2023-2024

TECHNICAL REPORT ROVOTICS

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Abstract

ROVOTICS is a sixteen-person company with over a decade of experience designing, manufacturing, and operating aquatic robotic solutions to ecological and industrial problems. This year, ROVOTICS presents its newest Remotely Operated Vehicle (ROV), *Orca*.

ROVOTICS values rigorous testing and continual improvement of our designs. *Orca* builds from ROVs designed over the past five years, utilizing time-proven technology. To meet dynamic market needs, *Orca* was designed to be easily adapted to any mission and task. This focus accelerated our tool development for MATE operations, increasing the time available to verify and validate the final product.

Documentation and communication are highly valued at our company. This technical report provides an overview of our design decisions and the process for developing Orca for the 2024 MATE ROV competition.

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Teamwork

Company Profile

ROVOTICS is a successful high school team dedicated to building ROVs aimed at maintaining Earth's resources and addressing environmental concerns, specifically climate change's impacts on oceans. The team, as well as MATE, uses the UN Decade of Ocean Science initiative as inspiration and guidance towards these goals. The team operates through three departments: Mechanical, Electrical, and Software, each led by a department lead responsible for managing assignments and priorities within their respective teams. The department leads play a vital role in determining department goals and assigning individual work tasks (see page 1 for specific member roles and responsibilities). In addition to the department leads, an integration lead supervises projects that involve heavy collaboration between departments. The Chief Executive Officer (CEO) is responsible for organizing the activities of the team and keeping track of objectives and progress made to achieve them. The CFO keeps track of the budget and spending. Lastly, the Safety Officer enforces protocols to ensure the safety of our team and the prevention of safety hazards during the operation of the ROV.

ROVOTICS places a strong emphasis on continuous learning and encourages cross-training among team members. Upperclassmen in each department take on the critical responsibility of mentoring and training underclassmen throughout the entire development process. This approach ensures that knowledge and lessons do not leave the team when members graduate.

Figure 1. ROVOTICS Team Members | ROVOTICS

JESUIT ROBOTICS

Project Schedule

ROVOTICS follows a three-phase timeline (Figure 2) which front-loads the ROV development, independent of the RFP (Request For Proposal) and mission specifications. Phase I encompasses the development of the Core-ROV, which includes all base components and software required for *Orca* to be remotely operated underwater with video feedback. The construction of the Core-ROV is performed by new team members referencing ROVOTICS design guides to provide an opportunity to learn about all of the components of the ROV through a hands-on build. Phase I concludes with the “Drive & See" test, which verifies that the Core-ROV has the basic requirements for functionality.

Phase II implements new improvements to the Core-ROV that do not relate to the mission spec, such as this year’s improved frame design, camera system, gripper, and software architecture.

Phase III begins when the RFP is released, and it consists of specialized tool development to meet mission specifications. Development closes with 50 dedicated project hours of comprehensive mission practice, validating the final ROV and preparing our crew for the product demonstration.

ROVOTICS employs a systematic engineering approach to guarantee consistent and reliable results throughout each development phase. This involves planning, prototyping, verification, integration, validation, and documentation to ensure the reliability and repeatability of ROV systems.

Resource, Procedure, & Protocol Management

ROVOTICS conducts weekly virtual meetings to discuss company-wide project progress and departmental updates. These gatherings serve as a platform for team members to share their weekly achievements and address resource and material requirements essential for maintaining project timelines.

To manage the overall project schedule, ROVOTICS utilizes a Plan-Do-Check-Act method

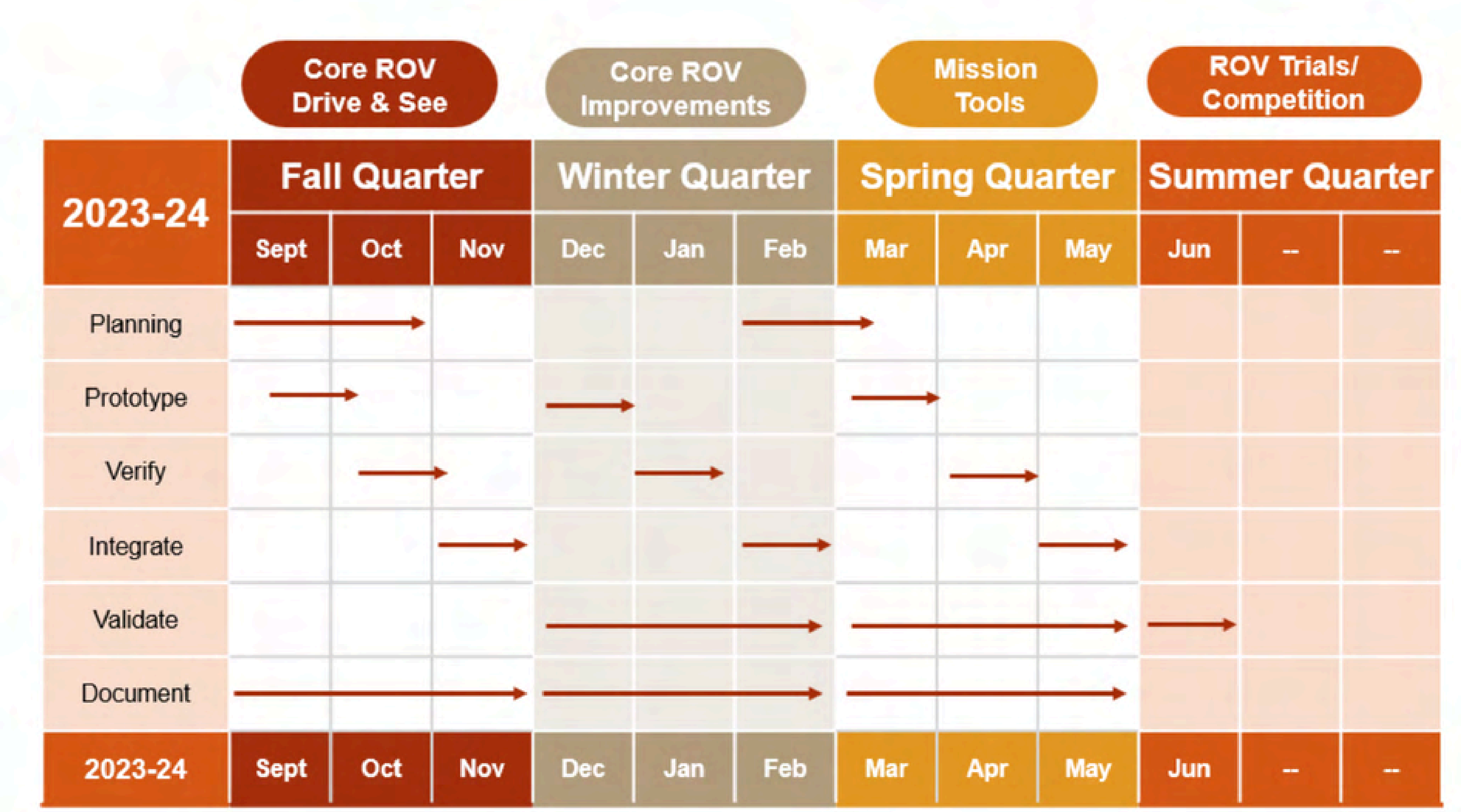


Figure 2. Project Schedule | ROVOTICS

with tools like Google Sheets and Kanban boards (Reference 1). This method ensures efficient resource allocation and focus alignment during day-to-day operations. Unlike traditional Gantt charts, this approach offers the advantage of quick task prioritization.

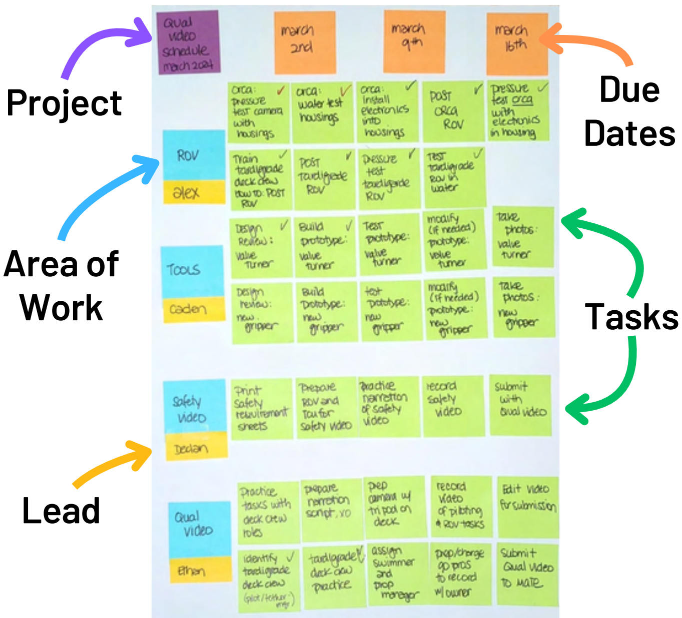


Figure 3. Kanban board | ROVOTICS

At the beginning and end of each workday, the team holds standup meetings, utilizing a project tracking board to review and adjust the schedule as needed. Through this interactive scheduling system, the team consistently meets project deadlines and remains aligned with scheduled development objectives.

Figure 3. ROVOTICS utilizing a Kanban board | ROVOTICS

Design Rationale

Engineering Design Rationale

ROVOTICS capitalizes on the successes of our previous ROVs to produce our current fifth-generation ROV, *Orca*.

Orca's overall design can be simplified into three primary systems: Mechanical, Electronics, and Software. The mechanical design includes the frame, waterproof enclosures for electronics, thruster placement, buoyancy, and tools such as grippers. The Electronics provide power for *Orca's* thrusters and, with the help of software, control the thrusters, stream video, and gather sensor data to allow the ROV to move as commanded by the pilot. Mission specific tools, sensors, and software expand *Orca*'s capabilities to include specialized tasks such as retrieving sediment samples, water temperature sampling, and the autonomous transplant of brain coral.

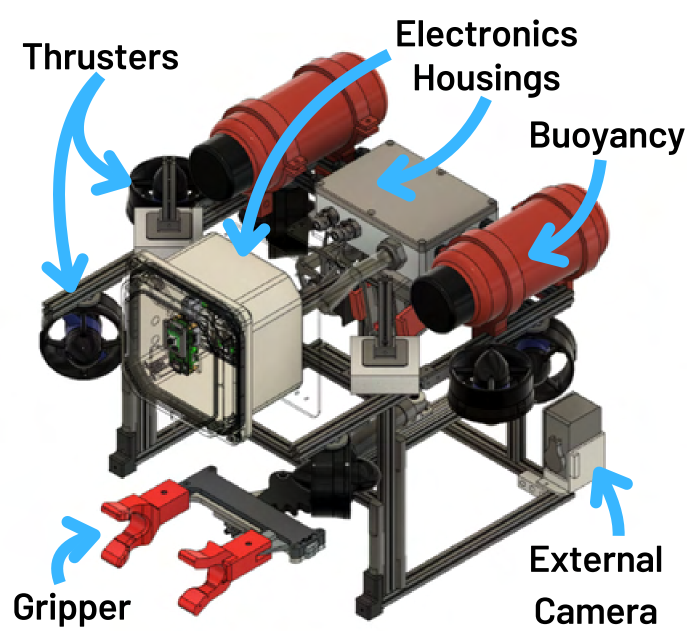


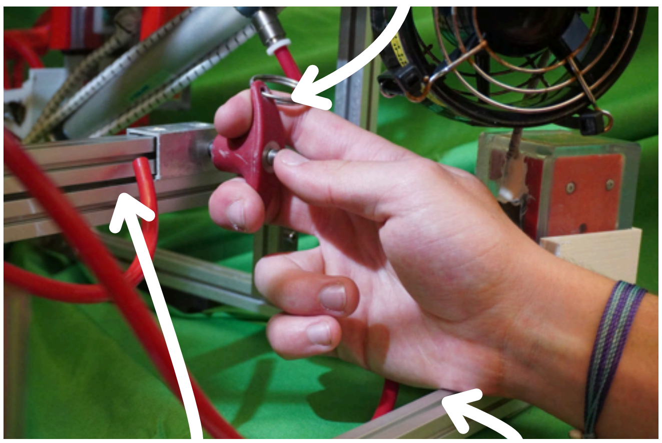
Figure 4. Complete ROV CAD | ROVOTICS

ROVOTICS' engineering design rationale is centered around using proven technology combined with a modular design approach to streamline system integration and development.

Designing core systems based off the success in previous ROVs, such as our modular frame design, avoids a full redesign, mitigating risk, and resulting in a more predictable development schedule.

A rigorous example of ROVOTICS' modular design philosophy can be found in the design of *Orca*'s frame. The frame, composed of 15 x 15 mm extruded aluminum, has T-slots that act as mounting rails, allowing frame segments and other components to be easily joined and adjusted. This modularity also enables tools to be mounted to nearly any point on the ROV. Additionally, through the use of quick-release pins, *Orca*'s tool payloads can be changed on the fly (Figure 5).

Quick Release Pin



Payload Being Released   T-Slot Frame

Figure 5. 15 x 15 Modular Frame Joints | ROVOTICS

These innovations accelerate prototyping and calibration of new designs, cutting development costs. In addition, because ROVOTICS has maintained the frame's modular standard, past ROVs can be used to test new designs, giving ROVOTICS a head start at each year's future development.

A modular design approach can limit high levels of specialization. However, focusing on modularity dramatically reduces overall development effort, leading to higher individual and holistic system performance with the limited resources available.

Design Process & Decisions

ROVOTICS employs a systematic design process that emphasizes using proven designs and industry-established practices. For instance, in the development of the CORE-ROV, designs from previous years are revisited and reviewed for what succeeded and what didn't. This facilitates the reuse of reliable systems while improving on previously discovered flaws, effectively reducing both development time and cost.

When reusing a prior system design is not an option, ROVOTICS follows a thorough brainstorming process that enables engineers to create innovative solutions. Design-decision matrices are used to guide choices and assess a product's efficacy in terms of its cost, manufacturability, and capability. Once evaluated, the design for iterative prototyping or final manufacturing is implemented.

For example, last year, the Profiling Float did not perform as expected at competition due to two fundamental flaws: a lack of stability and an overly complex drive mechanism. Because the previous year's design could not be leveraged, the new vs. reused decision was made and a new concept was built from the ground up. The team collectively brainstormed new ideas and, with the help of a design matrix (Figure 6), evaluated the trade-offs of different float designs.

Criteria	Weight (1-5)	Pump	Score	Syringe	Score	Inverted Syringe	Score
Battery Life	3	5	15	1	3	1	3
Cost	2	3	6	3	6	3	6
Length	3	4	12	2	6	1	3
Manufacturability & Simplicity	5	5	25	2	10	1	5
Reliability	5	4	20	4	20	4	20
Serviceability	4	5	20	3	12	2	8
Stability	4	4	16	2	8	4	16
Totals			114		65		61

Figure 6. Float Design Decision Matrix | ROVOTICS

It was concluded that a pump and bladder would best solve last year's complexity issues by reducing the number of moving parts. This change would also resolve the stability problems, moving the center of mass much lower and keeping the buoyancy engine on top, all in a smaller overall length (Figure 7).

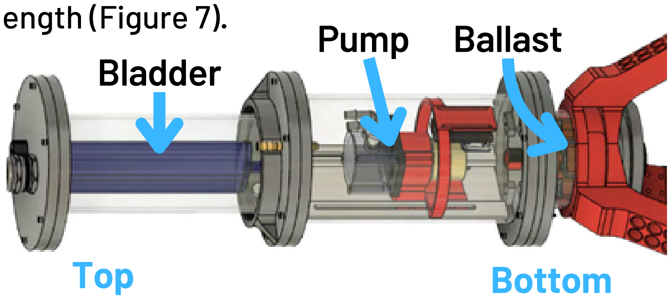


Figure 7. Bladder Buoyancy Engine | ROVOTICS

Problem Solving, Innovations

A prime example of ROVOTICS' ability to innovate and solve problems lies in the development of a tool to turn the Probiotic Sprinkler Stop Valve 360° (Figure 8). During development, ROVOTICS identified three design requirements. The first was to avoid using an electric motor due to the complex sealing process and the addition of enclosure penetration points, both of which would increase labor and the number of fault points within the system. Secondly, the tool must be time-efficient and easy for the pilot to use. Lastly, ROVOTICS wanted to minimize the tool's impact on the existing design to limit interference with existing functions.

ROVOTICS' members proposed three solutions during the brainstorming process. These solutions included a pneumatic-water turbine, a rack and pinion system driven by the front gripper, and a ratchet wrench driven by a pneumatic piston that incrementally rotates the valve as the piston contracts and expands. The front gripper-driven rack and pinion was not chosen as it would disable the use of *Orca*'s front gripper. The pneumatic-water turbine was identified as a viable option and was taken through prototyping.

During early testing, the design failed to generate significant torque and caused pressure loss to other pneumatic components such as the gripper.

The chosen design was the piston-driven ratchet. This design produced significant torque as the pneumatic piston directly rotates the valve. In addition, the pneumatic piston has been used in the gripper with great success, increasing the credibility of the design's reliability. The ratchet mechanism uses a corrosion-resistant ratchet wrench that is commercially available at low cost, in addition to the pneumatic components. Remaining components are 3D printed or purchased, reducing material and labor costs during manufacturing. The overall simple design limits points of failure, increasing reliability and easing maintenance. The piston-driven ratchet system went through a prototype phase to verify its functionality before the final design was created, tested, and integrated into the final ROV for validation.

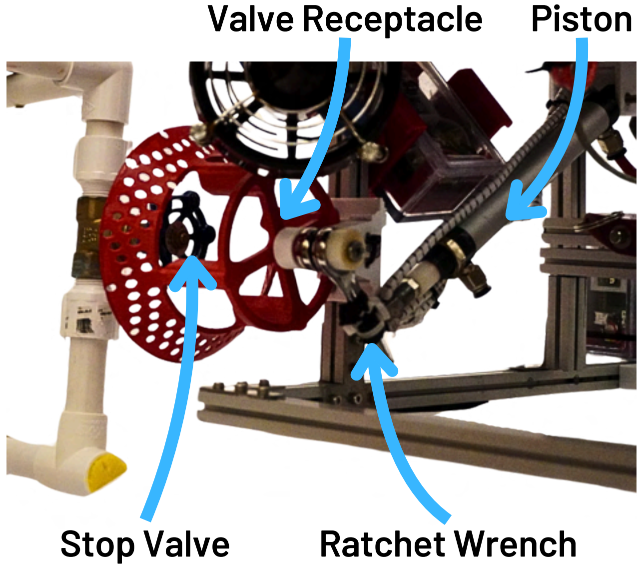


Figure 8. Ratchet-Piston Stop Valve Turner | ROVOTICS

The innovative design of the piston-driven ratchet provided a significant increase in reliability and performance compared to previous mechanisms, while simultaneously reducing the costs of manufacturing by an equal margin.

Systems Approach

The CORE-ROV, produced in Phase I of the development schedule, includes all core Drive-and-See systems such as the frame, propulsion, buoyancy modules, and cameras. This approach builds a reliable starting point for subsequent mission-specific modifications and enhancements. Through evolution and reuse, successful designs of core systems can be relied upon, allowing team members to dedicate more time to producing new innovative mission tools. ROVOTICS emphasizes reliance on the designs of ROV systems that have proven reliable in the past, such as *Orca's* thrusters, which are discussed in the "Propulsion" section of this document.

Conceptualizing the ROV as a combination of systems allows for greater modularity in tool design. The multipurpose gripper, which performs a variety of tasks, can be orientated and augmented with different attachments to meet specific needs (Figure 9).

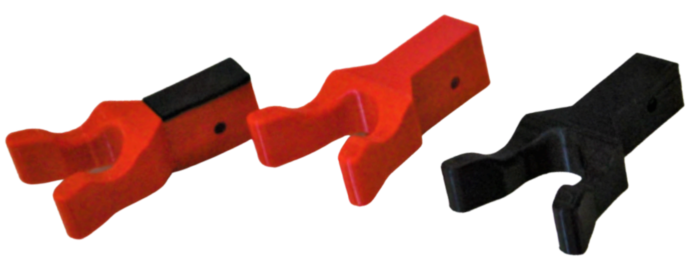


Figure 9. Different Gripper Finger Attachments | Jesuit ROVOTICS

This philosophy of prioritizing multi-purpose tools allows for the most tasks completed with the least amount of development time.

This approach also means that ROV systems can be tested independently. For example, the new ROS2 software stack allows all different software subsystems to be operated independently, meaning that the thruster system can be tested before the completion of ROV sensors.

Vehicle Structure & Systems

Orca's Vehicle Structure consists of a lightweight aluminum extrusion frame. ROVOTICS relies on 15x15mm aluminum extrusion because of its excellent balance of strength, size, and weight relative to other extrusions. Although larger extrusions like 20x20mm provide greater mechanical strength, ROVOTICS determined that the excess strength was unnecessary. Brackets and screws allow for the extrusion to be rapidly reconfigured, making *Orca*'s frame able to adapt to changing development needs. ROVOTICS efficiently cuts the extrusions to the proper lengths in a way that produces the least possible amount of waste, which reduces costs as the remaining material can be reused in future frames.

Orca's electrical system is split into two enclosures. Control electronics are housed in the easy to access Main Electronics Housing (MEH), while all high-power electronics are housed in the aluminum Power Systems Enclosure (PSE). The PSE (Figure 10) doubles as a heat exchanger, transferring thermal energy from the voltage converters and Electronic Speed Controller (ESCs) to *Orca*'s aquatic environment. ROVOTICS made the **tradeoff** to value the PSE's thermal properties at the downside of manufacturability, as aluminum is challenging for ROVOTICS to machine.

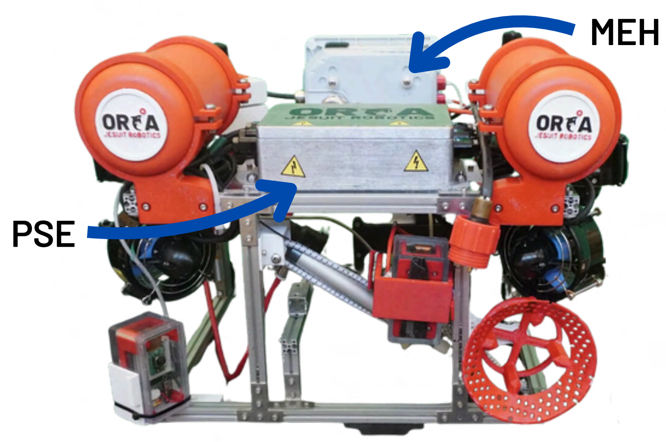


Figure 10. Rear View of Orca | ROVOTICS

This was overcome by making the Build vs. Buy decision to purchase a Commercial Off the Shelf (COTS) enclosure and machine in-house the additional features required. The MEH and PSE are connected with a clear tube which allows power and data passthrough between the two enclosures.

This year, to minimize unwanted pitch and roll during movement caused by a high center of drag, the MEH was mounted lower so the *Orca*'s center of drag would more closely align with its center of thrust. This also lessened *Orca*'s physical footprint, making it easier to maneuver, service, and transport for MATE missions. Relative to the ROV, buoyant housings are mounted at the top, and weighted ballast is mounted at the bottom to create inherent stability.

Control/Electrical Systems

The control system of *Orca* is composed of two main subsystems: Topside, responsible for surface control and pilot interface; and Bottomside, which governs all electronics and control systems within the ROV. *Orca*'s control architecture is structured around the Robot Operating System (ROS), which facilitates data and command exchange among the different parts of *Orca*'s control system. ROS acts as a software layer bridging hardware and application software, on which modular units called nodes can run individual control functions and communicate through the ROS network. Previously, ROS1 was used. However, due to its End of Life (EOL) status, and to provide a significantly more modular software stack, the framework was upgraded to ROS2.

ROS2 is at the leading edge of industry software standards with substantial improvements in dependency management over ROS1, where different nodes rely on each other. This contributed greatly to overall system stability and resilience while easing troubleshooting and development.

The new ROS2 software stack, called the CORE-System, is much more fault-tolerant than previous years. With ROS1, if a program on Topside crashed, Bottomside operation was disabled. Now with ROS2, software systems can be launched independently of each other, and should one system fail, others can continue operation.

The topside software handles pilot input and communicates it to bottomside. Bottomside runs on the Raspberry Pi (RPi) in the MEH, and it is responsible for controlling thrusters, cameras, and sensors. Figure 11 shown below displays Orca's control system flow.

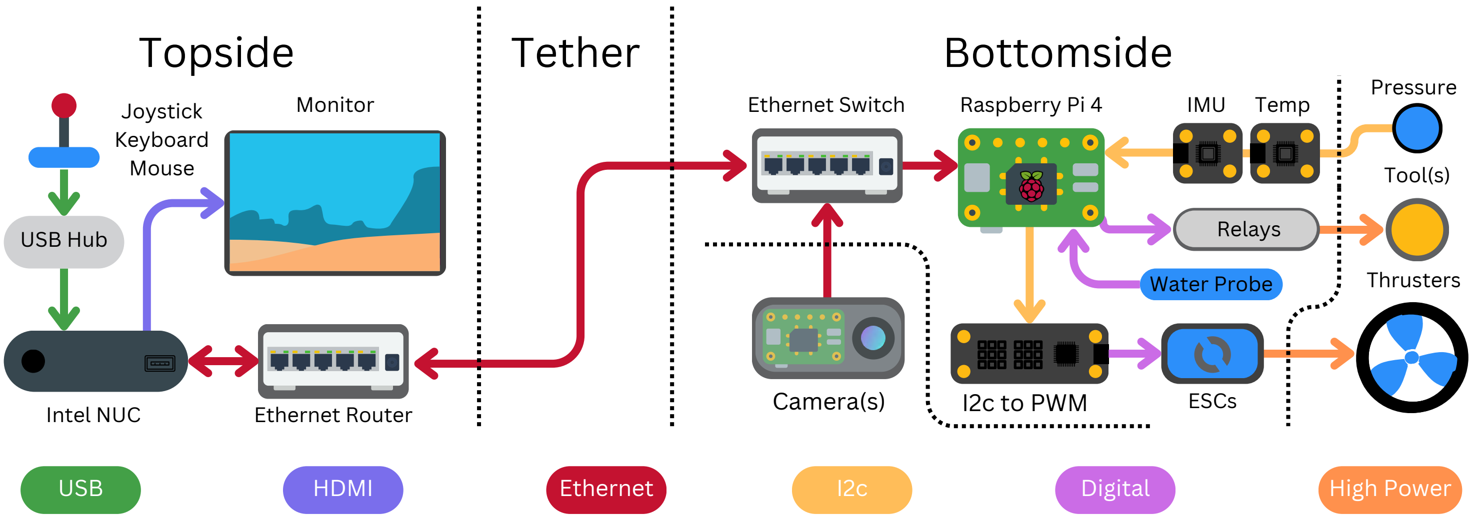


Figure 11. Control System Flow | ROVOTICS

Bottomside Control Electronics

Within the ROV's Main Electronic Housing, a Raspberry Pi 4 runs *Orca*'s control processes. A custom Raspberry Pi HAT (hardware attached on top), extends the General Purpose Input/Output (GPIO) native on the Pi. Connected to the HAT is a pressure sensor to measure ROV depth, a 9-axis IMU (Inertial Measurement Unit) to assist in orientation control, and water probes for leak detection. An eight-port ethernet switch connects the Raspberry Pi and *Orca*'s cameras through the tether to surface control.

Power Conversion & Thruster Control

ROVOTICS designed and manufactured a custom Printed Circuit Board (PCB) called the Power Board (Figure 12) to convert the 48V supply to lower voltages for use by *Orca*. It features two voltage converters which provide 12V at 100A for thruster and tool use, alongside another converter which provides 5V for the Raspberry Pi 4, tools, cameras, and ethernet switch. For safety, all converters have overvoltage, undervoltage, overtemperature, and overcurrent (short-circuit) protection. Blue Robotics ESCs are mounted to custom adaptor plates that allow for plug-and-play mounting, with low profile clearances to fit within the enclosure (Figure 12). Communication to the thrusters is facilitated by a custom PWM (pulse width modulation) board connected to the Raspberry Pi.

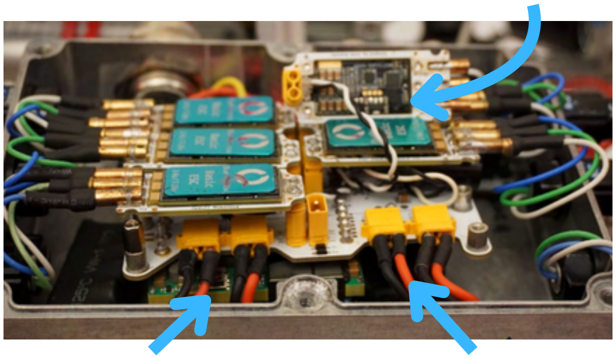


Figure 12. Power Board | ROVOTICS

Vision System

Low latency video feed and high-quality images are crucial to the accurate navigation of *Orca* and operation of mission tools. *Orca* is fitted with three cameras (Figures 13), one dedicated to navigation and two external cameras for mission-specific tools. External cameras require a single penetration as data and power each use the two pairs of a standard Cat 6a ethernet cable. Housed within each watertight enclosure is a Raspberry Pi Zero 2W computer, a Raspberry Pi V3 camera sensor, and an ethernet expansion board. The Raspberry Pi Zero uses open-source Linux shell tools to stream video at 60 frames per second with 1440p x 810p resolution and a minimal 100 ms of latency (Reference 2). This year's design decisions increased pixel throughput by 150% compared to the prior year*, enhancing *Orca*'s digital image processing capabilities necessary for tasks like the Coral Restoration Modeling.

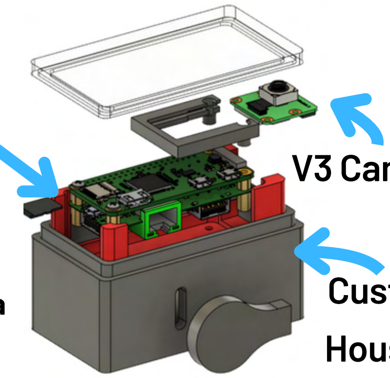


Figure 13. External Camera ROVOTICS

ROVOTICS made a build vs buy decision with the camera components by purchasing items that meet design requirements if the choice is reasonable in terms of performance and cost. The electronic components for the cameras were beyond ROVOTICS' manufacturing capabilities, so they were purchased, as commercial options performed suitably at reasonable prices. Desired camera housings were not available commercially, so ROVOTICS manufactured those components in-house.

$$^{*}\frac{1440p*810p*60fps = 69{,}984{,}000}{1280p*720p*30fps = 27{,}648{,}000} = 2.53.. \rightarrow \textbf{150\% increase}$$

Topside / Surface Control

All primary surface control systems are housed in the compact Topside Control Unit (TCU) (Figure 14). The TCU contains a powerful desktop computer and a monitor set into the lid, enabling operators to view the ROV's camera and control it using the Graphical User Interface (GUI). The TCU also features bulkhead connectors for USB, ethernet, power, and pneumatics. Strain relief attachment points ensure a sturdy connection between the Tether and TCU.

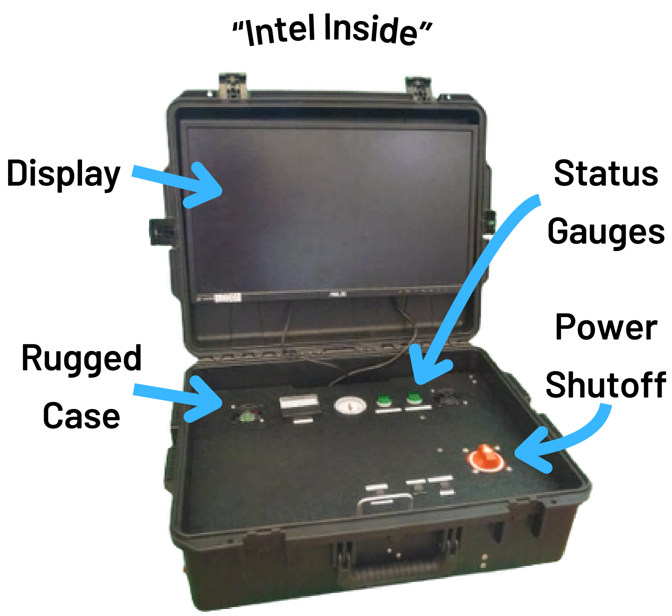


Figure 14. Topside Control Unit | ROVOTICS

This year, ROVOTICS added a new feature that allows the pneumatic solenoids, used to activate the gripper, to be controlled from the pilot's joystick. Previously, the pilot had to communicate to the copilot to open the grippers. This change increases the degree to which the pilot can quickly control and embody the ROV. The copilot's physical switches are still present as a failsafe in case there is an error with the software or relay switch.

TCU safety features include current and voltage meters which monitor ROV and TCU power supply conditions, a pneumatic pressure regulator and relief valve, and a highly visible main shut-off power switch.

Tether Design

ROVOTICS' tether is designed to offer reliable electrical power, compressed air, data transmission, and a physical connection to the ROV—all with nearly unrestricted movement. The tether length of 15m was determined by digitally modeling the required in-water tether reach (Figure 15) and adding it to the necessary surface length based on the MATE operating specifications outlined in the RFP. In order to prevent the tether from disturbing the environment or obstructing operation, buoyancy devices are attached along the tether.

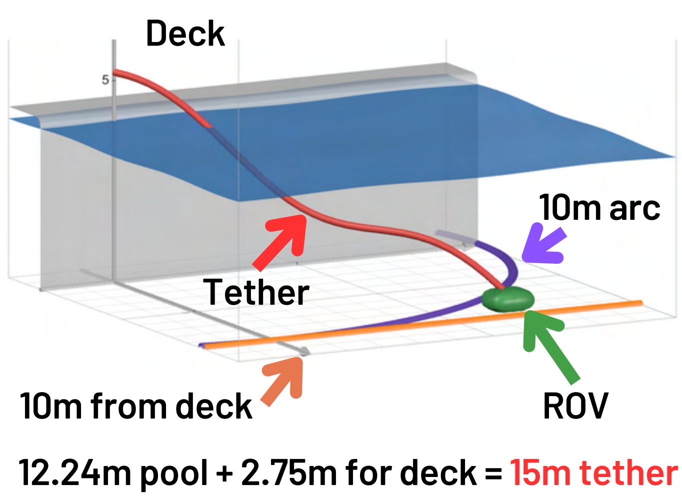


Figure 15. Tether Reach Disgital Model | ROVOTICS

To ensure safety during ROV operation, all lines are protected within a flexible and brightly-colored sheathing that greatly enhances visibility. Data is transmitted at gigabit speeds between surface control and the ROV via a Cat 6A Ethernet cable. Power is transmitted to the ROV through a pair of low-resistance 12 AWG wires that were selected after analysis of flexibility and power stability under heavy current loads.

With the 15m required length of the tether and the proposed use of 12AWG wire, the voltage drop and total power requirements of the ROV were calculated (Appendix A). It was verified that for this length of 12 AWG wire, the power budget would not be exceeded due to the cable's low resistance properties.

Pneumatic lines were chosen to maximize airflow and flexibility while adhering to the safety specifications provided by MATE. One pneumatic line is dedicated to the horizontal gripper, while the second line is shared with the vertical gripper and valve turning tool.

Tether Management Protocol

ROVOTICS' Tether Management Protocol (Figure 16) spans pre, post, and operational phases, and represents the culmination of over a decade of experience, prioritizing crew safety, mission effectiveness, and practical implementation.

Figure 16. Tether Management | ROVOTICS

Before operations, the tether is inspected for damage and wear. Tether management is handled by the tether manager, who is responsible for the proper deployment, tensioning, and stowing of the ROV's tether. At the beginning of a mission, the tether manager calls for all non-essential personnel to leave the deck. The tether manager then removes the tether from its carry bag, uncoils the tether, and lays it out on the deck with one end facing the TCU and the other end facing the ROV. The tether is connected to the TCU first, beginning with the strain relief connection, followed by the power, ethernet, and finally, the pneumatics line. The tether is then connected to the ROV, proceeding in the same order as the TCU connection. When the ROV is deployed, two deck crew members lower the ROV into the water using strain relief and hardpoints on the ROV. During *Orca* operation, the tether manager has constant contact with the tether and ensures a proper amount of slack is provided so as not to inhibit ROV movement. Upon the completion of the mission and the shut down of the ROV, the tether manager disconnects the tether from the ROV, detaching the strain relief last. Then they disconnect the tether from the TCU, again leaving the strain relief to the last step. Once the tether has been completely detached, the tether manager coils the tether and places it back in the carry bag. The tether manager coils the tether by alternating the winding of every other loop in an overhand, underhand manner, which prevents damage to the tether seen in continuous winding and helps with storage.

Propulsion

Orca's propulsion is implemented with six Blue Robotics T100 thrusters. The choice of thruster was initially narrowed by market research to the highly reliable Blue Robotics T100 and T200 thrusters. Additional tradeoff analysis led to the final choice of the T100 thruster for three primary reasons: First, the T100 thruster has been used by ROVOTICS for the past seven years, so previous thruster stock could be reused to reduce company expenses. Second, the T200 has a higher possible power draw at 12V than the T100, meaning a thruster stall could cause loads that exceed the available power, triggering

ROV shutdown. Lastly, although the T200 thruster can produce more thrust than the T100 thruster at a similar power draw (Figure 17) (References 3 & 4), the excess available thrust has negligible impact on mission performance as the majority of piloting time is spent in fine motion.

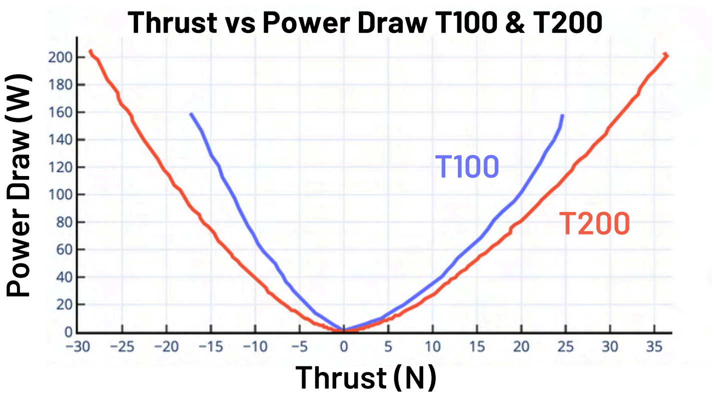


Figure 17. T100 vs T200 Performance | ROVOTICS

For these reasons, ROVOTICS made the **new vs. reused** decision to use T100 thrusters rather than purchasing new T200s for *Orca*. To further ensure the safety of operators, all thrusters have metal thruster guards to prevent intrusion of mission props and operator digits.

To allow for full lateral and rotational motion, four thrusters are mounted at 45° angles on the corners of the ROV frame. The remaining two thrusters are mounted vertically on either side of the ROV's frame for ascent and descent (Appendix D). This thruster layout minimizes thruster wash onto mission props and uses only six thrusters, reducing *Orca*'s power consumption and BOM cost.

Buoyancy & Ballast

Orca weighs 13.5 kilograms. Using Archimedes' Principle, it was calculated that 27.7 newtons of buoyant force (Appendix B) were required to make the ROV neutrally buoyant. To effectively meet this need, the buoyancy system (Figure 18) was divided into two categories: static and modular.

The static buoyancy system provides the majority of *Orca*'s buoyant force. It is composed of two incompressible stainless steel nacelles, along with the MEH and PSE housings.

The modular aspect of the buoyancy system is used for fine adjustments. Squares of hydrostatic foam can be stacked at different points on the ROV to balance pitch and yaw. The foam units are simply added or removed to make adjustments, accommodating changes to *Orca*'s payload configuration during mission runs.

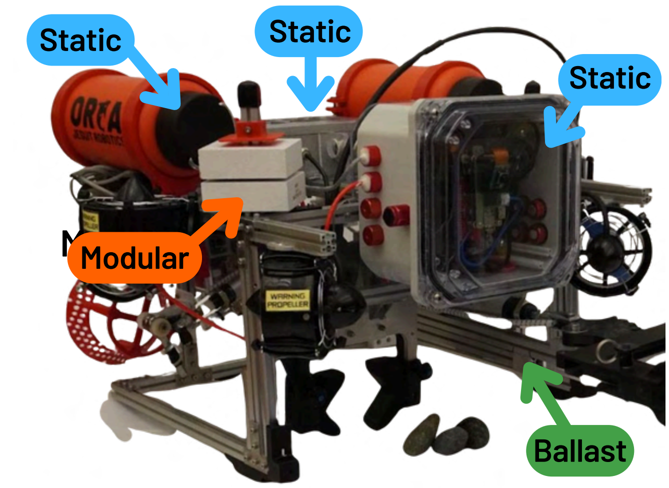


Figure 18. Static and Modular Buoyancy | ROVOTICS

In order to improve manufacturability and facilitate rapid design iterations, additive manufacturing was leveraged during the prototyping stage and production of the new buoyancy system. 3D printed brackets integrate directly into *Orca*'s modular frame for all buoyancy device mounting.

To ensure a stable ROV orientation, the center of buoyancy is placed above the center of gravity by locating buoyant devices at the top of the ROV and ballast at the bottom.

Payload & Tools

Orca is equipped with various tools, such as two multipurpose grippers, a mechanism to activate the probiotic irrigation system, and an autonomous control program for transplanting brain coral. To give the pilot optimal viewing angles when operating these tools, three cameras are placed throughout the ROV. The navigation camera located in the MEH allows the pilot to see the front gripper, and it is in the optimal position for controlling the ROV due to its position on the front center of the ROV. The under-view camera allows for viewing of the lower gripper and objects on the seafloor. The camera located out of the back is used for viewing the valve turner so the pilot can easily see where they need to navigate to successfully complete the task. These placements have been proven to work in previous years' ROVs, and they were verified through mission practice to be in ideal positions allowing the pilot to have the best viewing angles for the tasks at hand.

The ROV is also equipped with a modular sensor array, including a 9-axis Inertial Measurement Unit (IMU), a depth sensor, a leak probe, and an external temperature sensor. ROVOTICS carefully considers sensor placement when designing the ROV. For example, the external temperature sensor is located out in front of the ROV, on the gripper. The external sensor is used to validate the temperature readings of the SMART Cables serviced by the ROV, and placing the sensor on the gripper means the pilot can easily position the sensor as close to the cable as possible.

Multipurpose Grippers

The multipurpose gripper was specifically designed with modularity as the primary inspiration. Utilizing quick-release fingers (Figure 19) allows the gripper to be specialized for any task at hand. The quick removal and installation of the specialized fingers enable a single manufactured part to fulfill multiple tasks, resulting in cost reduction and improved efficiency for the deck crew. Two grippers are placed on the ROV, one vertical and one horizontal, to provide the best angles for manipulating anything, making them the most versatile tools. They are used to deploy SMART cables and repeaters that collect critical data such as temperature, pressure, and seismic acceleration data for better understanding of the oceans. The grippers can also retrieve sediments from sturgeon spawning sites, deploy the float, place probiotic irrigation systems helping heal diseased coral, recover acoustic receivers to monitor marine life, and more.

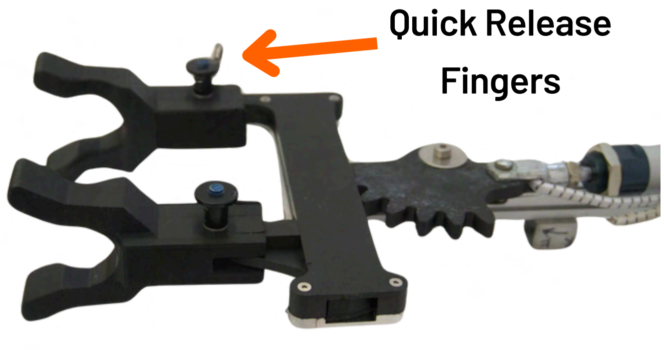


Figure 19. Gripper | ROVOTICS

This year, ROVOTICS dedicated time to greatly improve the manufacturability of the gripper by simplifying the number and complexity of the parts, as well as using new methods of manufacturing. This allows the gripper to be manufactured much quicker as fewer parts needed to be machined, and the parts themselves were produced faster with the use of carbon-fiber infused 3d printer filament and simplified designs for machined parts.

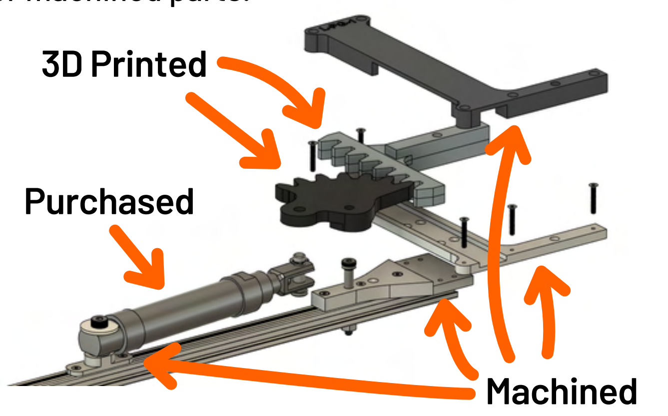


Figure 20. Gripper CAD Exploded View | ROVOTICS

Sediment Retrieval Tool

The Sediment Retrieval Tool is an example of the quick-release gripper fingers, which are attached to the vertical gripper. These are used to collect sediments from a potential spawning site of sturgeons with care and precision while still being effective for many other tasks. The shape of the fingers was carefully designed to capture the rock samples (Figure 21) in an efficient and controlled manner. Furthermore, these versatile fingers can deploy both probiotic irrigation systems, situate Acoustic Doppler Current Profilers to help monitor marine life, and install smart cables and receivers that collect data to better understand oceans' patterns.

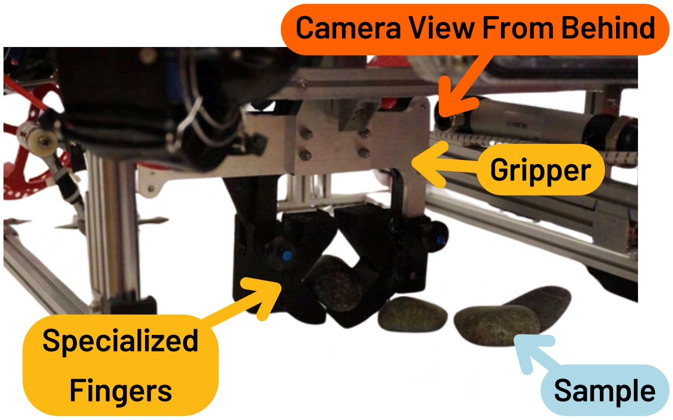


Figure 21. Sediment Retrieval Tool | ROVOTICS

Valve Turner

In order to activate the irrigation system, a tool was developed (see figure 22) that consists of two ratchet wrenches, a pneumatic piston, and a custom socket mechanism for securely grabbing the activation valve. The pneumatic piston has a fixed mounting position on one side, and the other side is connected to a ratchet wrench which is attached to the valve socket. Every activation of the pneumatics allows for a 60-degree rotation of the valve turning socket. The other ratchet wrench is used to prevent the tool from back-spinning when the pneumatic piston retracts, and this process is repeated to complete a full rotation, successfully releasing the probiotics to heal the diseased coral to assist in keeping the ecosystem healthy.

By using the same pneumatic piston that ROVOTICS has previously used for many grippers, the reliability of the tool is ensured. The pneumatic pistons have proven to be effective when used underwater, even without waterproofing. This piston is connected in parallel to the bottom gripper piston, so it will activate when the gripper is closed, and vice versa, to reduce the number of solenoids and improve simplicity. Additionally, using a pneumatic piston allows the tool to generate high torque.

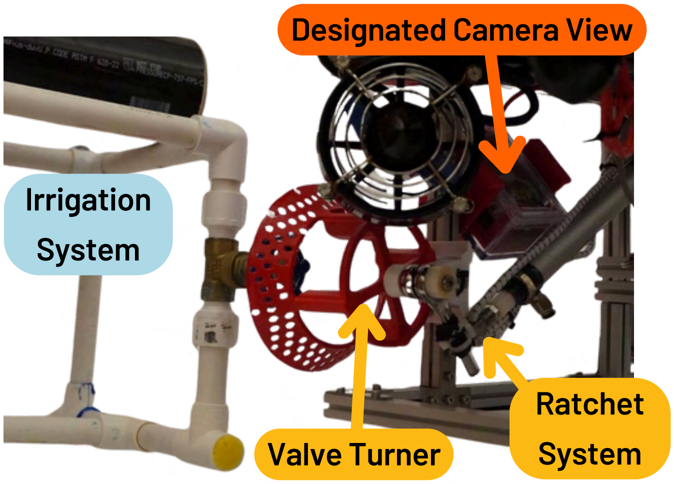


Figure 22. Valve Turner | ROVOTICS

Autonomous Transplant Program

Orca's autonomous control program allows the ROV to be self-piloted without the need for human intervention by giving directions to the ROV to transplant a piece of brain coral to a coral restoration area. Before the program begins, the pilot positions the ROV directly above the starting platform and retrieves the brain coral using the gripper. The pilot then activates the program, making the ROV autonomous where it ascends until it identifies the landing platform using a color filter. Next, it moves toward the landing platform while PID controllers stabilize the movement of the ROV, adjusting the thrusters' power to prevent overshooting until the platform is located in the center of the camera frame. Once this has been accomplished, the ROV descends, approximating the distance from the target with the depth sensor until it is ready to release the brain coral. Afterward, control is returned to the pilot, and the program exits gracefully.

Float

This year's float, P.O.D (Peristaltic Ocean Device) (Figure 23) underwent a complete redesign, featuring a peristaltic pump. Using a peristaltic pump in the buoyancy engine reduces the overall float size by 50% and contributes to a much lower power usage, allowing a longer profiling period. The electronics and batteries were repositioned closer to the bottom for increased stability. In addition, flanges and screws were used to fasten and seal the compartments to make the float more serviceable. Advancements in communication include a transition to LoRa (Long Range), an industrially-accepted wireless solution for command, control, and communication, delivering ultra low power consumption and reliability in harsh environments. The introduction of a depth sensor for capturing pressure data over time helps collect more data for scientists to monitor and predict the effects of climate change, making P.O.D the ROVOTICS' most functional Float yet.

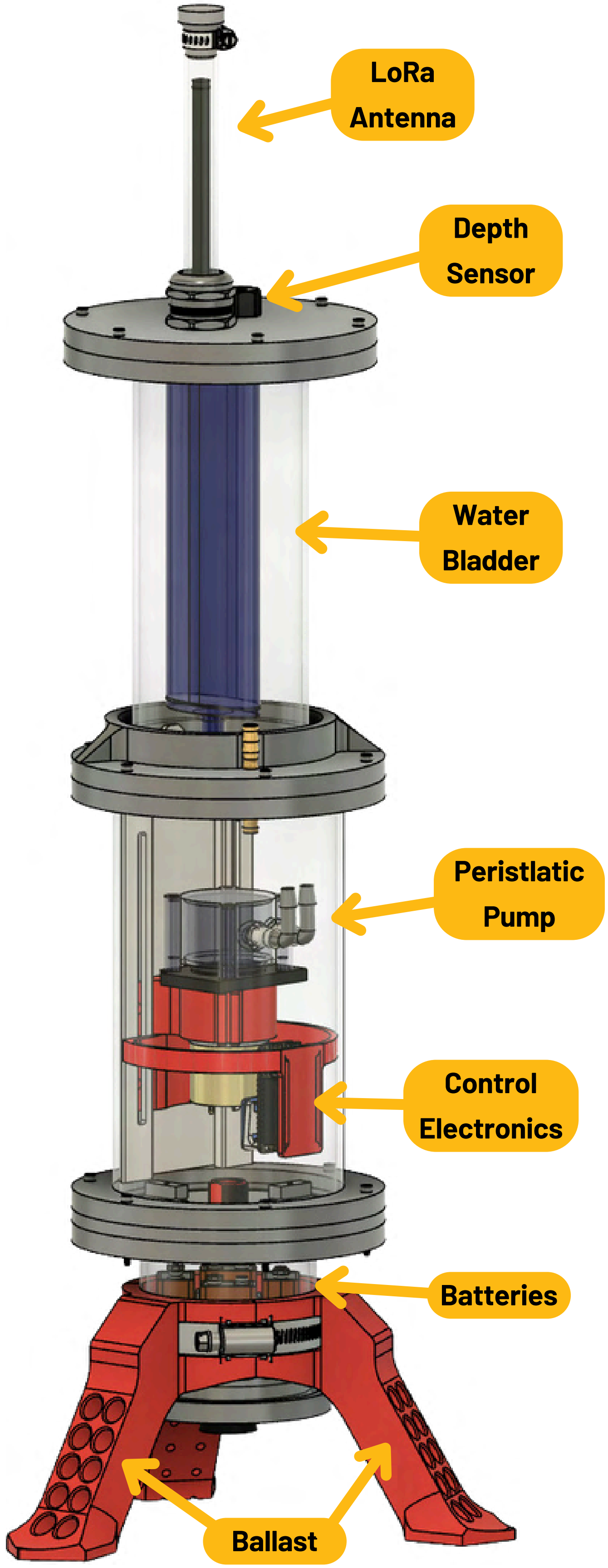


Figure 23. Peristaltic Ocean Device | ROVOTICS

Safety

Ensuring safety is a crucial aspect of ROVOTICS' work, both in building ROVs and during equipment operations and handling of ROVs. We understand that the right tools in the hands of competent employees create quality products, but we also realize that improper use of equipment can create serious consequences for operators. Therefore, everyone is required to adhere to operational procedures. These include the utilization of safety checklists, personal protective equipment (PPE), and a certification process in which a senior member demonstrates proper tool usage.

Furthermore, the use of appropriate personal protective equipment is mandatory. One particular risk ROVOTICS has identified is the use of computer numerically controlled (CNC) milling machines as their fast-moving sharp spindles can pose safety concerns to operators by launching small metal material into their eyes. Therefore, ROVOTICS requires that members adhere to strict procedures and ensures safety through training, supervision, and, of course, safety glasses and other PPE. For mission purposes, ROVOTICS has developed a scripted communication protocol to enhance further operational safety. For example, the deck crew calls the co-pilot to enable or disable tools and systems so the tether crew knows when it's safe to grab the ROV. Following the guidelines for fluid and power safety provided by MATE, our grippers are equipped with safety features, such as a shielded gear case and surface padding to reduce trapping or crushing accidents caused by pneumatic and hydraulic systems, protecting the operator and wildlife.

Critical Analysis

Testing

At ROVOTICS, we rigorously test individual components before integration into the complete ROV system. We use an industry-accepted verification and validation (Figure 24) process to ensure the quality and dependability of our product. Verification ensures each subsystem and component performs its function properly, while validation ensures *Orca* adequately meets the customer requirements outlined in the Mate mission specifications. Multiple stages of testing ensure safe development and efficient integration into the final ROV.

Each design department operates unique testing environments to ensure individual component verification. A prime example is how the software department implemented its new ROS2 software architecture. The transition to ROS2 was facilitated by a fleet of portable test benches (figure 25), which enabled software team members to verify that their code

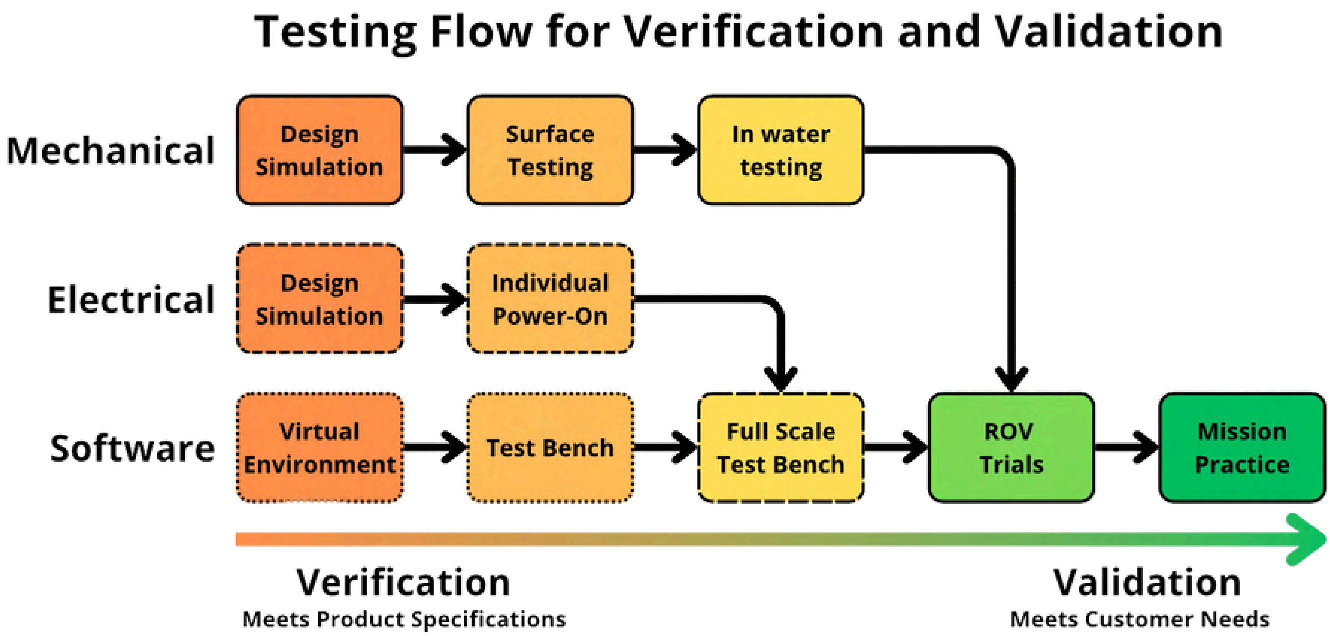


Figure 24. Testing Workflow | ROVOTICS

worked on Orca-equivalent hardware months in advance of Orca's "drive and see" configuration. This included hardware-specific functionality like camera streaming, sensor reading, and even thruster control. Once Orca's Core-ROV verification was completed, the ROS2 upgrade was implemented onto the ROV hardware. In-water ROV trials validated Orca met core requirements for the MATE mission specifications.

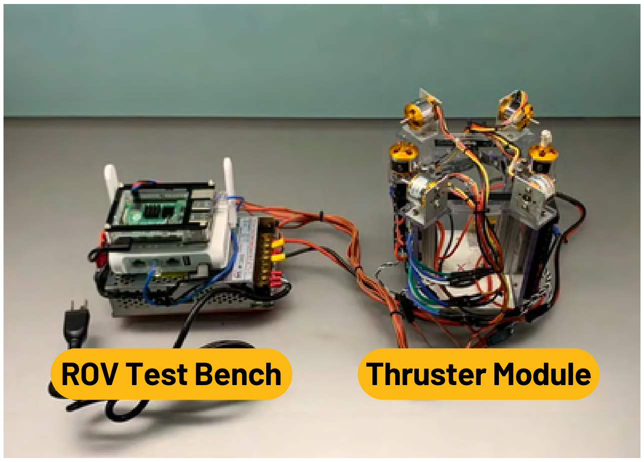


Figure 25. Thruster Testing Hardware | ROVOTICS

Troubleshooting

ROVOTICS' troubleshooting strategy prioritizes data-driven analysis to solve technical challenges. Preliminary information is first collected to contextually understand what the manifesting problem is. Hypotheses are created about the cause of the issue. Tests gather data concerning the hypothesis, then analysis of the data leads to the adjustment or creation of a new hypothesis. This process is continued until a viable solution can be created and tested.

For example, during validation, unexpected ROV behavior involving thruster shut-off and thrust imbalance was discovered. An initial hypothesis was created: the power rail for the thrusters was shutting down during rapid thrust change. The issue was replicated on full-scale testing hardware in the Jesuit Robotics lab, allowing key test points to be probed and quality data to be gathered. To increase accuracy, multiple sets of verified hardware were tested. Data collection and analysis confirmed that the power rail was shutting down during rapid thrust change, specifically when crossing between positive and negative thrust. This led to a second data-driven hypothesis: rapidly changing the thruster throttle caused motor instability, creating the aforementioned power rail instability, leading to shutdown. External research helped confirm this hypothesis (Reference 5).

Two solutions to the hypothesized causes were developed. The first solution was to limit the rate of change of thruster throttle to a safe value. The second solution was to further stabilize the power rail through the addition of capacitors. Both designs were individually and simultaneously tested with positive results on the simulated tub environment (Figure 26). Validation of the implemented solutions in ROV trials confirmed the problem had been solved. Data-driven analysis accelerated the troubleshooting process and allowed the problem to be attacked from multiple facets, leading to a better overall solution.

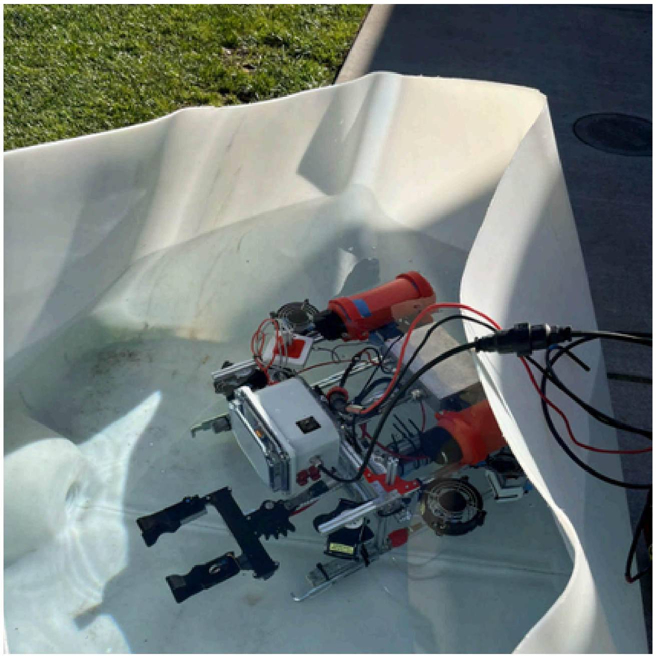


Figure 26. ROV in Testing Environment | ROVOTICS

Budget & Accounting

ROVOTICS creates a budget (Appendix E) at the start of each season, which includes estimated expenses. This was determined by considering the actual costs from the previous year. This year, forecasting the budget included subsystem BOM (bill of materials) cost data and actual project costs from last season's ROV. By using a standard ROV-based design, ROVOTICS focused on estimating costs for ROV enhancements and tools.

Expenses related to employee transportation and competition meals are estimated separately. ROVOTICS employees are responsible for covering these costs.

The estimated income for ROVOTICS is based on funding from Jesuit High School, donations, and employee dues. To ensure that the projected budget is followed, the company submits purchase requests for review and approval by a coach. All purchase receipts are tracked in a project costing sheet, which undergoes monthly review. The 2023-2024 Project Costing report can be found in Appendix E.

Acknowledgements

MATE Center and Marine Technology Society - Sponsoring this year's competition

National Science Foundation - Their funding of the MATE competition

Oceaneering International - Their support of the MATE competition

Jesuit High School - Generous donation of funding and pool time

Jay Isaacs, Head Coach - His time, creativity, knowledge, and guidance for the past seventeen years

Cheryl Kiyama, Program Director - Her time, experience, and guidance of the team

Steve Kiyama, Assistant Coach - His time, experience, and guidance for the team

Michael Sharp, Assistant Coach - His time, experience, and guidance for the team

Mentors: Marcus Grindstaff, Kevin Miyashiro, Mark Monroe - Their support for the team

Bulgin - Their generous donation of connectors

MacArtney Connectors - Providing connectors at a reduced rate

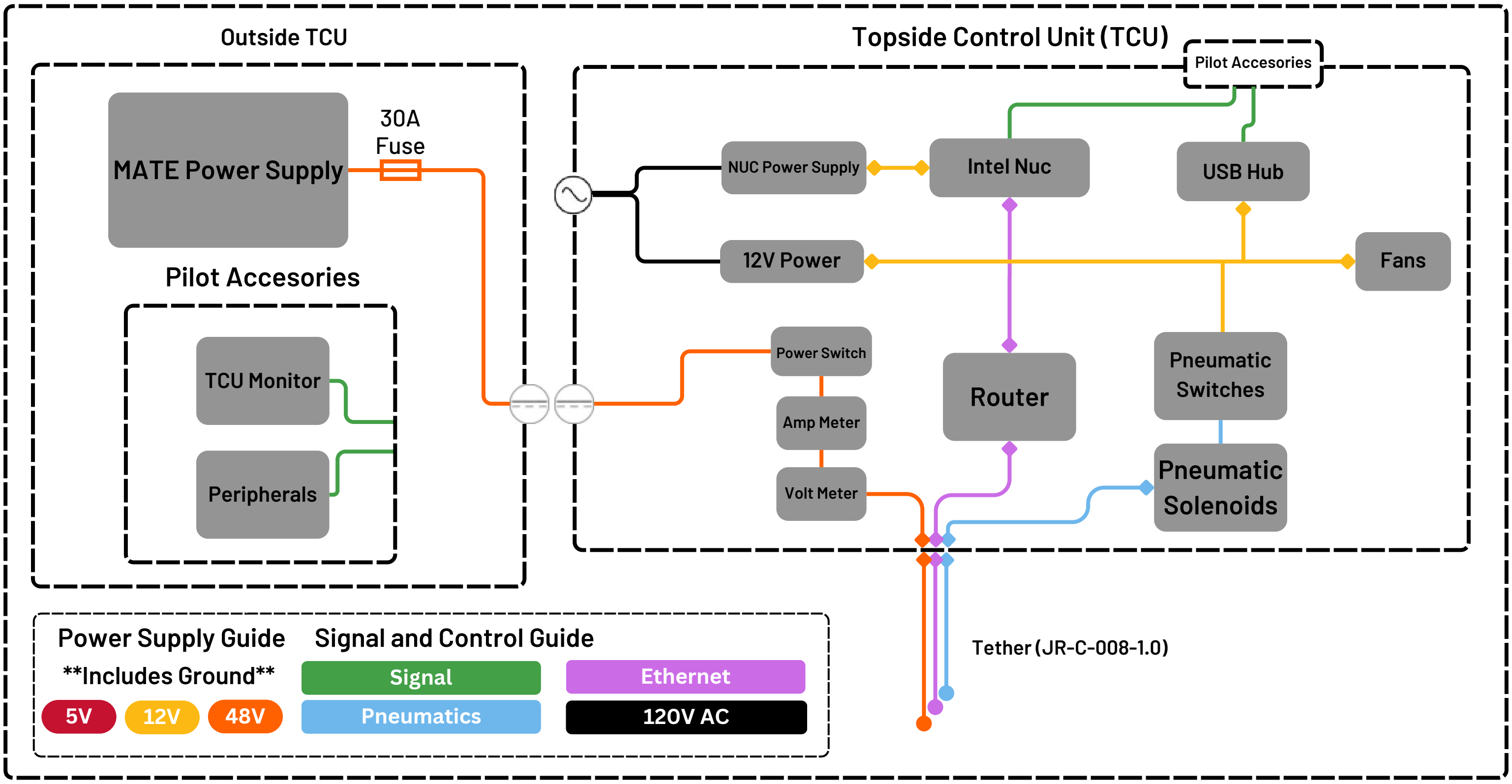
GitHub - Providing complimentary private code repositories

TAP Plastics - Donation of stock plastic

Our Families - Their continued support and encouragement

Appendix A: SIDS & Fuse Calculations

Electronics Systems (TOPSIDE/Surface Control)



Fuse and Power Calculations

Device	Quantity	Voltage	Max power Per	total (w)
t100s	6	12	130	780
ESCs	6	12	6	36
Rov Hat + RPI	1	12	7	7
Ethernet switch	1	12	13	13
Cameras	5	5	2	10
Total power consumption				846

↓

Voltage Drop: **(Resistance[2] x Power)/(Supply Voltage - Initial Voltage Drop) = Voltage Drop**

(0.3Ω x 846W)/(48V-Voltage Drop[1]) = 6.03V

Total Power Draw[3]: ROV Power/(Supply Voltage - Voltage Drop) x Supply Voltage = Total Power Draw

846W/(48V-6.03V) x 48V = 968W

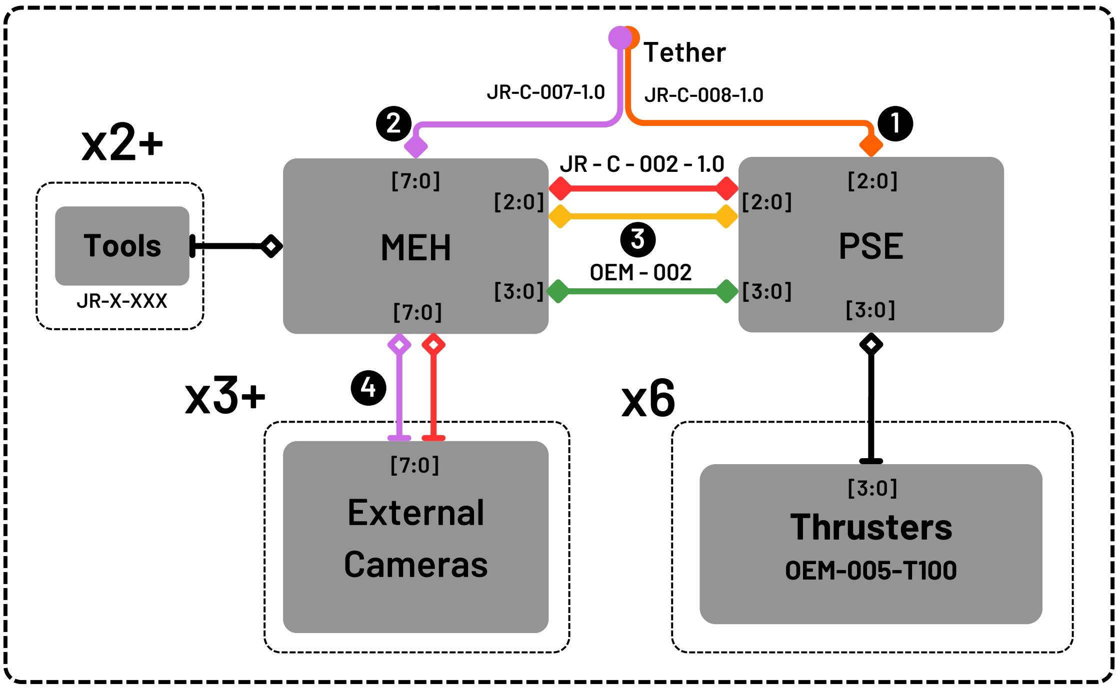
Fuse Calculation: 968 W / 48V = 20.167 * 150% = 30.25A. A 30A fuse is used.

Footnotes

1. Tether Power Draw/Voltage Drop Calculations are repeated until convergence https://instacalc.com/57447
2. Resistance is calculated taking into account the TOTAL 112ft circuit (POS/NEG sides) of a 56ft tether: (0.026Ω/ft) * (56ft + 56ft) = 0.3Ω
   (Resistance verified by manual testing with multimeter) (56 ft down the tether, 56 ft up)
3. Due to the voltage drop the current increases to compensate therefore, the tether will dissipate more power.

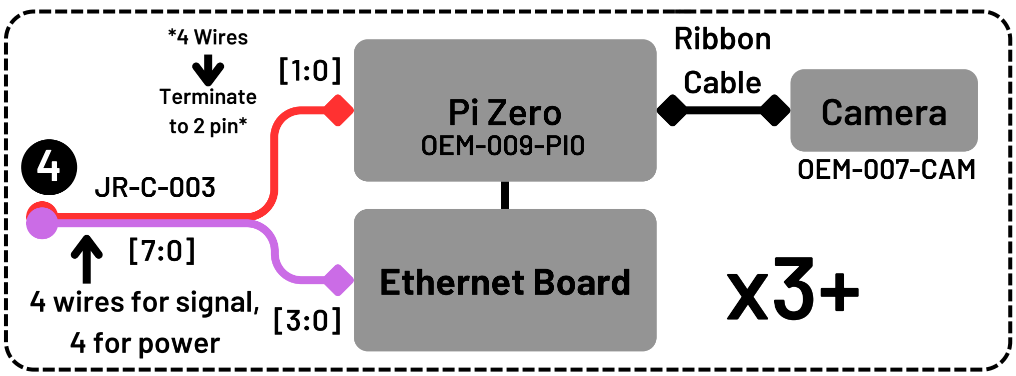
Electronics Systems (BOTTOMSIDE)

ROV Overview



External Cameras

Electronics are all incorporated into sealed housing, and at high level are treated as one component



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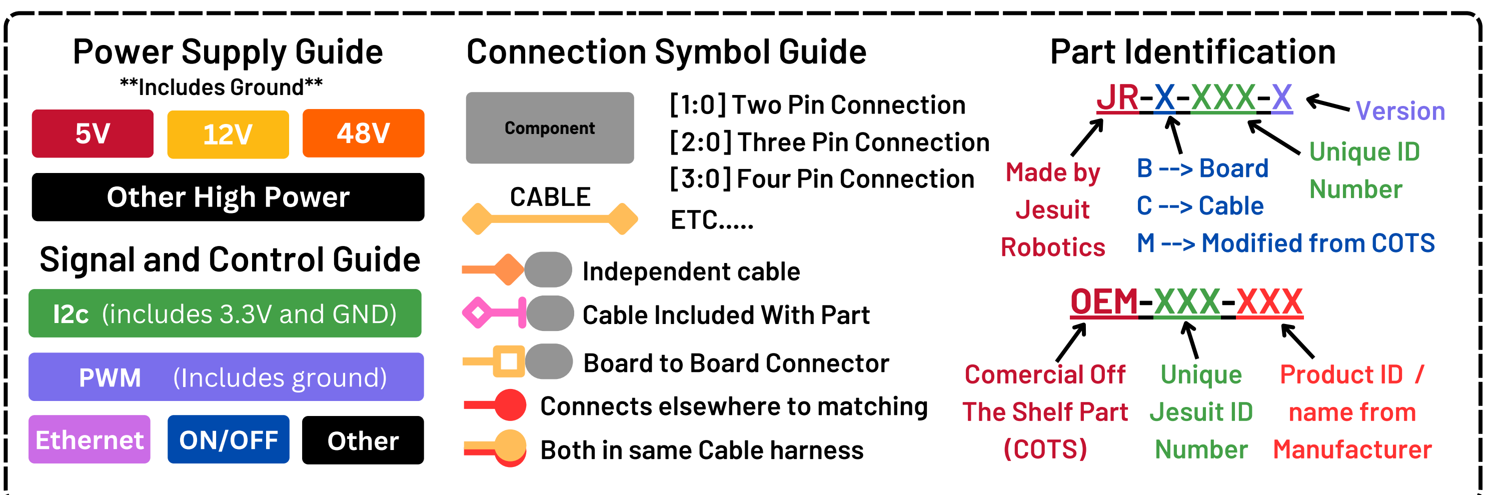
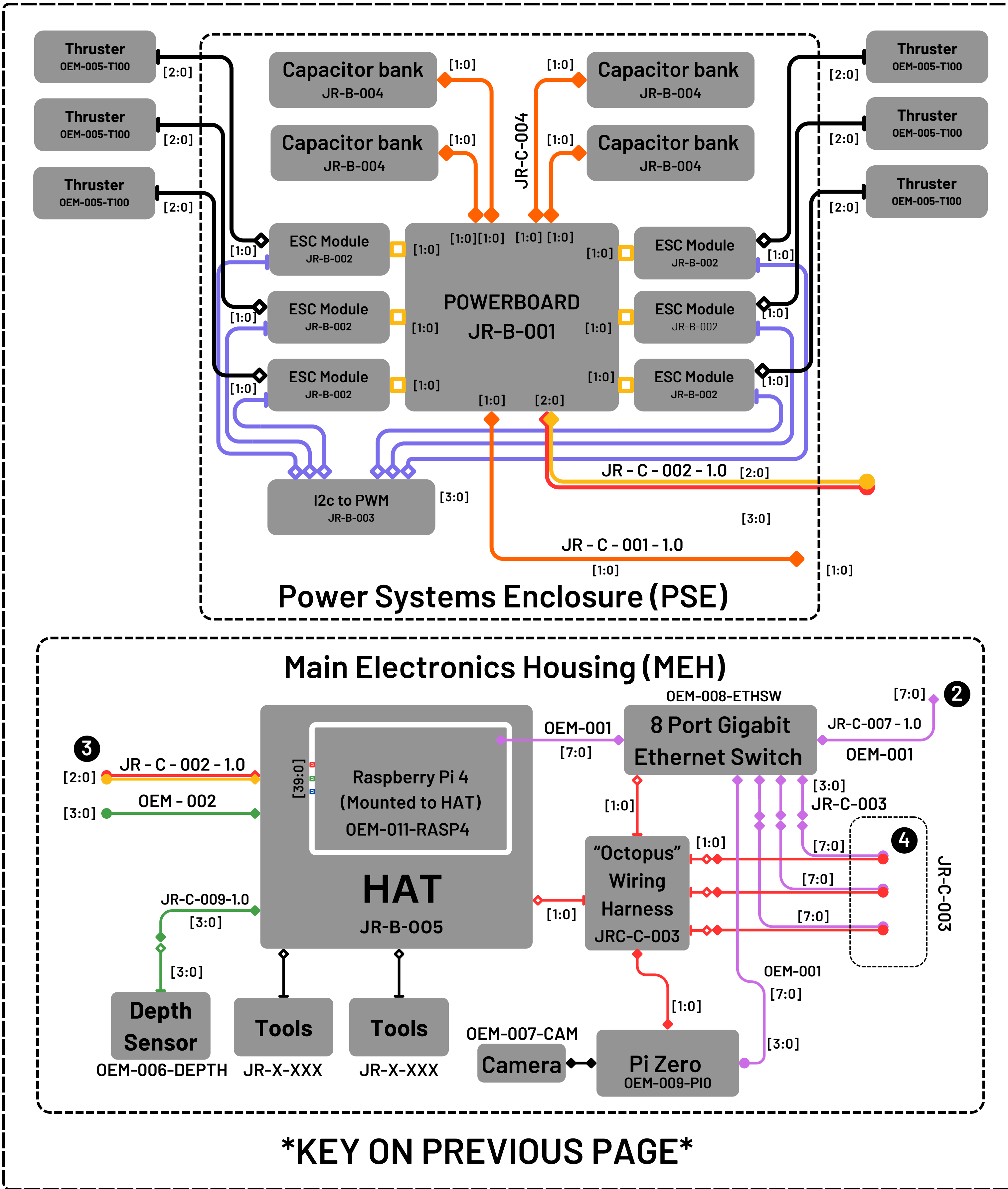


Electronics Systems (BOTTOMSIDE CONTINUED)



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Appendix B: Buoyancy Calculations

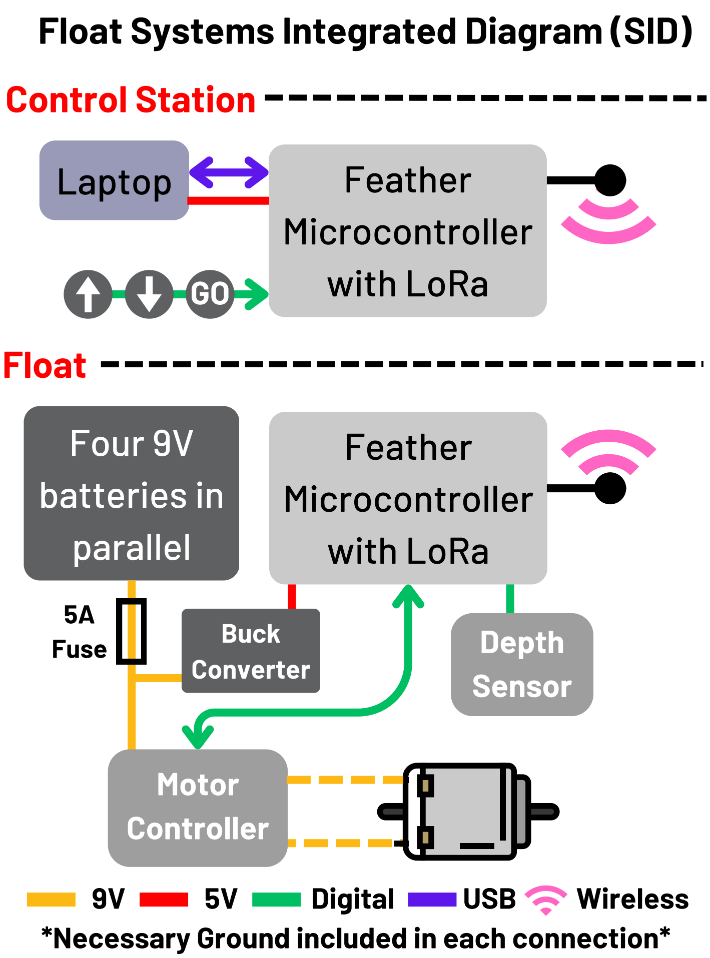
Item	Qty	Mass (g)	Volume (cm^3)	Water Displacement (g)	Net (g)	Net Force (N)
CORE-ROV[1]	1	-11,630	8800	8800	-2,830	27.734
Static Buoyancy[2]	1	-1880	4420	4420	2,540	-24.892
Modular Buoyancy[3]	2	-6.7	288	288	281.3	-2.75674
Total		**-13,517**	**13508**	**13508**	**-8.7**	**0.08526**

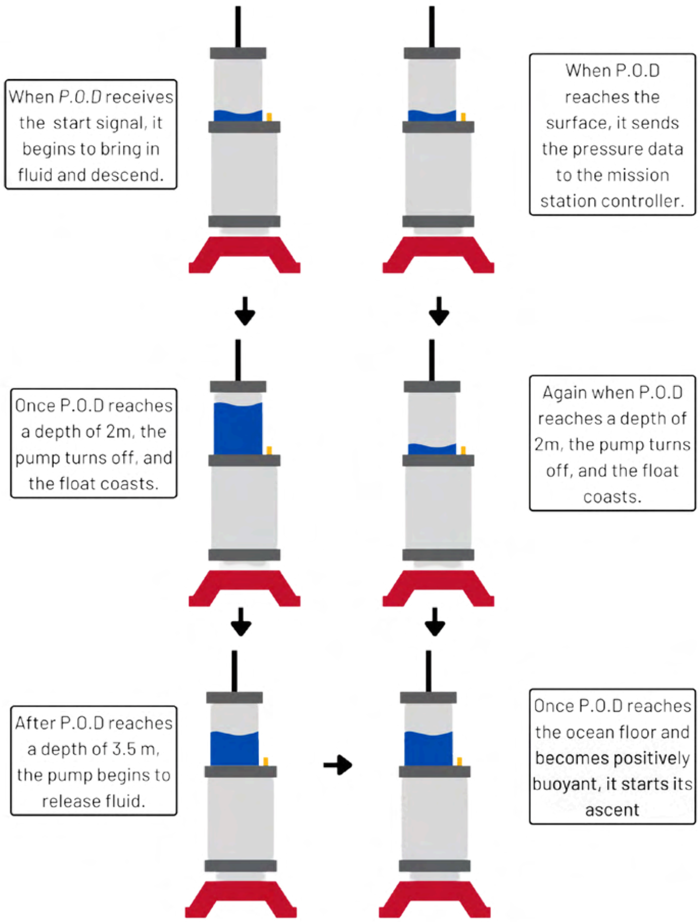
[1] Core ROV - cameras, thrusters, tether, aluminum extrusion, brackets, and screws

[2] Static Buoyancy - MEH, PSE, and nacelles

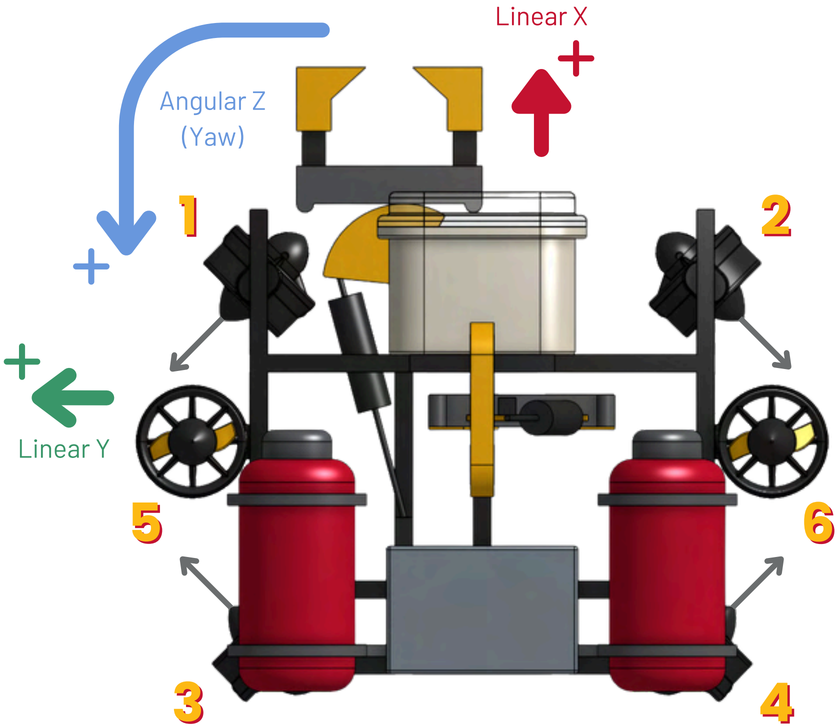
[3] Modular Buoyancy - hydrostatic foam

Appendix C: Float SID & Operation Logic





Appendix D: Thruster Orientation Guide



Thruster Effort Value Formulas:

T1 = LinearX - LinearY - AngularZ

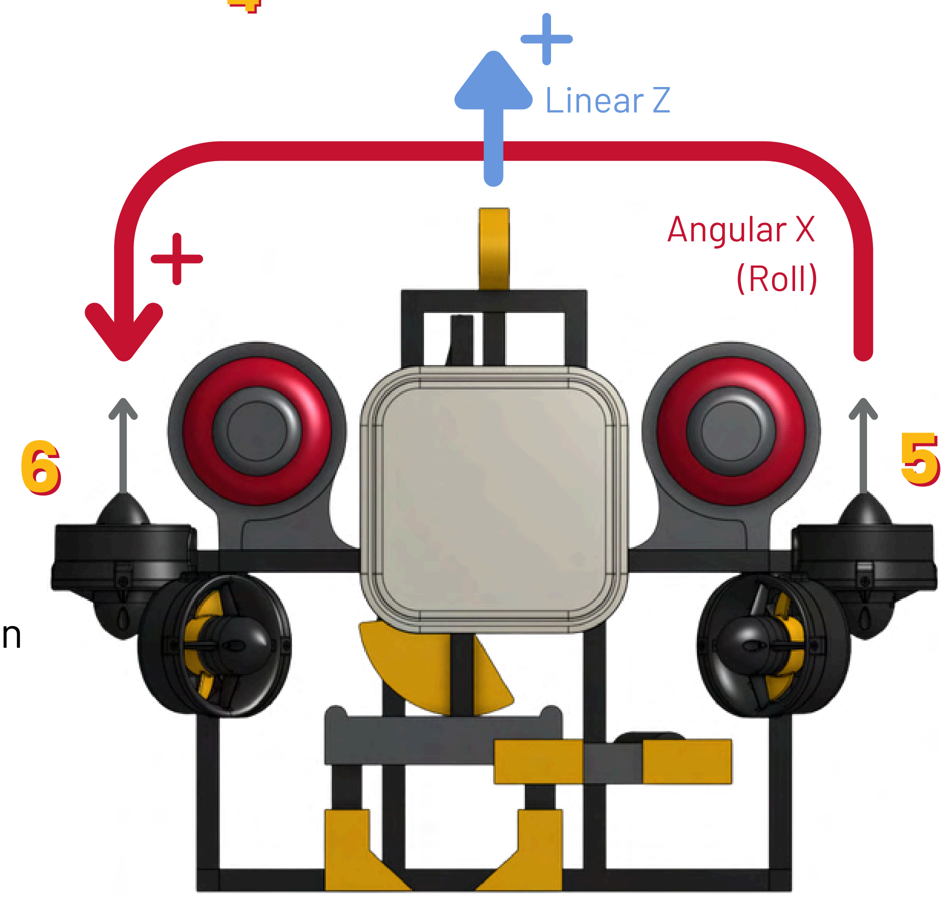
T2 = LinearX + LinearY + AngularZ

T3 = -LinearX - LinearY + AngularZ

T4 = -LinearX + LinearY - AngularZ

T5 = -LinearZ - AngularX

T6 = -LinearZ + AngularX



Roll	AngularX
Pitch	AngularY
Yaw	AngularZ

→ Direction of + Thrust

NOTE: This means that when the thruster is spun in the positive direction, the ROV moves in the direction OPPOSITE this arrow.

Appendix E: Budget & Project Costing

Income	Budget	Type	Production & Operations Budget & Cost Analysis	Project Cost	Difference
Jesuit School Funding	$ 17,375.00	Income	Available Income	$ 26,425.00	
Student Fund Raising	$ -	Income	Total Budget		$ 22,330.00
Donations	$ 5,150.00	Income	Production ROV Costs	$ 7,288.18	$ 1,191.82
MATE Competition Awards	$ 500.00	Income	Research & Development Costs*	$ 1,684.52	$ 2,115.48
Employee Dues	$ 3,400.00	Income	Operations Costs*	$ 7,652.63	$ 397.37
Total Income	$ 26,425.00		Capital Costs	$ 2,500.00	$ 277.08
			* Budget overage due to Lodging		$ 400.00
			Funds available for next season	$ 7,299.67	
Production Expenses	**Budget**	**Type**	**Description**	**Project Cost**	**Difference**
Frame & Housing	$ 660.00	Purchased	Polycase Housings, Bottom Deck, aluminum bar	$ 745.80	$ (85.80)
Thrusters	$ 1,400.00	Purchased	(6) T100 Blue Robotics thrusters & ESCs	$ 688.00	$ 712.00
Topside Control Unit (TCU)	$ 1,720.00	Purchased	Case, Monitors, electronics, pneumatics, NUC	$ 1,529.00	$ 191.00
Tether & Connectors	$ 400.00	Re-used	Si wire, CAT5e, coax cable, sheathing, connectors	$ 452.00	$ (52.00)
Electronics & Connectors	$ 1,500.00	Purchased	PCB Board Fab, components, connectors, cameras	$ 1,516.20	$ (16.20)
Electronics Rework	$ 500.00	Purchased	PCB revisions and components	$ 352.18	$ 147.82
Mission Tools	$ 600.00	Purchased	Grippers, valve turner	$ 310.00	$ 290.00
Raw materials	$ 1,700.00	Purchased	Plastics, metals, hardware, 3D filament, consumables	$ 1,695.00	$ 5.00
Production Budget	$ 8,480.00		**Total ROV Production Cost**	**$ 7,288.18**	**$ 1,191.82**
R&D Expenses	**Budget**	**Type**	**Description**	**Project Cost**	**Difference**
Test Benches	$ 900.00	Purchased	SW Test benches	$ 755.87	$ 144.13
Equipment	$ 2,000.00	Purchased	Bambu A1 mini's, qty 3;	$ 804.89	$ 1,195.11
Tools	$ 900.00	Purchased	Tool kits for new team members	$ 123.76	$ 776.24
R&D Budget	$ 3,800.00		**R&D Project Cost**	**$ 1,684.52**	**$ 2,115.48**
Operations Expenses	**Budget**	**Type**	**Description**	**Project Cost**	**Difference**
Lodging	$ 7,000.00	Purchased	11 hotel rooms for team/2 per room	$ 6,600.00	$ 400.00
Mission Props	$ 300.00	Purchased	MATE mission props, blue tooth module	$ 339.00	$ (39.00)
MATE Entry Fee	$ 425.00	Purchased	MATE entry fee	$ 450.00	$ (25.00)
Power Fluid Quiz Fee	$ 25.00	Purchased	MATE power fluid quiz	$ 25.00	$ -
Printing	$ 300.00	Purchased	Report, display, brochure printing	$ 238.63	$ 61.37
Operations Budget	$ 8,050.00		**Operations Project Cost**	**$ 7,652.63**	**$ 397.37**
Capital Expenses	**Budget**	**Type**	**Description**	**Project Cost**	**Difference**
3D printer	$ 2,000.00	purchased	Bambu X1 Carbon Printer	$ 1,722.92	$ 277.08
	$ -			$ -	$ -
Capital Budget	$ 2,000.00		**Capital Project Cost**	**$ 1,722.92**	**$ 277.08**
Employee Paid Expenses	**Budget**	**Type**	**Description**	**Project Cost**	**Difference**
Competition Meals	$ 3,060.00	Purchased	Cash collected for competition meals;14 people	$ 3,060.00	$ -
Transportation & hotel subsidy	$ 3,842.00	Purchased	Cash contribution for car rental, gas, & hotel subsidy	$ 3,842.00	$ -
Estimated Employee Fees	$ 6,902.00		**Actual Employee Fees**	**$ 6,902.00**	**$ -**
Total	$ 2,757.00			**$ 18,348.26**	

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