Underwater Remotely Operated Vehicles (UWROV) Team at the University of Washington

Seattle, WA, United States

Technical Documentation - *Nautilus*

MATE Explorer Class 2021 Competition

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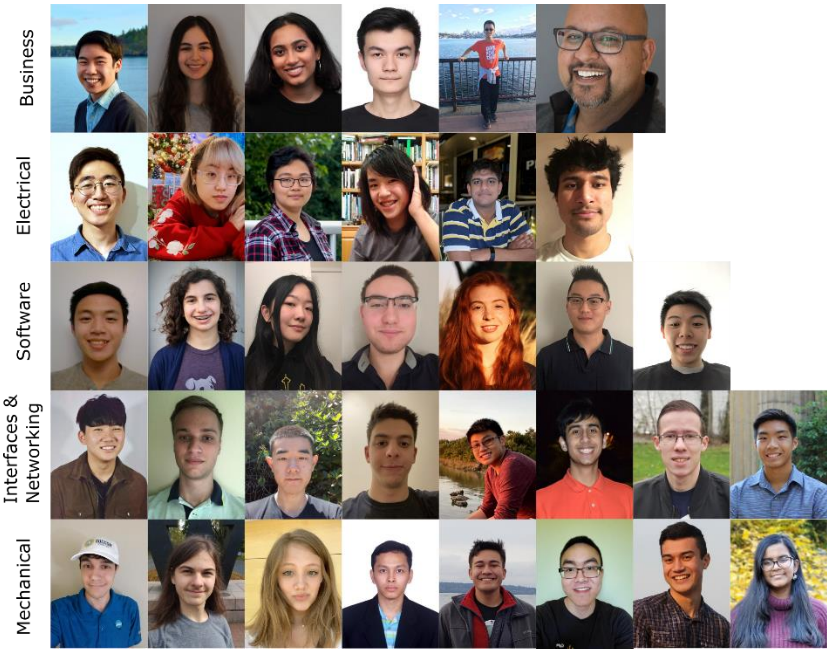

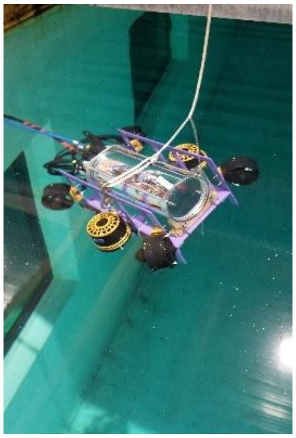

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Abstract

We are the Underwater Remotely Operated Vehicles (UWROV) Team at the University of Washington! Our entry into the MATE 2021 Explorer Challenge is the *Nautilus*, a new remotely operated vehicle (ROV) equipped to tackle plastic pollution, monitor the effects of climate change, and maintain healthy waterways! *Nautilus* comes packed with modernized software and hardware improvements, all fitting in a smaller and lighter package than its predecessors. It’s designed with maneuverability and modularity as a central focus.

Nautilus is the product of relentless work by UWROV members throughout the 2020-2021 season as we strove to complete our operations online. We underwent major overhauls of our ROV’s control and surface systems, migrating to the Robot Operating System (ROS) and redesigning the GUI from scratch. We aggressively cut down the weight of our frame, iterating on models from previous years to deliver a lightweight, easily maneuverable design. We also expanded our reliance on rapid prototyping in our CAD workflow, utilizing 3D printing, laser cutting, and waterjet cutting for faster, more precise results. The end result is a robust, reliable ROV ready for deployment in the MATE World Championship.

Design Rationale

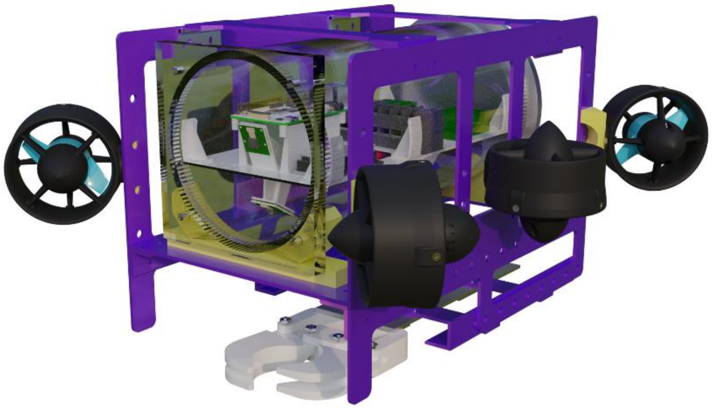
Design Evolution

Our initial prototypes for *Nautilus* were heavy and cumbersome to maneuver and deploy. Especially with so many of this year's tasks centering around careful manipulation of props, we quickly realized that our first design was far too limiting. In response, efforts this year centered around building an ROV that was nimble, both in the realms of hardware and software. Our engineering teams undertook major changes to our manufacturing and software design processes that enabled huge strides in development speed and flexibility.

Mechanical Systems

Vehicle Structure

The frame consists of three 1/8" aluminum plates joined by aluminum angle extrusion. There is an additional modular section of the frame that serves as the attachment and support structure for the manipulator. We use 3D-printed PLA to interface between the core frame and the mechanisms and other components on the ROV. Aluminum is used for structural components because of its ease of manufacturability, low cost, high strength, reasonable density, and saltwater compatibility.



Scan to see CAD model! (or click)

CAD Model of Nautilus. The frame is made of waterjet cut 1/8" aluminum, joined with aluminum brackets and stainless steel bolts.

The main fasteners we use are stainless steel bolts and nuts. The material choice allows our joining method to be resilient against salt water exposure while being mechanically durable. Most importantly, they are easy to disassemble and reassemble. Rivets, while being more space and mass efficient, cannot be repeatedly disassembled -- they must be drilled out and new ones must be installed. This results in a recurring cost to purchase new ones as well as risking the introduction of metal shavings near watertight seals, motors, and electronics. The constraints on space and mass are not strict enough to justify rivet use. Similarly, welds provide a more compact, lightweight method of joining components, but are also permanent and cannot be replaced. Additionally, welding aluminum is difficult, and we do not have the equipment to do it well. Therefore, welds also provide more disadvantages for our use case than they provide benefits.

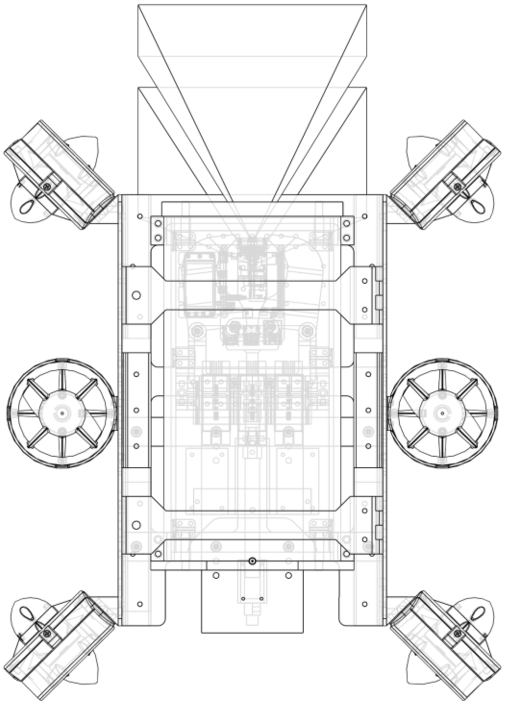
The metal structural members of the frame were either manufactured with waterjet cutting (material sheets) or cut with hand tools (stock). While these methods may not be at the cutting edge of today's manufacturing technology, they provide multiple major advantages. Waterjet cutting of metal is very accurate, inexpensive, and easy to do, making it ideal for our application. Similarly, cutting stock using hand tools is versatile, inexpensive, and does not require the training or machinery that advanced machinery does. Overall, for our team, a cost-effective, fast turnaround manufacturing method means that iteration is cheap and fast to do.

For our ROV, we have continuously miniaturized our designs each year. Having a smaller ROV means that we spend less on materials, need less propulsive power to move our ROV through the water, can transport our ROV more easily, and can more safely transfer it into and out of the water among other advantages.

However, there are also disadvantages to our ROV's smaller size: it is more difficult to package the electronics into the pressure hold, and there is some added difficulty to maintenance since access is, by the nature of small size, more challenging. We remedied this problem by iterating our internal electronics chassis. The main goals were to increase the ease of inserting and removing all internals by unifying all internals onto one structure. This now allows us to open and close the ROV in less than 10 minutes without risking damage to sensitive electronics. Additionally, for maintainability, we are continuously refining the components mounted on the ROV to connect via simpler interfaces and fastening methods. This makes disassembly fast, with our goal being a single "step" with no dependencies to go through to replace any subsystem on our ROV.

Thrusters

We used four Blue Robotics T100 thrusters for horizontal movement, placed diagonally in the four corners of our ROV, and two Blue Robotics T200 thrusters for vertical lift. We chose Blue Robotics thrusters for their robustness and reliability. We did consider potting our own thrusters, but due to constraints on the number of students we could have in our labs and the frequency of meetings due to COVID-19, we ultimately decided to pursue an off-the-shelf solution. This was also a cost-effective decision, as we had thrusters from previous years that we could reuse. Additionally, we have extensive experience working with the T100 and T200 thrusters from previous years in the competition.



Thruster layout on Nautilus. *The four T100 thrusters are located in the corners, and the two T200 thrusters face vertically.*

The layout of our thrusters allows us to strafe and rotate quickly and precisely. One disadvantage with this system is that we cannot alter our pitch or roll. However, because so many of the MATE 2021 Explorer Challenges require precision manipulation of small objects, such as the ghost net pin and the coral fragments, we decided to prioritize precise horizontal navigation over additional axes of movement. We use two vertical thrusters on either side of the ROV for balanced lift. To prevent the power draw from the motors from overloading our systems, we set limits within the control software to constrain their top speed.

The interfaces between the frame and mounted components (thrusters, pressure hold) were 3D printed from PLA plastic. Our primary 3D printers are a Creality Ender 3 Pro and a Creality CR-10S Pro. These printers are low cost, but have been tuned to have the precision required for strong 3D prints. The pressure hold that contains the electronics is supported by two 3D printed interface mounts. The connection is via the full-length threaded rods that compress the end caps to keep the hold watertight, lowering the complexity and part count of the ROV. By having the rods serve a dual purpose, we save on cost and increase structural integration, so we have less redundant structures and a simpler design overall.

The thruster mounts are custom 3D printed PLA mounts that precisely angle the motors without adding significant amounts of cost or mass. By making the mounts rigid at an optimal angle instead of adjustable, we increase their strength and durability.

A common theme throughout our design process is poka-yoke: the principle of designing systems to fit together in only one correct way. It is impossible to attach the pressure hold to the ROV without also properly sealing it against the water and it is impossible to attach the motors at an incorrect angle or in the wrong position. This means that when the ROV looks ready to go into the water, it is mechanically fully ready to go. Thus, our checklist on the safety, presence, and secure installation of systems is sufficient for deploying the ROV (Appendix A).

Manipulator

The manipulator was designed in 3D computer-aided design software before fabrication to ensure it would have the range of motion required to grip all of the objects we must manipulate. Additionally, the CAD model allows us to detect interference and other mechanical issues before fabricating any parts, so we can prevent costly rework and scrapped components. Finally, the CAD model allows us to directly produce manufacturing data for the 3D printers, something that would be impossible with purely paper-based or 2D computer-aided design work.

The manipulator is itself largely made from 3D printed PLA, but with some off the shelf components, such as the pneumatic cylinder. By combining COTS and custom components, we get the best of both worlds: subsections of the design can be optimized by iterating on the 3D prints, while maintaining the structural integrity and reliability of mass-produced components for the harder-to-produce aspects of the design.

The way the gripper functions is very simple: the core pneumatic cylinder is actuated by an operator activating an onshore valve. The pneumatic cylinder pushes a central lever section of the gripper backwards and forwards, actuating two interlocking, hinged fingers through a pin-slot motion. By keeping as many components onshore as possible, we reduce the number of parts experiencing contact with salt water, reducing the risk of failure over time.

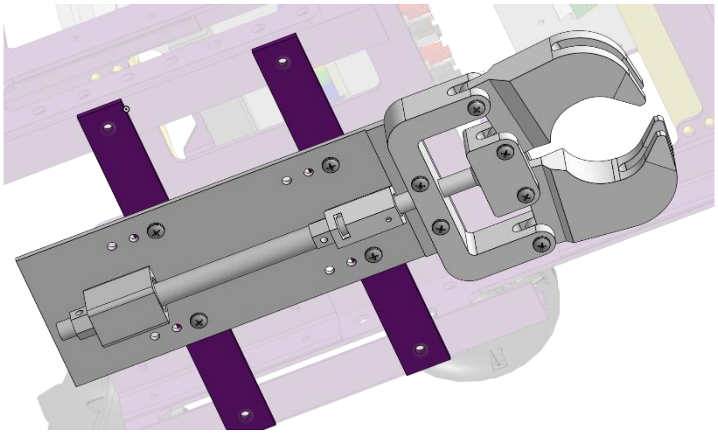
For the manipulator, we analyzed multiple potential design concepts before selecting our final pneumatic system. The three primary options we considered were:

1. Soft gripper inflated by pneumatics
2. Motorized hard gripper using waterproof electronics
3. Pneumatic hard gripper using waterproof pneumatics

Ultimately, we selected the pneumatic option because of its reliability, simplicity, and grip strength advantages over the other options.

Soft grippers in an underwater ROV context have design heritage at our club, but we have discovered that they have multiple disadvantages that we wanted to remedy this year. They require precisely regulated pneumatics (since they will otherwise pop and break), wear out over time, are limited in grip strength, are susceptible to punctures, and are complex to fabricate. Of course, they do provide several advantages: a more delicate grip, the ability to conform to hard-to-grip items, and mechanical simplicity since the only moving part is the gripper itself. However, these advantages do not weigh out the difficulty and risks because the failure mode of the gripper is catastrophic: misregulated pressure, sharp items, or spontaneous fatigue failure can all immediately incapacitate our ROV, which is not a risk we want to take on this year.

Both motorized grippers and pneumatic hard grippers have greater grip strengths, mechanical robustness, ease of fabrication, resiliency against damage, and durability over time. We chose the pneumatic hard gripper style because it reduces the electronics required, has a lower part count internally, and is less delicate than the electronic hard gripper style.



CAD design of our pneumatic hard gripper. Adding pressure causes the piston on the left to extend, which pushes the jaws of the gripper apart and allows it to open.

However, a disadvantage of our choice is that electronic grippers provide more precision with how an object is held as well as more precise control of the position of the gripper than pneumatic hard grippers.

We have continuously iterated each of the systems in the ROV, including the internal electronics mounting chassis, motor mounts, motor protection grills, and the exact mechanical design of the gripper. Even when things have worked well, we have continued to iterate to further improve them.

The electronics mounting chassis has been refined to improve ease of insertion, compactness, ease of assembly, and visibility as we have tested and assembled the electronics. By iterating the layout and design rather than committing to a single option, we continuously improve both the performance and maintainability of the ROV.

Similarly, the thruster mount designs have been refined to be easier to put on and take off of the robot, so maintenance is faster in the case of a broken motor. The motor protection grilles have also been custom designed in their second incarnation, in contrast to their first version, which was an open-source design from thingiverse. The grilles now have dimensions optimized specifically for our 3D printers, as well as some design modifications to prevent them from obstructing thruster cables.

Unfortunately, one aspect of our ROV that did not perform well in our initial tests was the gripper. While the gripper delivered on its promises of robustness, grip strength, and reliability, it fell short in a major area: ease of use. The gripper works well in isolation, but needs refinements to work better as a whole within the integrated ROV system. Therefore, our latest version has the following refinements:

1. Better positioning relative to the ROV. The old design is situated under the ROV, which makes visibility difficult, especially when gauging whether something is or is not gripped properly. We moved it out towards the front of the ROV to fix this issue.
2. Better camera visibility of the manipulator. To enhance the close-up visibility of the manipulator to the operator through the remote console, we adjusted the internal position of the camera in tandem with the new gripper location to ensure the operator can easily see what is going on in full detail.
3. Wider grip area of the claw. The old design had a very narrow band of horizontal alignments where it could successfully pick up the required objects. Therefore, we adjusted the gripper's geometry to widen this area to increase resiliency against misalignment.

Buoyancy

By lowering the overall size of our ROV and having a relatively large pressure hold, we almost entirely eliminate the need for buoyant foam. Most of the lifting force our ROV experiences comes purely from the hold's volume. This made it easier to assemble the ROV's internals without causing inadvertent damage.

Since our ROV is already approximately neutrally buoyant in salt water, we only need to add small blocks of foam as a part of the balancing process to make it perfectly neutrally buoyant and balanced. This further reduces the part count, simplifying assembly, lowering cost, and making modifications and iterations simpler.

We use two primary tools for balancing the ROV: small blocks of low density foam and lead weights in sealed containers. If the ROV is less dense than the water when we start to balance it, we add weights until it naturally begins to sink, using their positions to make major adjustments to the ROV's balance.

Then, for finer adjustments or if the ROV naturally sinks, we use foam that is less dense than the water. The advantage of using foam for fine tuning is that it can be easily nudged or shifted around slightly to get the balance just right, and it can also have portions safely cut off to more precisely adjust the buoyant force. On the other hand, the sealed lead containers cannot be safely cut down to smaller sizes.

As for roll symmetry along the front to back axis, we design our ROV to be symmetrical, with the manipulator, pressure hold, frame centroid, and tether connection point all staying relatively on the same line. Thus, as long as we add weights in the lower area of the ROV and foam in the upper area, the center of buoyancy will stay directly above the center of gravity, maintaining roll stability.

Finally, the tether itself has a non-negligible impact on the ROV's balance. To mitigate its effect on controllability and the ROV's natural resting orientation, we add foam floats along the tether to make its average density neutral. This ensures that our ROV moves with consistency, whether it's right by shore or far out and deep underwater.

Payload and Tools

Because our manipulator is designed to best handle vertical objects, we created a modified 50x50 cm square quadrat that includes a vertical post on the side for ease of handling. The rest of the frame was made out of ½ inch PVC, with holes drilled to allow for air to escape.

Likewise, we followed the design of the existing seabin power connector (as given in the MATE 2021 prop building instructions) and added a vertical length of ½ inch PVC to the handle for improved ROV handling.

We did not build a device for removing the sediment sample from the drain pipe.

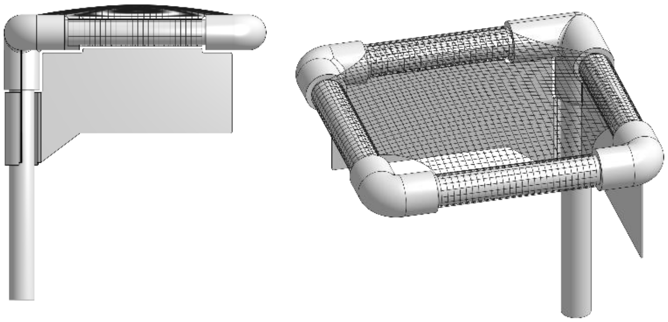
To retrieve the ping pong balls from the collection area, we will be giving our ROV a custom attachment tool to hold using its manipulator. The design consists of a net strung across a PVC pipe rectangle that connects to a length of vertical PVC pipe held by our manipulator. By using our manipulator to secure the net, we can quickly swap the tool in and out without needing to extensively handle the ROV. The vertical support post is both easy to grip for our manipulator and it allows us to reach out of the water with the net, making it easy to capture the balls.

The ROV's usage of the net follows this cycle:

1. Equip with the net at the shore
2. Move to the collection zone underwater
3. Emerge above the water beside the ping pong balls
4. Continuously move forward, using corralling edges to collect the balls under the net

5. Lower underwater, taking the ping pong balls with it in a scooping motion
6. Returns to shore for retrieval of the balls

Surface plastics net (ping pong ball collector)



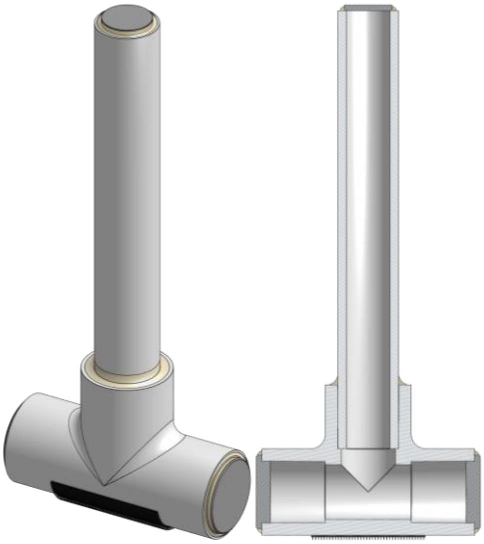
Our sea star injection device is designed to be similar in manipulation to the coral elements for optimal compatibility with our gripper. The design has three major requirements:

1. Satisfies all build rules
2. Easy to grip and deliver
3. Recoverability to prevent mission failure and accelerate cleanup

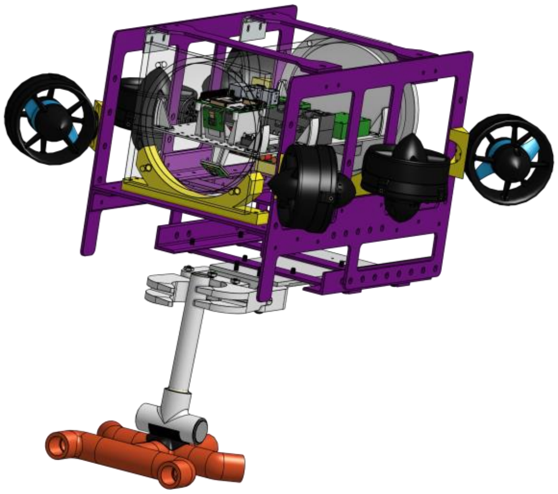
To satisfy these requirements, we are using a simple structure made from Schedule 40 PVC tubing, in general mirroring the build style of other elements in the challenge. The design has two major parts: the attachment section and the stabilization tube.

The attachment section has the velcro patch for attaching to the sea star analog and has greater density than the handle. Similarly to the provided example construction, the lower section consists of a PVC T joint with velcro wrapped on. The internals of the tool are sealed from the water, so there is a pocket of air that remains inside to help the tool stay close to neutral buoyancy. However, there is space inside the T joint for weights if needed.

The handle, on the other hand, is less dense and is intentionally not compact. It extends vertically to allow the gripper to pick it up efficiently if dropped and also during normal operation. Because of the handle’s lower density, the naturally stable orientation for the tool is to be vertically aligned, even though the tool sinks in water. This helps it stay on the sea star, even if not placed perfectly.



Sea Star Tool Design



Sea Star Tool Usage

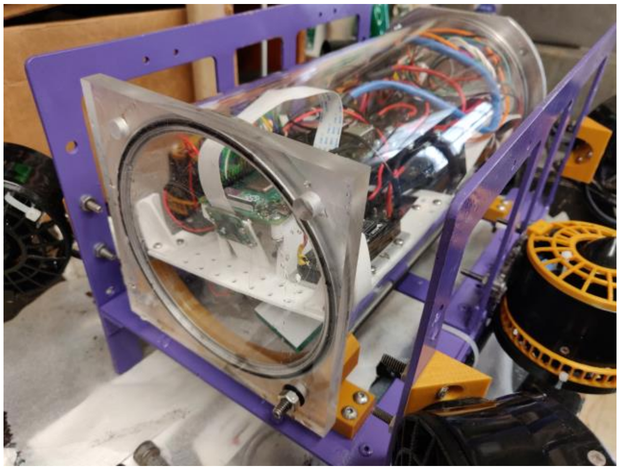
Electrical Systems

Surface System

Our surface system is divided into two major subsystems. One is our power supply, while the other is the control system.

The power supply relays 48V DC power to the ROV through the tether. It takes in power through an Anderson SBS50 power connector and includes a 25A Littelfuse fuse (0895025.U) for electrical protection. This connects to the splash-resistant power/control box which includes the main power switch for our ROV onboard system, enabling us to safely shut off power to the ROV. The control subsystem consists of a laptop and a router and is powered from any standard wall outlet (120 V AC). The control system relays information to and from the ROV through an ethernet tether.

For our surface control system, we have chosen to utilize a standard laptop. We have decided to use a laptop because our old control system had less than half of the computing resources of the Raspberry Pi we have onboard, making the surface control system unable to complete computer vision tasks. Using a standard laptop gave us access to significantly more computing resources than we had on the Raspberry Pi at a much lower price than assembling and waterproofing a small desktop computer. We will also include a pelican case in our surface control system set-up to protect our surface control system from potential water damage.



Our pressure hold is a large acrylic tube with endcaps made of clear acrylic and aluminum.

Onboard System

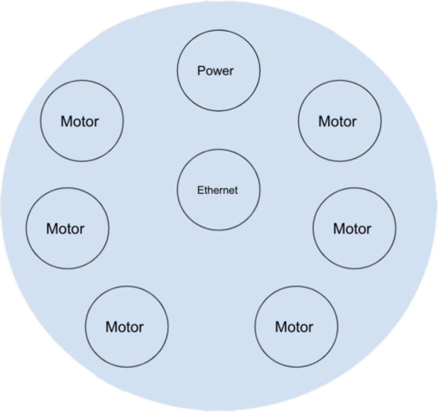
The majority of our electronics components are located inside of the pressure hold, which is a custom-built housing made from an acrylic tube. This component was reused from a previous year's research and development efforts, but is new to the competition.

The acrylic tube was bought and the ends were milled for precision. The acrylic end cap was a 1 inch-thick piece of acrylic that was milled with a CNC machine, and a similar process was done to create the structure and holes in the aluminum end cap. Close attention was paid to the o-ring grooves which required a great deal of precision. We also included a slight chamfer on the endcaps to allow for easier insertion of the cylinder without catching on or damaging the o-ring.

By using acrylic as the main material, the pressure hold has the advantage of being strong and stable, withstanding high underwater pressures to protect our ROV main system. Additionally, the ability to see into our pressure hold from all angles allows us to quickly diagnose issues and identify whether components are working, which we could not do with an opaque plastic or metal container.

The pressure hold has eight total connections that connect through the aluminum endcap. Two of these connections are surface connections for ethernet and power while the six others are connections to the thrusters (T100 and T200 thrusters). The power cable provides 48V DC power for all the components within the pressure hold which includes the ESC motor controllers, Raspberry Pi, power converters, and cameras. The ethernet cable allows for communication with the surface control system.

Internally, all components within the pressure hold are mounted onto a single baseplate for organization and easy removal. We designed our baseplate using 3D-printed PLA for prototyping and used laser-cut ⅛" acrylic for the final board. PLA was used for prototypes due to the cost-effective nature of the material, allowing us to quickly iterate on our layout. We originally shied away from acrylic



Layout of the pressure hold baseplate connections.

due to the higher material cost, but found that PLA did not provide sufficient rigidity under the weight of electronic components. The pressure hold contains two power converters which convert the incoming 48V DC power to 5V and 12V DC, both of which are protected by 15A blade-type fuses. The 5V DC power is supplied to the onboard computer, while the 12V DC power is supplied to the six ESC motor controllers.

A Raspberry Pi 4 acts as the main computer for our ROV, and is connected to the surface via the ethernet connection. One of our two cameras is connected via a USB cable, while the other has a direct wired connection. Additionally, all six ESC motor controllers have a wired connection to the Raspberry Pi, allowing the Pi to control the motor speed.

Most if not all of our connections are done via terminal blocks to ensure that wires could be laid out neatly. Using terminal blocks, rather than direct soldered connections, allows us to quickly replace faulty components in a modular fashion. We also utilized multiple fuses to protect ROV electrical system.

Tether

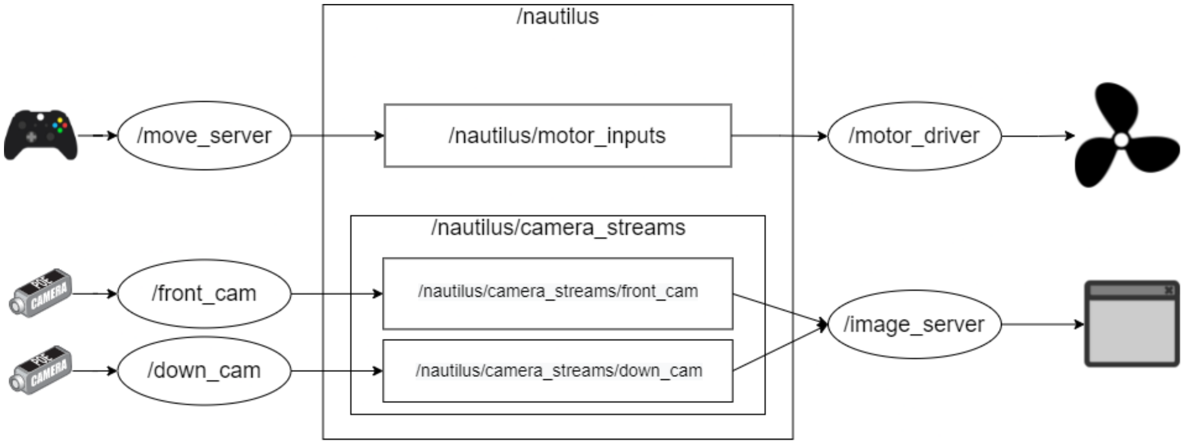
Currently, we are using Blue Robotics Fathom ROV tether designed specifically for ROVs to deliver power. The tether is easy to manage because it has a slim profile (diameter of 7.6mm) and it is neutrally buoyant. The tether has a breaking strength of 350 lb and working strength of 80 lb. It is also joined with a CAT 5 ethernet cable which ensures a fast and reliable connection to the onboard systems.

We have also chosen to reduce our tether size from 100 meters to 10 meters. We have made this decision to improve safety and efficiency of above-water action, reducing the likelihood of tripping and increasing the speed at which the tether can be stored.

During ROV operation, one employee is responsible for tether management. The tether is required to be neatly spooled before and after use to reduce tripping hazards and potential damage to the tether. If the ROV needs to be lifted by the tether, two employees are required, one to pull the tether to the surface and the other to wind the tether around the spool.

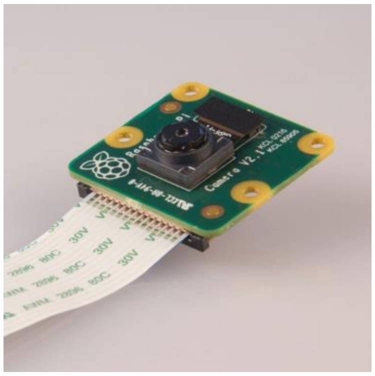
Software Systems

Robot Control System



Overview of the ROS system.

Our control system uses the Robot Operating System (ROS), which is the industry standard for robotics systems. Programmers can take a modular approach to developing for *Nautilus* while utilizing existing ROS libraries and packages, including the Gazebo simulation library. The onboard system is run entirely on the aforementioned Raspberry Pi 4, which is connected via ethernet tether to our surface control system. We chose to use the pre-existing Raspberry Pi 4 due to its small form factor, competitive pricing, extensive documentation, and ease of replacement in case of failure.



In our initial prototypes, we also used a secondary Arduino Uno to relay commands to the ESCs. However, the Arduino took up a large footprint in the pressure hold and the C programming language requirement added to the complexity of our student training process. We instead elected to remove the Arduino and directly use the I/O pins on the Raspberry Pi. Though there was a learning curve associated with using these pins and changing our existing system, the end result is takes up less valuable real estate in the pressure hold and has negligible differences in reliability.

Nautilus uses one forward-facing Raspberry Pi camera (1080p, 30fps) and one downward-facing USB camera (480p, 30fps), which is the minimum number of statically mounted cameras needed to accomplish the competition tasks. The forward-facing Pi camera supports underwater navigation, while the downward-facing USB camera assists in manipulating objects. Both the Pi camera and USB Camera are extremely compact and reduce space usage in the pressure hold. Both are cheap and easy to replace in case of failure. Additionally, the Pi camera is directly processed by the Pi's GPU, which gives it much better performance, while the USB camera has a swappable lens. While we originally attempted to use two Raspberry Pi cameras, we encountered issues with the quality of the solder pads on the cameras, making the camera setup more fragile. Rather than have the cameras be points of failure, we decided to use an alternate USB camera which plugs directly into the Raspberry Pi.

The Raspberry Pi Camera and USB camera used on the ROV.

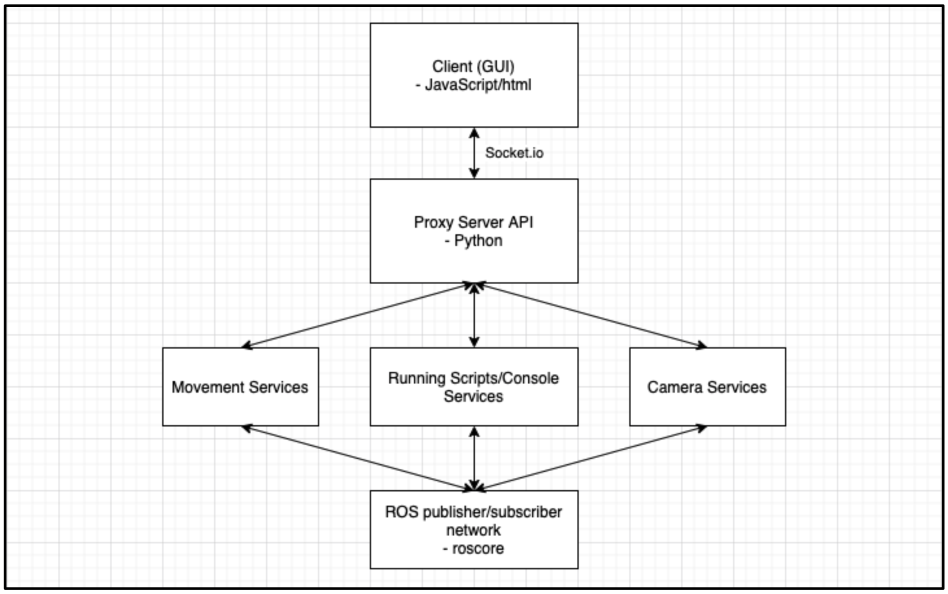
Surface Control System

For our surface control system, we are using a network of modularized servers. We have a simple microservice architecture which allows us to organize business capabilities and have loosely coupled services. This also allows us to efficiently work within the team by having people focus on separate modules and diagnose problems more accurately.

We have also developed a browser UI complementing the servers as an interface to access the ROV. The UI contains widgets that the team has created to display images and manage keyboard/controller input. The design of the UI is scalable and we are able to add more content in the future by creating individual components to extend the UI's functionality.

Design Overview

We decided on creating the UI through JavaScript in a browser because our previous UI was a browser-based GUI. However, we decided on using React.js to create the UI. React.js allowed us to create modular components that we could add and remove with our UI which made development easier and scalable for the future. There are also many open-source modules and components that we are able to utilize in our application.



A diagram showing the organization of our service-oriented GUI.

Coming into this project, the most important decision that we needed to keep in mind was that we were using ROS for our system; we needed our UI to interact with the ROS system to communicate with the robot. There were a few options that made it possible for us to make JavaScript communicate with ROS. The first one we considered was to use the roslibjs package to directly communicate with ROS with JavaScript. One issue with JavaScript was that JavaScript made it difficult to manage and work with files that were directly on the computer preventing us from easily launching scripts from the UI. The other big issue was that roslibjs was complicated and there wasn't a good reason to learn it compared to what we decided to use.

For our interface with ROS, we created a proxy server using Python that would act as a bridge between the ROS network and the UI. The UI would use the Socket.io library to communicate with the Python server which would relay all information to the ROS network. This was much simpler than learning the roslibjs because the ROS library for Python was much easier to use and we had already been working with Socket.io to communicate a UI built off of node.js and a Python server. There were additional benefits to using a Python proxy server because we had access to Python's many libraries (such as opencv) that could be used to work with the data that was being communicated between the ROV and the UI. This system was also not much different from how roslibjs was implemented. Roslibjs uses websockets to communicate with a rosbridge server that is connected to the ROS network.

Overall, this year's system was a big improvement from our previous control system with our migration to ROS as our base system. On the UI side, we improved our ability to develop the UI by designing a modularized component based UI that could be easily scaled with independent components for future years.

Competition Tools

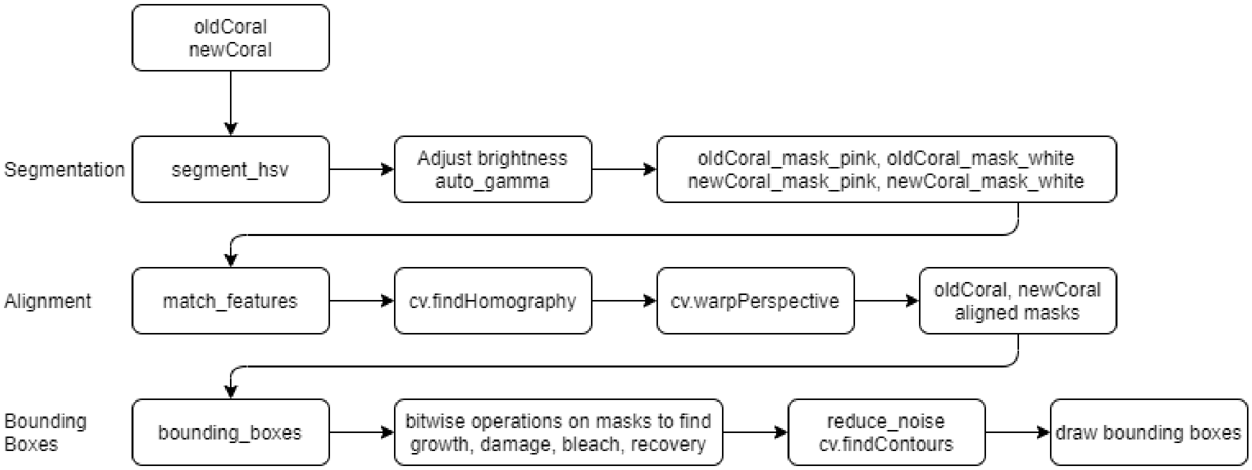
Computer Vision

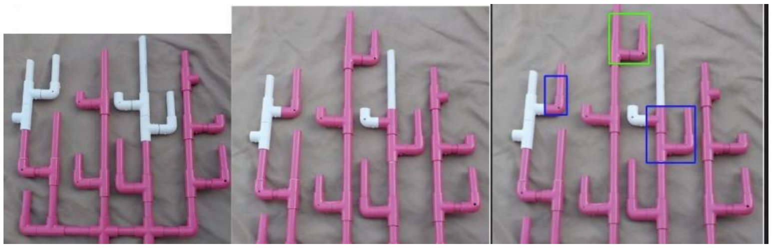
We developed a number of computer-vision algorithms to tackle the MATE 2021 demonstration challenges.

Our computer vision pipeline is as follows: the Raspberry Pi onboard the ROV connects to the two cameras on board, and serves their video streams to the surface controller via ROS topics. The surface controller can then take frames from those video streams and process them using OpenCV. Results from the surface controller’s video processing are then made available to see through our in-house interface.

For task 2.1 (Fly a transect line over the coral reef), we determined what organism (if any) was present in each square of the grid with color detection. The sponge is made of white PVC, the sea star is red, the coral fragment is mostly yellow, and the coral has a black base. With that knowledge, we could isolate these colors and create a binary image distinguishing where a certain color was present. Based on the contours and area of the binary image, we could determine the primary color of the shape, thus determining the organism.

For task 2.2 (Image recognition for health of coral), we ran a feature matcher over both images to map them on top of each other, and then take a “difference” of the before and after images using color masks which identify the live and dead areas. The differences between the images are then noted and reported.

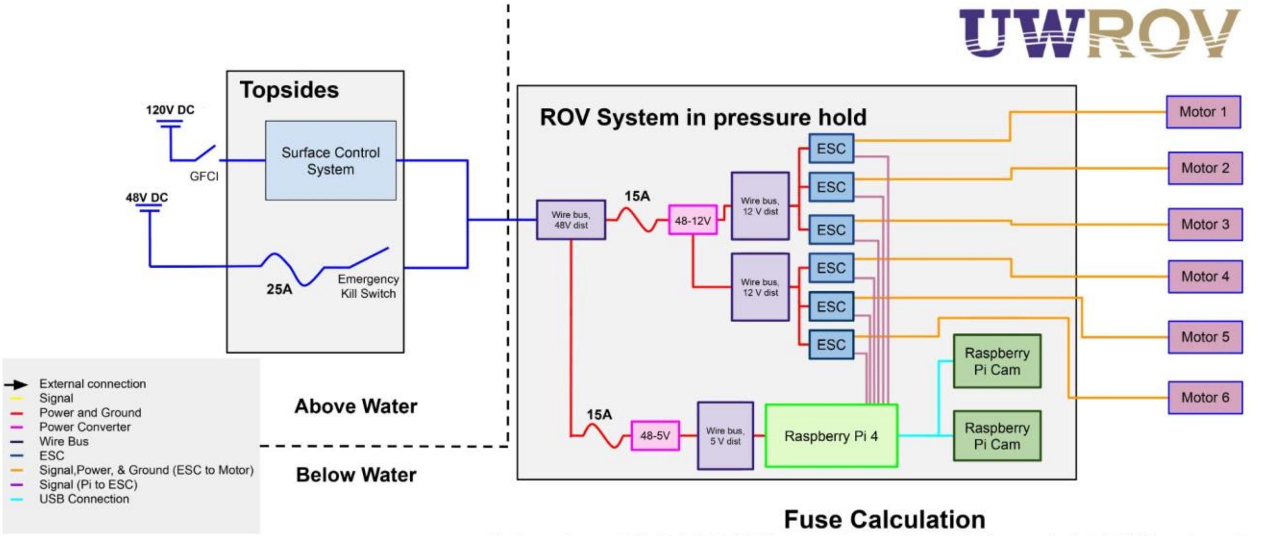




A breakdown of the steps in the computer vision algorithm that identifies coral health (task 2.2).

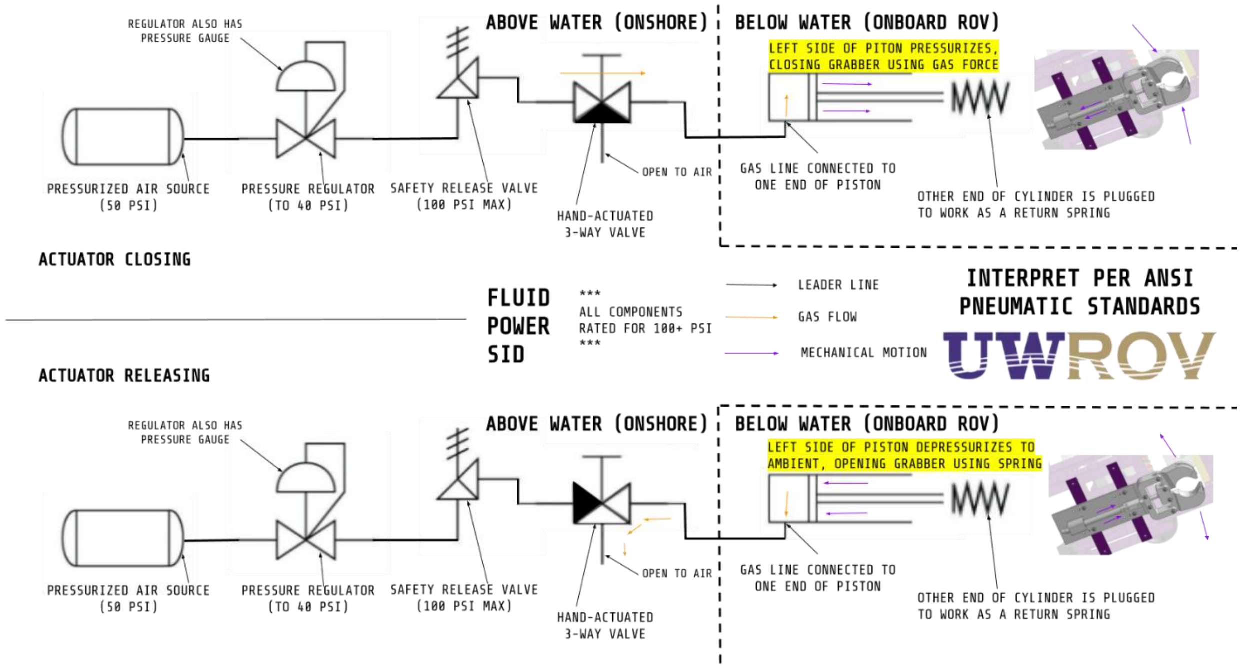
For task 3.4 (Create a photomosaic of a subway car), we have a predefined routing of images to take around the subway car. When an image is taken, a corner detector will identify the face the ROV is looking at, apply a transformation to make the detected face a rectangle, and insert it into its position in the photomosaic.

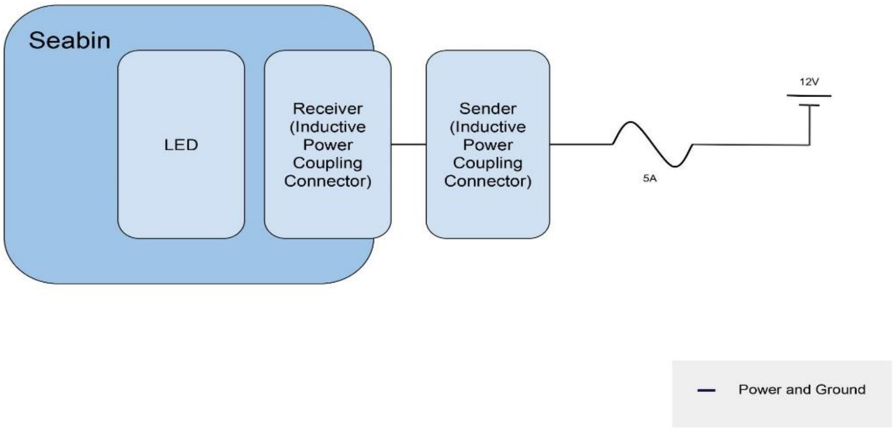
System Integration Diagrams



Fuse Calculation

As there is one (1) 48-12V DC/DC converters on board that are rated at 400W each, and one (1) 48-5V DC/DC converter on board rated at 90W, the ROV has a total of 490W of available power.
The maximum current required by the ROV is therefore 490W/48V = 10.2A
Applying the mandatory safety factor gives a required fuse value of 10.2x1.5 = 15.3A. As per ELEC-008E, the maximum current supplied to an ROV is 25A, so a 25A fuse is chosen.





Safety

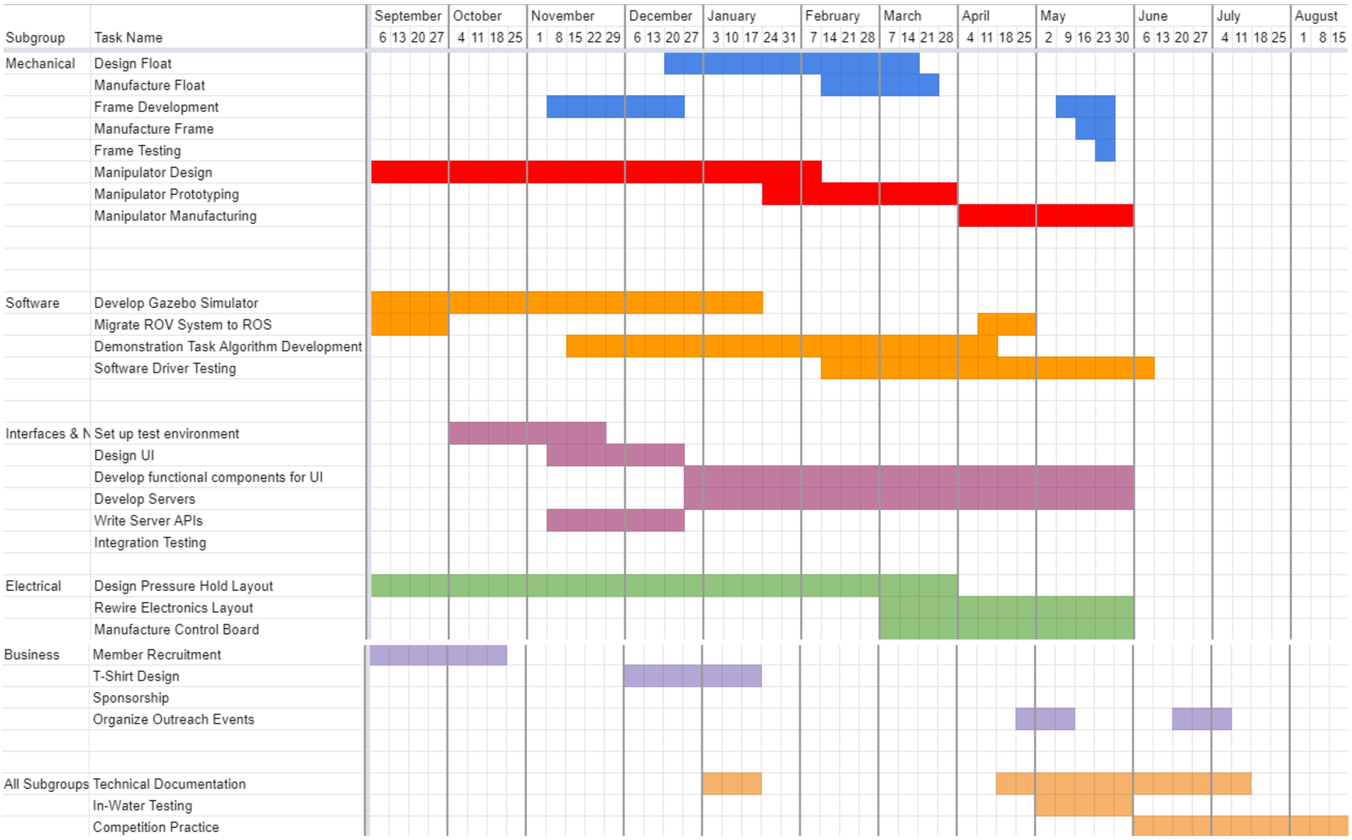
While we were able to perform the majority of the design process in an online environment, we implemented strict guidelines around COVID-19 safety for when in-person meetings were necessary. Before entering the lab spaces, students were expected to be in compliance with University of Washington’s coronavirus practices. This included providing a signed attestation that they were not experiencing COVID-19 symptoms and would adhere to COVID-19 precautions and procedures.

Students were required to work in separate rooms. To ensure this occurred effectively, lab sessions were coordinated through the lab manager, Daelyn Bergsman, and were approved by the club advisor, Rick Rupan. Students were required to wear masks and gloves in the lab spaces. Tools were sanitized after use and workstations and communal areas were cleaned and sanitized according to CDC guidelines. In the event that it was necessary for multiple students to occupy the same lab space, students were required to wear masks and gloves at all times and maintain social distancing (six feet).

We also created a series of safety checklists for use when closing our pressure hold and deploying the ROV to reduce the risk of harm to students or the ROV (see Appendix A).

Project Management

Project management was headed by UWROV’s Business Subgroup. We scheduled regular meetings with each subgroup to ensure progress on projects, working with team members to establish deadlines and milestones for the year. Biweekly goals and updates were also shared through a series of officer standups. This is shown here in visual format as a Gantt chart.



A Gantt chart showing the goals, by subgroup, and the estimated time to completion.

Testing and Troubleshooting

Many of our decisions this year were shaped by the COVID-19 pandemic, as many UWROV employees were working remotely and some were located out-of-state. We focused our attention on adapting our processes to suit remote work environments. These efforts included sending hardware to employees, using standardized environments, and changing our vehicle's operating system to a more modular system.

One of the earliest issues we encountered in the virtual training process were training programs failing to run due to differing operating systems, hardware, and library installations. As we were unable to work in-person in the labs, UWROV employees in the Electrical and Software subgroups were sent development kits, consisting of Raspberry Pi units and basic prototyping tools (breadboards, sensors, etc.). This allowed employees to test on our ROV's standard hardware without requiring in-person access to the labs. We also decided to use a virtual machine (VM) to standardize our programming environment. We originally used the

VirtualBox software to manage our VM, but eventually switched to the VMWare software, which had a higher limit on computer resource allowance that supported more intensive programs. These changes, along with the development kits, allowed for all employees to effectively run and debug their programs while minimizing complications caused by differing hardware and software installations. In the future, we would like to experiment with Docker images, which provide similar virtualization but use significantly slimmer installation files and are much more user-friendly.

One of the largest changes we made this year was migrating from our old control system to the Robot Operating System (ROS). This was a fundamental change in our design, as our previous control system was entirely in-house. This decision brought in some growing pains, but the feature set ROS provides allowed our team to streamline our collaboration process, reference tried-and-true documentation for niche use cases, and simulate all our software components without needing physical access to our ROV.

Reflections

Peter Gunarso, Software Lead: “Onboarding was one of the biggest challenges that working online presented - this club was a lot of members' first experiences using a VM and a Raspberry Pi, so having to develop teaching materials on how to use them was a big challenge. Overall I'm pretty satisfied with how we tackled this year working remotely, and I think it will serve as a great experience for making next year even better!”

Peyton Lee, UWROV President and Business Lead: “This year has been tough in so many ways, with limitations on in-person meetings making our normal operations impossible. We took on the challenge of adapting to an online environment and used it to improve our team communication and organization, to explore new tools and design processes. We made major pivots in our software, electrical, and mechanical systems, all of which represent hundreds (if not thousands) of hours of work from our members and leads. This year in particular there are so many students who stepped up as leaders, experts, and collaborators. Despite many of our members only joining us online, there is a level of commitment and dedication that surprises and delights me. I am so proud of all of our members and I'm so excited to see this community grow and flourish.”

Daelyn Bergsman, Mechanical Lead: “I love the UWROV community, it was a core pillar of my university experience, and being able to relax and work on a robot with a group of laid back students was always the highlight of my week.”

Andrew Jang, VP and Interfaces & Networking Lead: "I am very proud of the UWROV community, especially after working with everyone during the pandemic. Through all the difficulties and even working with those whom I have never met in person before, we were able to learn, collaborate, and develop software. If I were to describe my experience with UW and what sort of communities I was part of during my time here, I would definitely identify as a UWROV member during my time here as a student."

Shruthika Kandukuri, Mechanical Team: "I initially joined UWROV because I wanted to develop hands-on engineering experience working on a large project. I'm also very interested in environmental sustainability and research, so building a robot for underwater conservation tasks was perfect. I stayed because I learned a lot of new skills and enjoyed working with my team, and it was great watching the ROV come together."

Cindy Zou, Software Team: "I was looking for a robotics team to join and after going to a bunch of info sessions UWROV's team culture and challenge seemed the most welcoming and engaging at the same time. I think the mysterious artifacts in the lab were also a draw. I stayed for the team culture and the interesting software tasks that allow me to contribute individually as well as collaborate with other members and get guidance from the team leads."

Alnis Smidchens, Mechanical Team: "I am very proud of three things: The ROV we put together, the float we put together, and how we maintained a fun, low-stress environment throughout the whole year. Having success in engineering while enjoying it is tough to do, especially with all of the challenges surrounding remote work. Of all of the clubs I am participating in, UWROV has my favorite culture. I can't wait for the next year!"

Acknowledgements

We are incredibly grateful for the help and support we have received this year, and would like to thank the following organizations and people for their contributions:

- The University of Washington School of Oceanography for its continual support of our team and providing laboratory space for UWROV,
- Rick Rupan for supervision and guidance throughout our club's development,
- The MATE Center for their dedication to enriching student learning and and outreach in ocean technology,
- Our sponsors:
  - foundry10
  - The Boeing Company
  - The University of Washington College of Engineering
  - The Evergreen School
  - ArduCAM

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Appendix A: Safety Checklists

Opening Pressure Hold

- Power supply is off (announce "POWER OFF")
- Outside of pressure hold is completely dry
- Surface is free from tools or (metal) debris
- Static electricity discharged by touching a metal surface

Closing Pressure Hold

- Assembly is powered off and no power cables are connected.
- The control board is clean, with no residue or metal debris.
- No wires are disconnected, loose, or exposed.
- The inside of the pressure hold is completely dry.
- The pressure hold has no scratches, clouding, or cracking.
- All ports on the pressure hold are sealed tightly.
- O-rings are undamaged and lubricated.
- O-ring grooves are clean and undamaged.
- No wires are pinched between components or the walls of the pressure hold.
- O-rings form a complete seal around both ends of the pressure hold.
- Both endcaps are flush with the main cylinder.
- Internal assembly is horizontally level.
- All four bolts are tightly secured with double-nuts on each end.

Before ROV in Water:

- All ROV connections are screwed securely.
- No pressure hold ports are exposed.
- There is no damage in the ROV frame or pressure hold.
- All ROV attachments (motor shrouds, floats, weights, motors) are secured and do not move under force.
- There are no loose connections in the pressure hold.
- All connectors are screwed on tightly.
- Color-coding on the motor connectors match.
- The tether is laid out neatly without knots or tangles.
- Battery/power supply is completely dry and away from the side of the pool.
- Control box connectors are screwed in tightly.
- Control box is stable and on a level surface.
- Control box computer and router are plugged in and powered on.
- Control box monitor is securely in place and connected.
- All pool operators are following safety guidelines.
- Recovery equipment (pole, net, etc.) handy
- Poolside is clear of clutter and tripping hazards.

Before Powering On:

- No water is flooding the pressure hold.
- No parts have come loose from the ROV.
- All connections are secure.
- Announce "POWER ON" when the ROV power is switched.
- ROV is placed in the water.
- No students are directly touching the ROV

UWROV

Appendix B: Budget

Expenses

	Planned	Actual	Diff.
Totals	*$6,400*	*$5,848*	*+$552*
R&D Mechanical	$300	$90	$210
R&D Electrical	$600	$628	-$28
R&D Software	$700	$706	-$6
Materials	$100	$57	+$43
Operations	$400	$321	+$79
Competition Fees	$3,500	$3,355	+$145
Tools	$800	$689	+$111

Income

	Planned	Actual	Diff.
Totals	*$6,000*	*$7,525*	*+$1,525*
Grant Funding	$1,500	$2,150	+$1,025
Sponsorship	$5,000	$5,375	+$375

Expenses

Amount	Description	Category
$25.00	Fluid Power Quiz	Competition Fees
$400.00	MATE Pre-Registration	Competition Fees
$2,930.00	Student Travel Reimbursement	Competition Fees
$96.95	Raspberry Pi (Dev)	R&D Electrical
$205.90	Electronic Parts	R&D Electrical
$37.96	Cameras	R&D Electrical
$86.59	Electronics Parts	R&D Electrical
$200.72	Electronics Parts	R&D Electrical
$57.37	UWROV Props	Materials
$0.00 (est. $800)	Blue Robotics thrusters **(Reused)**	Materials
$0.00 (est. $130)	Pressure Hold **(Reused)**	Materials
$24.04	Website	Operations
$100.82	T Shirts	Operations
$123.20	Safety Goggles	Operations
$73.08	Power Pack (for outreach)	Operations
$369.04	Development Kits	R&D Software
$196.71	Sensors	R&D Software
$140.07	Cameras	R&D Software
$45.00	Frame R&D	R&D Mechanical
$45.00	Manipulator R&D	R&D Mechanical
$689.23	3D Printer	Tools

Income

Amount	Description	Category
$500.00	College of Engineering Grant	Grant Funding
$1,650.00	College of Engineering Grant	Grant Funding
$1,125.00	Boeing Donation	Sponsorship
$500.00	The Evergreen School Donation	Sponsorship
$1,500.00	Boeing Donation	Sponsorship
$2,250.00	foundry10 Donation	Sponsorship