Bruin Underwater Robotics

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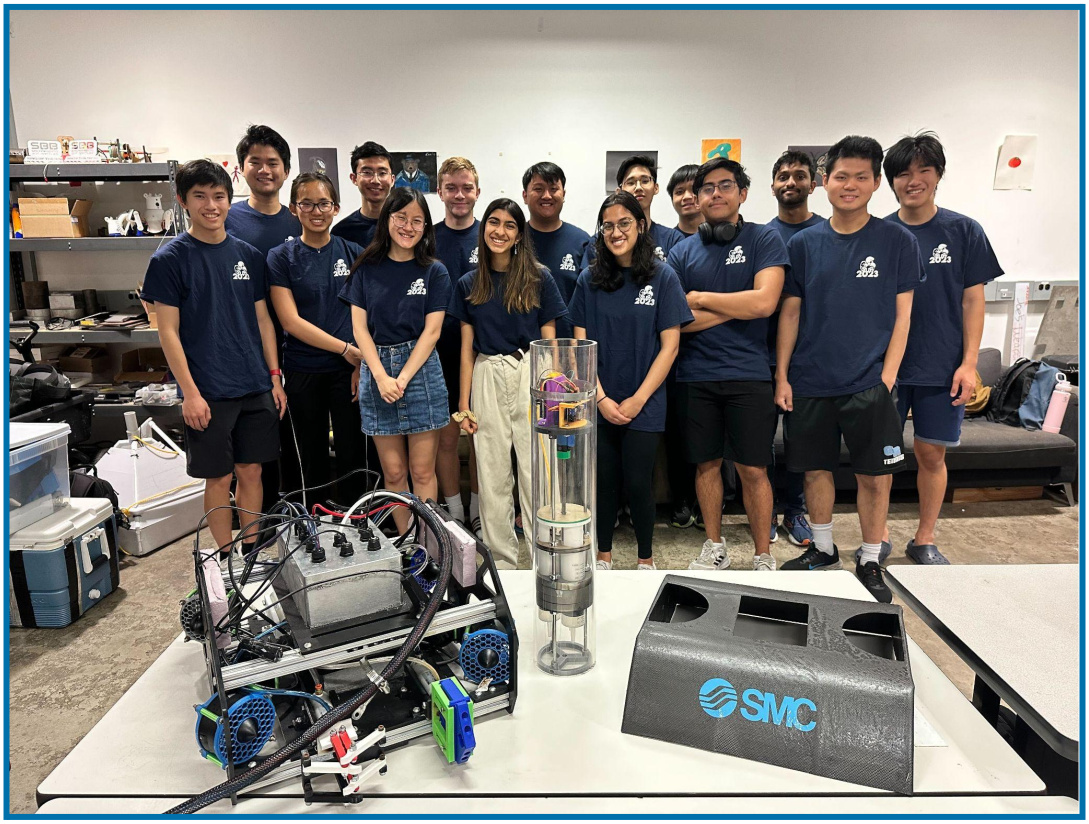


Team Photo

1. Abstract

Bruin Underwater Robotics (BUR) was founded with the goal of aiding the global community in deploying renewable energy resources and protecting critical ocean resources. In order to support those goals, we present Genesis, an ROV capable of deploying floating solar arrays, treating endangered coral reefs, and utilizing profiling floats to collect additional data. After our formation last year, our team of 30 employees has been working to improve upon our foundations, and deploy Genesis as our first robot in the Explorer class.

Our company is divided into three subteams: Aquaframe, Dive Operations (Dive-Ops), and Electronics. Each subteam is responsible for the design and manufacture of a critical component of the ROV. Given the lessons that were gleaned from our inaugural year, our design focused on mechanical simplicity and ensuring that the fundamentals of our robot were solid. The following technical document illustrates our design rationale, processes and practices that created Genesis.

2. Safety

2.1 Philosophy

At Bruin Underwater Robotics (BUR), we operate under a simple, yet effective, safety philosophy: Safety First. That idea is emphasized across all areas of our design, manufacturing, and testing cycles. Our goal is to ensure that no one gets hurt while working on Genesis, and we believe that the best fun in engineering is safe fun.

2.2 Standards

Due to our safety philosophy, we hold ourselves to the highest standards when it comes to safely designing, building, and operating Genesis. Before anyone can use any power tools and machines, from a hand drill to a lathe, he or she must be given safety training by one of our core safety officers. Our core safety officers are experienced employees from the year prior who have shown the ability to responsibly operate and teach operation of various machines. Proper personal protective equipment (PPE) is worn at all times in the lab, which consists of safety glasses anytime work is being done in the lab and masks whenever any sanding or filing is being done. The lab itself is equipped with an eyewash station, safety shower, fire extinguisher, first-aid kit, and more, so every employee could minimize any damage in the event of an accident.

In addition to general safety standards, we designed additional protocols and mechanisms with regard to the design and operation of Genesis. The thrusters on Genesis were equipped with 3D-printed safety mesh which blocked the ingress of any material larger than a human finger. This shroud ensured no fingers could be damaged while the thrusters were operating. Genesis had robust top-side and ROV-side strain relief to prevent unnecessary tension on critical lines, specifically ethernet, power, and air-inlet lines.

Our pneumatics and electronics were also carefully made to make sure no one in the company could get hurt. All wiring for electronics, including top-side and ROV, was covered with either heat shrink or electrical tape to prevent any short-circuits. All pneumatic components, such as tubing, actuators, and more, were carefully chosen to be able to operate at over 2.5 times our operating pressure (40 psi). Our electronics box was carefully made and robustly tested to ensure no water could get in, preventing the electronics from getting damaged.

3. Mechanical Design Rationale

3.1 Mechanical Design Overview

The mechanical design of Genesis focused on keeping weight to a minimum while ensuring it was still structurally sound. One of the primary decisions was to heavily use high-density polyethylene (HDPE) sheets. That is because HDPE is relatively light while still providing enough strength to support Genesis, and it could easily be machined with a laser cutter. Every part was designed and analyzed with SolidWorks and tested constantly to ensure it would not fail during operation.

The primary improvement between Genesis and last year's ROV was the reliability of the electronics bay. Last year, the electronics bay had constant leaking issues, both with its sealing gasket as well as the gaskets used to pass through cables. Genesis greatly improved on this, as its gasket was constantly tested until it was proven to withstand 15 feet of water pressure, and different cord grips were bought to allow wires and tubes to pass into the electronics bay.

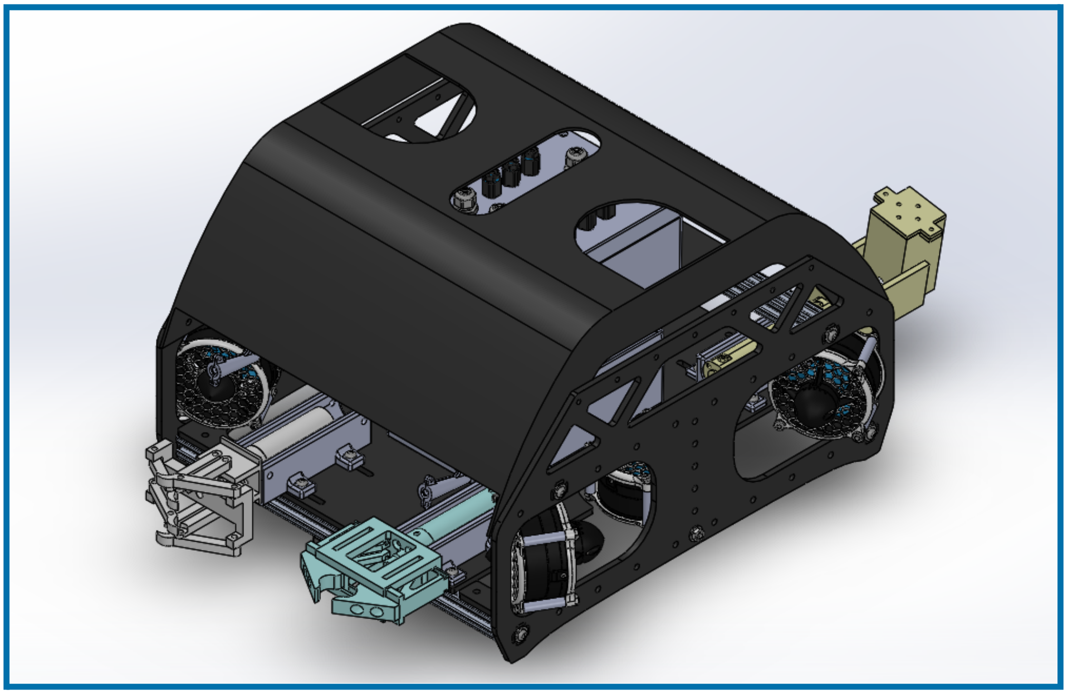


Figure 1: Full 3D CAD from Solidworks.

3.2 Chassis

The main feature of the chassis is the 2 HDPE side plates connected with 8020 aluminum extrusions. The 8020 extrusions provided stability for Genesis while naturally providing easy mounting points with slots for T-slot nuts. This made it easy to mount a top and bottom plate, both made of HDPE. The bottom plate was needed to hold the solenoid box and actuators, while the top plate held the electronics bay. To cover the entire ROV, a carbon fiber cover was made using a wet-layup.

Genesis utilized 6 T200 Blue Robotics thrusters in order to maneuver. They were attached to the ROV using brackets made of HDPE. 2 thrusters provided vertical movement for Genesis, while the other 4 provided in-plane movement. In total, Genesis had 5 degrees of freedom, although only 4 could be controlled by the pilot. Each thruster was guarded with a 3D-printed mesh, which prevents fingers from getting caught in the propeller.

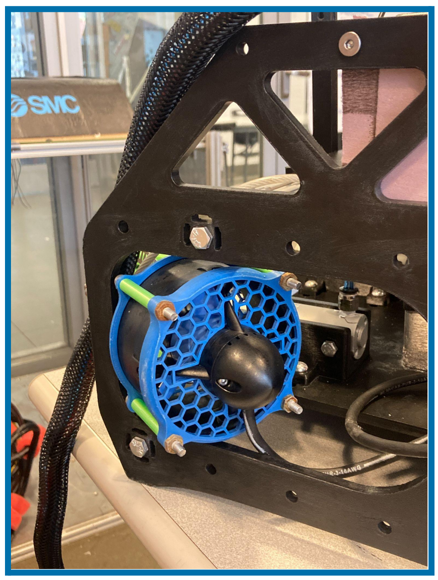


Figure 2: Mesh Protector Attached to Thrusters.

3.3 Electronics Bay

The electronics bay is a critical component of the ROV, supporting all basic functionality and linking Genesis to our topside controls. The electronics bay is connected to power and receives commands through cord grip cable pass throughs which support both a powered connection and Ethernet. The electronics bay also supports connections to 6 thrusters, 3 USB cameras, and pneumatics components were housed in an additional watertight enclosure. Operations are supported by 6 electronic speed controllers that drive the thrusters, an Arduino Mega, and a Raspberry Pi. These electronics are in turn supported by a 48-12 buck converter, and a custom made rectangular PCB. The rectangular shape of the electronics bay fits the form of the electronics and manufactured electronics sled.

The electronics bay is formed of a purchased Polycase watertight box, which is rated with IP68 waterproofing. Initially we intended to manufacture our own using clear acrylic tubing, but were unable to acquire aluminum necessary to machine the seals. To accommodate the necessary electronics, and cable connections, the holes were milled into the top of the box, housing cordgrips. This design was a significant improvement upon past designs, which required many more bolts to properly seal the enclosure, and had multiple issues with waterproofing from the cable gland and face seal.

3.4 Solenoid Box

The solenoid box housed all pneumatic manifolds and solenoid valves for Genesis. The primary focus of the solenoid box was to ensure that the valves would stay safe from the marine environment. This was done with a purchased IP68 Polycase watertight box, and cord grips were used to pass tubes in and out of the solenoid box. The reliability of the solenoid box was tested with the electronics bay, ensuring that any electronics components would stay safe.

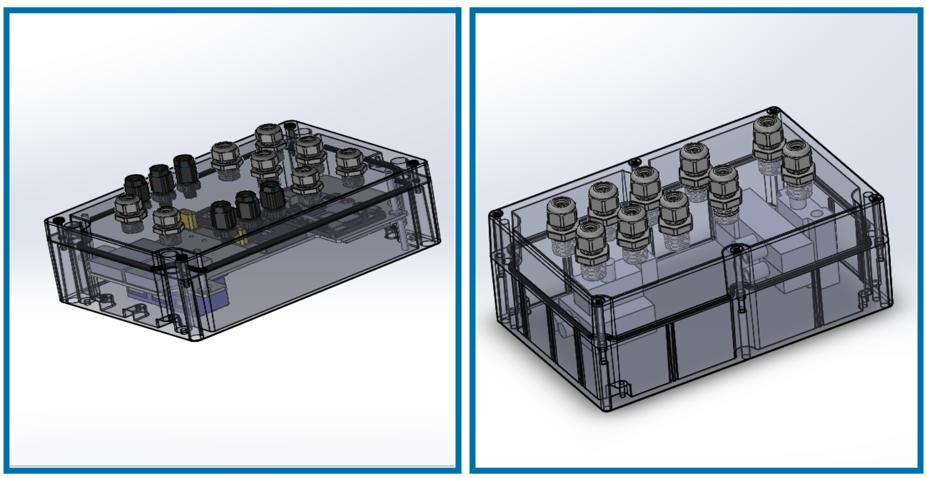


Figure 3: 3D Model of the Electronics Bay (left) and Solenoid Box (right).

3.4 Camera Layout

Genesis relied on 3 different cameras to see the pool. USB borescopes were used because of their inherent waterproofing, and 3D-printed brackets were attached to the outside of the borescopes using silicone to ensure no water could possibly damage them. The cameras were attached to Genesis using 3D-printed mounts. Because of the slots in the 8020, the cameras could be mounted anywhere along the ROV, allowing the pilot to test out multiple different views easily. One camera was placed above the two main arms so there would be a clear view of both of them at once, another camera was placed underneath the claw arm to easily see any objects it would have to grab, and the final camera was pointed toward the fish container.

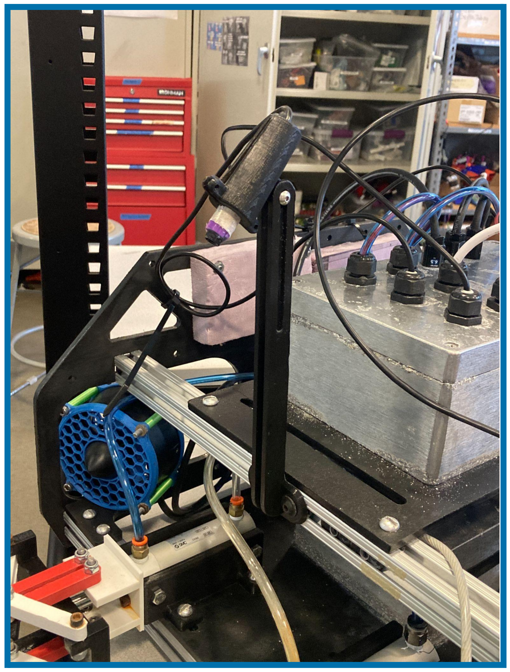


Figure 4: Front Facing Camera.

4. Mission Tools

4.1 Overview

This year, BUR utilized pneumatics to control the different arms of Genesis. An arm is defined simply as a tool controlled by a pneumatic actuator that could be used to complete a task. Pneumatics was chosen this year because of the amount of force that can be applied by 40 psi compressed air. 4 different actuators were used aboard Genesis, 2 being double-action and 2 being spring-return single action actuators. Each actuator was controlled with a different solenoid valve. Genesis only ended up with 3 different arms, but it still had 4 actuators to keep it balanced in the water.

4.2 Claw Arm

The claw arm was made to easily grab PVC pipes of all sizes due to its large range of motion. It was made of 3D-printed PLA so it could be easily iterated on. The claw was mounted horizontally so it could grab any vertical PVC pipes, and its one degree of freedom made it very simple yet effective. Since its claws overlap, it was able to fit onto any PVC pipe tightly and since it was powered by a pneumatic actuator, it had considerable grip strength, rarely losing grip upon a pipe.

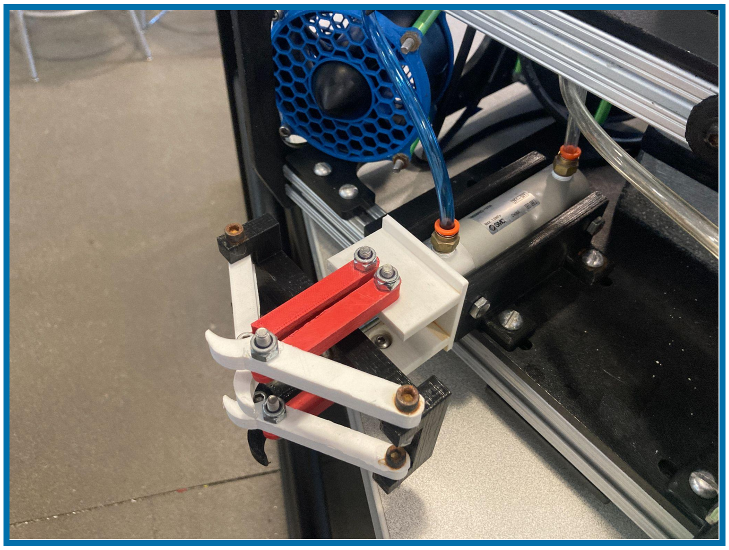


Figure 5: Claw Arm Attached to Genesis.

4.3 Slider Arm

The slider arm was also made of 3D-printed PLA, and was designed to grab horizontal PVC pipes. By mounting the arm vertically, the pilot could easily see any object in the arm, as it was positioned to be right in the middle of the camera. The slider arm utilizes a sliding mechanism to turn the actuating mechanism from the pneumatic actuator into a clamping motion, although this sacrifices a lot of force due to the friction of sliding. The camera mounting further aided the pilot by focusing on the two central arms, allowing the pilot to focus on a single view for both arms.

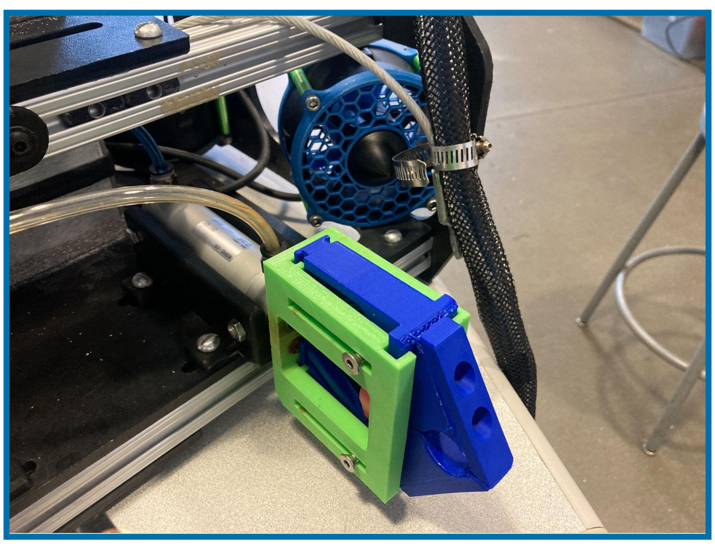


Figure 6: Slider Arm Attached to Genesis.

4.4 Fry Arm

The Fry Arm was specifically designed to complete the fry release task. The fry would be loaded into the arm prior to the start of the Product Demonstration, and the pneumatic actuator would push the box out when it needed to be released, causing the fry to fall down onto the pool floor.

A camera was placed to see the fry arm to allow the pilot to easily navigate to and drop off the fry in the safe area.

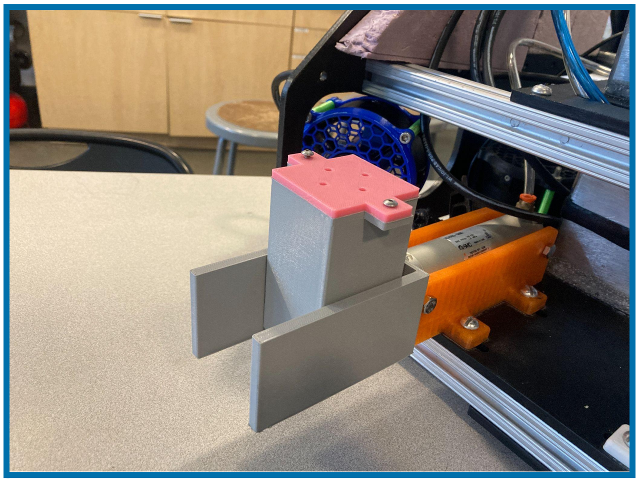


Figure 7: Fry Arm Attached to Genesis.

4.5 Profiling Float

The vertical profiling float is a separate device constructed to communicate data in between vertical profiles. After being deployed by the ROV, the float utilizes a buoyancy engine to alter its density, thus causing upwards or downwards acceleration. While on the water surface, the float utilizes bluetooth communication to wirelessly transmit data to the topside controls systems. The development of the float occurred in four stages (buoyancy engine, chassis, electronics, integration), with each posing their own challenges and setbacks. The design philosophy of the float was accessibility first — how could this be created using available materials and production methods? As such, much of the float is created using student-designed components that are possible to make in either a makerspace or machine shop. If not possible, components were purchased out of necessity after careful consideration. As a result, our team managed to produce a fairly affordable profiling float that successfully accomplishes the tasks it set out to do.

Figure 8: Assembled Profiling Float.

5. Electronic Hardware

5.1 Topside Electronics Overview

The topside electronics were kept as simple as possible. The 48V power supply provided power to the tether on the topside, with a fuse preventing any overcurrent from occurring. A laptop and controller were used to control the ROV, communicating with Genesis using an Ethernet cable. By keeping the topside electronics system simple, the pilot had little to worry about when piloting, allowing him to focus on doing the tasks.

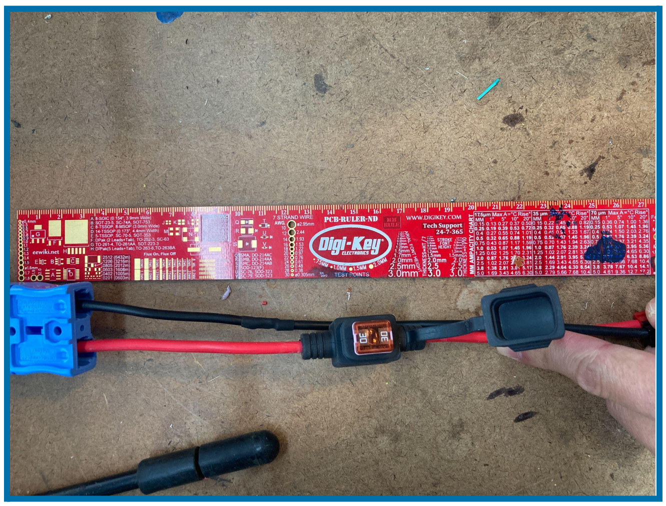


Figure 9: Fuse within 30 cm of power supply

5.2 Onboard Electronics Overview

The electronics on Genesis were chosen to be as reliable as possible while conserving space. The 48V from topside was converted to 12 V through 2 different buck converters, and those 12 V lines were routed to the ESCs, solenoid valve control, and a 12 to 5 V buck converter, which powered the Raspberry Pi. The Raspberry Pi communicated with the topside electronics using an Ethernet cable, and it had 4 USB outputs: 3 for the 3 different onboard cameras and 1 for the Arduino Mega. The Arduino Mega was responsible for providing signal to the ESCs while also controlling the solenoid valves. The ESCs were from Blue Robotics, and they controlled the 6 different thrusters that allowed Genesis to maneuver.

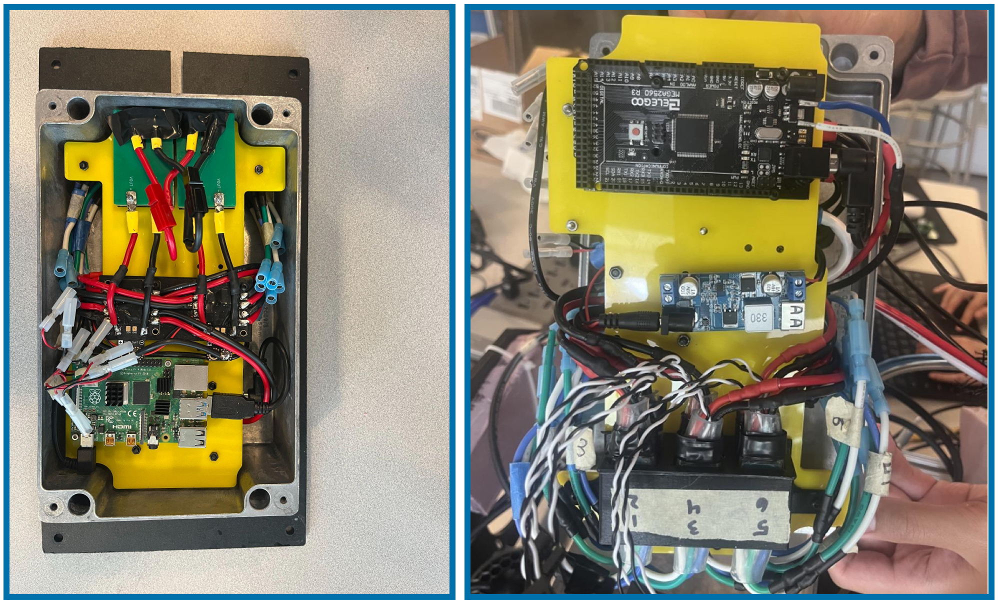


Figure 10: Top side (left) and bottom side (right) of onboard electronics tray

5.3 PCBs

Unlike last year, BUR chose to integrate printed circuit boards (PCBs) onto the ROV. The main PCB that was constantly tested with and iterated upon was a shield for the Arduino Mega. This shield provided pins for the ESC signal wires, making it easy to plug in and use different ESCs. In addition, the PCB was able to control the 4 different solenoid valves. This was done by utilizing MOSFETs, so a simple digital HIGH signal from an Arduino pin could allow the 12V power to flow through, powering the solenoid valve.

6. Software

6.1 Software Design Overview

This year marked the team's transition from Ardusub to Robot-Operating-System (ROS). The main reason for this change was due to Ardusub's lack of customization, the lack of compatible hardware, and the numerous separate programs that we had to run. Additionally, ROS's prominent role in the robotics industry allows members to gain valuable experience in robotics development.

The team chose to use the 2020 distribution of ROS called Noetic and Ubuntu version 20.04 (Focal Fossa). This distribution was chosen because Noetic is the last version of ROS1 before the switch to ROS2 so it has the most updated packages. The team didn't want to use ROS2 because some packages such as Rosserial have not been ported over, but the option to upgrade to ROS2 Foxy is still available as both Foxy and Noetic run on Ubuntu 20.04.

6.2 Node Overview

Over the course of developing the controls for the ROV, the team used several pre-made ROS packages such as:

- Joy
- Rosserial
- Cv_camera
- Dynamic_reconfigure

With so many packages, it was important to keep the pre-made packages which are made for very general applications to our specialized needs. In order to accomplish this, the team created a package called controller which contains all the relevant controller code for the connection from the Joy package to Rosserial. Although the controller has some ROV specific code such as a set of arrays for thruster movement, the aim was to keep the controller as generalized and modular as possible.

Additionally a package called rov was created which contains very little code, but is for ROV-specific things such as the computer and Raspberry Pi launch files, the custom messages, the pilots' chosen controller parameters, and the RQT configurations. This package is not meant to be very modular, but it keeps all the ROV-only code in one place.

6.3 Front End

Overview: All GUI views were done using RQT which allowed us to quickly make several different GUIs while testing.

Joystick: The joystick used is a standard PS4 controller. The left joystick controls rotation and up-down motion and the right joystick controls forward-backward and strafing. The four colored buttons on the right control our grippers. The upper left and right buttons are an overall power multiplier which changes in increments of 0.1. This was used when we felt that the power was too strong for precise tasks. Additionally, the upper left switch was used as a rotation lock. When pressed, the rotation on the left joystick becomes unresponsive. This feature was implemented because the pilots had trouble with the ROV turning as it ascended/descended.

Rates and Expos: Our controller has rate and exponential settings for every axis of our robot that the pilot can change. The rate setting controls how strong the input is and the expo setting controls the sensitivity of the sticks near the middle or the end. An expo value greater than 1 means that the pilot can do small precise movements because the joystick is less sensitive near the middle. All of these values can be changed during runtime with the help of the ROS package dynamic_reconfigure.

Camera View: Our three cameras are visualized on one screen with the RQT Image_view plugin. For our final configuration, the camera view was prioritized so all other settings and views such as the rates and expos were on another tab.

Pose View: Although the IMU did not end up being used, one GUI feature that was useful during testing was the Pose view. The pose view takes a ROS pose message and applies the transformation to a cube. This allowed the pilots to understand the orientation of the ROV better.

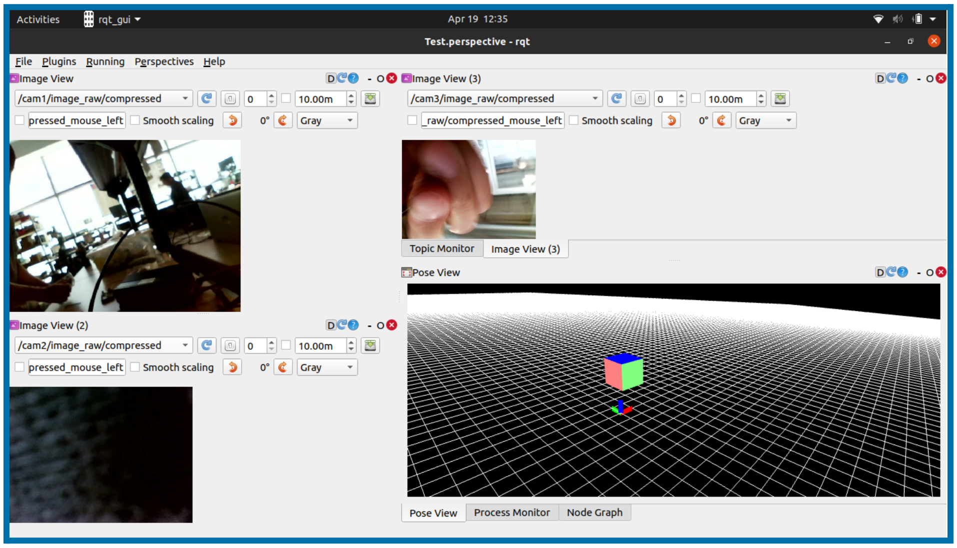


Figure 11: Pose View generated by RQT.

7. Logistics

7.1 Company Organization

Bruin Underwater Robotics is split into 3 different subteams: Aquaframe, Dive Operations (Dive-Ops), and Electronics. The Aquaframe subteam focuses on the overall design of the ROV, including chassis, electronics box, and more. The Dive-Ops team works on the pneumatic system, manipulators, and topside control setup. The electronics team is responsible for all the hardware and software for the ROV, creating a robust system capable of allowing the ROV to run. The Aquaframe and Dive-Ops team each had 3 leads, while the Electronics team had 4 leads. The leads report directly to both the team President and CEO.

7.2 Project Management

The company President and CEO were both responsible for day-to-day operation of the team, on both the business and technical side. At the beginning of the year, they met with the subteam leads to determine the goals for the year along with creating a Gantt Chart. This provided explicit goals for employees so they could all see the plans and expectations throughout the year.

The company had 3 main cycles throughout the year: design and prototyping, manufacturing, and testing. The design and prototyping phase started at the beginning of the school year and went until Christmas break. It started with creating basic designs along with researching possible pneumatic and electrical setups for Genesis. For anything that the team had never done before, such as creating custom printed circuit boards (PCBs) and pneumatics, lots of prototyping was done to verify that they could be used. This included test-PCBs for thruster control and experimental pneumatically-controlled arms.

The manufacturing cycle started right after Christmas break. At that point, all prototyping had been finished, and the company moved forward with the designs that were proven to work well. The frame was laser cut and milled, the arms were 3D printed, the PCBs were sent out to manufacturers, and more. Once the components came in, especially the electronics bay, they were tested extensively in water to prove they could survive the pool conditions.

Once the manufacturing cycle was complete, the company moved onto the testing phase. At this point, Genesis was pilotable, and the company worked tirelessly to iron out any problems. Most problems were found at the pool, and all of them were fixed, allowing the company to fine-tune Genesis for competition.

7.3 Costing

Because this is the first year that BUR is competing in the Explorer class, the company knew that there would be a lot of expenses at the beginning of the year, such as an air compressor, 48-12 V buck converters, 48 V power supply, and more. Because of this, a large emphasis was put on subteams to cut back on spending whenever possible. Both the Aquaframe and Dive-Ops teams were able to spend below their expected budget, giving the Electronics team room to spend a little above their budget. The Electronics team needed a larger budget because they wanted to buy and test newer cameras, and a lot of the electrical components were much more expensive than expected at the beginning of the year. With the help of sponsors, such as SMC for their pneumatic components, Genesis cost about $5000, which is what BUR expected at the beginning of the year. Because BUR was able to raise around $5000 to fund the project, the company broke even for the 2022-2023 year.

7.4 Budget

Subteam	Item(s)	Amount	Budget
Aquaframe	8020 Aluminum Extrusion	$97.65	$100
	Fasteners	$300.22	$350
	Electronics Bay	$170.71	$150
	Props	$405.20	$400
	Carbon Fiber Layup Materials	$350.12	$500
	Cord Grips	$400.81	$500
Dive-Ops	Solenoid Box	$125.12	$150
	Profiling Float	$480.24	$500
	Air Compressor	$135.61	$120
	Pneumatic Components	$427.32	$500
Electronics	Buck Converters	$670.35	$600
	Power Supply	$124.30	$120
	PCBs	$124.60	$150
	Wires & Misc. Components	$405.11	$300
	Cameras	$300.95	$300
	Tether	$191.22	$200
Total		$4,709.53	$4,940

8. Conclusion

8.1 Testing

One difference between Genesis and the previous year's ROV was that Genesis was consistently tested until it was proven to be reliable. This testing allowed the company to identify any weaknesses in the design and quickly iterate upon them until they had been fixed. The biggest aspect of Genesis that was tested was the electronics system. Because the entire electronics system was overhauled since the last ROV, it needed constant tweaking and testing in order to run reliably. From these changes, Genesis went from an experimental ROV that could only operate for about 20 minutes before shutting down to a consistently reliable ROV that could run for almost 2 hours with no pauses.

8.2 Lessons Learned

Because so many employees were new to BUR, a significant portion of them started off with almost no engineering experience. However, through BUR, they learned a lot of the fundamentals of engineering, from SolidWorks to milling to safely operating high-pressure systems. This turned them from students who would walk wide-eyed into the lab to full-fledged engineers who could confidently design and manufacture any part. As a whole, the team learned the value of consistent communication and teamwork. With a project as large as Genesis, it required not just the constant effort to make individual components but also the necessary teamwork to ensure those components could fit together. Because of Genesis, BUR grew from a collection of talented engineers into a close, tightly-knit team.

8.3 Future Improvements

In the future, BUR hopes to improve on many aspects of Genesis. On the mechanical side, it hopes to avoid using 8020 extrusions, as these tend to be pretty heavy. While it has to sacrifice on mounting accessibility, BUR hopes to get to the point where it doesn't have to rely on the slots of the 8020 to ensure all the pieces fit. The goal would be to create a chassis entirely of carbon fiber, as it has some of the best strength-to-weight ratio of any material. On the electrical side, BUR hopes to make the system more autonomous and reduce reliability on the pilot. Next year, it hopes to tackle a lot of the autonomous tasks offered by the MATE competition, and it also wants to help the pilot out by having a more reliable control system. Improvements include automatic stabilization of the ROV, roll-locking, and more.

9. Acknowledgements and References

9.1 Acknowledgements

The company would like to acknowledge ASME at UCLA, our parent organization, for providing us mentorship, financial support, and advertisement. We would also like to acknowledge the UCLA Engineering Alumni Association and the UCLA Undergraduate Students Association Council for their significant financial contributions.

We would like to thank our student and alumni mentors, namely Gabriel Alpuerto, Erin Hall, Jacob Greenwood, Rebecca Celsi, Rob Glidden, Sam Gessow, and Willy Teauv.

We would like to thank Veronica Santos, our faculty advisor, for her help with logistics before the competition and her continued support of ASME and all of its projects.

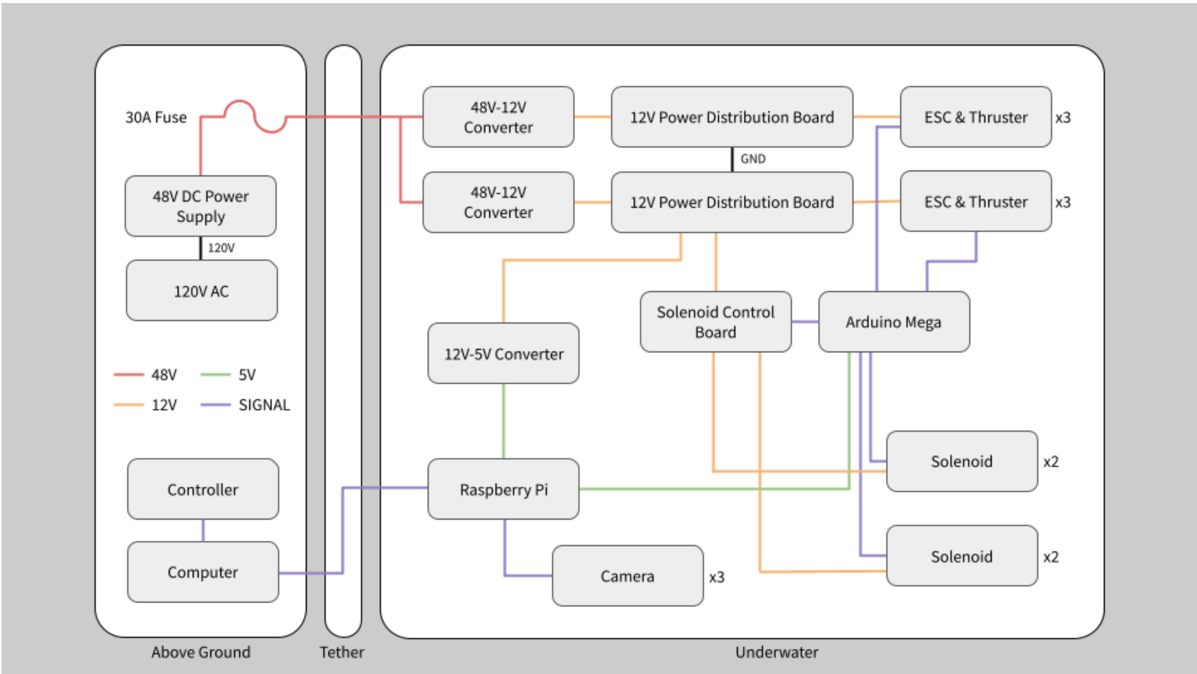
Finally, we would like to thank our project founders Ethan Brandt and Ethan Cai for creating this opportunity for UCLA engineering students and integrating the project into ASME at UCLA as one of their technical projects.

9.2 References

Steven W. Moore, Harry Bohm, Vickie Jensen *Underwater Robotics Science Design & Fabrication*
MATE 2022 Manual

10. Appendix

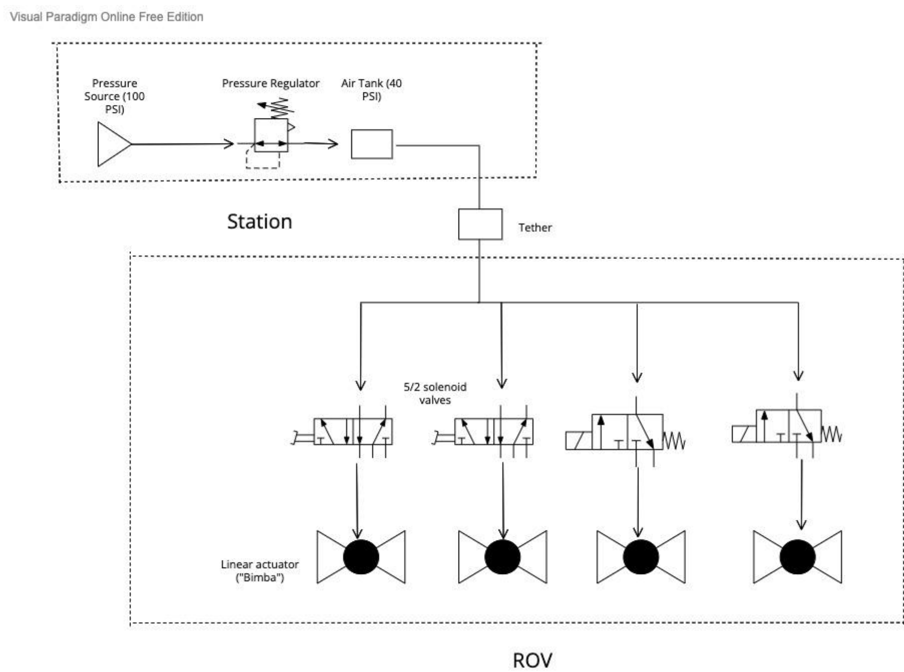
Appendix A: SID



Fuse Calculations

Component	Number of components	Voltage (V)	Current (A)	Total Power (W)	Current drawn from Power Supply (A)
Raspberry Pi (Includes camera and Arduino)	1	5	5	25	0.52
Solenoid Valves	4	12	0.0667	3.2	0.0667
Thrusters	6	12	13.33	960	20
Total					20.59
ROV overcurrent protection = 1.5 x 20.59 = 30.88 A ROV uses 30A fuse					

Appendix B: P&ID



Appendix C: Corporate Sponsors

SMC

PROTECH COMPOSITES

IPS

BlueRobotics