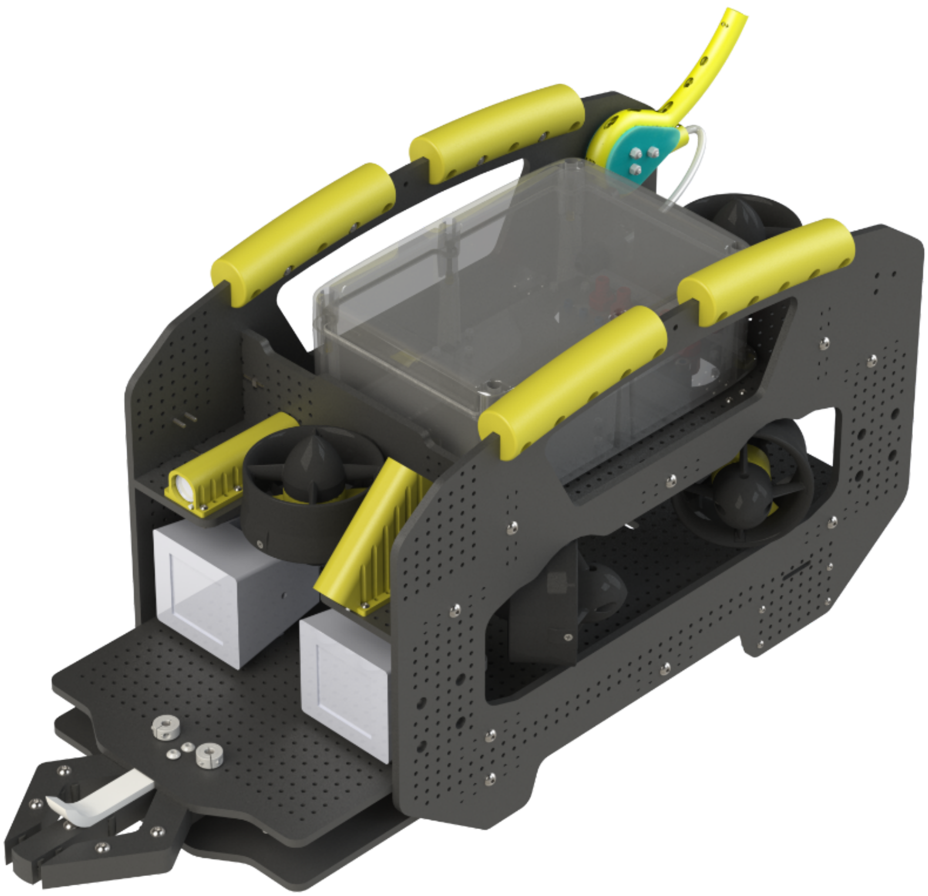
Slugbotics

University of California, Santa Cruz | Santa Cruz CA



Technical Report

Table of Contents

Abstract

Slugbotics is proud to present Trident, an ROV designed to address the impacts of human pollution and climate change on the waters of our planet. Trident is equipped with a multi-pronged claw designed to remove pollution from water, safely interact with coral nurseries, and conduct key maintenance on critical waterway infrastructure. Additionally, Trident is equipped with several cameras for monitoring reefs and taking data on obstacles in the water. Trident's simple and versatile design makes it perfect for addressing the request for proposals.

1: Design Rationale

1.1: Frame

The frame of the ROV consists of seven High Density Polyethylene (HDPE) machined "plates" which are attached to each other via screws and nuts. Using HDPE allows for two major benefits: the ability to easily machine it using a CNC mill (Inventables X-Carve), and that the material's buoyancy is slightly less dense than water (roughly 940 kg/m^3 vs 1000 kg/m^3). This latter point means that the frame is slightly buoyant, which reduces the need for additional buoyancy.

The ROV's plates have 3mm diameter holes machined into them at 1 cm intervals at certain areas, much like a pegboard. This allows for simple and modular attachment of accessories and devices at various open areas of the ROV. For other devices that require a stronger or more complex attachment, custom mounting points are machined into the HDPE as needed. Most notably, this includes the claw, areas for dive weights at the four corners of the ROV, the T100 thrusters, the electronics enclosure, and more.

1.2: Buoyancy & Ballast

Trident is designed to be slightly positively buoyant, but not enough to affect normal operation. Slugbotics chose this design as a safety measure. In the event of complete ROV failure, the positive buoyancy will ensure the ROV floats to the surface for easy and safe retrieval. The main source of buoyancy on Trident is the electronics enclosure, which is mounted above the upper frame sheet of Trident. This gives Trident passive roll and pitch correction, as the heavier frame components will naturally want to sink underneath the buoyant enclosure. Furthermore, four custom rigid foam floats are bolted to the top edges of the frame to provide additional buoyancy and stability.

The buoyant force of the ROV was deduced using the well known relation given by Archimedes' Principle:

$$F_b = \rho_{H_2O} V_{ROV} g$$

The volume of the ROV was determined by the water displacement method:

$$V_{ROV} = V_{H_2O\ displaced}$$
$$V_{H_2O\ displaced} = (V_{before} - V_{after})$$
$$= \rho_{H_2O}{}^{-1}(m_{before} - m_{after})$$

Where the mass of the container that stored the fluid used to measure the ROV's volume was deduced not to play a role in the derivation as follows:

$$= \rho_{H_2O}{}^{-1}([m_{total\ before} - m_{container}] - [m_{total\ after} - m_{container}])$$
$$= \rho_{H_2O}{}^{-1}(m_{total\ before} - m_{total\ after})$$

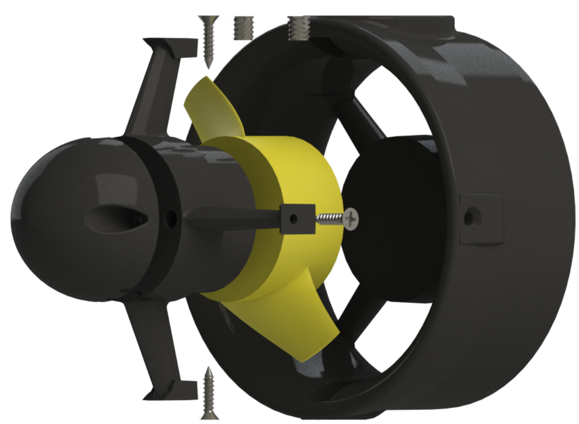
The mass of the fluid before the displacement and after were reported respectively as mtotal before = 17.63 kg and mtotal after = 8.31 kg. Thus slugbotics calculated the mass of the displaced water to be 9.32 kg. Using the density of water (998 kg/m^3), the volume of the fluid displaced and thus the volume of the ROV was calculated to be 9.33x10^-3 m^3. Using the mass of the displaced water, the buoyant force on the rov comes out to a positive value of 91.336 N, which is slightly greater in magnitude than the gravitational force on the ROV due to its own mass.

1.3: Propulsion

The propulsion of the ROV is carried out by six 12V Blue Robotics T100 thrusters. These are the same thrusters as used on the previous year's ROV and were chosen again because, for a reasonable cost compared to similar products, they:

- Provide reliable and easy to control thrust.
- Are compact and easy to mount packages.
- And require no waterproofing.

Slugbotics chose to reuse existing T100 thrusters instead of purchasing new Blue Robotics T200 thrusters. The added cost of purchasing new motors ($179 each) did not justify the slight boost to performance over the team's existing stock of T100 thrusters.

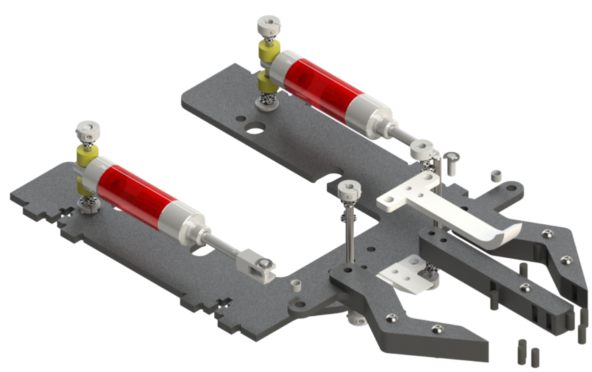


T100 thrusters have a fully open inlet to the propeller which poses an injury and propeller obstruction hazzard. Slugbotics designed and manufactured thruster guards that provide increased safety when handling the ROV and prevent medium sized debris from damaging the thruster blades. The guards were 3D printed because the process allows for relatively high quality and repeatability at a low cost. They are made of PETG since it is durable, relatively light-weight, and easy to 3D print.

This year the Slugbotics ROV design uses six T100 thrusters; two vectors of propulsion are used for Z-axis movement and pitch and four for stable X and Y-axis movement and yaw. In the previous version of the ROV a third Z-axis motor was employed, but it has been removed as it was deemed unnecessary.
The four horizontal thrusters are mounted at 45° angles on each corner of the ROV and two vertical thrusters mounted on the bow and stern of the ROV respectively with thrust in the vertical direction.
The vertical thrusters are mounted in opposite directions so that the gyroscopic forces cancel out when both thrusters provide thrust in the same direction.
To run the thrusters the ROV uses the Blue Robotics Basic ESC. The Basic ESC was selected because of its low cost and ease of integration compared to similar commercial ESCs. Slugbotics did attempt a prototype custom ESC, but it was decided the effort was not justifiable when a better option was available.

1.4: Claw
When approaching the claw design, Slugbotics began by analyzing the props that needed to be manipulated by the ROV. The primary concerns were the coral samples and the ghost net pin.

The first prototypes were based on the previous year's vertically oriented claw design. However, this vertical design was phased out in favor of a horizontal design that could grip the coral props and move them into place. The vertical claw design could not grab any coral piece that did not have branches without disturbing the base, and appeared to struggle when faced with the challenge of relocating the coral piece to a new location as the bottom of the coral would be offset an inconsistent distance from where the claw had grabbed it.



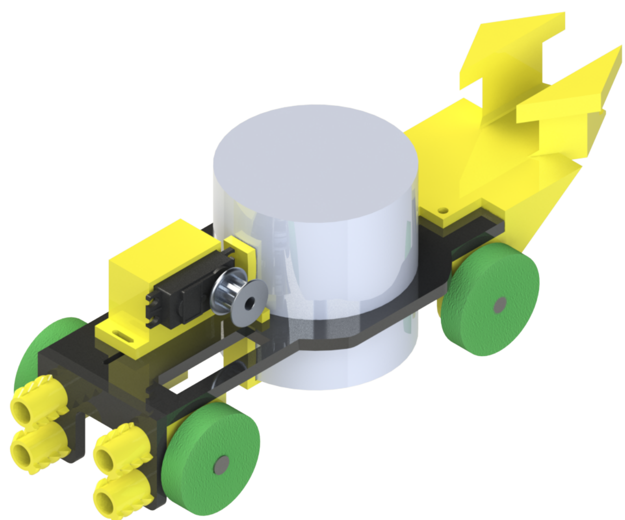
It soon became apparent that a horizontal claw would be the superior design. With this in mind, the next step was to determine the best shape to grip the coral. After several prototyping phases the team found that by adding rubber pads along the inside of an angled finger, a stationary centerpiece could be used as a brace plate that the single moving claw finger would press

against. This created a firm grip, capable of grabbing a coral piece or the ghost net pin using a single moving part.
This design also allows the moving finger claw piece to be mirrored and have two independent claws sharing the stationary center piece as a brace plate. This allows the ROV to independently grab two coral pieces in a single trip, greatly reducing the amount of time needed to complete the coral colony task.

Throughout the prototyping process the team found that they could quickly manufacture precise claw pieces by using a CNC router table to cut HDPE pieces. By stacking several copies of the same shape cut out, it was easy to manufacture a claw of any given shape and height as needed. This allowed for the rapid prototyping, testing, and revision of the design. With an abundance of HDPE stock material and a fast manufacturing time, this method proved to be the most efficient way to manufacture the claw and ultimately beat out the slower 3D printed prototypes.

1.5: Probe

One of the main lessons learned from our team's 2019 probe design was that having a probe tether was undesirable. The probe tether was hard to manage as it could easily get tangled or dangle loose from the main ROV which would cause a myriad of problems. Furthermore, a tethered probe meant that the main ROV had to sit still and wait while the probe was in use, unable to accomplish any other competition tasks in the meantime. The main reason for using a tether in 2019 was the requirement for video feed from the probe, but since the competition requirements for 2021 do not explicitly require this video feed we did away with the tether this year.



The first change that allowed for the forgoing of the tether was using wheels instead of a propeller for propulsion. The wheels could be driven reliably at much lower speeds and power, which allowed for the probe to be operated on a small battery rather than tethered to the main ROV power. While this does slow the retrieval process, it is not an issue as the main ROV is free to go about completing other tasks in the meantime. The second change with the no-tether design was with control and communication. The communication between the probe and the ROV is made possible by an ambient light sensor on the probe. A flashing of the lights from the ROV signals to the probe that it has been placed in the drain pipe and can begin driving forwards. The probe is controlled by a simple timing loop. It simply drives forward for long enough to reach the end of the pipe and grab the sediment sample, then reverses back out in the same manner. When the probe is finished it drives itself out of the pipe and comes to a stop on the floor of the pool, where the main ROV can collect it whenever is most convenient.

The retrieval of the sediment is made possible by a set of springs with hook-sided tape attached to the ends of the springs in a sort of net. When the probe reaches the end of the pipe, the spring net gets pushed onto and wraps around the sediment sample which gives the hook tape as much contact area as possible. This ensures a secure grab of the sediment sample so that it can be reliably extracted.

1.6: Electronics Enclosure

The current electronics enclosure consists of a Polycase ML-70F waterproof enclosure, modified to include electronics hardware and cable potting. In order to construct the enclosure, Slugbotics chose to stick with what is known to work, and bought a commercial waterproof enclosure. The enclosure was modified to include holes for fitting Blue Robotics penetrators to allow cables, such as power and Ethernet, into the enclosure while keeping the box watertight. Inside the enclosure, the input power (12V DC converted from 48V DC by a 48V to 12V buck converter attached to the ROV frame) connects to a power hub for all 6 Blue Robotics ESCs, which are in turn connected to the 6 T100 thrusters described earlier. This power hub also provides power to the three analog cameras, whose power is regulated by a full bridge rectifier and booster circuit, and both headlights. The input 12V DC is also stepped down to 5V DC within this enclosure by a 12V to 5V buck converter, and this 5V powers the Arduino Mega 2560 that functions as the main ROV controller. This Arduino, connected to an Ethernet shield, is programmed to decode strings of text from the topside computer (sent over Ethernet), and turn them into 6 motor vector values, each sent to an ESC.

In past years, Slugbotics attempted to create custom electronics enclosures and sealing. While there was some success, it was simply more efficient to purchase a commercial waterproof enclosure, as the team did this year. This allowed Slugbotics more time to work on the actual electronics in the enclosure. This year, Slugbotics has removed the need for an onboard computer, using only a microcontroller which interfaces with the topside via an Ethernet connectivity shield. In removing the onboard computer, Slugbotics decreased the complexity of the ROV's electronics and control, and freed space within the enclosure.

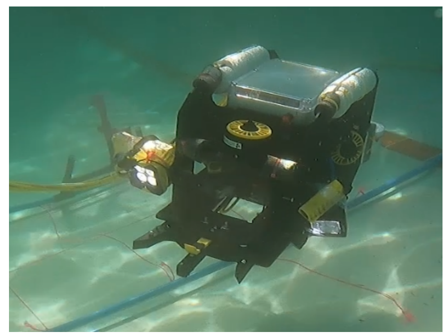
1.7: Cameras

The ROV uses three analog RCA cameras. Cameras are placed at three key areas for easier navigation, precise claw operation, and simplified computer vision. To succeed in these three areas, one camera is placed at the front of the ROV pointing straight forward, one is placed at the front pointing downward at the claw, and one is placed at the bottom center of the ROV pointing straight down. While the front two cameras are more general-use, the straight-down camera is more limited, and is used primarily for navigating the transect line and mapping the subway car.

Slugbotics chose to use analog cameras due to their lower cost and superior reliability compared to the digital camera setups that were used in previous ROVs. There is also no visual difference in image quality when compared to the digital equivalent. The three composite video signals run through a shielded Cat7 cable in the tether, with passive baluns on both ends. This fully eliminates any noticeable signal interference that often plagues analog camera setups on ROVs.

1.8: Lights

The ROV uses two Blazer offroad floodlights. These bright lights, originally intended for cars, allow the ROV cameras to provide consistently illuminated images to those maneuvering the ROV when at pool depths (< 5.5 meters). The lights are mounted to the ROV using their original mounting hardware. This bracket allows the angle of the light to be easily adjusted when repositioning it. The lights required little waterproofing since they were already designed for outdoor use. To waterproof the lights, optical resin was poured directly onto their light emitting diodes (LEDs), which allowed the resin to flow onto the circuitry beneath, preventing water from reaching it.



Slugbotics chose to use two lights on the front of the ROV to light the ROV's path and light the area surrounding the claw, allowing for higher visibility of props.

Tether & Cable Management

The Slugbotics tether connects the ROV to topside controls and contains the power wires, pneumatic lines, and camera signal cables. Power runs directly from the 48V power supply, through the tether, and is converted to 12V onboard the ROV via a buck converter. Three pairs of RCA signal wires for the three onboard analog cameras are wired through a singular repurposed CAT7 Ethernet cable as twisted pairs, keeping the signal wires organized and contained within the tether. The tether contains four quarter inch pneumatic lines which connect the topside pneumatic components to the two claw pistons on the ROV. Two pneumatic lines connect each solenoid to a piston. The tubes are placed in a square pattern around the tether so that the stiffness is evenly distributed around the tether, so an imbalance in the flexibility of the tether's sides does not influence the way the ROV drives. The tether is held together by zip ties and self bonding tape placed approximately every 20 cm, preventing the many wires and tubes from tangling.

The tether is strain relieved by wrapping it around a thimble. The thimble is attached to the ROVs frame, transferring the force of the ROV away from where the tether connects to the enclosure and onto the frame. For further strain relief, the tether is looped before it wraps around the thimble, and this loop is attached to the ROV. This allows for more of the force on the tether to be diverted to the frame. The parts of the tether that may experience friction (such as the loop) are wrapped in a layer of self bonding tape, which protects the innards of the tether.

To manage the tether, the tether is to be kept loosely coiled (~30 cm diameter) on the floor beside the pool when not being actively spooled out. When spooling the tether, the ROV end of the tether is gently fed into the pool while being held above the pool's edge while the remaining tether is left coiled. This prevents the tether from dragging on the poolside surface and becoming damaged. The poolside tether operator must also take note of and prevent tight kinks (circular, <15 cm diameter) in the tether from appearing.

1.9: Control Station

The topside control station consists of a laptop and a small control panel. The control panel contains the purely-mechanical pneumatic controls for the claw on the ROV, as well as the 48V DC power switch. All other aspects of vehicle control are handled by the laptop, which is directly connected to the ROV. The main benefit of this setup over an all-in-one control box is operational flexibility; any laptop with three USB ports and a RJ45 port can be used to control the ROV. In the event of an unexpected topside electrical failure, the control computer can be quickly replaced in order to minimize downtime. The pneumatic controls would continue to operate as well, since they are completely independent from the electrical system.

With respect to the software within the Control Station, to simplify this year's development Slugbotics swapped to a framework based approach rather than developing raw C code for the entire ROV. The biggest issue with last year's code design was the poor user interface that stemmed from solely using the command line; because of this, the C++ GUI framework Qt was chosen. Its software stack is developed on the concept of event-driven programming, which allows us to react to movements of the ROV, or any other event that could occur during operation, and properly handle it. As previously stated, the ROV is controlled through the use of a wired Xbox controller, connected to the control station. The software takes in the controller's joystick positions and translates these values to representative motor vectors that correspond to the proper ROV thrust. This is done by mapping the range of the controller's input (-1 to 1) to the range allowed through our ESCs (1200 - 1800) before tweaking these values accordingly to the angle each motor is positioned at. After the motor thrusts are calculated, the Control Station packages them up into a singular string; this is sent over a UDP network connection through a CAT 7 ethernet cable to the Arduino onboard the ROV.

2A: Build Versus Buy

The 2021 Slugbotics ROV includes a mix of commercially available solutions and custom designs to accomplish the various functions and structures of the ROV.
Off-the-shelf parts include the lights, cameras, electronics enclosure, enclosure penetrators, electronic speed controllers (ESCs), thrusters, on-board microcontroller, topside signal interface, fastening hardware, pneumatics lines, claw pistons, and manual pneumatic valves.
The ROV has two lights to assist with camera vision under the water. While a custom solution could have been more compact and cost-effective, the easy mounting and minimal need for waterproofing of the purchased vehicle trail lights made them a convenient and time efficient solution.

The ROV has three analog cameras. Commercially available cameras were chosen because they offer simpler, higher quality, and cheaper solutions than any in-house design.
The ROV uses a modified outdoor equipment enclosure as the on-board electronics enclosure. While an in-house design could have been cheaper and potentially more hydrodynamic, the reliability of the water resistant seal and relatively minimal need for modification meant that an off-the-shelf solution was both a more time efficient and more reliable solution.
The ESCs used on the ROV are the Blue Robotics Basic ESCs. Slugbotics chose a commercially available solution for the ESCs because it was far more time and space efficient to do so. While an in-house design was attempted, it was quickly scrapped as the Basic ESCs proved wholly adequate for the task and any potential cost savings from a custom design were outweighed by the time savings of the existing off-the-shelf solutions.
Slugbotics chose to go with an off-the-shelf thruster for reasons similar to the ESCs. The Blue Robotics T100 thrusters provide the functionality needed for the ROV and make up for their cost in the time saved and ease of use. Unlike the thrusters, the motor shrouds were built in-house because no comercial options exist.
The onboard microcontroller and the board to interface it with topside communication are both off-the-shelf solutions in the form of an Arduino Mega and Arduino Ethernet Shield. Using commercially available solutions for the microcontroller and Ethernet shield was far more time efficient and the costs were low enough that an in-house design is not worth the extra time commitment.
Due to limited access to the team lab space and thus heavier tools like the lathe, the manufacture of screws and penetrators was all but impossible. Additionally, the time cost of in-house machining paired with the ready availability of low-cost off-the-shelf hardware meant that commercial solutions were an obvious choice.
Commercially available pneumatics equipment were chosen because they were safer compared to custom in-house printed or machined parts which would not be able to achieve the low tolerances necessary for pneumatics. Purchasing these items ensures that the pneumatics used on the ROV are compatible and safe.
The custom, in house parts of the ROV include the frame, tether, claw, various PCBs, and component waterproofing solutions.
The frame is made up of custom High Density Polyethylene (HDPE) panels designed to fit the ROV components compactly and securely with all mounting holes carefully planned and cut by CNC router. A commercially available solution would have been less space optimized, less convenient, and far more expensive.
The tether was specifically designed to fit the electronics onboard the ROV, so no convenient, commercial solutions exist. Each part needs a different wire gauge, level of shielding, and type of wire termination. It should be noted that an off-the-shelf CAT-7 Ethernet cable and cable sheath are used as part of the tether because they were the most cost and time effective solutions for their respective roles.
The claw was custom designed to fit into the frame and grab items as the team deemed ideal. While off the shelf products do exist, none were of an ideal shape, and the cost outweighed the usefulness

The power filter circuit for the analog cameras was designed in-house because doing so allowed for an easier to integrate and more cost effective solution.
The PCBs to connect the various off-the-shelf parts together were designed in house for similar reasons to the tether and frame. Since the ROV uses a novel combination of components, no off-the-shelf solutions exist to integrate them together into a single design.
To waterproof both custom and commercial parts, Slugbotics used in-house designs because it allowed for the integration of waterproofing into custom mounting brackets, which was more space and cost efficient than any off-the-shelf solutions. Using in-house waterproofing as opposed to buying off-the-shelf waterproofing products or pre-waterproofed components also leads to easier repairability.

2B: New Versus Used

Most of the 2020 Slugbotics ROV is composed of new parts due to the many design differences and upgrades over last year's design. The only reused parts are the 48 volt to 12 volt buck converter, the T100 thrusters, and the Blue Robotics Basic ESCs. All three were reused since their used state was good enough that replacing them was deemed an unnecessary expense. All other parts are new since they were either not present on the previous ROV or are custom parts.

3: Safety

3.1: Safety Features and Philosophy

The ROV includes a few key safety features to protect both the ROV and divers around it during operation.

As mentioned in the thruster section, Slugbotics included thruster guards to prevent foreign objects from contacting the thruster propellers. This protects the thrusters from damage and, more importantly, protects the fingers of divers and ROV handlers during its launch, operation, and retrieval.

Since the ROV is powered by 48 volts supplied via tether it is imperative to protect the tether and its connection to the ROV so as to prevent any form of current leakage into the surrounding water. To protect the wires making up the tether, they are wrapped in a plastic mesh sheath which serves to both keep the various cables together and add an extra layer of protection against any sources of wear that occur during operation. To protect the connections of the tether cables to the ROV, a strain relief technique is employed in the form of a stereolithography (SLA) printed resin thimble, which securely holds a small loop of the cable close to the penetrator connections. This loop serves to transfer most of the naturally occurring tugging forces experienced by the tether from the penetrator connections to the frame, which is much more resilient to those forces.

Along with the specific safety features for protecting parts of the ROV, Slugbotics also designed the ROV with human interaction in mind. The majority of the ROV components are mounted within the bounds of the frame and carry points have been included in both side panels to make handling the ROV easy and safe. A user can retrieve the ROV from the water or redirect it underwater without any chance of interfering with the on-board electronics or snagging any exposed wiring.

3.2: Safety Procedures

Due to the COVID-19 pandemic, Slugbotics shifted to a primarily remote working environment and did all in-person work outdoors with strict masking and testing procedures.

For the limited in-person work, an emphasis was placed on maintaining safety despite being outside of the normal lab space. All fire or electrical shock hazards like soldering equipment and power supplies were powered through separate power strips with a designated person ready to disconnect their power at a moments notice throughout their entire operation.

Additionally, all high voltage power supplies were placed in designated, conductively isolated locations and all connections, including temporary ones, were fully insulated with heat shrink and electrical tape before use to prevent shorts and accidental electrocution.

For all work involving power tool usage (including soldering) PPE in the form of safety glasses, tied back hair, rolled back sleeves, and appropriate respiratory protection was required for all personnel present.

4: Logistics

4.1: Project Management and Scheduling

Slugbotics has struggled with project management and scheduling, as evident by the fact that nobody wrote the project management and scheduling section.

4.2: Onboarding

Unlike other years, this year Slugbotics offered the opportunity for new members of the team to take a structured course run by experienced members for three university credits. This course was offered alongside Slugbotics' normal onboarding sessions, simply providing students with credits for completing it. This course was split into three tracks, each corresponding to one of the three main sub-teams of Slugbotics: Electronics, Systems, and Mechanical. Students were encouraged to pick one track to follow for a grade, and all materials were available online if they wished to learn from another track. Returning members from each respective team developed lesson plans, syllabi, and then presented the material to new members as in any standard university course. Both returning and new members were required to record a notebook, filled with lecture notes for new members and notes on the development and running of the course for returning members. The success of the onboarding course was mixed, as many new members successfully completed the projects assigned to them, but member retention was relatively poor. The learning structure provided by the course was still a step up from previous years' onboarding sessions, and the material created will provide a good base to build from in the future, as Slugbotics plans to continue to offer this onboarding.

Code and CAD - Management and Review

Working on a complex project with a large team can make collaboration a daunting task. To facilitate this, Slugbotics used GrabCAD and GitLab, two Version Control Systems, allowing team members to easily upload to and update files in the team's repository. The GrabCAD repository contains all CAD designs for the ROV, both past and present, making it easy to edit ROV parts and reference past work. The GitLab repositories likewise contain all code and electrical schematics, and can similarly be used to view the project's progress.

GrabCAD has been an essential part of Slugbotics' operations this past year. With nearly all meetings and collaboration being conducted online, GrabCAD provided an easy way to share and collaborate on CAD files. To keep track of the design process, Slugbotics maintains a full CAD assembly of the ROV, located in the GrabCAD repository. Using this, any member anywhere can examine or contribute to the ROV. The full assembly was useful in planning the placement of components on the ROV, and was especially helpful when assembling the ROV.

The Slugbotics GitLab group is another essential part of this year's Slugbotics operations. It holds project folders containing the various electrical designs and code files that make up those elements of the ROV. GitLab, which leverages the Git version control system, provides a powerful system for tracking file changes, accessing those files from different locations, and keeping team accessible files up to date during parallel development.

5: Budget

Similar to prior years, Slugbotics took a holistic approach to budgeting, involving as many members of the team as possible. This allows for people to advocate and propose expenditures that will be best for the team while enabling rapid feedback and iteration in the same space.

With this method of budgeting, the team was able to prepare for major purchases well in advance. Knowing this allowed for more rapid ordering of all purchases, speeding up prototyping and repair projects throughout the year.

Cost Accounting

In order to keep track of purchases and total costs throughout the year, Slugbotics created a spreadsheet where new items were broken down by subteam. Included with this spreadsheet are links to items, notes, and part numbers so that rebuying is made easier in future years.

A large difference made to the company's purchasing workflow this year was the ability for any member to submit a purchase request. In prior years, these had to have been submitted by a lead, which led to backlogs of purchases piling up. With this new method, purchases were often placed same-day, meaning parts arrived sooner and projects were completed faster.

6: Critical Analysis

6.1: Testing and Troubleshooting

Slugbotics continuously used testing and troubleshooting throughout the ROV design process. The mechanical subteam had many opportunities for testing and troubleshooting. The designs for ROV parts were initially created in CAD and went through a CAD test fit and design review. The part was then prototyped using 3-D printing, and then the final part was manufactured.

After completing the CAD and initial manufacturing phase of ROV construction, Slugbotics took the completed ROV to several pool tests in order to troubleshoot and test general functionality. During the first pool test it was clear that adjustments were needed for the camera positioning and claw superstructure. This entailed quickly 3d printing new camera components and milling new frame components on the team's router. Over the course of two pool tests and testing mechanisms in the lab, these simple mechanical issues were resolved.

6.2 Challenges and Lessons Learned

One of the issues that Slugbotics encountered was that there was poor communication between subteams due to once-a-week meetings that were held during different times of the day. This resulted in slow progress on ROV parts that required cross-team collaboration. To remedy this, Slugbotics plans to hold more frequent and collaborative meetings that will help facilitate cross-team work and communication.

Another lesson learned was that while decentralized computer aided design and programming was relatively effective, distributing physical work on the ROV was very inefficient. Slugbotics initially tried to mail out components and tools to remote members as part of efforts to evenly distribute work; the time delays inherent to the mailing process paired with decreased inter-team communication stretched short jobs into multi-week endeavors. In the future, remote physical work efforts will be avoided, especially if the project is time sensitive.

While Slugbotics did perform in-person, physical work on the ROV, it was not performed at the lab space due to COVID restrictions. Instead, in-person work on the ROV was performed outside of one of the member's homes. While this allowed us to resume crucial work on the ROV, there were multiple challenges with this setup. These included a lack of work space compared to the lab, no big tools or machines, extensive setup and teardown times, and observing COVID precautions. Once the COVID situation is resolved, Slugbotics plans to resume work at the lab.

Future improvements

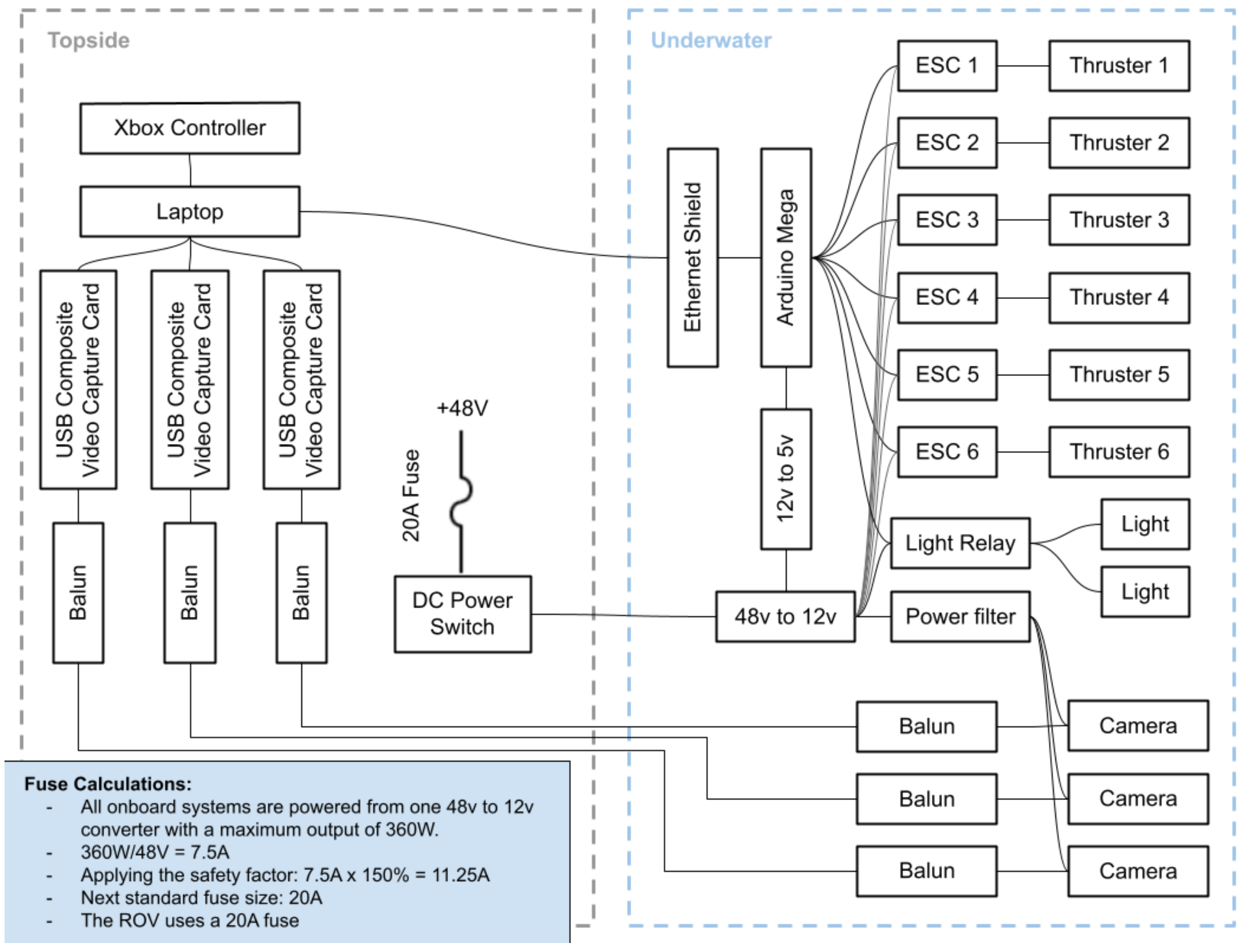
Based on the lessons Slugbotics learned, there are many improvements we plan to make in the future. In general, the company should plan better. By beginning work on the autonomous systems sooner, the team would have been able to progress further on development and have more time to test. Autonomous would have also been more successful if Slugbotics had recruited more members.

- Begin autonomous work earlier, such that the team is able to complete more of the autonomous tasks. Recruiting more members to the autonomous subteam and obtaining more experience with OpenCV is also critical to improving the autonomous portion of the ROV.
- Develop a specific mechanism for the surface item manipulation. Collect surface debris using a pool skimmer-like object that attaches to the claw or other part of the ROV.
- Reduce the footprint of the ROV by using space more efficiently. The claw currently protrudes far out of the ROV to put it in the camera's vision, however this puts the ROV in the second sizing ring. To maximize points earned, the length of the ROV should be reduced.
- Custom electronics to replace the commercially available ESCs and lights would allow us to add more control features and task specific functionality.

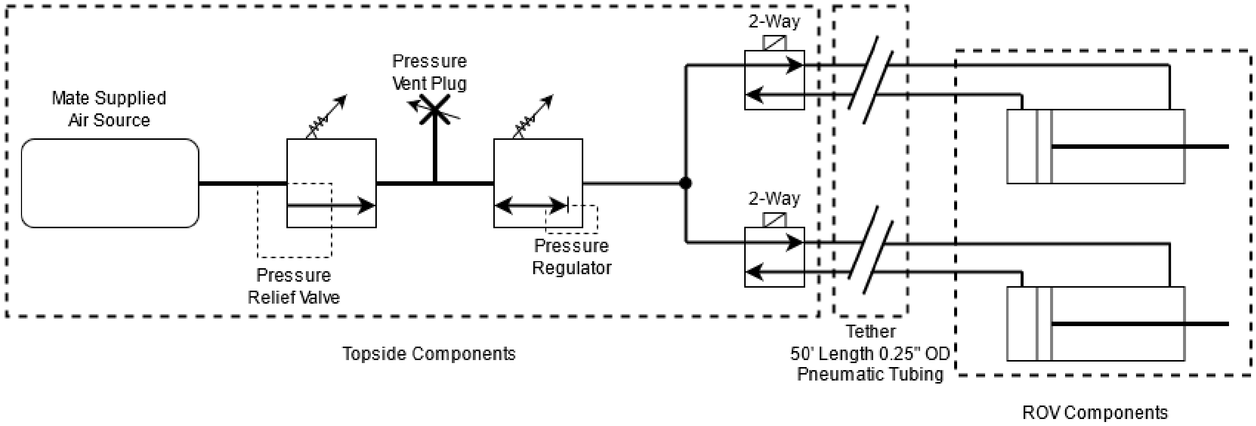
- Optimizing buoyancy by adding weights and optimizing the placement of parts. Buoyancy (pool noodles) could be a bit more professional, but it’s ok.
- Improve the control panel. The current control panel is functional, but it has room for improvement. A future iteration could be more carefully designed and manufactured to better enable the topside functionality and protect it from water.
- Centering the point of connection between the tether and the ROV. Currently the tether strain relief is on the side of the ROV. Moving it to the center would prevent it from imparting skewing torques on the ROV as it moves.

Appendices

Electrical SID



Fluid Power SID



Budget Breakdown
Refer to section 4.1.

Project Costing
Refer to section 4.1.

Thank Yous
First and foremost, we would like to thank Matt Gardner, Jill Zande, Timmie Sinclair, and everyone else at the MATE Center and MATE II for giving us the opportunity to participate in such a fantastic event once again. We would also like to thank Professor Ricardo Sanfelice for his mentorship and continued support of the team. Additionally, Slugbotics would not be able to function without the help of Kait Cole, Eric Guerrieri, and Michael Matkin, thank you all for supporting the team behind the scenes. Thank you to UC Santa Cruz, the Baskin School of Engineering, the Electrical and Computer Engineering Department, and the Cyber Physical Systems Research Center for supporting our continued work on campus.

Thank you to the Student Fee Advisory Committee for their incredibly generous grant which allowed the team to purchase much needed equipment and supplies over this past year. Thank you to Tela Favaloro, Sue Carter, and the Sustainability Lab at UCSC for continuing to provide us with lab space and access to tools. Thank you to Pete Pearson and the Westcliff Village Homeowners Association for providing us with a pool to test Trident in.

We would also like to thank all of our individual donors from the past year, both big and small. A special thank you to Bob Pederson, Bruce Ungari, Chris Tacklind, Chris and Tamara Meckel, Gary Trimble, Jean Morrissey, Kathleen Pederson, Kerrie Gavgavian, Lorette Jenkins, Louise Meckel, Nanette Monson, Shailen Tuli, Steven Pederson, Tom Craig, and Trish Dally for their especially generous contributions.

- Mentors

    - Professor Ricardo Sanfelice
- UCSC Staff
    - Kait Cole
    - Denise Ilarina
    - Robin MacAngus
    - Eric Guerrieri
    - Tela Favaloro
- Other UCSC
    - Cyber Physical Systems Research Center
    - ECE Department
    - Sustainability Lab
    - Student Fee Advisory Committee
- Logistics
    - People who let us use their pool (ask if we can put them here)
    - Theo's pool person
- MATE organizers
- All of our Giving Day donors
    - Especially
        - Bob Pederson
        - Bruce Ungari
        - Chris Tacklind
        - Chris and Tamara Meckel
        - Gary Trimble
        - Jean Morrissey
        - Kathleen Pederson
        - Kerrie Gavgavian
        - Lorette Jenkins
        - Louise Meckel
        - Nanette Monson
        - Shailen Tuli
        - Steven Pederson
        - Tom Craig
        - Trish Dally