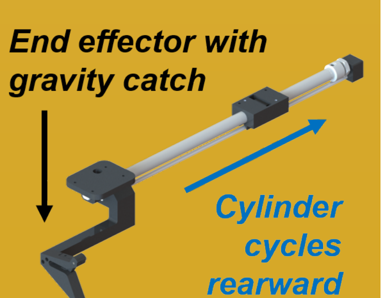


Fig. 14 - Pin Extractor Too

C.Pin Extractor

The Pin Extractor is a pneumatically-driven mechanism designed to free the ghost net by removing the pin securing it. The tool consists of a pneumatic cylinder with a 30 cm stroke and an end effector with a locking gravity catch. To extract the pin, the pilot must vertically align the end effector, strafe the vehicle left to engage the gravity catch, grip the PVC pipe with the Primary Manipulator, and retract the end effector by actuating the pneumatic cylinder. Using the Primary Manipulator in conjunction with the Pin Extractor was deemed necessary, as testing demonstrated the vehicle must brace against the PVC while extracting the pin to prevent towing the ghost net across the pool. At the end of the process, the pin is retained in the Pin Extractor, the net is in the Primary Manipulator, and the vehicle can return to the surface.

D. Sediment Sample Retrieval Tool

The Sediment Sample Retrieval Tool is designed to be extended down a 152mm long Corex corrugated pipe; the tool's goal is to retrieve a sediment sample contained within a PVC tube covered in hook and loop straps. Utilizing a Blue Robotics M200 motor, the tool is designed to emulate the mechanism by which a tape measure extends and retracts in order to travel down the entire length of the pipe while still maintaining a small footprint on the ROV. The extrusion of the steel tape from the tool is monitored via a video camera and will be stopped upon reaching a predetermined length. Once the predetermined length is met, the end effector, that is attached to the end of the steel tape, will attach to and hold the sediment sample until extraction. The end effector uses a hook and loop strap to easily grip onto the hook and loop strap attached to the sample. Both the housing of the steel tape extruder and the end effector can be 3D printed with PLA; this makes the tool a cost effective alternative to buying and modifying a tape measure.

Fig. 15 - Sediment Sample Retrieval Tool

E. Surface Scraper

The Surface Scraper tool is a passive device that affixes to the top of the foam in order to collect floating debris from the surface. The position of the tool above the foam allows it to “skim” the surface of the water, using its blunt leading edge to nudge the debris below the surface. Once the tool has moved over the debris, the floating objects are able to resurface, and are then trapped in the cage by their own buoyancy. This system allows the pilot to quickly and effectively collect floating debris without the need for precise actuation of an active tool.

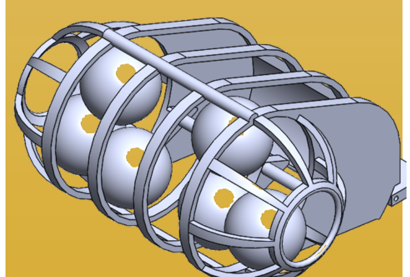


Fig. 17 - Surface Scraper

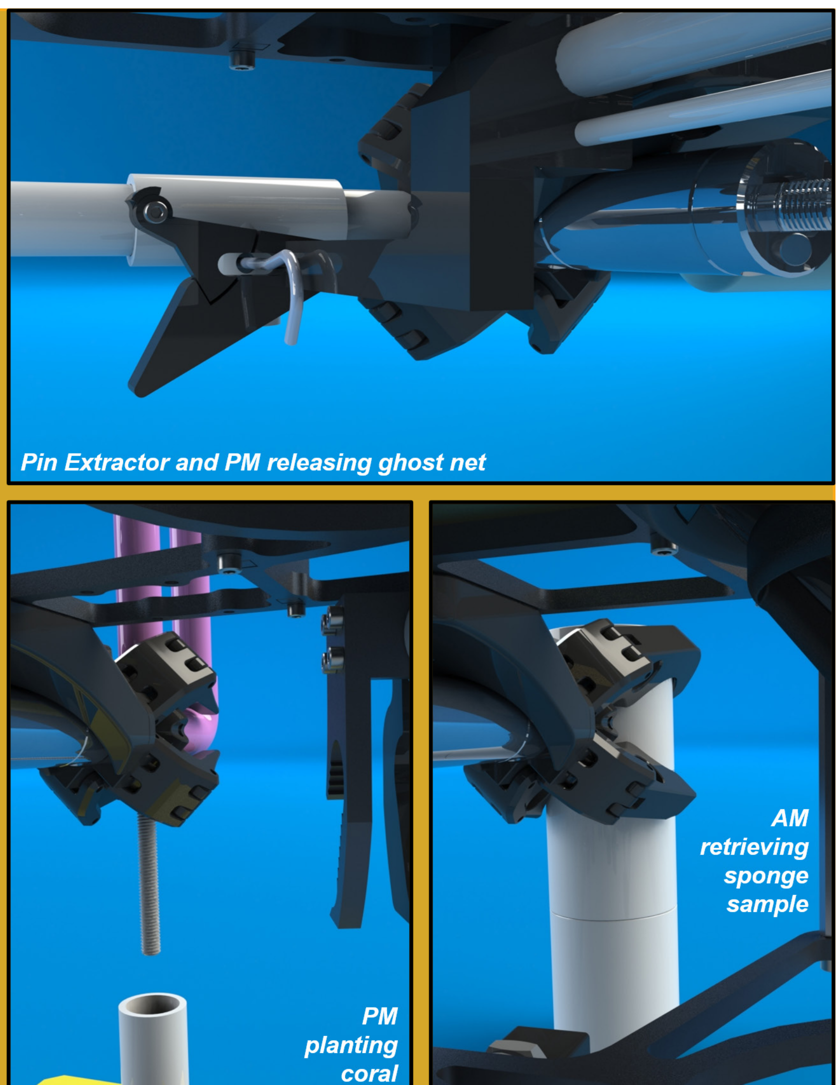


Fig. 16 - Secondary Camera Views

Fig. 18 -Primary Camera view

V. Electrical Design Rationale

A. Electrical Overview

ROV Triton's electronics iterated upon the electronics designed for the 2020 competition, but with improvements to modularity, accessibility, reliability and power delivery. The ROV control starts with the surface base station which includes the pilot's computer, monitor, and gamepad. An Ethernet cable and the 48-V power supply comprise the electrical connection in the tether. Both cables plug into the rear of the Power Box. A Category 6 Ethernet cable is used to provide noise immunity alongside high data through for low latency and six 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 housed in two separate enclosures. The Raspberry Pi, Pi Shield, and Pi Camera are in the Logic Tube and the remaining PCBs in the Power Box: two Power Bricks Boards, the Distribution Board, the Power Conversion Board, the Backplane Board, the Solenoid Board, three ESC Controller Boards, three ESC Adapter Boards, and a five-port Ethernet switch. This division provides noise isolation and greater accessibility for the Pi-related electronics. The boards in the Power Box are split into two vertical stacks to provide modularity and access to the most frequently removed boards. The Power Brick Boards produce a nominal 12 V for thrusters and solenoids, and the Power Conversion board produces both 5 V and 3.3 V for logic electronics. The power and signals from these boards are routed through the Distribution Board to the Backplane, which interface to the remaining PCBs: ESC Controller, ESC Adapter, and Solenoid. The Backplane also routes the signals to the appropriate panel jacks on the Power Box to connect to other enclosures.

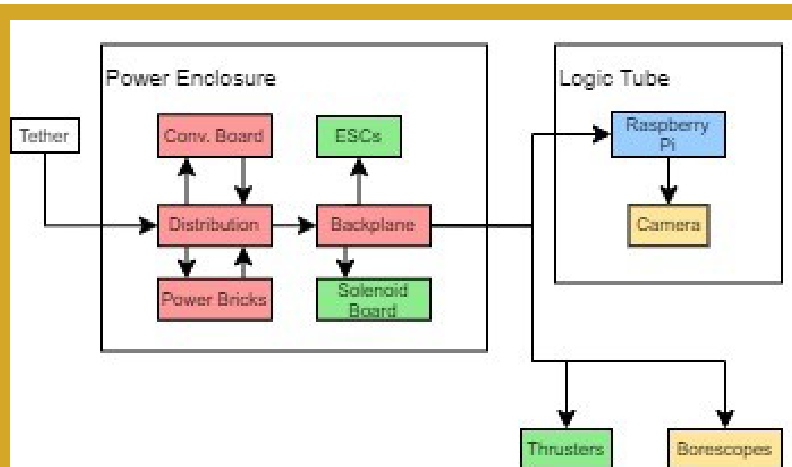


Fig. 19 - Simplified SID

The Ethernet cable goes directly to an onboard Ethernet switch then connects to the primary Raspberry Pi for control and sensor and the secondary Raspberry Pi for additional camera feeds. Both are supplied with 5 V produced by the Power Conversion board. The Pi Shield also communicates with the ESC Controller Boards and Solenoid Board 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, borescopes, and Ethernet switch.

B. Power Bricks Board

The Power Bricks Boards are a shield for the Delta Q48SC12050 Quarter Power Bricks, which convert 48 V to 12 V. It connects both of these to the Distribution Board for usage across the power stack. Several significant improvements include a boost inoutput voltage 10% to increase ESC power and communication through SMBus.

C. Power Distribution Board

The Distribution Board receives 48 V from the tether and sends it to the Power Brick Boards. It also receives 12 V from the Power Brick Boards and sends it to the Backplane and Conversion Boards, and it receives 5 V and 3.3 V from the Conversion Board and sends it to the Backplane as well. Power supply or-ing is implemented on the Distribution board from the bricks to achieve greater power output and redundancy.

D. Power Conversion Board

The Conversion Board takes 12 V from the distribution and steps it down to 5.2 V for the Raspberry Pis and cameras and 3.3 V for microcontrollers. An early revision of the board produced 5 V from 48 V, to circumvent the brownouts on the 12 V line from the bricks. After the brownouts were resolved, the board switched back to 12-V input for better reliability and less noise. The board was streamlined with one buck converter for 5 V and a smaller linear regulator for 3.3 V.

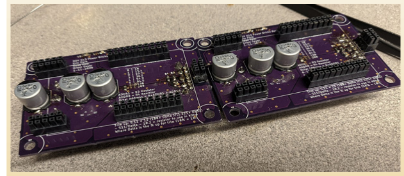


Fig. 20 - Power bricks

E. Backplane

The Backplane exists with the purpose of routing signals throughout the ROV. The board works through receiving 12 V, 5 V, and 3.3 V from Distribution. It then sends those power rails along with other signals such as the CAN bus and solenoid control to the Solenoid board, the ESC Adapters, the ESC controllers, and the Pi Shields. The Power Distribution connection was split across two separate connectors to make routing and connecting more user friendly. To ensure enough current for the ESCs, 6 AWG wire was soldered directly to the board for the 12-V line.

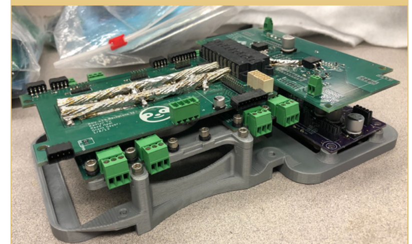


Fig. 21 - Backplane (left)

G. ESC Controller and Adapter Boards

The Quad ESC adapter board connects the all new Lumenier 4in1 ESCs to the backplane for input power and the thrusters they drive. The new ESCs allow for a more compact design, while providing new telemetry data during their operation. Bulk capacitors are placed on the board to provide current during startup for the ESCs.

The Quad ESC controller board connects the backplane to the new Lumenier 4in1 ESC control signals, which was split from the controller board to add modularity. The STM microcontroller generates the PWM sent to the ESC, and communicates with the Lumenier via the telemetry pin. Notable changes include programming connections that allow for reprogramming ESCs without needing to desolder the PWM wires from the board or dismantle the ROV and dynamic IDs that make the boards hot-swappable.

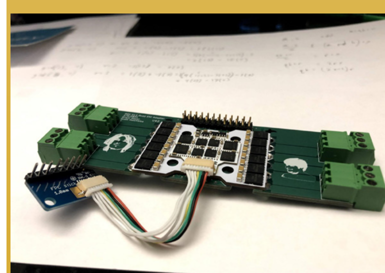


Fig. 22- Lumenier 4in1 ESC and adapter board

G. Raspberry Pi and Pi Shield

The Pi shield acts as a shield to the Raspberry Pi that allows for sensors and peripherals to be connected. The board is located in the logic enclosure with connections to the power enclosure, specifically Ethernet, power, and CAN. The board was improved by adding a bulk capacitor to prevent voltage dips and support for two different IMUs.

The Raspberry Pi is the computer on board the vehicle; the main one is in the logic tube and the second one is in the power box. The main pi runs the process that allows for the vehicle to be controlled and provide feedback and information to the surface. The secondary pi is for providing more camera feeds for the pilot. The company upgraded to using two Raspberry Pi 4s, the newest and best pi available. The use of the Raspberry Pi is due to the large flexibility to program and design around.

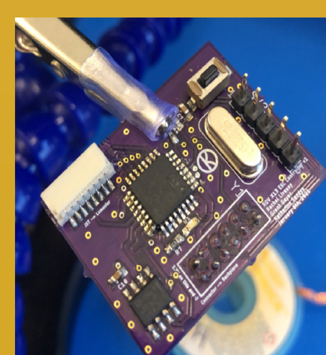


Fig. 23- ESC controller board

H. Solenoid

The Solenoid board is responsible for driving the solenoids for the ROV. It interfaces with the Backplane, receiving power and IO in. With a common 12 V to all solenoids, it either grounds the solenoid or leaves it floating to control the state of the solenoid. The Solenoid board was moved from the

Solenoid enclosure to the power box. With this change, the solenoid board is significantly less likely to be damaged in the case of a solenoid enclosure leak and less space is needed in the enclosure for a PCB.

I. Cameras

The ROV's cameras consist of Teslong borescope cameras. These are a series of off-the-shelf, compact, and waterproof USB devices that deliver camera feeds for the various vision needs on the ROV. The cameras are five megapixels, have built-in lights, and utilize an auto-focus mechanism. The borescopes are easily movable to various locations, which enables the ROV to have 5 constant secondary video feeds around the ROV. The output is a ffmpeg video stream that is displayed directly in the pilot interface without requiring additional processing from the Raspberry Pi.

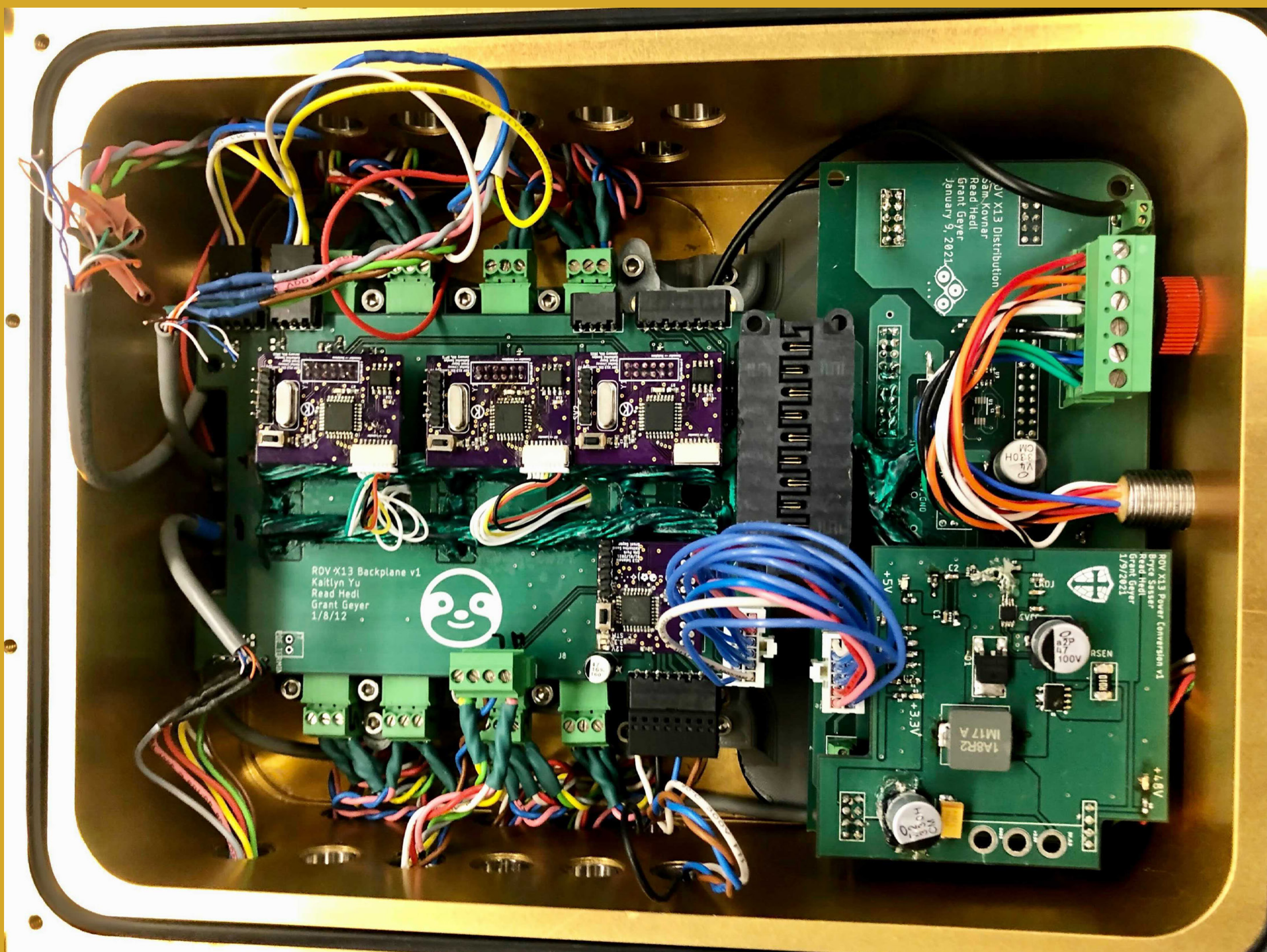


Fig. 24 - Full power electronics stack

Fig. 25 - Camera

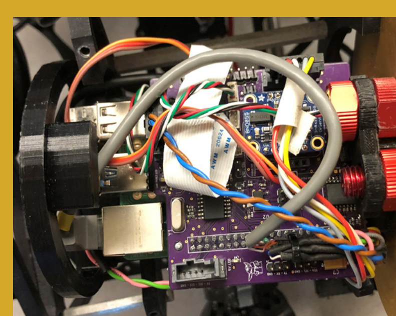


Fig. 26 - Pi Shield

VI. Software Design Rationale

A. Software Overview

Proven Robotics hold modularity and flexibility as core design principles for ROV software. This year's software builds on the solid foundations and institutional knowledge of the company's previous ROVs. The software department utilizes a ROS network that displays a unified core of functionality. This allows us to integrate the frontend functionality as well as ROS sub-modules in consistent patterns. This aids in achieving the goals of modularity and flexibility through defined standard interfaces. The software department can more fully use its employees working as teams to develop independent modules that integrate predictably into the full system.

Looking towards the future and increased third party library support, this year's ROV and Pilot Interface were upgraded from the ROS Kinetic framework to the ROS Melodic framework. This software upgrade complemented the increased power and capabilities of the RaspberryPi 4 and Python 3. The Software Department updated and ported the old code base to avoid deprecation risks such as those posed by Python 2.7 deprecation. From that foundation many new innovations and improvements were designed and implemented with large strides taken with Pilot Interface capabilities. More information and customization is presented to the pilot because of the flexibility gained by developing modules with ROS combined with the tight integration of the frontend.

B. Pilot Interface

The Pilot Interface combines as many of the individual components needed to run the ROV from a laptop into a single Electron desktop application with an Xbox controller being the only other hardware requirement. While Electron serves as the backbone of the application itself, Node.js and ReactJS fill in with ROS/PC integration and layout design respectively.

A major focus this year was on the development of a more modular design of components and greater separation of frontend and backend systems to improve performance of the application. In addition, TypeScript was used instead of JavaScript for easier debugging and improved data structures that can be used between components and with Inter-Process Communication (IPC) as Electron is separated into a “Main” and “Render” process.

ROS nodes were written as separate Python scripts that can be executed individually for debugging. IPC with these scripts was designed on an as-needed basis, where nodes used for telemetry need only use the OS’s standard output (stdout). However, if commands needed to be sent, sockets were used on top. With this framework, the Software Department was able to design modular nodes and components that were useful both in testing and as a final product within the Pilot Interface, such as a center of mass (COM) tweaker, 3D ROV attitude visualizer, and various other useful components.

The interface was designed to be as clean and user-friendly as possible with a natural flow of features. Pilots also have the ability to change between preset movement sensitivity profiles within the interface that can be used for specific environments and conditions without having to individually modify values pertaining to ROV behavior.

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) 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.

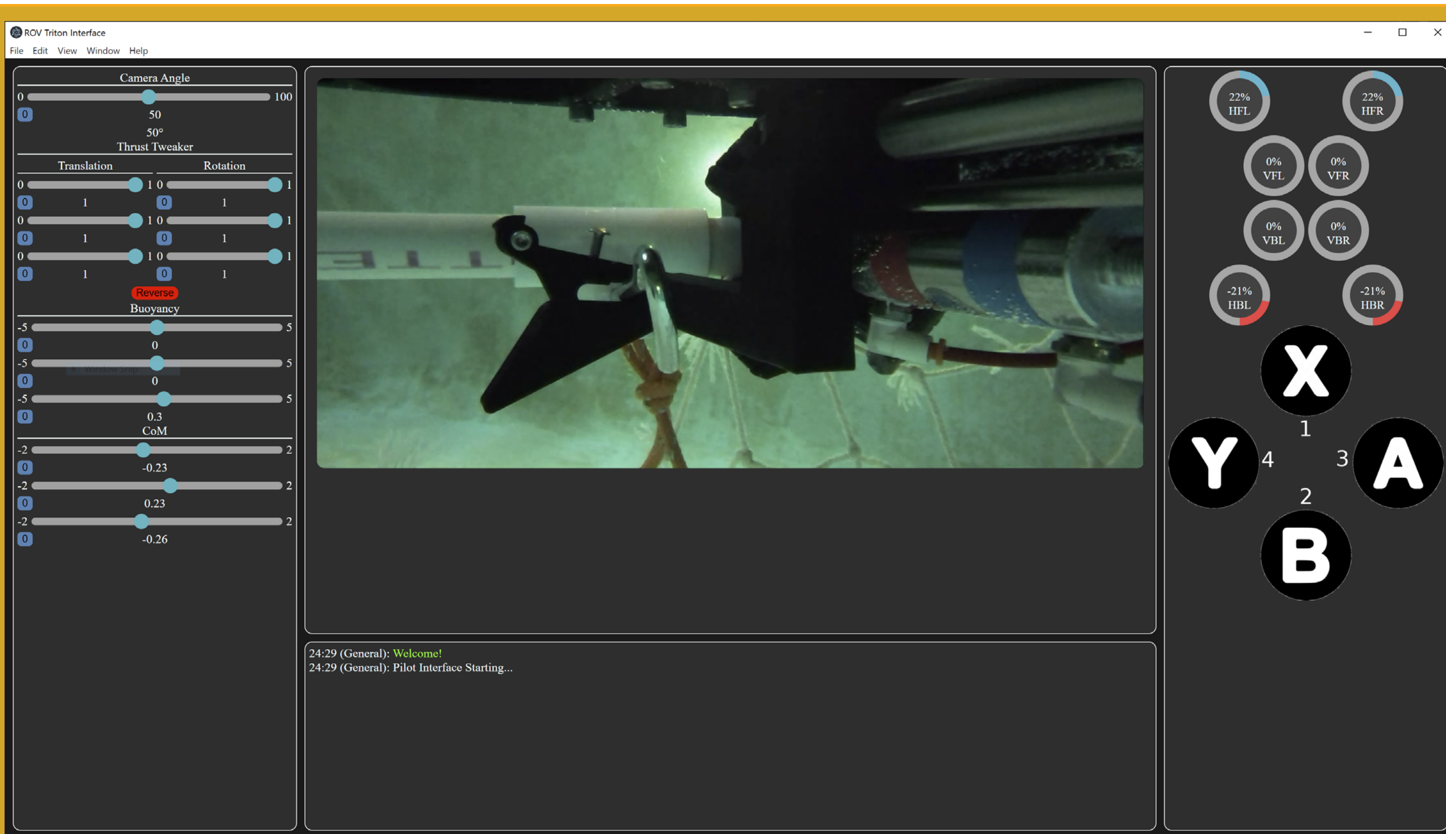


Fig. 27 - Pilot Interface display showing adjustable thruster controls

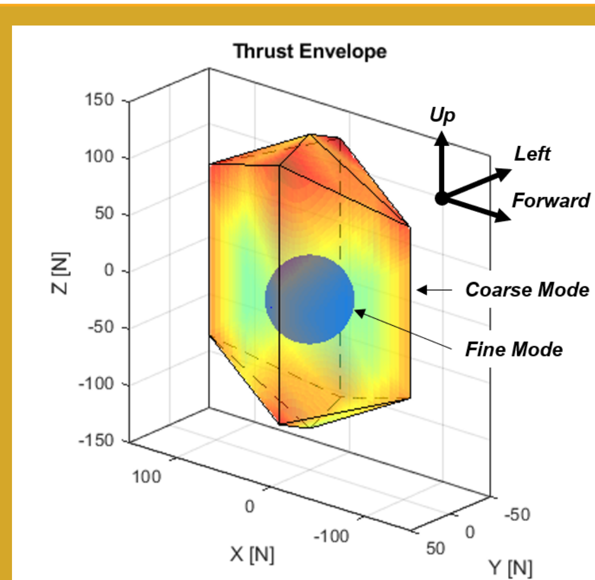
D. Embedded

Embedded communication on the ROV is handled via the CAN protocol. This provides a high level of noise immunity at a high data rate to many simultaneous systems. The Raspberry Pi communicates on the CAN bus using drivers built into the Raspbian OS for the MCP2515 SPI controlled CAN controller. Each STM32F042K6T6 microcontroller on the ROV has custom firmware written in C which receives the CAN messages and then performs the appropriate action based on the message received. This allows the pilot to control the embedded portion of the ROV efficiently through a custom built API, tailored to the tasks set forth by the mission.

The Raspberry Pi sends distinct CAN messages to each ESC Controller board to provide input for the corresponding attached thrusters. The microcontroller on each ESC Controller board interprets its CAN messages to control the duty cycle of the four PWM signals sent to the ESCs to control its corresponding thrusters. The Lumenier ESCs provide telemetry data such as current and temperature. The microcontrollers on the ESC Controller boards interpret the telemetry UART packets, then relay the data over CAN to the Raspberry Pi to be displayed to the pilot.

The Solenoid Board receives two distinct CAN messages: solenoid operation and power brick communication. The STM32F0 microcontroller interprets this CAN message to toggle digital outputs to activate or deactivate the solenoids. Power brick CAN messages instruct the STM32F0 microcontroller to send data to or receive data from the power bricks via SMBus. This data includes requesting information about the brick's

Fig. 28 - Visual representation of the thrust envelope



input voltage, output voltage, temperature, and current. Once the microcontroller receives the information from the bricks, it sends a CAN message in response that is then interpreted by the Raspberry Pi.

E. Propulsion and Control

ROV Triton has six degrees of freedom, a relatively low mass, powerful thrusters, and is less passively stable than many previous vehicles. As such, it has a very high performance ceiling, but demands a well-developed control system to take advantage of its maneuverability and ensure smooth and intuitive piloting. A mission-critical section of the software is that which commands the eight thrusters to maneuver the vehicle as directed by the pilot or an autonomous closed loop controller. The Thrust-Mapper receives a six dimensional vector describing the desired net force and net moment with respect to the vehicle's coordinate system, and uses the Moore-Penrose pseudo-inverse to find a minimum energy combination of thruster values that achieves them. The position and orientation of the eight thrusters on the frame create a thrust envelope that prioritizes control authority in yaw and thrust in the X and Z directions. This enables the vehicle to surface, dive, and traverse the environment rapidly, but can be unintuitive for the pilot when performing fine motions. To resolve this, the Thrust-Mapper has both a coarse and fine mode, the former unlocking the maximum thrust envelope, and the latter limiting the pilot to the thrust envelope's inscribed sphere. This ensures changes in heading are smooth and predictable.

The pilot also has the option through the front-end interface to lock the vehicle's depth. This engages a PID controller that uses the data from a Blue Robotics depth sensor to maintain a constant depth. The proportional, integral, and derivative gains can be optimized using ROS's dynamic reconfigure package, ensuring the controller is well-tuned and stable.

F. Computer Vision

Video streaming and encoding on the ROV is handled by a FFmpeg and FFserver stack. These software libraries enable the department to freely and readily add camera sources that are then simultaneously broadcasted over the network to any number of clients. FFmpeg abstracts the encoding, piping, and hardware interfaces, while FFserver abstracts the settings, streams, and networking. Multiple hardware inputs can all be handled by one server, and a server can stream to multiple clients through a standard web interface. Multiple servers are able to exist on one network without collisions or other problems.

Solutions to computer vision tasks are executed via separate Python scripts using the OpenCV library to handle image processing while the Numpy library is used for algorithms relating to clustering and linear algebra
All solutions to computer vision tasks utilize the mentioned libraries in similar ways employing some form of thresholding algorithms to detect edges, metadata storage to deal with shapes or colors, and repeating passes to achieve the best results. For CV tasks requiring ROV control, ROS is used on top to pass messages based on solution output.

Fig. 29 - Computer vision program identifying the benthic species

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 their 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 team: Frame and Buoyancy, Tools and Pneumatics, Power Enclosure/Electronics, Logic Enclosure/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 formidable integration.

B. Project Management

Proven Robotics' design cycle is split into four stages: training, designing, 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, 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 Triton. Proven Robotics nearly completed the design phase before mission specifications were released, but allowed ample room to adjust for mission specific needs. With the extension due to Covid-19, several elements were redesigned in the second year with complete knowledge of mission requirements. 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 time they were attended and 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 conclusions of the design phase, all designs had been thoroughly vetted and were ready for manufacturing.

During the manufacturing phase, all components for the ROV were built. 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 thoroughly 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 thoroughly tested in isolation before introduction to the system in air to ensure it can work as designed before deployment in the water. If it failed testing, 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 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 Triton and the costs of attending 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: Mechanical: Connectors which increased $1,000 to support more design flexibility and more research into optimal connector choices and Electrical: Cameras which increased $500 to prototype with different options and purchase higher quality cameras. Proven Robotics pays for flights and lodging for many employees to attend competition as the budget allows, rewarding them for their hard work throughout the year. The company receives income from various grants from Purdue University organizations along with sponsorships from companies and discounts on purchases. Due to the cancellation of competition in 2020, the company will have a surplus for the year after the competition. This will go into future improvements for the team, including equipment for the workspace, increasing prototyping, and research and development for custom ESCs and thrusters.

Budget

Proven Robotics' 2021 Budget					
Budget Category	Item and Description	Type	Amount	Total Amount	Budget Allocated
Electrical: Boards	PCB Fabrication	Purchased	$ 248	$ 248	$ 400
Electrical: Cameras	Borescopes, USB components	Purchased	$ 350		
	Nano Pi Duos	Purchased	$ 247	$ 596	$ 800
Electrical: Components	Power Bricks	Purchased	$ 195		
	ESCs	Purchased	$ 236		
	SMD components and board connectors	Purchased	$ 1,404		
	Wires, cables, heatshrink, etc.	Purchased	$ 160		
	Raspberry Pis, IMU, etc.	Purchased	$ 138	$ 2,133	
Electrical: Equipment	Multimeters, power supplies	Purchased	$ 316	$ 316	$ 200
Electrical: Prototyping	Test parts and boards	Purchased	$ 274	$ 274	$ 800
Mechanical: Connectors	Binders, Cable Penetrators	Purchased	$ 421	$ 421	$ 1,850
Mechanical: Equipment	Elegoo resin printer and curing station	Purchased	$ 435	$ 435	$ 200
Mechanical: Materials	Aluminum and Polycarbonate Stock	Purchased	$ 751		
	Expanding foam	Purchased	$ 156		
	3D printer filament, resin, epoxy	Purchased	$ 407		
	Parts for tools (Screws, bolts, epoxy, etc.)	Purchased	$ 437		
	Basestation parts (riffle case, wood, etc.)	Purchased	$ 154		
	Prop Parts (PVC, corrugated plastic, etc.)	Purchased	$ 104	$ 2,010	$ 4,100
Mechanical: Prototyping	Test prints and enclosures, etc	Purchased	$ 714	$ 714	$ 1,200
Mechanical: Thrusters	Blue Robotics T200s and other parts	Purchased	$ 552	$ 552	$ 1,750
Total Expenses for ROV Construction				$ 7,699	
General: Competition and Lodging	Hotels, registrations	Estimated	$ 3,800	$ 3,800	$ 5,000
General: Travel	Gas, flights, etc.	Estimated	$ 6,000	$ 6,000	$ 6,000
General: Apperal	T shirts and polos for the team	Purchased	$ 1,174	$ 1,174	$ 1,200
General: Other	Miscellaneous purchases	Estimated	$ 300	$ 300	$ 500
Total Expenses for Competing				$ 11,274	
Income	Purdue Office of the Provost	Cash	$ 6,000		
	Caterpillar	Cash	$ 4,500		
	PESC	Cash	$ 2,000		
	Northrop Grumman	Cash	$ 1,500		
	Purdue Electrical and Computer Engineering	Cash	$ 4,000		
	Purdue College of Engineering	Cash	$ 3,000		
	Kleppinger Family and Northrop Match	Cash	$ 2,000	$ 25,000	$ 30,00
Total Cash Income for 2020-2021				$ 25,000	$ 24,000
Donations and Discounts	Binder USA	Discount	$ 135		
	Advanced Circuits	Discount	$ 500		
	Digikey	Discount	$ 68	$ 703	N/A
Total Expenses				$ 18,973	-
Total Cash Income				$ 25,000	-
Net Balance				$ 6,027	-
Next Year Investment				$ 6,027	-

VIII. Conclusion

A. Testing and Troubleshooting

With the two year design cycle due to Covid-19, the testing on ROV Triton was orders of magnitude higher than on recent company ROVs. As a result, several fundamental systems were completely overhauled, including the thrust mapper, CAN communication, cameras, pneumatics, and connectors. For the first several months of design, software was tested and improved on ROV Remora from 2019. To get ROV Triton's foundations in working order boards were continuity and functionality checked, and seals were pressure tested before the complete vehicle was assembled. Functionality of cameras, thrusters, and tools is 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 brush 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 both the Fall 2020 and Spring 2021 semesters, the company had employees in person and online. Prior to the pandemic, all meetings were held in person, but due to restrictions enacted by Purdue, Microsoft Teams was utilized to host meetings remotely. The adjustment period as well as capacity limitations for those in person hampered development early in the year. To counter this, the company moved to a mixed-development system where functions that didn't need direct access to the ROV 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. The largest technical challenge the team faced over the past year was the functioning of secondary camera systems. From the initial design cycle, the PCB was never ordered, little attention was given to electrical-mechanical integration, and the enclosure was left poorly done after the employee working on it left. The company continued to find issues with running Ethernet over longer lengths of cables and had some issues with flaky connectors. Once most issues had been resolved with the original NanoPi Duos, a short damaged the boards which couldn't be resolved before the end of the semester. After a brief attempt to use a Nanopi Neo Core as a hub for USB borescopes, a second raspberry pi was added to stream additional borescope feeds. The end result was a low latency, reliable, effective system that will set the approach for years to come.

C. Lessons Learned and Skills Gained

All Proven Robotics employees learned valuable technical skills both of their own departments, and of 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.

This year has provided the company a unique opportunity to improve management skills to adapt to the effects of the pandemic. To ensure a safe working environment for all, the company improved 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

Custom ESCs: The current electronics stackuses Lumenier ESCs. A custom ESC is in development to provide greater flexibility in board placement. Control and communication can occur closer to the motor, providing better response for the vehicle.

Custom Thrusters: Motivated by the introduction of the custom ducts for thrusters, the company began exploring custom thrusters. The project is very expansive including the waterproof coating on a brushless motor, the replacement of bearing with bushing for in water, the design of a propellor, and the measuring of thrust produced by a design in both steady state and startup. Future vehicles will have greater flexibility in thruster arrangement. Additionally, the team will have a waterproof motor to use for tools after the discontinuation of the Blue Robotics M200.

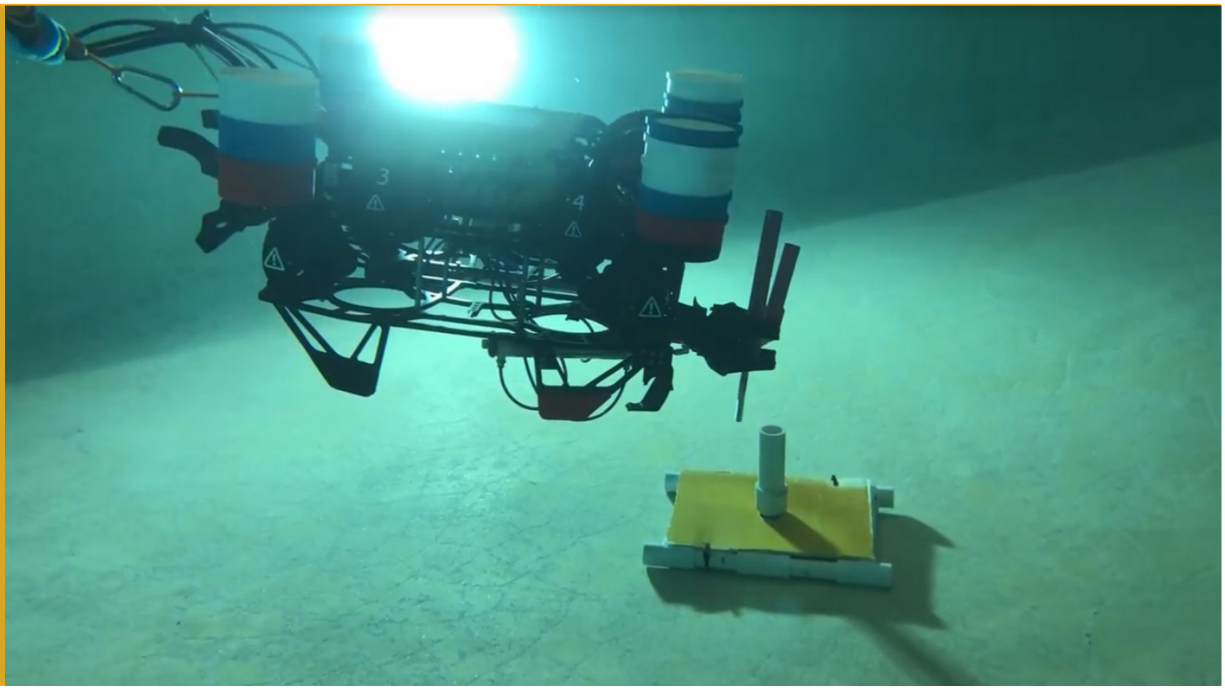
E. Reflections

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.

> *My first year on Purdue ROV was better than I could have ever imagined. Despite all of the limitations of the COVID-19 pandemic, I was still able to feel welcomed and have an educational and fun experience. I joined the mechanical team and was immediately given a substantial task that allowed me to really push myself to learn new skills and to improve existing ones. What really made my experience on the team amazing, however, was my teammates. They fostered a collaborative and supportive work environment, and I was never afraid to ask questions. No matter what, somebody was willing to take the time to explain things to me, even if it did not directly relate to my work on the team. Joining ROV was one of the best decisions I made my sophomore year, and I can't wait to continue working on the team in the future.*
>
> - Corina Capuano (Mechanical Department, New Member)

> *My time on ROV has taught me so much to become the engineer that I am today, and I wouldn't trade it for anything else. Every year, I was challenged to learn something or take on a new responsibility and push to make the team better. It's rewarded me with more than just technical experience on an interdisciplinary project. On the team, I've built lasting friendships, shared countless late nights working on the ROV, and discovered a passion for electronics. My time on ROV has been unlike any other and I'll miss it as I go forward into my career.*
>
> - Grant Geyer (CEO, Graduating Senior)

Fig. 30 - ROV Triton during a 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

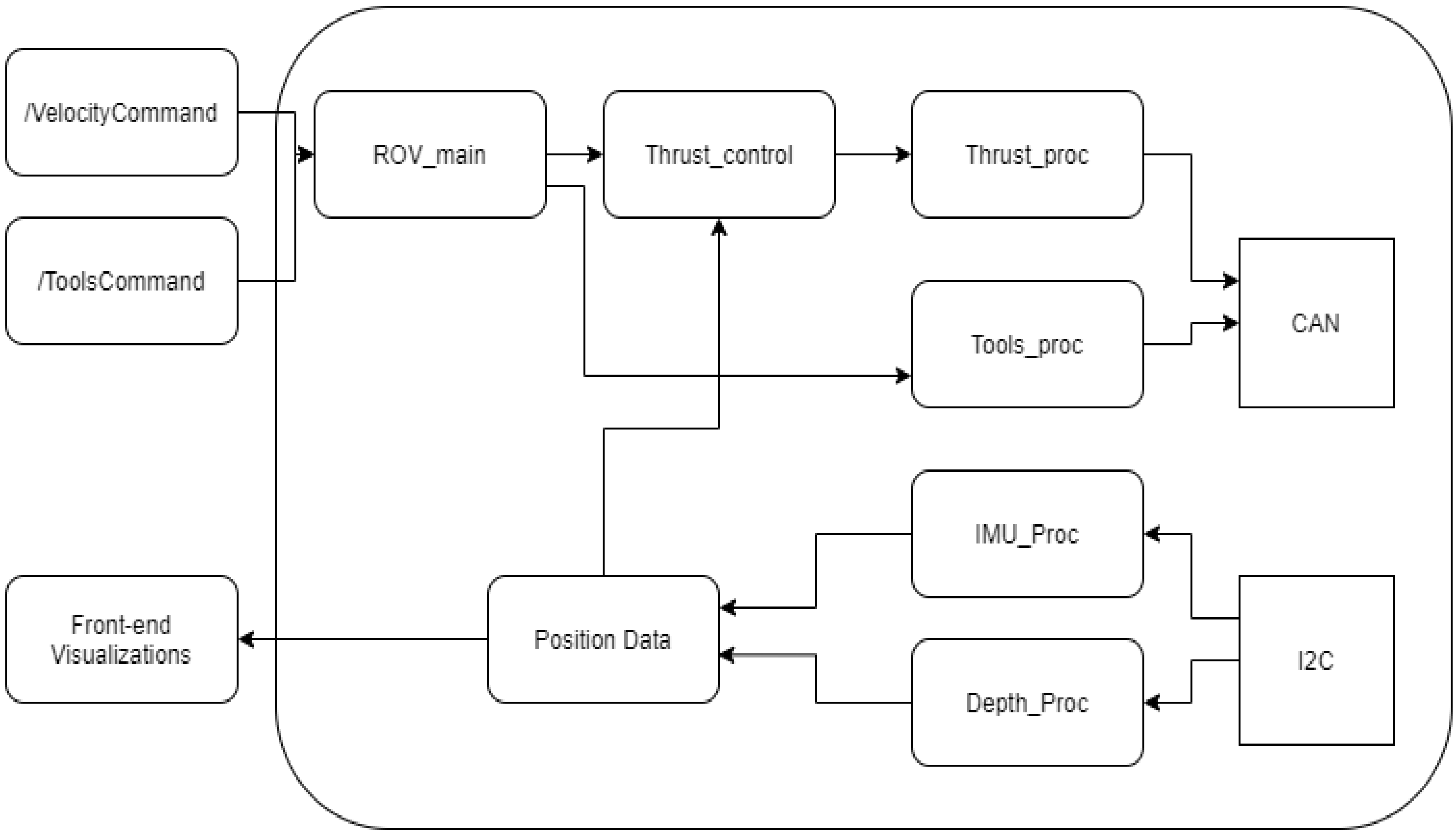
Lost Communication
- ☐ Steps attempted in order. Mission resumes when one succeeds.
- ☐ Co-pilot checks tether and laptop connections on the surface
- ☐ Pilot attempts to reset the BattleStation
- ☐ Co-pilot cycles the power supply
- ☐ If nothing succeeds, the mission stops
  - ☐ Co-pilot turns power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

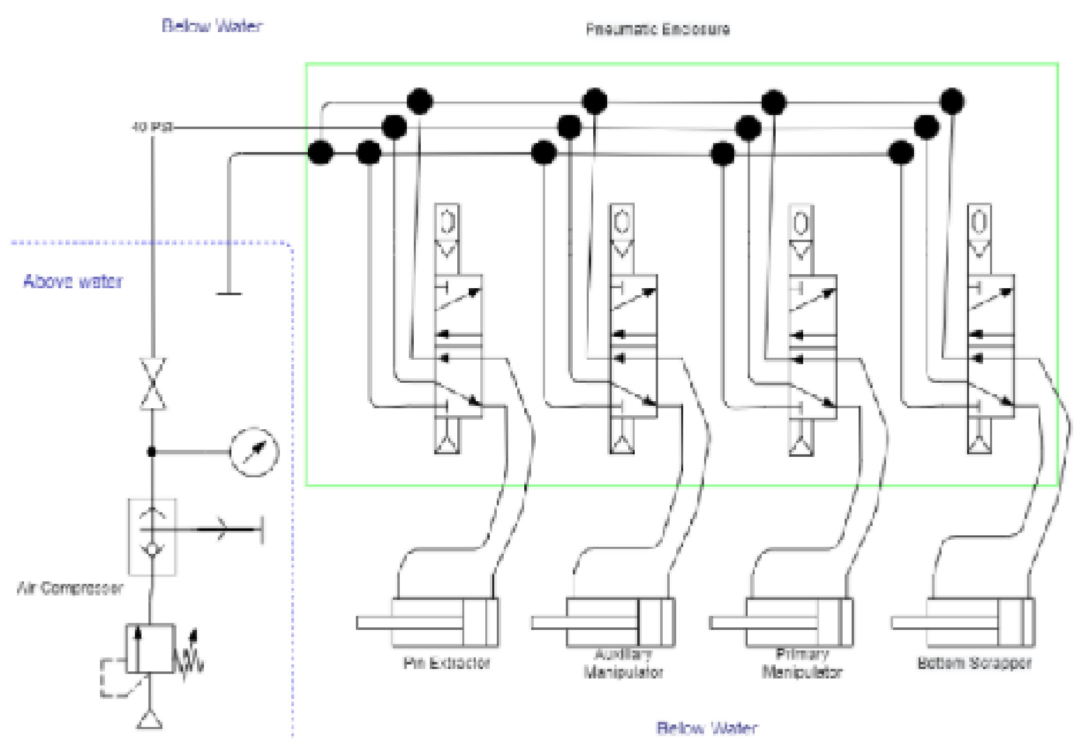
Demobilization
- ☐ Co-pilot turns power supply off and calls out, "Power off"
- ☐ Deployment members do a quick visual inspection for leaks or damage on ROV
- ☐ Pilot stops BattleStation and powers off laptop
- ☐ Anderson connectors of tether are removed from power supply
- ☐ Turn off air compressor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

B. System Interconnect Diagrams

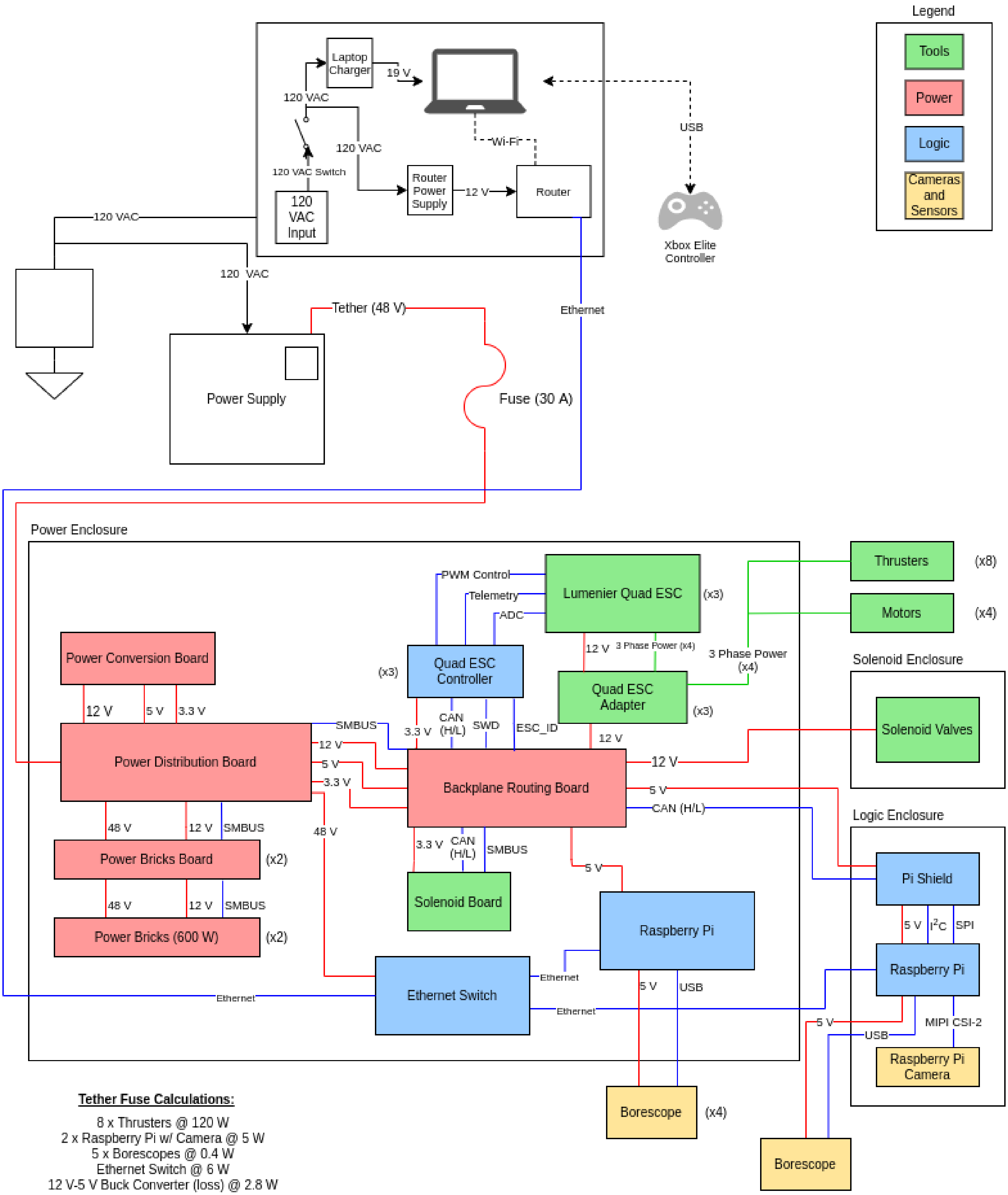
Software Flowchart



Fluid Power System Interconnect Diagram



Electrical Systems Interconnect Diagram



Tether Fuse Calculations:

8 x Thrusters @ 120 W
2 x Raspberry Pi w/ Camera @ 5 W
5 x Borescopes @ 0.4 W
Ethernet Switch @ 6 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: 1059.31 W

Current = 1059.31 W / 48 V = 22.1 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	9/5/2020	9/18/2020
New Members Attend Info Sessions	9/5/2020	9/9/2020
First Electrical Design Phase (Board sizing)	9/5/2020	9/30/2020
First Mechanical Design Phase (General component designs)	9/5/2020	10/24/2020
First Software Design Phase	9/5/2020	2/15/2021
Second Electrical Design Phase (Finalize size)	10/1/2020	10/28/2020
Third Electrical Design Phase (Start layouts)	10/28/2020	11/25/2020
Third Mechanical Design Phase (Start mission-specific components)	10/26/2020	12/18/2020
Fourth Electrical Design Phase (Finalize all designs)	11/25/2020	1/8/2021
Boards Sent Out and printed	1/4/2021	1/18/2021
Select Competition Team	1/7/2021	12/1/2020
Machine Parts	1/7/2021	1/26/2021
Soldering	1/19/2021	2/5/2021
Assemble ROV	2/1/2021	2/9/2021
Register Competition Members	2/1/2021	2/16/2021
Electrical Integration and Testing	2/9/2021	2/13/2021
Second Software Design Phase (Iterations and new updates)	2/15/2021	5/21/2021
Full ROV Integration and Testing	2/15/2021	2/27/2021
Pool Tests and Qualifying Runs	3/1/2021	5/14/2021
Write Individual Sections of Tech Report	3/1/2021	2/28/2021
Compile Tech Report and Edit	5/12/2021	6/30/2021
Write and Edit Poster	6/16/2021	7/1/2021
Practice Presentation	7/1/2021	8/5/2021
Competition	8/5/2021	8/7/2021

-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

Sponsors

Gold Partner

College of Engineering

OFFICE OF THE PROVOST

School of Electrical and Computer Engineering

Silver Partner

Purdue Engineering Student Council

Bronze Partner

Proven Robotics Thanks

The Kleppinger Family and The Geyer Family
Parents and Family for advice and support
MATE Center for providing us this opportunity
Volunteers and Judges at the MATE Competition
Company alumni for their support throughout the year
All our employees for their hard work throughout the year
Purdue IEEE Student Branch for being a great parent organization
Launch Apartments, Home2Suites, and Hampton Inn for their pool use

E. References

1. "ALUMINUM BARE SHEET 6061 T6" ONLINEMETALS.COM. http://www.onlinemetals.com/merchantcfm?pid=1246&step=4&showunits=inches&id=76&top_cat=60.

2. Binder-USA. "09 3481 700 08 - Series 763: Male receptacle, front-mounted, M16x1.5, wire leads | Binder-USA." Binder USA. Accessed May 24, 2017. https://www.binder-usa.com/products/partsdetail/89312.

3. "Divinycell HCP 30" DIABGROUP.COM. http://www.diabgroup.com/en-GB/Products-and-services/Core- Material/Divinycell-HCP

4. I2SS - 2.00 mm Single Row Discrete Wire IDC System Cable Assembly Housing, Socket | Samtec. https://www. samtec.com/products/i2ss.

5. IPT1 - .100" Mini Mate® Isolated Power Connector Terminal Strip | Samtec. https://www.samtec.com/products/ ipt1.

6. MATE. EXPLORER Challenge. 2021. https://materovcompetition.org/explorerspecs

7. MATE. MATE ROV Competition Manual Explorer. 2021. https://files.materovcompetition.org/2021/2021_EXPLORER_Manual_10May2021.pdf

8. Murata Power Solutions. "DBE0125V2NBSC." https://power.murata.com/data/power/dbe-dve.pdf

9. Oceaneering. HSE Employee Handbook. 11-01-2013th ed. https://www.marinetech.org/files/marine/files/ ROV%20Competition/2015%20files/HSE_Handbook_number_3_As_of_11_19_2013_AW.pdf.

10. Parker O-ring handbook. Lexington, KY: Parker Seal Group, O-Ring Division, 2001.

11. "SubConn Micro Circular - 10, 12 and 16 contacts." MacArtney.com. https://www.macartney.com/what-we-offer/ systems-and-products/connectivity/subconn/subconn-micro-circular-series-subconn-micro-circular-10-12- and-16-contacts/.

12. "T200 Thruster." Blue Robotics. http://www.bluerobotics.com/store/thrusters/t200-thruster/.
"Melodic - ROS Wiki." Wiki.ros.org, Open Robotics, 14 Aug. 2018, wiki.ros.org/melodic. Accessed 28 June 2021.