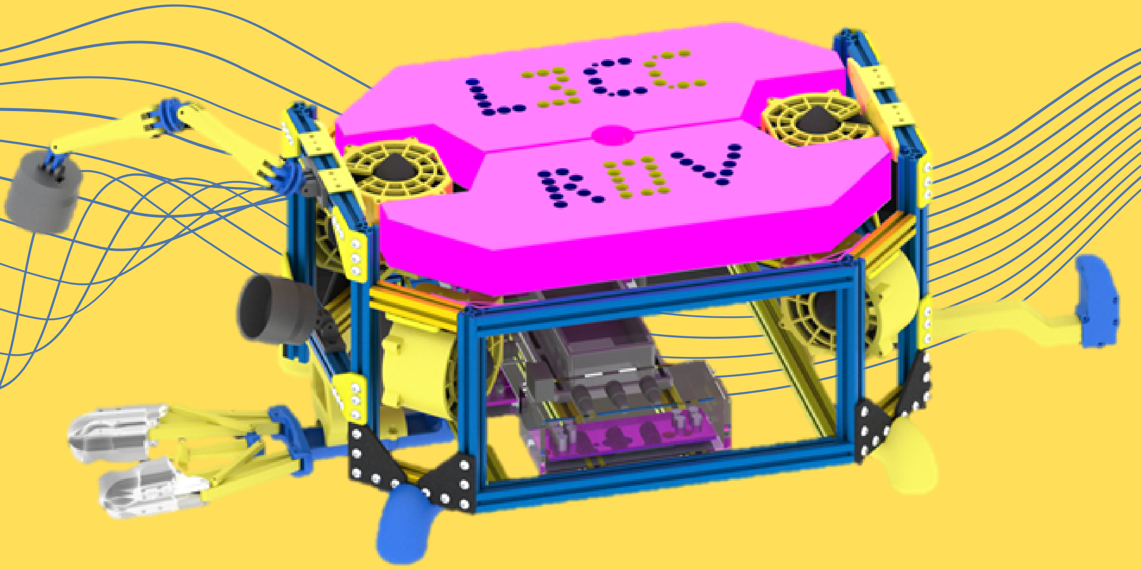

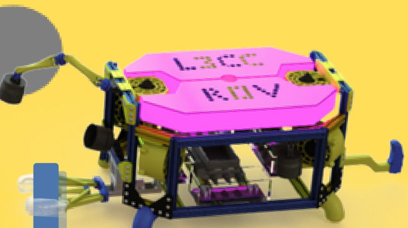

LEONARDO

LINN-BENTON ROV

Linn-Benton Community College

Albany, OR USA | MATE 2023

TEAM MEMBERS

Theon Abbott, Mechanical
Nolan Andersen, Mechanical
Titus Black, Mechanical
Sierra Brightly, CFO
Kyle Davis, Mechanical
Jason Fanger, Software
Levi Kaup, Pilot
Dominique Klahold, Mechanical
Sara Leathers, COO
Chloe Madden, Mechanical
Aren Mowreader, Logistics
Asher Richmond, Mechanical
Fernando Salazar, Software
Riley Smith, Safety Officer
Caden Sullivan, Mechanical
Dale Sydnam, CEO
Emilia Watts, Mechanical
Mentors: Greg Mulder, Heather Hill, Kathy Austin

INTRODUCTION

Figure 1. Linn-Benton ROV Team Members

ABSTRACT

Leonardo, the latest Remotely Operated Vehicle (ROV) developed by the innovative team from Linn-Benton Community College (LBCC), showcases exceptional maneuverability, versatility, and dedication. Designed specifically for the 2023 Marine Advanced Technology Education (MATE) competition, Leonardo belongs to the esteemed EXPLORER-class of ROVs. Its primary goal is to address the escalating ecological disasters that pose a significant threat to underwater ecosystems worldwide.

Leonardo's design is centered around modular and detachable components, including the tether, thrusters, cameras, and power converters. This thoughtful design approach allows for continuous improvement and expansion, ensuring that Leonardo stays at the forefront of technological advancements.

Meticulous planning, precise designing, and rigorous testing have been undertaken by the team to meet stringent safety standards. This comprehensive development process has yielded a highly capable and adaptable ROV.

With a compact size, remarkable maneuverability, and ease of maintenance, Leonardo is well-equipped to ensure the health of underwater life, install renewable energy sources, and maintain the well-being of aquatic habitats. The dedication and expertise of the seventeen-person LBCC team are evident in Leonardo's construction and demonstrate their commitment to environmental preservation efforts. This comprehensive document provides an insightful overview of Leonardo's development process, highlighting its capability to tackle not only the challenges of the competition but also real-world issues impacting waterways globally.

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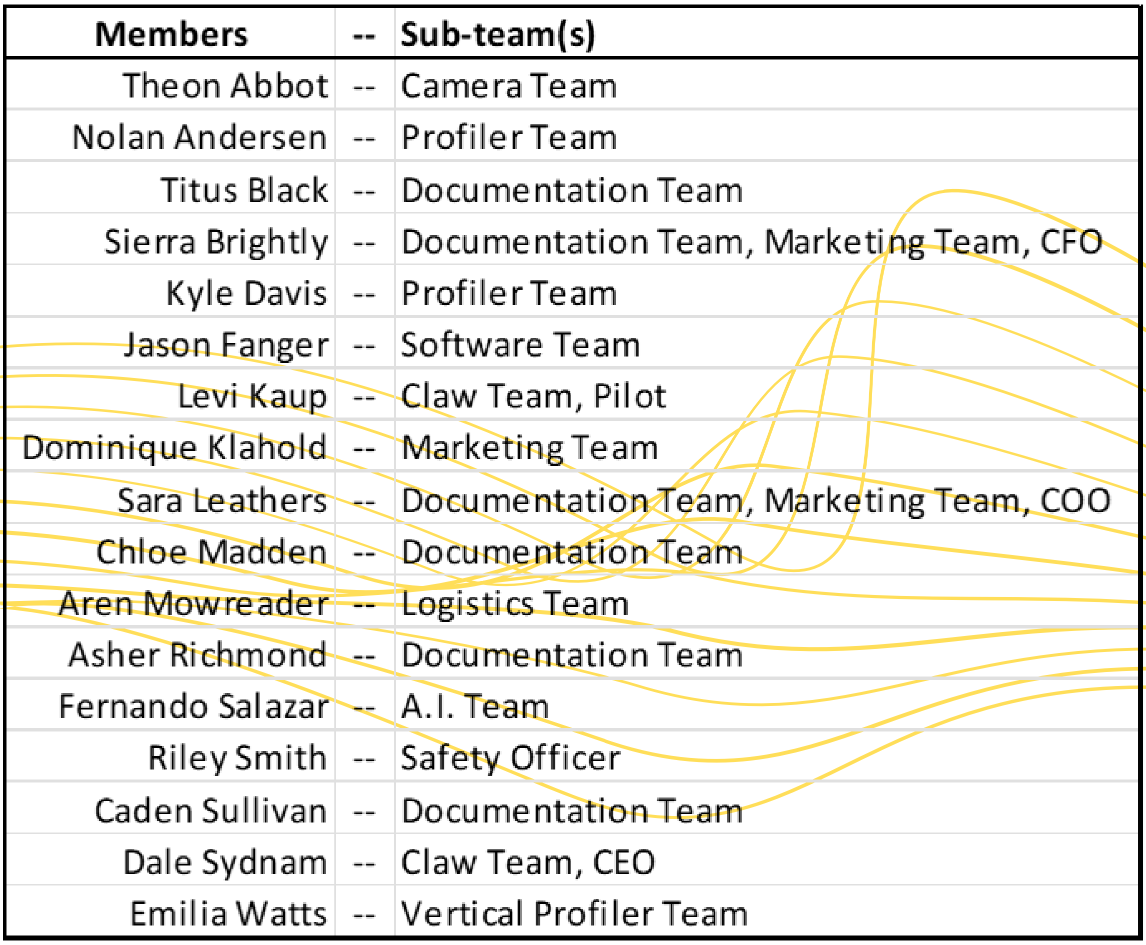
Teamwork

Company Philosophy

Linn-Benton ROV is based out of Linn-Benton Community College in Albany, Oregon. The project of designing and building an underwater remotely operated vehicle (ROV) provided over a dozen members with an opportunity to put their skills, both new and pre- existing, to the test in a collaborative and fun environment. With returning members, Sara Leathers, Dale Sydnam, Levi Kaup, Nolan Andersen, Emilia Watts, Kyle Davis and Chloe Madden, the team (Table 1) came together from seven disciplines spanning science and engineering to partake in the engineering challenge set forth by MATE.

By not dividing the team into clear departments, or distinguishing superiors and subordinates, Linn-Benton ROV opened all activities to all members so that all may learn as much as possible during the process. Frequently, sub-team leaders would emerge naturally, taking on the role of organizer for the project to ensure that all goals and deadlines are met efficiently. Occasionally, the project was discovered to require input from various team members with varying areas of expertise, such that no individual organizer was necessary; instead, accomplishing goals and meeting deadlines was the responsibility of the entire team.



Members	--	Sub-team(s)
Theon Abbot	--	Camera Team
Nolan Andersen	--	Profiler Team
Titus Black	--	Documentation Team
Sierra Brightly	--	Documentation Team, Marketing Team, CFO
Kyle Davis	--	Profiler Team
Jason Fanger	--	Software Team
Levi Kaup	--	Claw Team, Pilot
Dominique Klahold	--	Marketing Team
Sara Leathers	--	Documentation Team, Marketing Team, COO
Chloe Madden	--	Documentation Team
Aren Mowreader	--	Logistics Team
Asher Richmond	--	Documentation Team
Fernando Salazar	--	A.I. Team
Riley Smith	--	Safety Officer
Caden Sullivan	--	Documentation Team
Dale Sydnam	--	Claw Team, CEO
Emilia Watts	--	Vertical Profiler Team

Table 1. Linn-Benton ROV members and roles

Planning and Scheduling

Linn-Benton ROV met bi-weekly during the school term on Tuesdays and Sundays. The Tuesday meeting, organized by head mentor Greg Mulder, served to review what was completed the previous week as well as organize what will get done in the coming week. Round robin style, individuals or sub-teams would take turns explaining their plan, progress, and/or the hurdles they faced. If any assistance or collaboration with another sub-team was needed, it would be discussed at this time.

The Sunday meeting served as an in-person collaborative workday, and/or a day for testing, often at a local pool. These meetings would always end with a Tuesday-style group discussion of what had gone well, what hadn't gone well, and what direction to go next. Sub-teams and individuals often planned their own meetings and workdays during the week in addition to those shared by the whole team in order to accomplish goals more quickly.

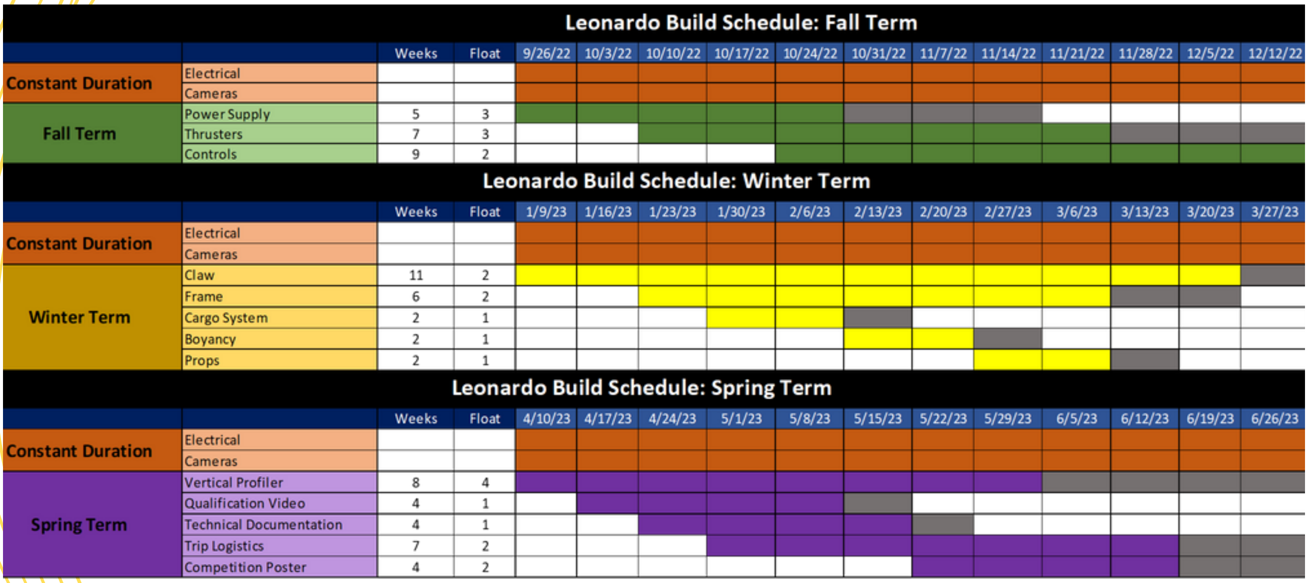
Since building an ROV takes extensive time and effort, the team decided to schedule out the overall progress of the ROV over Fall, Winter, and Spring term. The team already had the base frame from the previous year's model, so the team was able to schedule out specific tasks and components needed for this year's competition, as well as plan with the sub-teams and their progress. The overall schedule for Fall, Winter and Spring term are shown in Table 2 below.

Resource Management

To make all company resources and knowledge available to every member of the company, Linn-Benton ROV used Google Drive to manage and store all company files. The shared drive ensured a variety of company information, including employee training, past design proposals and outcomes, and vehicle operational procedures, were available to all employees at all times.

For day-to-day communication and problem solving, the team used a common Discord server so that all members could participate in conversations about how to best address each mission or issue as it came up.

Additionally, the team regularly met in-person in a common lab room where all materials and supplies were stored, so that all members had access to the vehicle and components as needed.



Leonardo Build Schedule: Fall Term

		Weeks	Float	9/26/22	10/3/22	10/10/22	10/17/22	10/24/22	10/31/22	11/7/22	11/14/22	11/21/22	11/28/22	12/5/22	12/12/22
Constant Duration	Electrical			🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	Cameras			🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
Fall Term	Power Supply	5	3	🟩	🟩	🟩	🟩	🟩	▨	▨	▨				
	Thrusters	7	3			🟩	🟩	🟩	🟩	🟩	🟩	🟩	▨	▨	▨
	Controls	9	2					🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

Leonardo Build Schedule: Winter Term

		Weeks	Float	1/9/23	1/16/23	1/23/23	1/30/23	2/6/23	2/13/23	2/20/23	2/27/23	3/6/23	3/13/23	3/20/23	3/27/23
Constant Duration	Electrical			🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	Cameras			🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
Winter Term	Claw	11	2	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	▨
	Frame	6	2			🟨	🟨	🟨	🟨	🟨	🟨	🟨	▨	▨	
	Cargo System	2	1				🟨	🟨	▨						
	Boyancy	2	1						🟨	🟨	▨				
	Props	2	1								🟨	🟨	▨		

Leonardo Build Schedule: Spring Term

		Weeks	Float	4/10/23	4/17/23	4/24/23	5/1/23	5/8/23	5/15/23	5/22/23	5/29/23	6/5/23	6/12/23	6/19/23	6/26/23
Constant Duration	Electrical			🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	Cameras			🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
Spring Term	Vertical Profiler	8	4	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	▨	▨	▨	▨
	Qualification Video	4	1		🟪	🟪	🟪	🟪	▨						
	Technical Documentation	4	1			🟪	🟪	🟪	🟪	▨					
	Trip Logistics	7	2				🟪	🟪	🟪	🟪	🟪	🟪	🟪	▨	▨
	Competition Poster	4	2							🟪	🟪	🟪	🟪	▨	▨

Table 2. Build schedule by term

Design Rationale

Design Philosophy

At the very heart of our design philosophy is the idea of iterative design. We believe that one of the best ways to learn is by doing, and along those lines we have placed emphasis on high modularity and affordability for our design. This allows for more iterations of any given part without redesigning the overall system. An additional bonus to this approach is that it lends itself to quicker (not unusually 3-5 minute) repair times.

As a practical ramification of this design philosophy, our build features a large quantity of 3D printed polylactic acid (PLA) parts. This medium lends itself to our overall design philosophy by allowing a piece to be tested, edited, and the next version printed all within a day or two. While 3D printed parts are not as strong as aluminum or other metals, they are much cheaper to make, do not need to be outsourced, have a much lower barrier to entry, and have plenty of strength for our applications. Recently this process has been further improved by upgrading to professional-grade PLA.

The first step for any solution is understanding the question itself. As such, the first step of our design process is always an examination of the objectives. After breaking down the question into smaller pieces, we start with a loose prototype, test it, and then review the results. After looking at what went well and what could use improvement, we incorporate our findings into a new design. Then we continue to test, review, and redesign until we arrive at a satisfactory product. This practice of iterative design can be seen in the creation of every component of Leonardo.

Frame and Structure

One of the few non-3D printed components of Leonardo is the vehicle's modular, powder-coated 20 mm × 20 mm extruded aluminum frame (Figure 2). While powder-coating is necessary to cover sharp edges and prevent oxidation, Leonardo's aluminum frame provides ample strength and helps keep weight low, while still allowing older components to be easily exchanged with new ones.

While the bulk of the frame is aluminum, true to the company design philosophy, 3D printed brackets hold the aluminum frame together. These brackets were iteratively designed to provide the necessary strength without hindering the function or design intentions of the frame itself.

The size and shape of this frame was chosen as a happy medium between room for equipment and ease of transportation; a large, "roomy" ROV is great until you have to fly to an international competition, but a small ROV often fails to contain the components necessary for every task. It is for this reason that the frame was purpose built to both contain all components and fit inside a TSA approved travel tote, making air travel much easier.

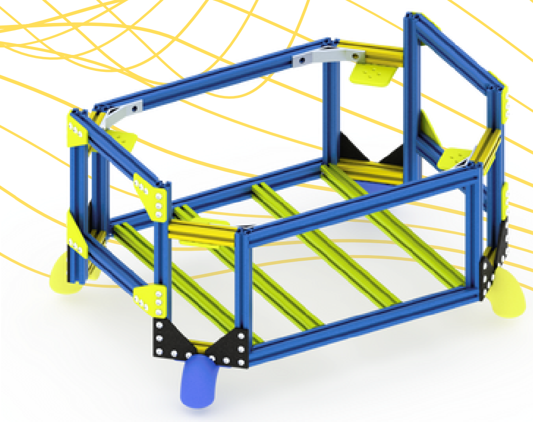


Figure 2. Leonardo's frame

To allow for as much space as possible, the frame has a basket-like shape to hold the electronics. However, a tradeoff of this design is that the lowest part of the vehicle has a large surface area, which both causes increased drag when moving at the bottom of a body of water and inhibits the attachment of any component to the bottom of the frame. In response to this, the design engineers at Linn-Benton ROV developed a unique and aesthetic solution rivaled only by millions of years of biological evolution: 3D printed tetrapod feet. These appendages are now a key contributor to the ROV's turtle-like resemblance.

Buoyancy Systems

To stay afloat, Leonardo wears a hat (or, rather, two hats) of R-3312 polyurethane foam, cut to fit just inside the frame while allowing room for the two upper thrusters and the tether (Figure 3). Attached to hinges, each foam piece can open to provide access to the vehicle's onboard electronics without the need to remove the modules completely. While Leonardo is on-the-move, the foam "hats" are secured laying down by a bungee cord system.

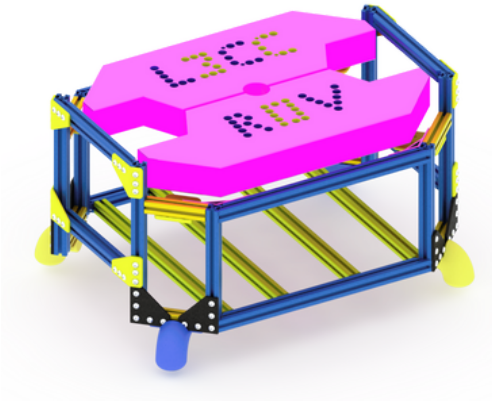


Figure 3. Leonardo's buoyancy on the frame

The foam makes up a volume of 5600 cubic centimeters, providing approximately 55 newtons of upward buoyant force to the ROV. When attached to the vehicle, the system is slightly positively buoyant. The team has had great success adjusting this buoyancy to be more neutral with the use of a set of Allen keys as weights.

In addition to this fixed buoyancy, Leonardo features a detachable variable buoyancy bag, which can be inflated during operation to aid in lifting heavy objects to the surface.

Tether

Linn-Benton ROV designed Leonardo's tether (Figure 4) to be neutrally buoyant and detachable. The tether measures 12 meters and is composed of five wire cords, three air hoses, and a strip of polyethylene foam for buoyancy, all of which are contained in a wire sheathing.

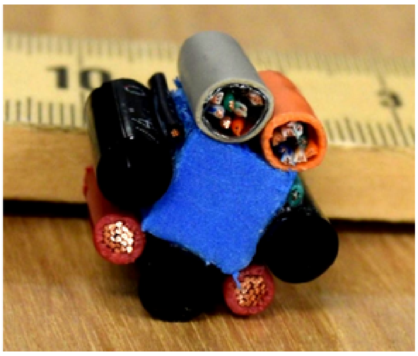


Figure 4. Leonardo's tether

Wires contained in the sheathing are:

- Ethernet for the analog camera signal
- Ethernet for the digital camera signal
- Ethernet for the Arduino signal
- Two 18-gauge power wires for 48 VDC power
- Two pneumatic air hoses with a 148-psi (1.02 x 10^6 pascal) rating for the claw
- One pneumatic air hose with a 120-psi (8.3 x 10^5 pascal) rating for variable buoyancy
- Polyethylene foam for tether buoyancy

Also contained in the tether, as a remnant of a past vehicle component that is no longer in use, is a Swan visual signal cord. This cord is safely capped at both ends and is not used.

At the topside of the tether, there is a closed-mesh, single-eye strain relief that connects to a plastic clamp on the control station. Coming from the strain relief, we have an orange Ethernet which connects to the Dry Arduino at the control station, a grey Ethernet which connects to the video control system, a black Ethernet with connects to a computer for digital camera use, and two power wires entering an Anderson SBS50, which connects to our fused power supply box. There are also three air hoses coming from the strain relief, which connect to our pneumatic control station.

On the ROV-side of the tether, there is a closed-mesh, double-eye strain relief that connects to two frame points on the ROV. The connections from the tether wires come from the strain and connect to their specified places. The two 18-guage wires are divided into four 48 VDC power connections, which connect to the onboard power converters through SubConn® Low Profile two-contact connectors. The three Ethernet cables have circular SubConn® eight-contact connectors; the grey and black Ethernets connect to the analog and digital camera system, respectively, and the orange Ethernet connects to the Wet Arduino. The three air hoses connect to the pneumatic claw and lift bag.

The tether was designed to be neutrally buoyant, however it proved to be marginally negatively buoyant, so there are rings of polyethylene on the bottom end of the tether near the ROV, so that the tether does not interfere with the ROV flight path.

Electrical Systems

All electronics on Leonardo are encased in clear epoxy. While the permanence of this approach to waterproofing may be a deterrent to some, Linn-Benton ROV embraces the guaranteed security based on years of experience and comparison with more traditional waterproofing methods. Similarly, all Linn-Benton ROV builds use waterproof SubConn connectors to aid in system modularity while maintaining the highest standards of waterproof safety. While these two waterproofing methods may be costly in the short term, the effectiveness and longevity of the methods make them more than worthwhile to the Linn-Benton group.

Using these methods, Leonardo hosts up to four onboard power converters (Figure 5, Figure 6) which convert the provided 48 VDC to the more commonly used 12 VDC. All powered components of Leonardo connect to one of these power converters. As with all of Leonardo's components, the power converters were designed with modularity in mind – each converter is an independent unit that can be removed or replaced as needed to accommodate different functions.

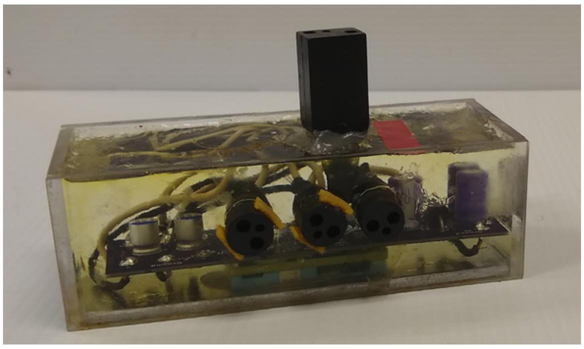


Figure 5. Leonardo's Power Converters

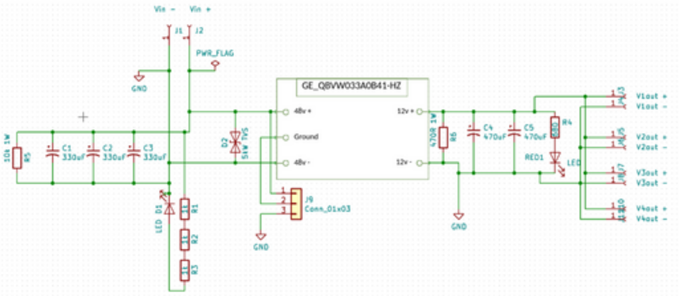


Figure 6. Circuit diagram of power converters (see Appendix for larger image)

Likewise, Leonardo's onboard control system consists of an independently epoxied Arduino which communicates via SubConn cabling with six electronic speed controllers (ESCs), each individually epoxied to a T100 thruster from BlueRobotics.

Control Systems

Leonardo’s primary control is through the use of a PlayStaion2 controller (Figure 7), this communicates with the Dry Arduino on the surface. The Dry Arduino then compiles the controller inputs into an ethernet packet and sends this information to the Wet Arduino located on Leonardo. The Wet Arduino takes the ethernet packet and calculates what is needed for each thruster, this is then sent to the ESCs. In addition to controlling the motion of the ROV the controller also commands electrical tooling. This is done using the controller buttons and the same communication path used for motion.

The goal for the motion code was to have a ROV that moved like a character in a video game. The code takes input from each of the joystick axis, it then adds these inputs together while reorienting these values in relation to each of the individual thrusters position and the expected motion. Then this summed value is divided by the number of joysticks currently engaged for the final output to the ESC. The code allows for adjustments to individual thrusters both in magnitude and direction for each type of movement individually, allowing us to tune the vehicle for the varying amount of drag on a vehicle that is asymmetrical.

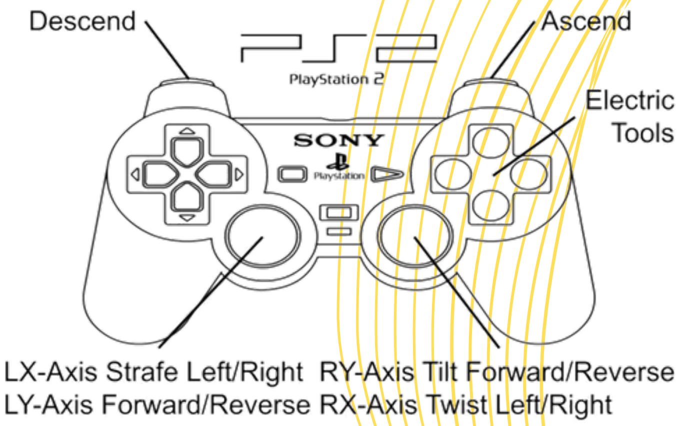


Figure 7. Leonardo's Controller Layout

Leonardo’s secondary control system is for its pneumatic tools. The pneumatics are controlled through the use of a bi-directional switch to open and close the claw and a ball valve for engaging our variable buoyancy tool. The switch is connected to a series of electric pneumatic valves allowing us to control the flow of air. From the control interface pneumatic tubing is ran through the tether directly to the tools on Leonardo.

Propulsion System

Leonardo uses six BlueRobotics T100 thrusters to get from Point A to Point B. These units were chosen for their reliability as proven in past Linn-Benton ROV builds. Four of these thrusters are mounted at a 90° offset from one another, one at each corner, and function in main directional movement. The remaining two thrusters are mounted on top of the ROV, positioned for up/down and tilt movements.

The main directional movement is accomplished via vector geometry, with thrusters arranged as shown in Figure 8. The decision to approach movement in this way comes at the cost of movement power, as half of each thruster’s output is canceled by another thruster when moving linearly; this issue is further complicated by the significant limitations of the power converters. The benefit to this approach, however, is the ability to accomplish yaw

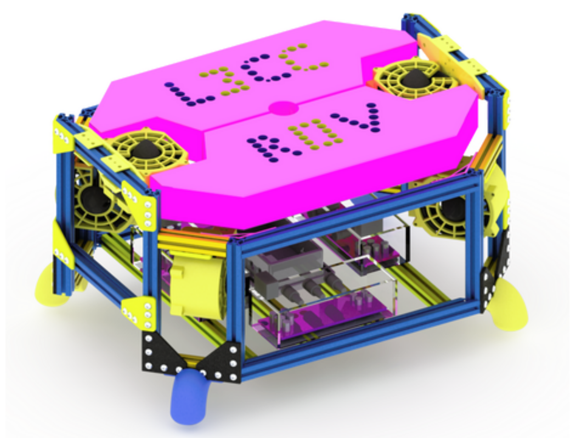


Figure 8. Leonardo's Thruster Layout

movement to change the direction the ROV is facing, without compromising stability or using additional thrusters.

For safety, the thrusters are each shrouded in 3D printed cases, which prevent fingers or other objects from encountering moving propellers (Figure 9).

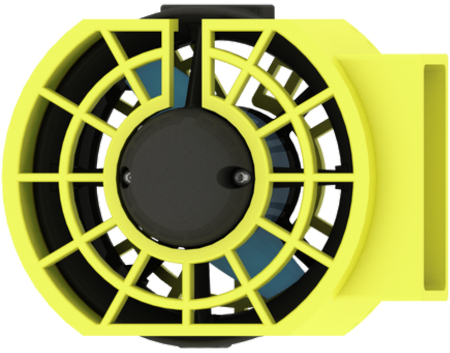


Figure 9. Leonardo's Thruster Shrouds

Cameras & Computer Vision

Achieving a balance between form, function, and economic viability is crucial in product development, especially for specialized equipment such as underwater hardware. While there are numerous products specifically designed for underwater applications, their high price points often make them prohibitive for many projects. Submersible cameras are a prime example of this scenario.

To overcome these cost barriers, Leonardo's camera team, led by Levi Kaup and Theon Abbott, decided to develop and integrate systems sourced from more generic, cost-effective options. This strategy allowed them to maintain their budget while creating innovative solutions tailored for a marine environment.

During the development process, the team discovered an advantageous characteristic of our analog cameras: they can share a common ground. This discovery has enabled us to increase the number of cameras on the ROV from 4 to 7, without needing to increase the number of wires—a significant benefit both in terms of cost and complexity.

The analog camera system currently comprises four cameras, with plans to add more. These cameras are strategically positioned to capture a comprehensive view of the environment.

One camera is mounted to provide a direct rearview, while another is set to look forward, aiding navigation and obstacle detection. The third camera is attached to a flexible arm, enabling dynamic adjustments to its position based on specific needs (Figure 10). This camera is currently oriented to offer a top-level perspective of the claw's operations, ensuring precise manipulation and effective task execution.

In essence, these varied camera positions contribute to a versatile and thorough visual system, enhancing the overall control and efficacy of the remotely operated vehicle's operations.

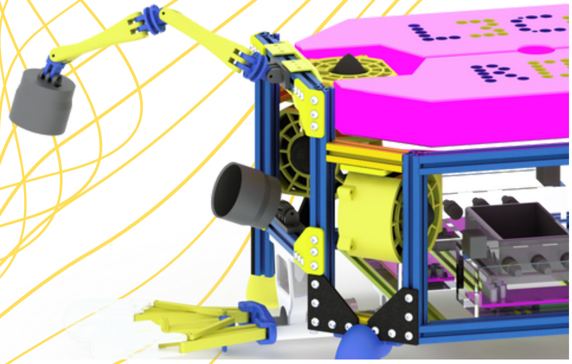


Figure 10. Leonardo's Camera Arm

Furthermore, in our quest to enhance the functionality of the ROV, we've added a super-wide-angle camera to the system. This addition greatly improves the general locational awareness, providing a broader field of view and thus enabling more effective navigation and exploration.

This combination of cost-effective sourcing, innovative integration, and thoughtful expansion demonstrates the team's commitment to striking the right balance between form, function, and economic viability in our underwater camera system.

All the cameras, both digital and analog, are enclosed in custom-made cases. These cases provide a dual benefit: they not only shield the cameras from water damage, but also offer a substantial level of protection against other potential hazards. Each case is designed with a dome at the front, a feature that ensures a clear, unimpeded view for the camera. This design consideration maintains the quality of the captured images and footage, regardless of the challenging conditions inherent in underwater exploration.

The digital camera system for Leonardo is composed of three distinct cameras, each strategically positioned to serve a specific purpose.

The primary camera is affixed to the front of the ROV. This crucial positioning allows it to serve as the guide for the vehicle, capturing real-time footage of the environment directly in front of the ROV. This camera provides an essential first-person view. It effectively acts as the 'eyes' of the ROV AI system, capturing high-quality images and videos.

The second and third cameras are strategically positioned on the bottom of the ROV. These cameras play a critical role in the 3D scanning of the environment beneath the vehicle. They function in tandem, using stereo vision techniques to create a detailed three-dimensional representation of the ROV's immediate surroundings. This 3D imaging capability is particularly useful in complex or challenging environments, providing valuable data about the terrain, potential obstacles, or points of interest.

The combination of these three cameras creates a comprehensive digital camera system for the ROV, enabling both effective navigation and detailed environmental analysis. Whether the ROV is exploring the ocean floor or navigating intricate tunnel systems, this camera setup ensures a thorough understanding of its environment, promoting safe operation and successful mission outcomes.

The core components of the digital camera system include Blue Robotics Low-Light HD USB Cameras, a 50-foot Ethernet Cable, an SGEYR 4-port USB Ethernet Extender, and a NUC (Next Unit of Computing) to manage all operations. Modifications were made to the Ethernet cable for better suitability. One end of the cable was replaced with a SubConn connector, a modification designed to enhance the system's underwater performance.

Further alterations were made to the SGEYR 4-port USB Ethernet Extender. Both of its ends were replaced with SubConn connectors, enhancing their resistance to the rigors of underwater usage. Furthermore, the main board of the extender was encased in epoxy. This measure was taken to waterproof the equipment.

Manipulator

A new approach for Linn-Benton ROV, Leonardo features an innovative new claw design. This pneumatic claw is constructed of two opposing concave “fingers” designed to automatically center whichever object it is manipulating. This works particularly well with rounded objects, such as PVC pipe. These two “fingers” are then manipulated by three couplings each, and then all connected to a single pneumatic piston. This allows the claw to be opened or closed with the flip of a switch. Pneumatics were used for their price point and ease of integration.

Each “finger” features a mounting bracket on the exterior edge. This allows the claw to be customized for the task at hand. Three task specific attachments have been manufactured (Figure 11): a fry release globe, syringe positioning cones, and a carabiner clip. Each tool customizes the core apparatus to a mission specific task.

The fry release globe contains fry within and opens with the claw. Fry are allowed to acclimate to local water conditions through 5mm holes that have been printed in the design. The syringe positioning cone assists in administering Rx to diseased coral.

Linn-Benton ROV's greatest achievement is in the simplicity of the carabiner clip. The clip allows the solar array carabiner to be held open during placing and released when the claw is opened. This significantly decreased the demands on thrusters and controls. Additionally the carabiner clip saved significant amounts of time during the qualification process.

Leonardo's claw "fingers" are 3D printed in clear resin to allow the control team more visibility when manipulating objects underwater. As an added benefit, the resin claw proved to have more grip ability than PLA.

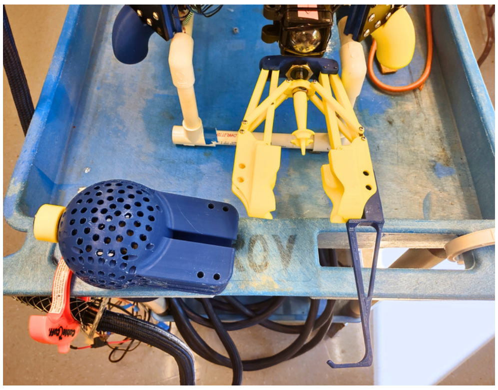


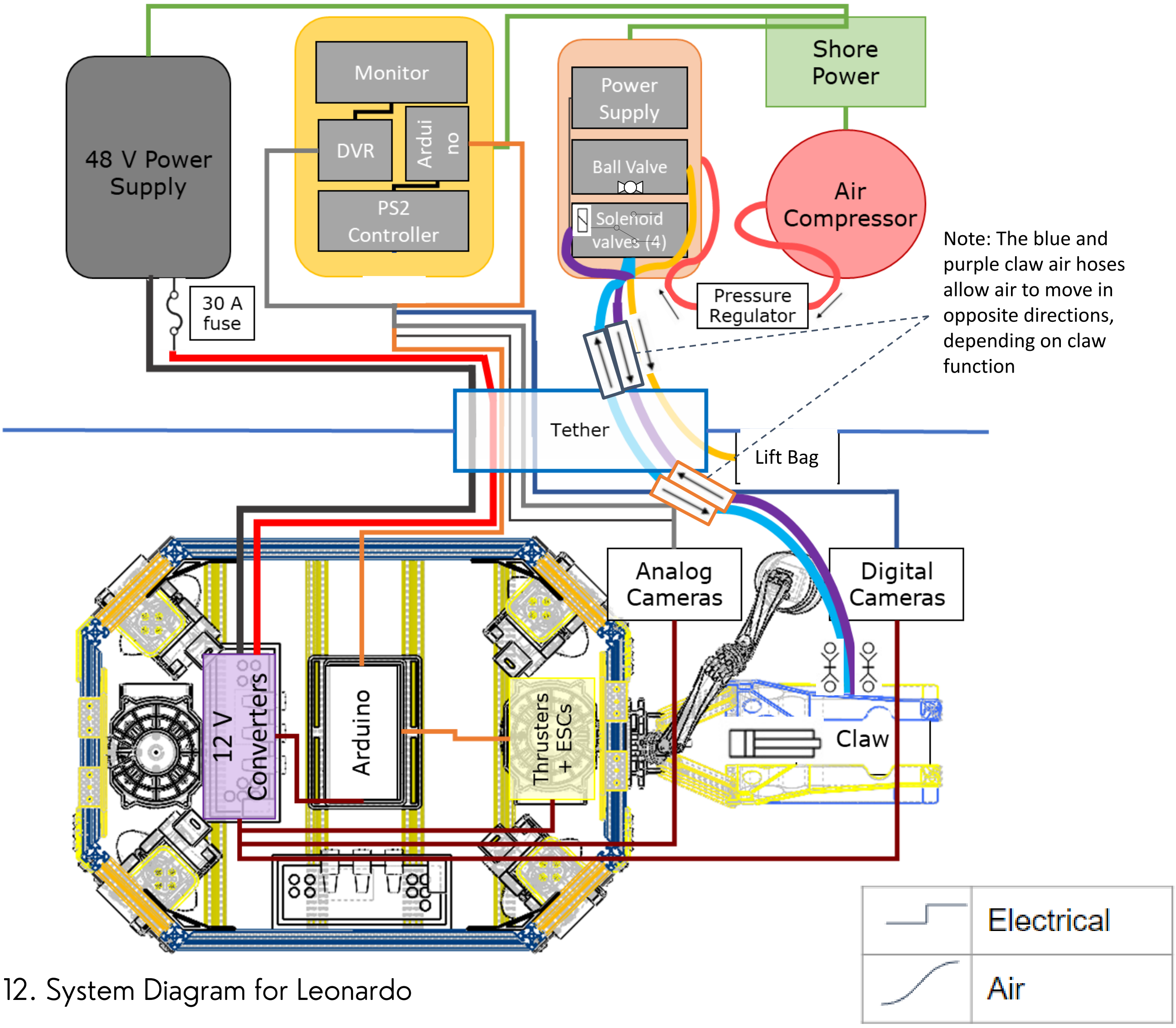
Figure 11. Leonardo's Manipulator and Tools

Vertical Profiler

Vertical Profiling systems are devices designed and produced to travel vertically through open waters and collect data at different depths. The Vertical Profiling system for this year's MATE ROV competition is a non-ROV device required to autonomously profile the height of the pool twice, similar to previous challenges, but is now also required to communicate with the base team before and after each profile.

The primary operation of the vertical profiler is the variable buoyancy engine, which consists of an air bladder driven by a linear actuator, that is controlled by an Arduino Mega. The system is powered by a 12 V battery pack, attached to a 7.5 A fuse. Communication between the profiler and the base is achieved with a Bluetooth antenna connected to the Arduino. The Arduino is then connected to an android phone, and operated with an .APK program on the phone. The shell of the profiler is built with clear plastic tubing, with caps on either end of the tube. The electronics are held in place with a 3D printed interior frame.

Leonardo System Diagram



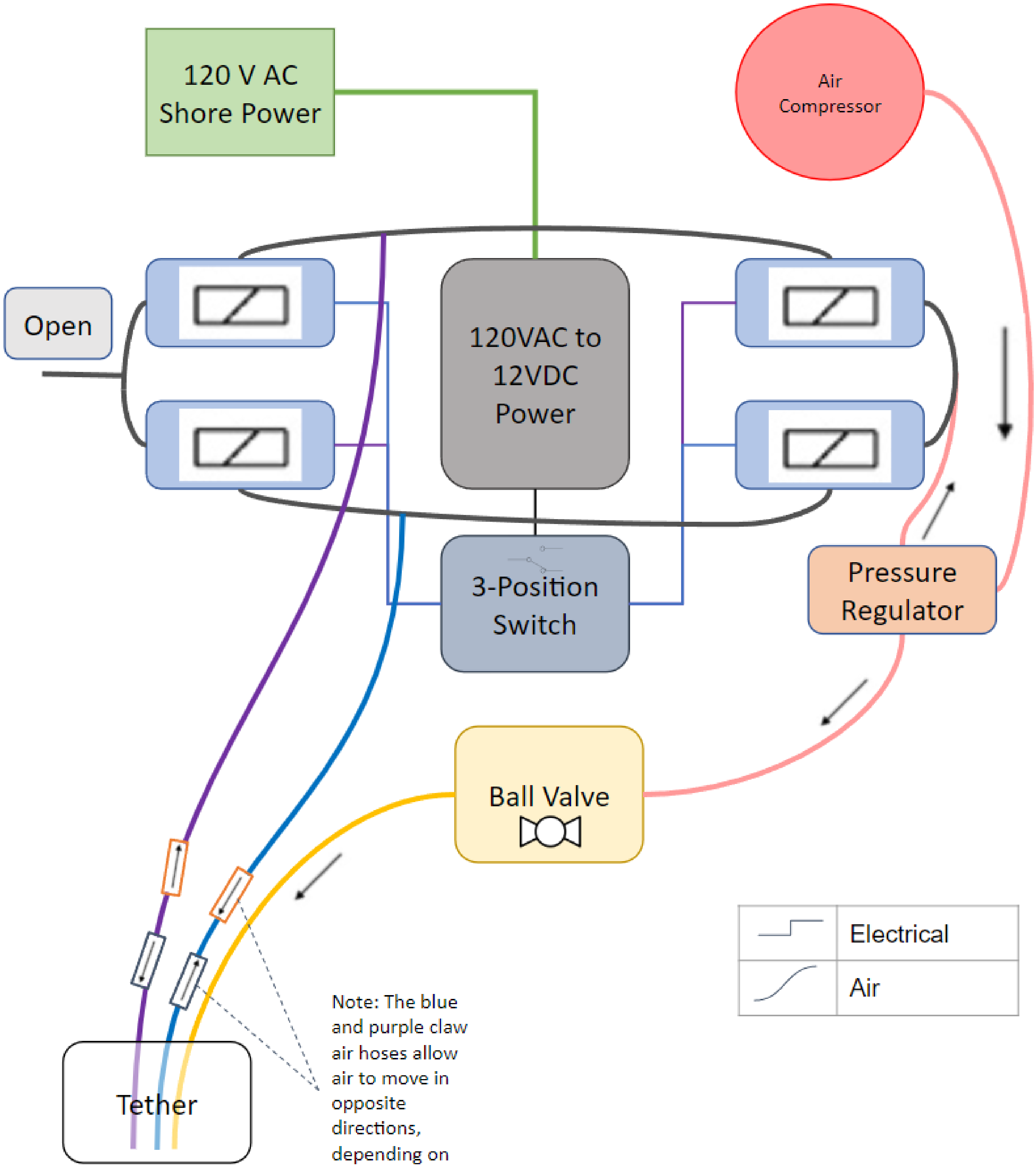
Note: The blue and purple claw air hoses allow air to move in opposite directions, depending on claw function

Figure 12. System Diagram for Leonardo

Component	Quantity	Nominal Voltage	Max Current Each (A)	Total Power Draw (W)	Current @ 12 V (A)
Thrusters	6	12	13	936	78
Cameras	4	5	0.22	4.4	0.3667
USB Transmitter	1	12	1	12	1
Arduino Uno	1	12	0.2	2.4	0.2
Depth Sensor	1	3.3	0.001	0.004	0.0003
				Total Current Draw:	79.57
				150%	119.35
				@ 48 V	29.8
				ROV uses 30 A fuse.	

Table 3. ROV Fuse Calculations

Pneumatic Control Diagram



Note: The blue and purple claw air hoses allow air to move in opposite directions, depending on claw function

Figure 13. Pneumatic Control Diagram

Vertical Profiler Diagram

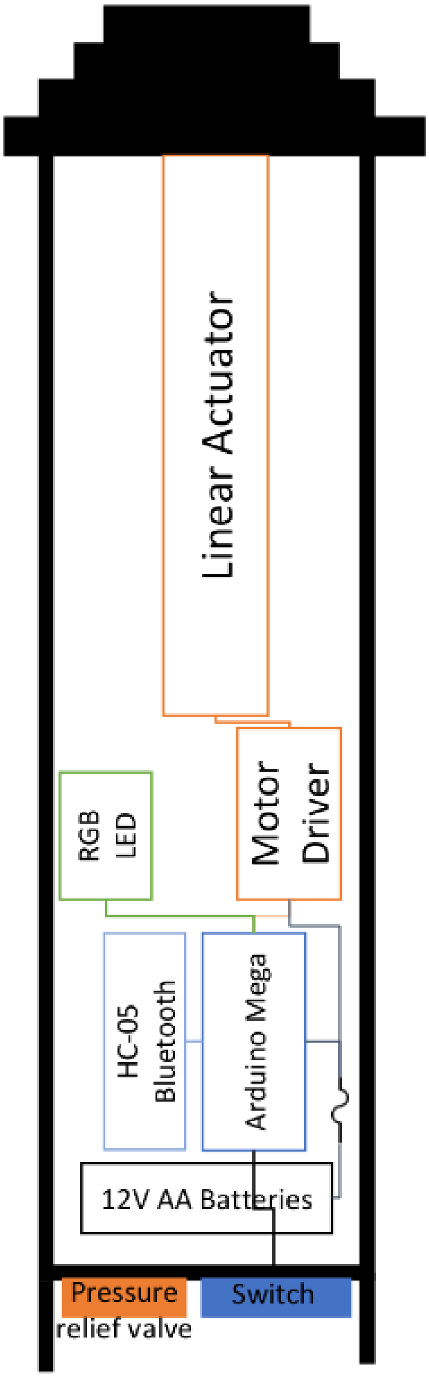


Figure 14. Vertical Profiler Diagram

Component	Nominal Voltage	Max Current (A)	Power Draw (W)	Current @ 12 V (A)
Arduino	12	0.200	2.4	0.200
Actuator	12	5.000	60	5.000
Bluetooth	3.3	0.050	0.165	0.014
			Total Current Draw:	5.214
			150%	7.82
			NRD uses 7.5 A fuse.	

Table 4. Vertical Profiler Fuse Calculations

Safety

Safety Philosophy

Employee safety is the company's top priority. All members are committed to the adherence and vigilance of all safety guidelines and procedures published by MATE, and have consistently exceeded all expectations of safety policies.

Linn-Benton ROV members must pass a training course designed to bring awareness to safety protocols and potential hazards prior to participation in any poolside operations. Protective eyewear is worn at all occasions that may include potential eye injuries.

Company Safety Protocols

Safety protocols are strictly enforced, with all members having a designated job to ensure the safety of the group and machinery. For example:

- Sara and Aren are designated to perform vehicle safety checks during setup for operation. The vehicle may not enter or be near water prior to completing the safety checks. In performing this inspection while keeping the vehicle away from the water, we reduce the risk of electrocution and harm to personnel, in addition to reducing the risk of shortages and damage to both the control station and the ROV.
- Levi is responsible for control station checks, including assuring that all wires are properly connected and protected. This procedure is performed prior to events as well as during setup.

Additionally, Linn-Benton ROV enforces the following lab protocols:

- Two people are required in lab when using tools.
- Safety glasses must be worn if using power tools.
- Closed toe shoes must be worn.
- While using knifes or razors maintain arms length from teammates.
- During hot-work team members are encouraged to remove synthetic materials.
- If unsure of a task, ask for assistance.
- An organized workspace is the best way to prevent accidents. Clean often.

The setup and operational plans can be seen in the Appendix.

Vehicle Safety Features

Just as the company's personnel are held to strict safety standards, the company's vehicle's are designed and built with safety as the ultimate goal.

When building Leonardo, the company paid special attention to the following safety features:

- smooth edges
- shrouded propellers
- securely waterproofed components
- highly rated waterproof connections between components
- fused power converters
- tether is fused at point of connection to power

Additionally, the vehicle's power supply features a single switch for quick disconnect of power in case of emergency.

Critical Analysis

Testing & Troubleshooting

Iterative design has been the keystone of Leonardo's development. New solutions always bring new challenges. With finite funds, power, space, weight, and time many solutions are theoretically viable but economically impractical. The white board and brainstorming sessions have been crucial for discovery during this process. Attempting to represent a concept graphically or verbalize it to a diverse set of perspectives yields substantial results. It allows team members to clarify their thoughts and discover shortcomings that may not be apparent to them. Trust and respect are crucial for this.

Debriefs are held immediately following every pool test. Each team member is encouraged to identify one thing that went well, and one thing that did not work with a solution moving forward. The process does take time, and a little patience, but the results lead to a practical consensus that could not be achieved otherwise. This also facilitates a shared set of skills where members know the design rationale of other subgroups within the team.

Manipulator design has benefited the most from this process. It has led to a core apparatus with several task specific adaptations from the syringe cone, to the fry release globe, and carabiner latch. The goal has been to minimize turnaround between tasks. Credit should go to Dale Sydnam for his ability to interpret team needs then design, and print new iterations in a timely and concise manner.

Many sections of the ROV went through multiple iterations before an efficient design was discovered. The front claw of the ROV passed through four iterations before a sufficient design was found. One problem that the team looked to solve was the use of the carabiner in the solar panel task. The challenge included attaching a carabiner on a PVC configuration to a U-bolt on the floor of the pool. Each iteration of the manipulator was printed using a 3D printer to evaluate the efficiency and functionality of the design.

The power supply was also modified after a complete failure during a pool test. Since no power converters were available for the project time frame, a creative solution was presented. A 12 V power converter intended for use in a golf cart was attached to the power system and functioned exceptionally well for the intended purpose.

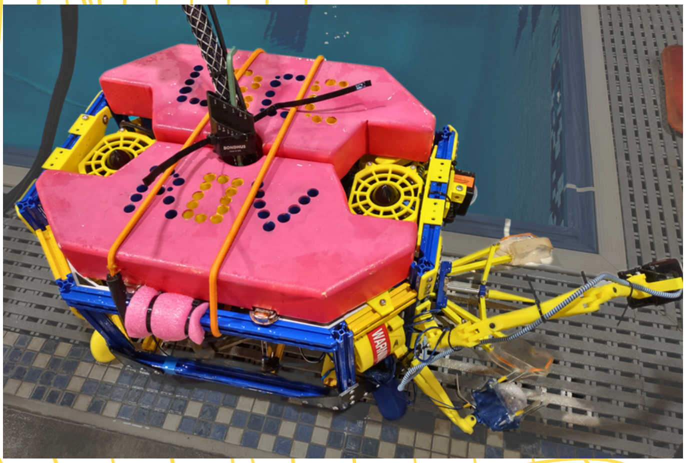
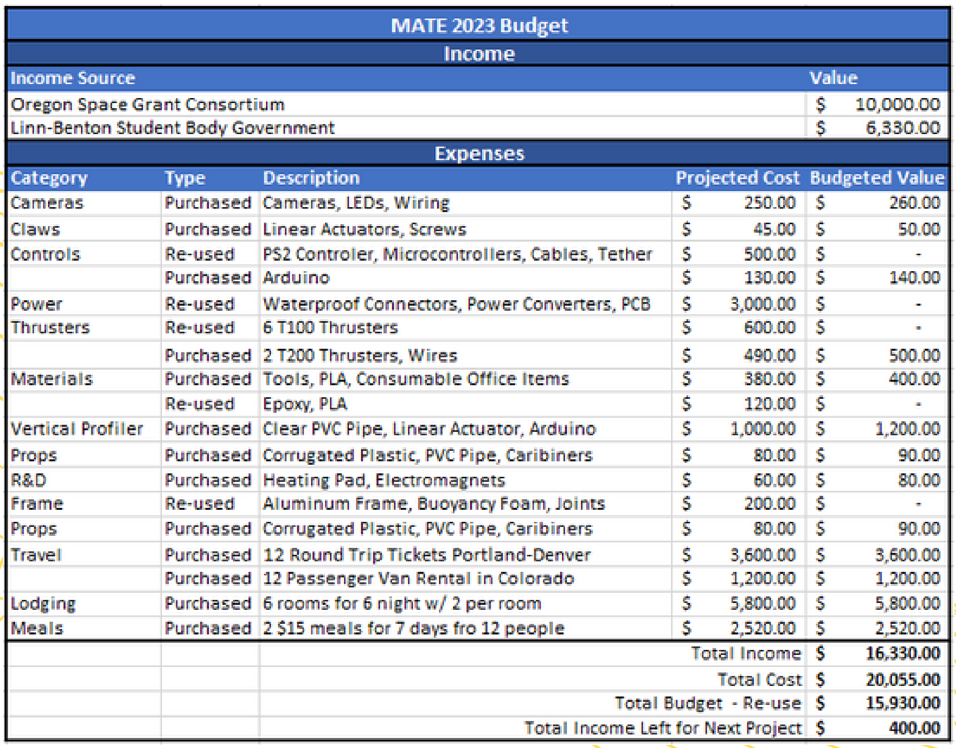


Figure 15. Leonardo prepared for testing, May 5th 2023

Accounting

Budget

The budget for the 2023 competition year was structured around a $10,000 grant awarded by the Oregon NASA Space Grant Consortium. Initial estimates were for $3,000 to be allocated to the project build. The remaining $7,000 would be allotted to competition travel expenses. The completion of a travel expense projection revealed an approximate budget deficit of $5,000. This deficit was ultimately covered by the generous contribution of Linn-Benton's student government. Further partitioning of build expenses was achieved through team estimates. A contingency fund was established for budget overages. Multiple checks and balances were implemented to ensure appropriate spending. Expenses would be submitted by teams to a shared Google Sheets document. These requests were to be approved by faculty advisor Greg Mulder. Purchases were executed by treasurer Teresa Woods.



MATE 2023 Budget

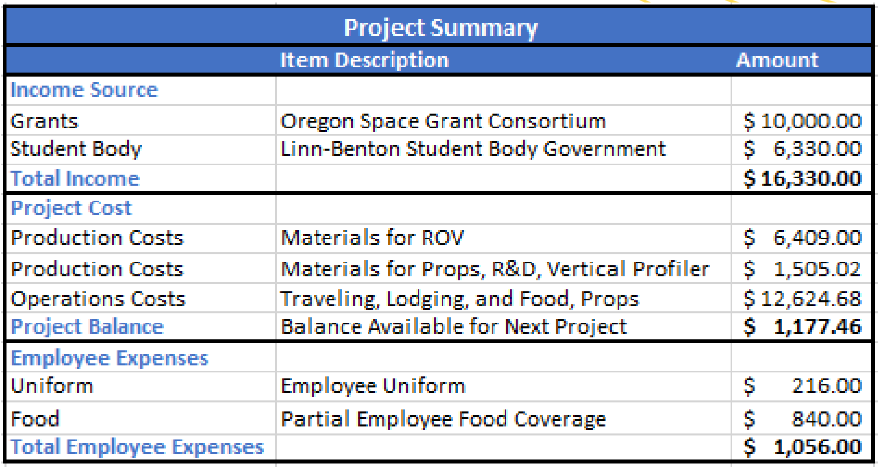
Income

Income Source	Value
Oregon Space Grant Consortium	$ 10,000.00
Linn-Benton Student Body Government	$ 6,330.00

Expenses

Category	Type	Description	Projected Cost	Budgeted Value
Cameras	Purchased	Cameras, LEDs, Wiring	$ 250.00	$ 260.00
Claws	Purchased	Linear Actuators, Screws	$ 45.00	$ 50.00
Controls	Re-used	PS2 Controler, Microcontrollers, Cables, Tether	$ 500.00	$ -
	Purchased	Arduino	$ 130.00	$ 140.00
Power	Re-used	Waterproof Connectors, Power Converters, PCB	$ 3,000.00	$ -
Thrusters	Re-used	6 T100 Thrusters	$ 600.00	$ -
	Purchased	2 T200 Thrusters, Wires	$ 490.00	$ 500.00
Materials	Purchased	Tools, PLA, Consumable Office Items	$ 380.00	$ 400.00
	Re-used	Epoxy, PLA	$ 120.00	$ -
Vertical Profiler	Purchased	Clear PVC Pipe, Linear Actuator, Arduino	$ 1,000.00	$ 1,200.00
Props	Purchased	Corrugated Plastic, PVC Pipe, Caribiners	$ 80.00	$ 90.00
R&D	Purchased	Heating Pad, Electromagnets	$ 60.00	$ 80.00
Frame	Re-used	Aluminum Frame, Buoyancy Foam, Joints	$ 200.00	$ -
Props	Purchased	Corrugated Plastic, PVC Pipe, Caribiners	$ 80.00	$ 90.00
Travel	Purchased	12 Round Trip Tickets Portland-Denver	$ 3,600.00	$ 3,600.00
	Purchased	12 Passenger Van Rental in Colorado	$ 1,200.00	$ 1,200.00
Lodging	Purchased	6 rooms for 6 night w/ 2 per room	$ 5,800.00	$ 5,800.00
Meals	Purchased	2 $15 meals for 7 days fro 12 people	$ 2,520.00	$ 2,520.00
			Total Income	**$ 16,330.00**
			Total Cost	**$ 20,055.00**
			Total Budget - Re-use	**$ 15,930.00**
			Total Income Left for Next Project	**$ 400.00**

Table 5. Budget for MATE 2023 Project

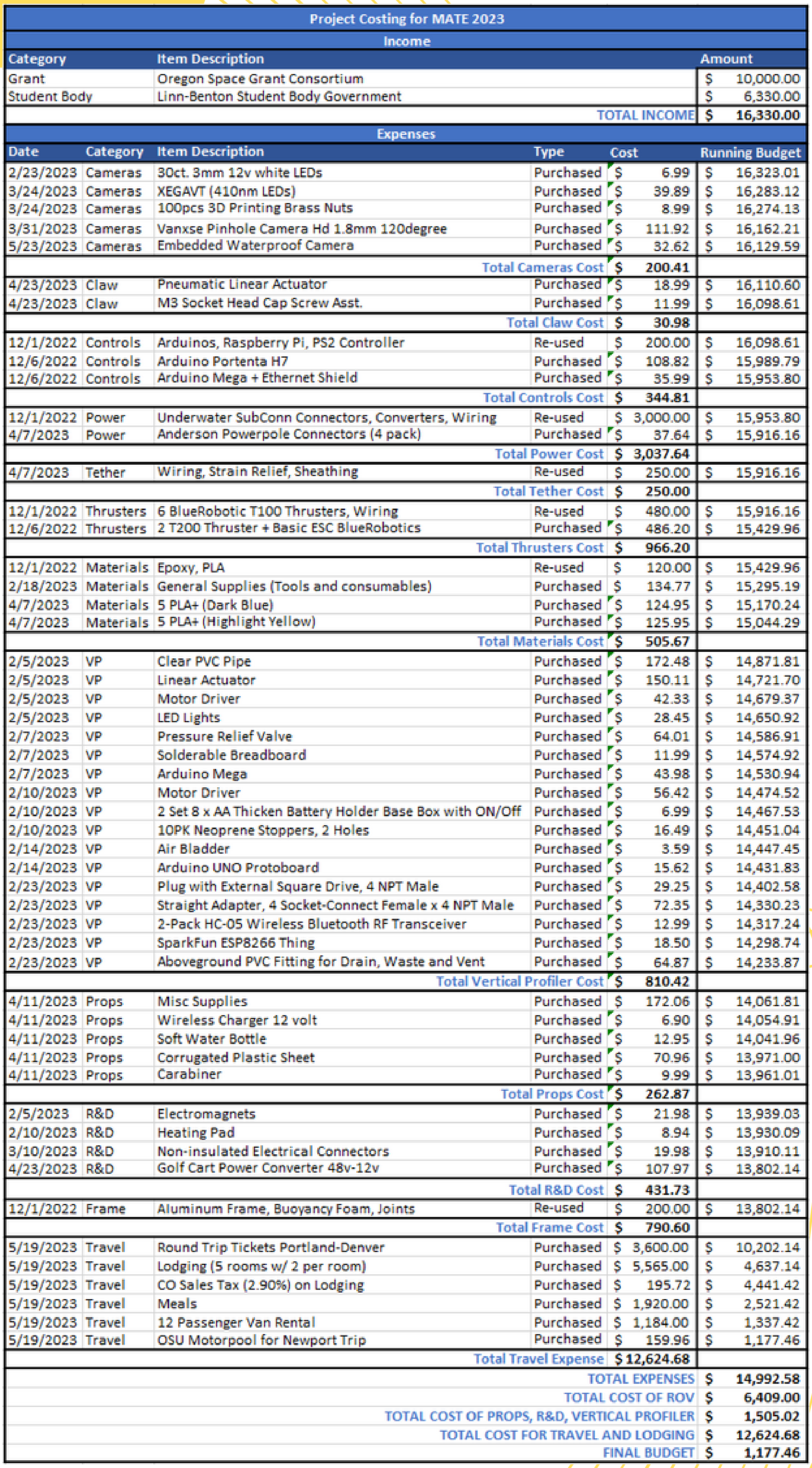


Project Summary

Item Description		Amount
Income Source		
Grants	Oregon Space Grant Consortium	$ 10,000.00
Student Body	Linn-Benton Student Body Government	$ 6,330.00
Total Income		**$ 16,330.00**
Project Cost		
Production Costs	Materials for ROV	$ 6,409.00
Production Costs	Materials for Props, R&D, Vertical Profiler	$ 1,505.02
Operations Costs	Traveling, Lodging, and Food, Props	$ 12,624.68
Project Balance	Balance Available for Next Project	**$ 1,177.46**
Employee Expenses		
Uniform	Employee Uniform	$ 216.00
Food	Partial Employee Food Coverage	$ 840.00
Total Employee Expenses		**$ 1,056.00**

Table 6. Project Cost Summary

Cost Accounting



Project Costing for MATE 2023

Income

Category	Item Description	Amount
Grant	Oregon Space Grant Consortium	$ 10,000.00
Student Body	Linn-Benton Student Body Government	$ 6,330.00
	TOTAL INCOME	$ 16,330.00

Expenses

Date	Category	Item Description	Type	Cost	Running Budget
2/23/2023	Cameras	30ct. 3mm 12v white LEDs	Purchased	$ 6.99	$ 16,323.01
3/24/2023	Cameras	XEGAVT (410nm LEDs)	Purchased	$ 39.89	$ 16,283.12
3/24/2023	Cameras	100pcs 3D Printing Brass Nuts	Purchased	$ 8.99	$ 16,274.13
3/31/2023	Cameras	Vanxse Pinhole Camera Hd 1.8mm 120degree	Purchased	$ 111.92	$ 16,162.21
5/23/2023	Cameras	Embedded Waterproof Camera	Purchased	$ 32.62	$ 16,129.59
			Total Cameras Cost	$ 200.41	
4/23/2023	Claw	Pneumatic Linear Actuator	Purchased	$ 18.99	$ 16,110.60
4/23/2023	Claw	M3 Socket Head Cap Screw Asst.	Purchased	$ 11.99	$ 16,098.61
			Total Claw Cost	$ 30.98	
12/1/2022	Controls	Arduinos, Raspberry Pi, PS2 Controller	Re-used	$ 200.00	$ 16,098.61
12/6/2022	Controls	Arduino Portenta H7	Purchased	$ 108.82	$ 15,989.79
12/6/2022	Controls	Arduino Mega + Ethernet Shield	Purchased	$ 35.99	$ 15,953.80
			Total Controls Cost	$ 344.81	
12/1/2022	Power	Underwater SubConn Connectors, Converters, Wiring	Re-used	$ 3,000.00	$ 15,953.80
4/7/2023	Power	Anderson Powerpole Connectors (4 pack)	Purchased	$ 37.64	$ 15,916.16
			Total Power Cost	$ 3,037.64	
4/7/2023	Tether	Wiring, Strain Relief, Sheathing	Re-used	$ 250.00	$ 15,916.16
			Total Tether Cost	$ 250.00	
12/1/2022	Thrusters	6 BlueRobotic T100 Thrusters, Wiring	Re-used	$ 480.00	$ 15,916.16
12/6/2022	Thrusters	2 T200 Thruster + Basic ESC BlueRobotics	Purchased	$ 486.20	$ 15,429.96
			Total Thrusters Cost	$ 966.20	
12/1/2022	Materials	Epoxy, PLA	Re-used	$ 120.00	$ 15,429.96
2/18/2023	Materials	General Supplies (Tools and consumables)	Purchased	$ 134.77	$ 15,295.19
4/7/2023	Materials	5 PLA+ (Dark Blue)	Purchased	$ 124.95	$ 15,170.24
4/7/2023	Materials	5 PLA+ (Highlight Yellow)	Purchased	$ 125.95	$ 15,044.29
			Total Materials Cost	$ 505.67	
2/5/2023	VP	Clear PVC Pipe	Purchased	$ 172.48	$ 14,871.81
2/5/2023	VP	Linear Actuator	Purchased	$ 150.11	$ 14,721.70
2/5/2023	VP	Motor Driver	Purchased	$ 42.33	$ 14,679.37
2/5/2023	VP	LED Lights	Purchased	$ 28.45	$ 14,650.92
2/7/2023	VP	Pressure Relief Valve	Purchased	$ 64.01	$ 14,586.91
2/7/2023	VP	Solderable Breadboard	Purchased	$ 11.99	$ 14,574.92
2/7/2023	VP	Arduino Mega	Purchased	$ 43.98	$ 14,530.94
2/10/2023	VP	Motor Driver	Purchased	$ 56.42	$ 14,474.52
2/10/2023	VP	2 Set 8 x AA Thicken Battery Holder Base Box with ON/Off	Purchased	$ 6.99	$ 14,467.53
2/10/2023	VP	10PK Neoprene Stoppers, 2 Holes	Purchased	$ 16.49	$ 14,451.04
2/14/2023	VP	Air Bladder	Purchased	$ 3.59	$ 14,447.45
2/14/2023	VP	Arduino UNO Protoboard	Purchased	$ 15.62	$ 14,431.83
2/23/2023	VP	Plug with External Square Drive, 4 NPT Male	Purchased	$ 29.25	$ 14,402.58
2/23/2023	VP	Straight Adapter, 4 Socket-Connect Female x 4 NPT Male	Purchased	$ 72.35	$ 14,330.23
2/23/2023	VP	2-Pack HC-05 Wireless Bluetooth RF Transceiver	Purchased	$ 12.99	$ 14,317.24
2/23/2023	VP	SparkFun ESP8266 Thing	Purchased	$ 18.50	$ 14,298.74
2/23/2023	VP	Aboveground PVC Fitting for Drain, Waste and Vent	Purchased	$ 64.87	$ 14,233.87
			Total Vertical Profiler Cost	$ 810.42	
4/11/2023	Props	Misc Supplies	Purchased	$ 172.06	$ 14,061.81
4/11/2023	Props	Wireless Charger 12 volt	Purchased	$ 6.90	$ 14,054.91
4/11/2023	Props	Soft Water Bottle	Purchased	$ 12.95	$ 14,041.96
4/11/2023	Props	Corrugated Plastic Sheet	Purchased	$ 70.96	$ 13,971.00
4/11/2023	Props	Carabiner	Purchased	$ 9.99	$ 13,961.01
			Total Props Cost	$ 262.87	
2/5/2023	R&D	Electromagnets	Purchased	$ 21.98	$ 13,939.03
2/10/2023	R&D	Heating Pad	Purchased	$ 8.94	$ 13,930.09
3/10/2023	R&D	Non-insulated Electrical Connectors	Purchased	$ 19.98	$ 13,910.11
4/23/2023	R&D	Golf Cart Power Converter 48v-12v	Purchased	$ 107.97	$ 13,802.14
			Total R&D Cost	$ 431.73	
12/1/2022	Frame	Aluminum Frame, Buoyancy Foam, Joints	Re-used	$ 200.00	$ 13,802.14
			Total Frame Cost	$ 790.60	
5/19/2023	Travel	Round Trip Tickets Portland-Denver	Purchased	$ 3,600.00	$ 10,202.14
5/19/2023	Travel	Lodging (5 rooms w/ 2 per room)	Purchased	$ 5,565.00	$ 4,637.14
5/19/2023	Travel	CO Sales Tax (2.90%) on Lodging	Purchased	$ 195.72	$ 4,441.42
5/19/2023	Travel	Meals	Purchased	$ 1,920.00	$ 2,521.42
5/19/2023	Travel	12 Passenger Van Rental	Purchased	$ 1,184.00	$ 1,337.42
5/19/2023	Travel	OSU Motorpool for Newport Trip	Purchased	$ 159.96	$ 1,177.46
			Total Travel Expense	$ 12,624.68	
				TOTAL EXPENSES	$ 14,992.58
				TOTAL COST OF ROV	$ 6,409.00
				TOTAL COST OF PROPS, R&D, VERTICAL PROFILER	$ 1,505.02
				TOTAL COST FOR TRAVEL AND LODGING	$ 12,624.68
				FINAL BUDGET	$ 1,177.46

Table 7. Project Costing Summary for 2023 MATE

Conclusion

Acknowledgements

Linn-Benton ROV would like to acknowledge the countless contributors that allowed the company to thrive in the MATE competition.

Members of the ROV team would like to personally thank our mentors, including Greg Mulder, Kathy Austin, and Heather Hill, for their immense efforts towards leading and guiding the efforts of the team for the greater success of our ROV.

We would also like to thank Oregon Space Grant, miniROV Physics, and LBCC Leadership for providing the funds to allow the team to come together and participate in a truly amazing learning and professional experience. From their contributions, we were able to design, build, and operate an ROV of our own.

We must also thank the Willamette-Valley Family YMCA and Lindenwood Apartments for graciously allowing our team to use their pools each week for crucial testing of ROV piloting and tasks. Through their help, we have been able to greatly improve nearly all aspects of the ROV, allowing us to achieve many more of our company goals.

References

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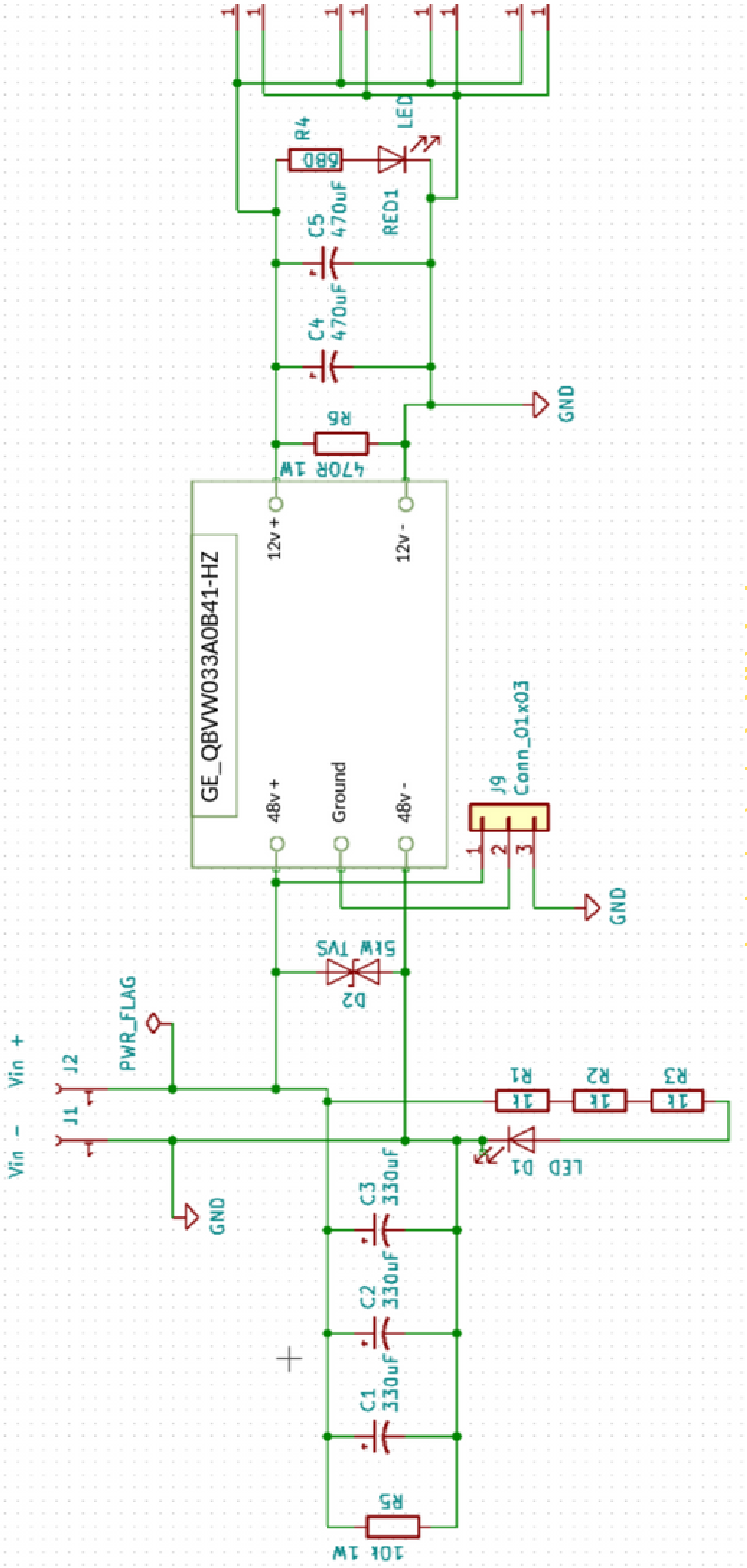
Appendix

Power Conversion Circuit Diagram



Setup Plan

ROV Setup

Topside:

- ☐ Ensure the air compressor drain valve is closed.
- ☐ Charge air compressor.
- ☐ Ensure tether is securely mounted to the control station.
- ☐ Set up ROV power supply:
  - ☐ Ensure power supply is switched *OFF*.
  - ☐ Ensure ROV power supply is switched *OFF*.
  - ☐ Connect White Power Cord to power supply input.
  - ☐ Connect White Power Cord to shore power (extension cord may be needed).
  - ☐ Connect blue Anderson Connector from tether to power supply.
- ☐ Set up yellow monitor box:
  - ☐ Connect Orange Ethernet from tether to Topside Arduino (blue/yellow box).
  - ☐ Connect PS2 Controller to Yellow Ethernet from Topside Arduino.
  - ☐ Connect the Topside Arduino to power using the 12 V power supply.
  - ☐ Connect Gray Ethernet from tether to Orange Ethernet in the monitor box.
    - ☐ Ensure orange camera ethernet connects to DVR through baluns.
  - ☐ Ensure the power strip is switched *OFF*.
  - ☐ Ensure DVR, Monitor, Pneumatic Control Box and Arduino are connected to the power strip.
  - ☐ Plug the power strip into shore power (extension cord may be needed).
  - ☐ Switch on the power strip. Ensure the monitor, DVR, and Arduino are receiving power. Ensure the red *analog* light on the PS2 Controller is on.
- ☐ Set up pneumatic control box:
  - ☐ Ensure the toggle switch is in the *middle* position.
  - ☐ Ensure the ball valve is in the *closed* position.
  - ☐ Connect the red pressure regulator hose to the red IN fitting in the pneumatic control box.
  - ☐ Connect the air compressor to the red pressure regulator hose.
  - ☐ Connect the purple air hose from tether to the purple fitting.
  - ☐ Connect the blue air hose from tether to the blue fitting.

Wait for ROV Side setup to complete before continuing.

ROV Side:

- ☐ Ensure tether is securely attached to ROV with both strain relief hooks.
- ☐ Connect the 2-pin square connectors (4 total) to the power converters. Ensure any unused 2-pin connectors are securely covered with a dummy plug.
- ☐ Connect the orange 8-pin circular connector to the ROV Side Arduino (8-pin) and fasten the screw casing.
- ☐ Connect the purple 8-pin circular connector to the analog camera connector (8-pin) and fasten the screw casing.
- ☐ Connect the purple air hose to the purple claw fitting.
- ☐ Connect the blue air hose to the blue claw fitting.
- ☐ Ensure all connections are secure.
- ☐ Ensure all unused connections are covered with dummy plugs.

  Commonly unused connections:
    - ☐ Arduino FTDI
    - ☐ 48 V Power from tether
    - ☐ 12 V output from PCBs (*2*)
    - ☐ Digital Camera CAT5 from tether
- ☐ Have a second person check all connections before proceeding.

Operations Plan

ROV Pre-Operation Power-On Test (Pilot & Co-Pilot):

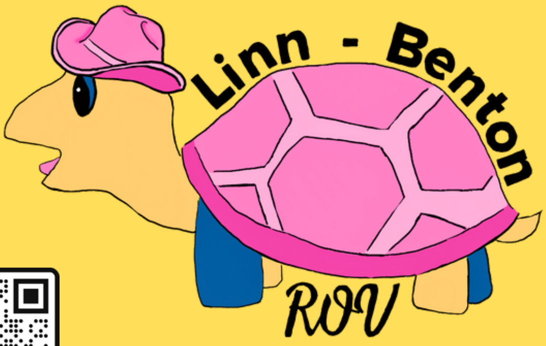
- ☐ Verify with those who set up the ROV that all connections are plugged and secure.
- ☐ Verify that the Red LED on the PS2 Controller is glowing red.
- ☐ Turn the main power on to the power supply and following this, turn on power to the ROV.
- ☐ Ensure no controls on the controller are engaged and verifies that no thrusters are moving when the controller is not receiving input.
- ☐ Verify cameras are operational and communicate the camera view adjustments to the tether team.
- ☐ Verify thrusters do respond to input by slightly bumping controls.
- ☐ Disengage power from the ROV, keeping the power supplies main power engaged.

ROV Operation Plan:

- ☐ The tether team lowers the ROV into the water.
- ☐ Co-Pilot engages power to the ROV as it is lowered into the water.
- ☐ Pilot communicates with the tether team necessary adjustments to all cameras.
- ☐ Pilot then completes mission tasks communicating with the tether team as needed to interact with mission components and adjustments in tether tension.
- ☐ At the end of the mission Pilot returns ROV to the poolside it entered on and requests the tether team to remove the ROV from the pool.
- ☐ Co-Pilot Disengages power once they confirm the tether team has control over the ROV.

ROV Post-Operation Plan:

- ☐ Remove all items brought from the pool.
- ☐ Remove all connections from the control system interfaces (Arduino, DVR, Pneumatic Control Box, Power Supply).
- ☐ Return all tools and wiring to the location it arrived in.
- ☐ Move control system interface containers to the bottom of the ROV cart.
- ☐ Leave all connections that directly attach to the ROV attached. It is quicker and allows more water to be removed before exposing the electrical connections.
- ☐ Wrap the ROV tether up on top of the ROV .
- ☐ Move the ROV to the top of the cart.
- ☐ Release the pressure drain valve on the air compressor.
- ☐ Pack all Props and ROV components.
- ☐ Double check we have gathered everything we brought.



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Linn-Benton ROV

For the ROVs who say "dude!"

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