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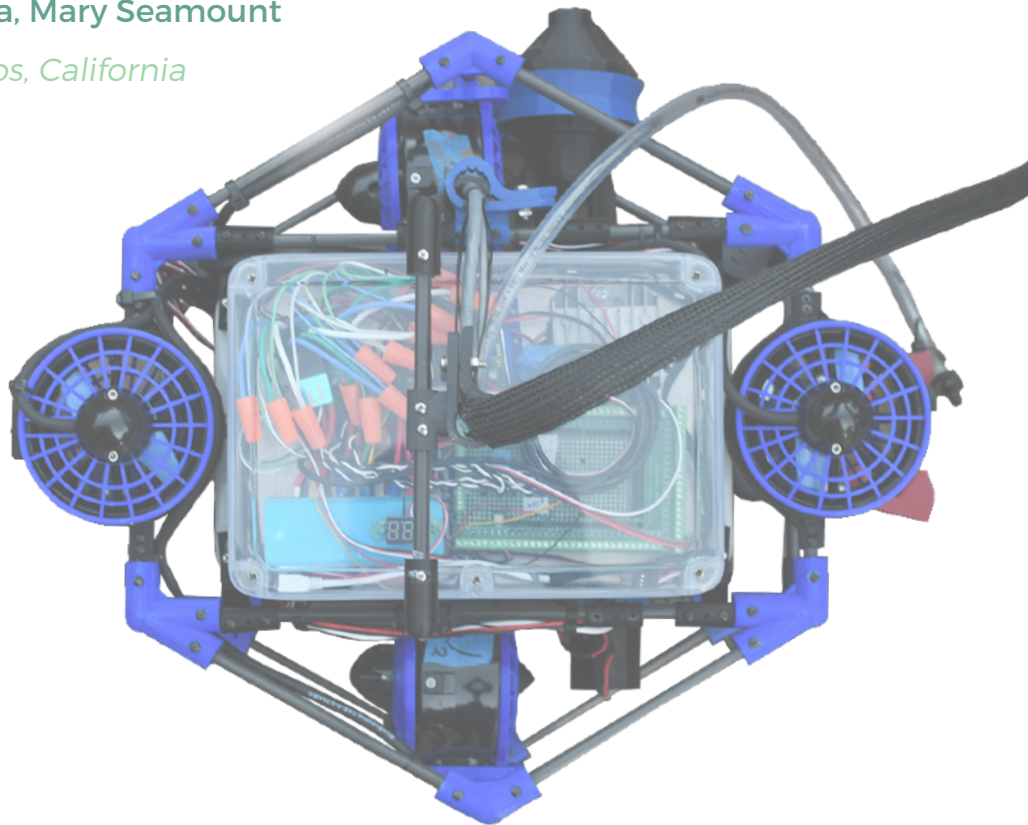
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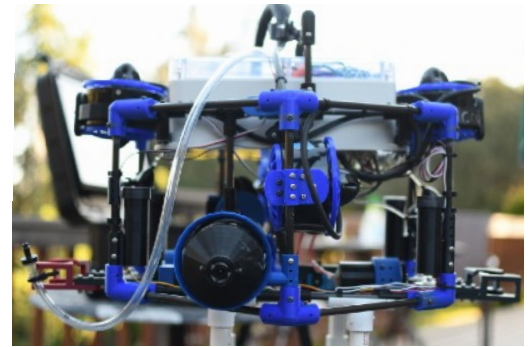
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1. ABSTRACT

Our engineers at Seal Team Scalyr have released the newest model for underwater navigation: the *Argo VI*, designed to complete three essential tasks for the Boone Dam in Tennessee. The *Argo VI* is specially built to locate and recover civil war era cannons, inspect dams for cracks, and test surrounding water quality for ecosystem health. It is lightweight, compact, and filled with advanced features, including five cameras, two fully rotational claws, and a microROV. Our engineers constructed the frame from light, solid carbon fiber rods, and equipped the vehicle with four Blue Robotics T100 motors. These high-power thrusters allow the *Argo VI* to position a civil war era cannon and navigate easily through lakes and rivers. Both claws can rotate infinitely in both directions, allowing the *Argo VI* to move a diverse range of objects from any angle, from Mexican beach pebbles to degraded rubber tires. In addition to inspecting dams with the *microROV* and hauling cannons with a lift bag, the *Argo VI* also preserves local life by removing human-made wreckage from the area of the dam, restoring trout fry, and repairing trash collection systems. To achieve this goal, the ROV's frame has rounded edges to protect itself and wildlife. Safety is a top priority in our company; all members and vehicle parts adhere to in-depth safety guidelines. The *Argo VI*, the most innovative Seal Team Scalyr model yet, is perfectly suited to assist the Boone Dam team in conserving Tennessee's ecosystem.



The Argo VI. (Photo Credit C. Barrett)

Important Note: All photographs in this report are credited to C. Barrett unless otherwise stated.

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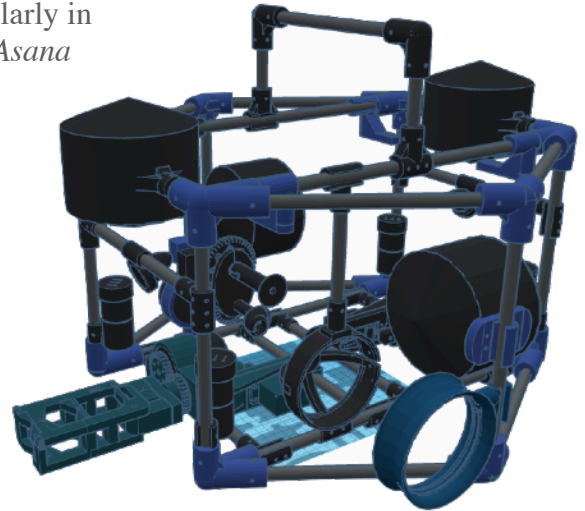
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2. PROJECT MANAGEMENT

PLANNING, ORGANIZING, AND SCHEDULING (2.1)

We incorporate a variety of systems to meet mission objectives and follow an effective long-term schedule. At the first team meeting of the year, we documented our primary goals for constructing the *Argo VI*. These goals included broader objectives, such as opportunities for every member to gain experience in different departments, as well as specific improvements for the vehicle, such as thruster upgrades. Throughout the year, these goals laid the foundation for design and team management decisions.

Documentation was a major component of organization, particularly in formulating a year-long schedule of tasks. The online program *Asana* allowed team members to assign jobs to certain people, record what was completed in a meeting, and keep track of overall progress as construction of the *Argo VI* developed. Each team member had an account and received notifications if they were assigned a task. At the end of each meeting, team members reported the jobs they completed to our CEO, who entered this information into *Asana*. In addition to day-to-day operation management, *Asana* allowed us to plan and keep track of long term projects. In addition, we developed a Gantt Chart to plan and evaluate our long-term progress succinctly (see Appendix). With both systems in place, we were able to maintain a schedule for the entire design process that ensured the completion of the *Argo VI*.



The scale model of the Argo VI in TinkerCad used for visual documentation. (Created by K. Walton)

We took documentation one step further by creating a working scale 3D model of the vehicle throughout the year. With a complete conceptualization of the *Argo VI* as it developed, everyone at Seal Team Scalyr could see the progress on the actual vehicle and evaluate what still needed improvement, even outside of meetings.

TEAM ROLES (2.2)

At the beginning of the design process, we assigned roles to each team member based on their area of interest, such as Head of Safety, Head of 3D Design, and Head of Onboard Electronics. Each department head was responsible for the tasks which fell under their jurisdiction, which meant no was task forgotten or completed haphazardly. For instance, our Head of Software was in charge of Arduino to Arduino communication. Since this was such a large task, he delegated smaller jobs within it, ensuring that everyone with an interest had the opportunity to learn and participate. The system of department heads had the following effects:

1. Maximized organization and communication.
2. Expanded department management and accountability.
3. Increased efficiency in the building process.

While the department heads were responsible for the long-term success of their projects, they were free to contribute to any part of the engineering process, allowing everyone to develop a variety of skills.

MEETINGS (2.3)

We met weekly throughout the year to design and construct the *Argo VI*. At the beginning of each meeting, we reviewed a set of notes and determined the most important tasks to work on. Each set of notes contained announcements, a list of newly purchased or 3D-printed parts, an agenda of operational problems to discuss, and a list of jobs to complete, organized by department. If the *Argo VI* encountered a significant problem during or since the last meeting, we used this beginning time to collaborate and explore solutions. Assessing new parts as a group at the beginning of each meeting also kept everyone up-to-date on the resources available and which features had been added or modified. Once these items were discussed, team members found the jobs listed in their department and began to work on the ROV in small groups. At the end of the meeting, these jobs were entered into Asana. If a job was finished, the date of completion was saved to the system, while unfinished tasks were recorded for the next meeting. This protocol meant that we maximized our time and resources in a collaborative engineering process to create a stellar vehicle on schedule.



Team members collaborating to construct the Argo VI.



For the first time this year, we also implemented an attendance requirement: every member must attend at least 80% of weekly meetings to stay on the team. If someone did not fulfill this requirement by the end of the first semester, they received a warning; if their attendance in the future still did not meet the requirement, they could remain a member. After implementing this procedure, attendance was rarely a problem; members began to commit to the majority of meetings, and the workload this year was evenly distributed.

The organized nature of the meetings allowed for fun and productive learning experiences for every team member (Photo Credit J. Walton).

3. SAFETY PHILOSOPHY

At Seal Team Scalyr, safety is our number one priority. Constructing an underwater vehicle is hands-on work, requiring electricity, power tools, and precision. For such work with both potential fun and hazard, we make sure to follow a set of rules that guide us away from danger and make practices run as smoothly as possible. Some of these guidelines include: always grabbing the ROV from the top with both hands, protecting the claw when carrying or setting down the ROV, gently putting the ROV in the water, and keeping aware of the tether. We have also installed safety instruments on our ROV to further minimize risk. The instruments include: 3D printed shrouds around all four thrusters, 3D printed clips that keep wires away from propellers, a leak detector, and smoothed edges. We used waterproof heat shrink on our electrical splices where needed. This heat shrink combines internal glue that flows when heated, sealing each end of the splice as it shrinks, ensuring that no water can enter.



(Left to Right) Leak detector in the control box; 3D printed motor shroud; waterproof heat shrink used on all splices

Pre-Run CheckList

- ✓ Make sure deck crew is in place
- ✓ Uncoil and organize tether
- ✓ Connect tether
- ✓ Inspect control box and make sure there are no exposed wires or debris
- ✓ Make sure no liquid is close to control box or battery
- ✓ Ground is always connected first to the external power supply
- ✓ Tuck airline into proper position for mission
- ✓ Pilot calls out when power is turned on to alert crew
- ✓ Test all motors and attachments before putting the ROV in the water

Construction CheckList

- ✓ Professional behavior during meetings
- ✓ Handle tools properly and safely
- ✓ Have supervision from another teammate while using power tools
- ✓ Wear safety glasses while soldering and sawing
- ✓ Wear rubber gloves when handling epoxy/chemicals
- ✓ Unplug power tools when they are not in use
- ✓ Clean and organize workstations after a construction task has been completed

4. DESIGN RATIONALE

In all aspects of the design process, from mechanical to electrical engineering, we utilize a step-by-step process to create state-of-the-art features. Every component begins with an idea, whether to solve a problem we encounter or complete a mission task. With this idea in mind, we ways to make it a reality in small groups and make a list of possibilities while considering the benefits and drawbacks of each one. We then pick the option with the greatest likelihood to be successful and set to work creating a prototype. We then evaluate the component experimentally and mathematically. We prototype, test, fail, and prototype again, until we create the best possible design. From this process of creativity and perseverance, our engineers have created a vehicle that truly stands out, featuring 3D printed parts in nearly every component, a dual claw system, advanced software, onboard electronics, a custom designed *microROV*, and more.



An early prototype of the claw. (Photo Credit J. Walton)

Our Step-by-Step Design Process



THEME SIGNIFICANCE (4.1)

Our engineers designed the *Argo VI* to ensure public safety, maintain healthy waterways, and preserve historical artifacts in the South Fork Holston River in Kingsport, Tennessee. Throughout the process, we reviewed how other ROVs have addressed similar problems in other missions. Drawing from real life innovations allowed us to truly tailor our design for specific mission tasks.

The first mission is to inspect the foundation of a dam by following a transect line and recording the sizes and locations of cracks. Bergström, et al (1987) deployed an ROV to follow a transect line in a study of shrimp populations. Their ROV is capable of “3-dimensional movement” (Bergström et al, 1987, 98), allowing for precise maneuverability in tight spaces. To accomplish 3-dimensional movement in the *Argo VI*, the *microROV* is docked on the side of the main ROV frame to act as a lateral motor for sideways movement.



An ROV performing safety inspections similar to the *Argo VI*'s dam inspections (Photo Credit DeepOcean).

The *Argo VI* also deploys a *microROV* to inspect a narrow pipeline for mud blockage. When traveling through pipelines, several ROVs in the current market use a set of wheels to navigate the bottom of the pipe (Deep Trekker n.d.; Envirosight 2019). For our purposes, wheels would be

inefficient due to the pipe’s ridges, which would prevent smooth transportation; using wheels underwater would also require enough weight to keep the *microROV* at the bottom of the pipe, which would add unnecessary weight to the main ROV when the *microROV* is docked. Instead, our *microROV* has a much simpler design with a single motor for forward and backward movement. The front-facing camera on the *microROV* has an infrared light for the dark interior of the pipe.

For the second mission, we used image recognition to determine the number and type of benthic species in a sample. We identified contour detection as the most effective tool for this mission. Eggert (2012) writes that contour detection relies on “changes in brightness, color or texture” to distinguish objects from their background. Since the benthic species in the product demonstration are black silhouettes on a white background, contour detection is ideal for evaluation.



A cannon buried underwater, which the Argo VI is equipped to recover with a lift bag (Photo Credit Rick Collier).

The last mission is to determine the lift capability of the ROV and recover a Civil War-era cannon from the bottom of the river. We calculated our theoretical lift capacity based on thruster strength and practical lift capacity based on what the ROV could actually lift in the water. To assist the *Argo VI* in carrying the cannon, we attach a lift bag before recovery. Some lift bags are closed, meaning they have no gaps in material and are filled with air, but these designs are used primarily for missions close to the water’s surface. In contrast, open lift bags are more effective in deeper waters because the hole in the bottom allows the lift bag to adapt to changes in water pressure (“What is a Lift Bag and Why Use It,” 2018). We chose to use an open lift bag to accommodate the changing air pressure in the river. In addition, this ability to release pressure is especially

useful on ascent, when trapped air can cause the bag to expand and rip, dropping the cannon before reaching the shoreline.

BUILDING, BUYING, AND REUSING (4.7)

To design a cost-efficient ROV, we developed a policy for which parts to build, reuse, or buy new. Whenever possible, we save money by 3D printing our components. Having a small team of engineers that focus on 3D printing maximizes our innovation and results in an ROV with many customized parts.

Next, we try to preserve parts from previous models that are intact and won’t malfunction with extended use. This allows us to save money on components that we cannot 3D print, without compromising functionality. For example, for our claw, we reused the DC motor from last year that was potted, worked consistently, and continues to function well this year. We also reused our control box because it provides enough space for all our new electronics and was still in good condition. We reused most of the electronics in the case, including the 19” display, the video processor, and the power and ground bus connectors. as they continued to function sufficiently to meet our continuing poolside electronics needs.

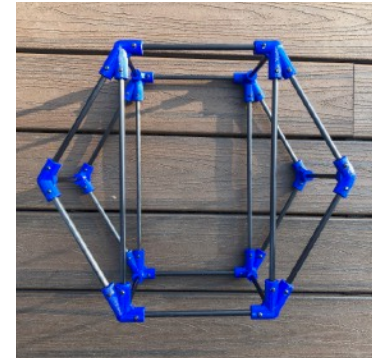
Finally, we buy parts when it is efficient to do so, considering availability,



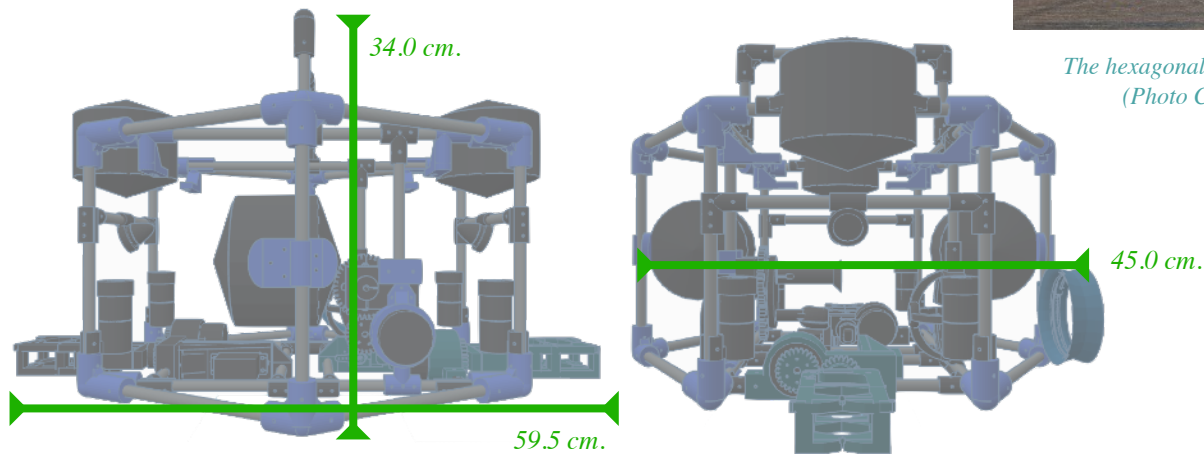
cost, and labor. Electronics frequently fit this category. For example, instead of adding additional motors, we bought new Blue Robotics T100 thrusters to increase the speed of the ROV. However, we found that trying new parts can come with surprise costs. Besides the purchase price, these powerful thrusters required a power cable in our tether with a higher gauge cable.

MECHANICAL DESIGN (4.2)

Frame. We specially designed the *Argo VI*'s frame to accommodate a dual claw system, a watertight enclosure for on-board electronics, and the *microROV*. After evaluating different shapes, we decided that a hexagon allows for optimal turning and maneuvering, with the added benefit of larger internal storage, and increased number of structural attachment poles for mounting ROV components. Lateral thrusters may be placed farther apart on a hexagon, which allow for faster turns.

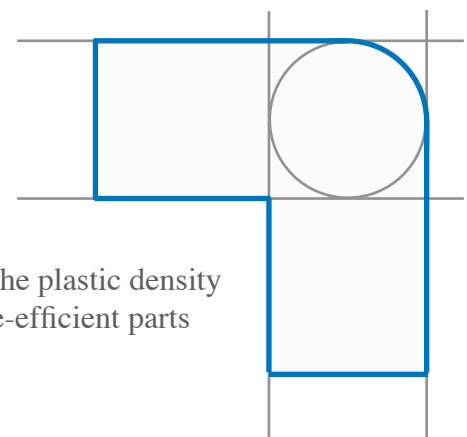


*The hexagonal frame skeleton.
(Photo Credit J. Walton)*



The solid carbon fiber rods are lightweight, thin, durable, and strong. They are only 8 mm. in diameter, creating less drag in the water, as a smaller radius reduces the cross sectional area, which is directly related to the magnitude of the drag force. The frame is assembled with 3D-printed clips and connectors for quick and easy changes.

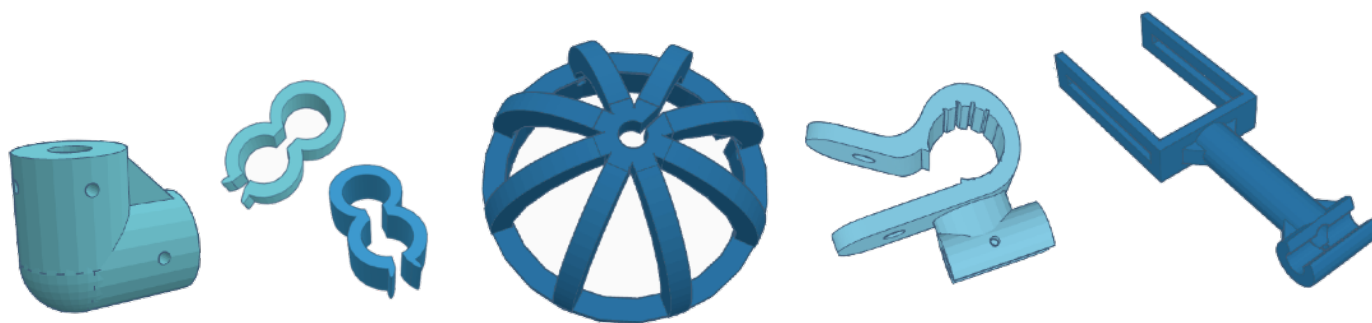
3D Printed Parts. We 3D design nearly all of the *Argo VI*'s attachments using a web-based software tool called Tinkercad, which allows our engineers to tailor every vehicle component for specific mission tasks. This method is also cost-competitive compared to buying pre-constructed attachments: while 3D-printed attachments comprise the majority of the frame, they only accounted for about 2% of this year's expenses. 3D printing also allows our engineers to adjust the plastic density for increased strength on mission critical parts, as well as building space-efficient parts that reduce the total size of the vehicle.



*Mechanical drawing of a corner piece
illustrating the combination of basic
geometric shapes for all 3D designed parts.*

We follow an organized procedure to design and print original features for the *Argo VI*. Department heads collaborate with our Head of 3D Design to conceptualize components and print a low-density prototype for testing.

We construct complex shapes from basic ones such as cylinders to create highly specialized components. To ensure a sleek and elegant final product, we consider symmetry, precise angle measurements, and exact dimensions that can be easily used in calculations.



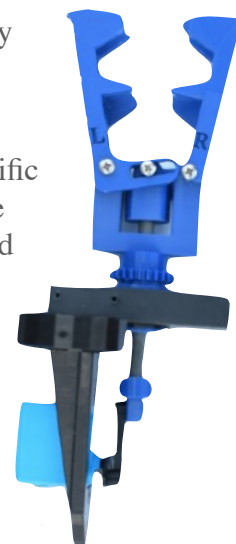
Examples of the 3D printed components. (From Left to Right) Corner connector, wire clips, bilge pump motor shroud, tether clip, camera mount

3D-printed features on the *Argo VI* are unique to this year's model; few designs were derived from previous models or any other ROV on the market.

Main Claw. The *Argo VI* is equipped with two state-of-the-art claw devices designed entirely with 3D technology. This claw redundancy means that users are never stranded without a gripper if one malfunctions.

The claw features an ideal design for opening, closing, and rotating. To best suit it for scientific missions, we referenced grippers of professional level ROVs in our design process. We were especially inspired by the Blue Robotics' claw, in which a rod moved the claw arms back and forth, without the need for gears. One of our members realized that the rotational symmetry of this rod would translate well to angular movement, since the rod could continue to function no matter the angle of the surrounding claw. Thus, our design includes a similar mechanism, with software-controlled servo arms that push a rod of carbon fiber forward and backward. This causes the arms to rotate about their hinges, forming an opening and closing motion.

Using a gear attached to a software-controlled DC motor, the entire gripper can rotate 360° for easy maneuvering, while simultaneously opening and closing. Because of its seamless rotation and optimal gripping ability, users can position the claw perfectly for every task.



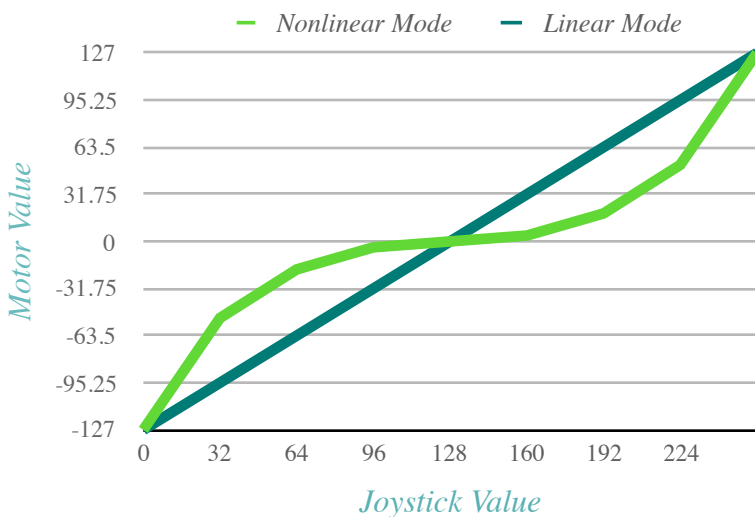
The *Argo VI* claw.

SOFTWARE DESIGN (4.3)

MEGA to MEGA Communication. With a *microROV* and thrusters that required three wires each, we needed to adopt on-board electronic control in the ROV, rather than relying solely on surface control, which would create an unreasonably bulky tether. On-board electronics allow control of the *Argo VI* with only two simple data transmission wires. To accomplish this, we created advanced software to use serial communication between two Arduino Megas.

These two Arduino Megas make up the control system, and are equipped with individualized code corresponding to their distinct functions. The first Arduino Mega, located in the poolside control box, interprets the input from the controllers and converts it to a small 20 byte data structure for transmission to the ROV. It sends this output data down the tether to the second Arduino Mega, located in the *Argo VI* itself

(see Software Flowcharts in the Appendix). We use simple serial communication for this transmission. We found that a 58 kBaud rate was fast enough for the ROV to be responsive to the pilot. Furthermore, we could transmit this data reliably through 30.48 meters of twisted pair cable. Our actual tether cable length is only 15.24 meters, ensuring a large design margin. We partitioned the code so that we uploaded the more complex control data processing to the Arduino Mega in the control box which is easy to access. Keeping only simple data processing in the Arduino Mega located in the ROV itself eliminates the need to break the waterproof seal whenever we have to reprogram the high-risk software.



Sticky Mode. With Sticky Mode on, the pilot can increase the speed of the vertical motor by small increments, where joystick values map to the the increment of speed added to the existing value, instead of the value itself. When the pilot doesn't touch the joysticks, the vertical motors retain their speed.

Reverse Mode. Reverse Mode allows the pilot to change which end acts as the front of the ROV by reversing the direction of the motors and switches the primary claw.

Pitch Mode. Pitch Mode gives the *Argo VI* an extra degree of freedom. When activated, the vertical motors will move in different directions,

allowing the *Argo VI* to tip up or down. This is helpful for tasks which require picking up objects, including retrieving the broken trash rack screen and degraded tire.

Nonlinear Mode. Non-Linear mode (see graph above) changes the motor speeds to follow a logistic curve response rather than the normal linear response. With this mode, smaller joystick movements result in minuscule changes in speed, while larger joystick movements allow the *Argo VI* to accelerate to full speed quickly.

Sensitivity Mode. Sensitivity control allows the pilot to adjust the maximum range of the ROV thrusters during the mission, allowing for extremely precise control. This is especially useful in tasks that require fine tuning of movement, such as the precise motion of following the transect line of a dam.

ONBOARD ELECTRONICS (4.4)

Onboard Electronics Enclosure. One of our many challenging objectives for the 2019 season was to significantly reduce our tether size and ameliorate power attenuation and fluctuation. We considered many possible solutions, such as simplifying our underwater components and/or potting each individual component. We found that the best solution was to move some of our traditionally poolside electronic components to a waterproof enclosure on the ROV itself, which would be easiest to work on and most capable of expansion. This flexibility is due to its durability even when opened and closed frequently, and a spread-out interior for expansion and repair. We chose a waterproof enclosure produced by PolyCase, which is tested to be waterproof to a depth of 30 meters. It incorporates an o-ring sealed, clear plastic lid over the top of the ROV, allowing all components to be easily viewed, even with the lid attached. Furthermore, when access to the components is required, the lid can simply be removed, exposing the *Argo VI*'s electronics.

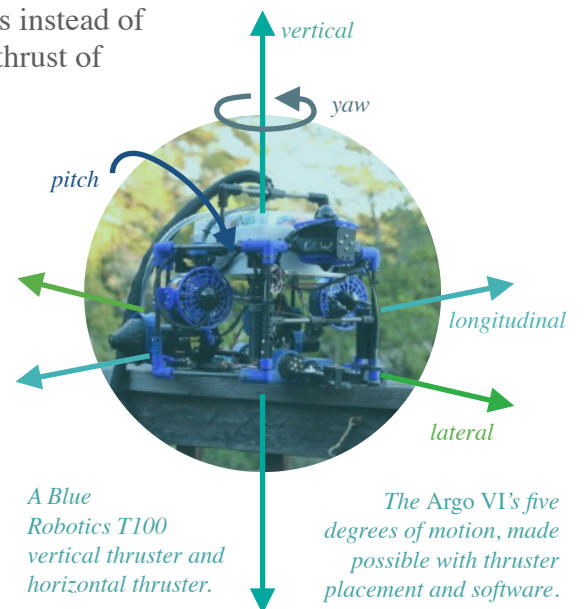


The onboard electronics enclosure housing the brains of the Argo VI with innovative electrical design.

This enclosure houses an Arduino Mega, a 12V to 7V converter, two Sabertooth motor controllers, and four Blue Robotics ESCs. This major shift in design was facilitated by many iterations of calculation and assembly. We determined a housing size large enough to meet our needs and small enough to fit inside the *Argo VI*. Within the enclosure, we mounted the onboard electronics to a metal plate resting within the enclosure at a height of 3 cm. Subsequently, we drilled an array of holes through the metal plate and the enclosure. We fed all tether and underwater ROV component cables through the holes, being careful to remove any jackets from all cables as they entered the enclosure. We then poured a 2 cm thick layer of marine epoxy into the bottom of the underwater enclosure to ensure that water

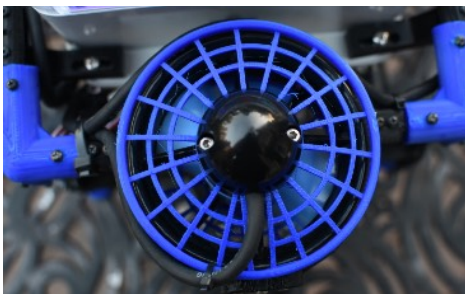
does not penetrate through the cable feeds. In order to accommodate a low spot for the electronic leak detector, we poured the epoxy at a slight slope. Thus, if water is detected, the ROV can transmit an alert to the poolside control box, creating an additional degree of safety.

Propulsion. The *Argo VI* features four Blue Robotics T100 thrusters instead of the bilge pump motors we used in previous designs. The increased thrust of the T100s allows the *Argo VI* to propel much more easily through the water. Electronic speed controllers (ESCs) in the onboard electronics enclosure control the T100s. They take in Pulse Width Modulation (PWM) signals from the Arduino Mega and convert them into the three phase power that the T100s use.



A Blue Robotics T100 vertical thruster and horizontal thruster.

The Argo VI's five degrees of motion, made possible with thruster placement and software.



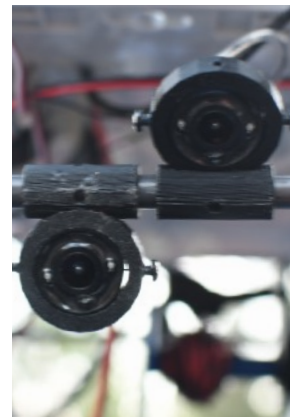
We also tested the thrust of our motors to determine if they were capable of lifting the cannon. Using Blue Robotics specifications of 22 Newtons of thrust per motor, our potential total thrust was 44 Newtons. We then factored in our propellor shrouds, which we estimated restricted the water flow by 30%, giving us a projected 31.1 Newtons of upward thrust, which isn't enough to lift the maximum specified cannon mass of 40 Newtons. Therefore, we utilize a lift bag instead, which provides the necessary lift capability (see Lift Bag in §4.6).

Cameras. The *Argo VI* features six waterproof cameras, positioned strategically to make piloting the ROV and *microROV* an easy task. The two main navigation cameras, one on each end of the ROV, allow the driver to maintain a clear view of each claw on both the front and back. The third and fourth cameras orient downward above each claw. These two cameras are used for precise tool placement and software recognition of the benthic samples. A fifth camera is located on our *microROV* and allows for easy and reliable inspection of small diameter pipe. This camera turns on an infrared light source when low light levels are

automatically detected, which allows the *microROV* to see obstructions deep within a dark pipe. Finally, a sixth camera monitors the *microROV* dock and auto-spooler.

All six are analog fish finder cameras, which minimize the lag associated with digital cameras and are waterproofed by the manufacturer (AquaVu) to a depth of 100 m. The thin 1.27 m. waterproof cable that runs from the cameras are fed directly up the tether, avoiding potential leaks in the waterproof ROV enclosure.

Poolside, we use a video processor to combine four video feeds onto the main monitor. The camera monitoring the *microROV* spool feeds to the small secondary monitor, which allows for easy viewing for a secondary pilot. We use a video splitter topside to send the video feed from the *microROV* to a laptop computer that runs image recognition on the benthic samples.

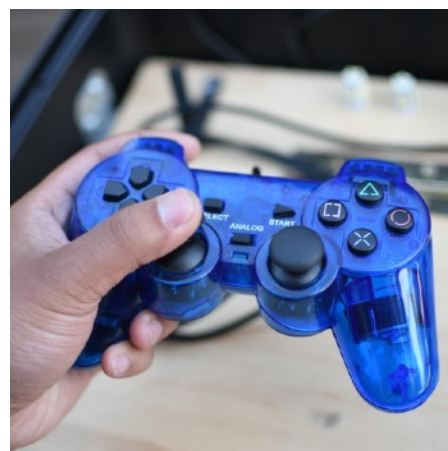
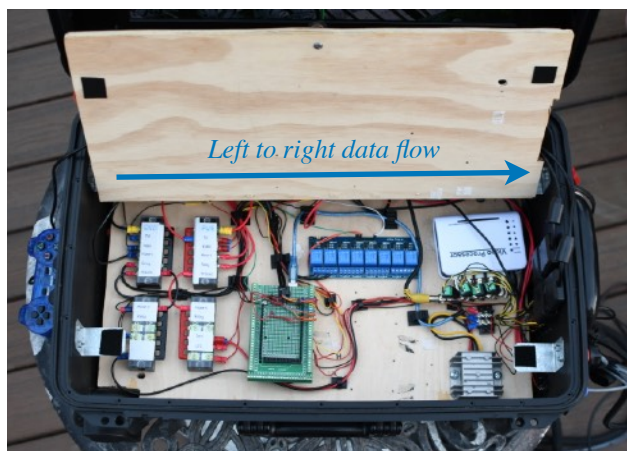


Main navigation cameras.

CONTROL BOX (4.5)

Controls. Our poolside control box is composed of a waterproof, industrial travel case that measures 62 x 38 x 26 cm, proving plenty of space for evolving electrical design. Users can easily access all electronic components by lifting the wooden lid, which protects the electronics from potential water splashes

The 19 in. (4.8 m.) TV, displays up to four camera signals at a time, allowing the pilot and copilot to easily analyze the dam, identify the cannon, and maneuver the vehicle. The box also contains a digital readout of the status of the electronics, including monitors of both current and voltage. Another small LCD shows the status of the ROV, leak detector, and output of the temperature sensor.



(Left to Right) The inside of the control box; the open control box; the main PS2 controller.

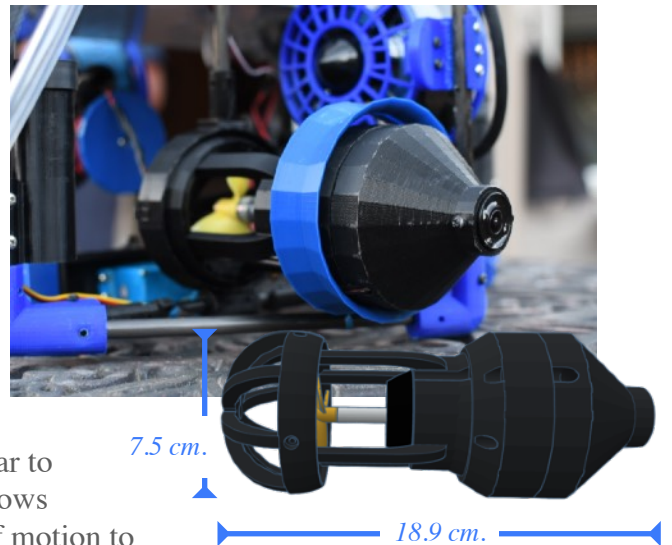
The Arduino Mega, the brains of the ROV (see Software in §4.3), is located in the poolside control box. It receives power and inputs from the PS2 controllers. Our design includes two controllers that direct the *microROV* and the *Argo VI* independently of each other so that the pipe inspection can be done as swiftly and efficiently as possible. All components within the control box are neatly laid out with labels for every wire, allowing our engineers to modify and repair with ease.

PAYLOAD TOOLS (4.6)

MicroROV. This year's tasks require a *microROV* that can be deployed to inspect drain pipes for evidence of

dam failure. According to the Association of State Dam Safety Officials, “overtopping” is the primary cause of dam failure, which is the spilling of water over the top of a dam (ASDSO). Debris blockage in pipes is a substantial cause of overtopping, making it essential for ROVs to monitor pipes. The *microROV* is compact enough to allow our deck crew to identify blockages at their source. In addition to this integral task, our team found additional uses for the survey bot:

1. The *microROV*'s thruster allows the main ROV to move sideways. The docking mechanism is attached onto the *Argo VI* and is oriented perpendicular to the main ROV's forward/backward direction. This allows the *microROV*'s thruster to serve as a lateral degree of motion to the main ROV in other missions; this feature is especially useful when the *Argo VI* inspects the foundation of a dam for cracks.



A photograph and mechanical drawing of the microROV.

2. The *microROV*'s camera contributes another set of eyes for our pilot.

Custom-made 3D-printed parts protect the motor with a completely rounded design to promote safe and smooth movement in and out of the docking mechanism. This bullet shape reduces drag and eliminates ridges that can get caught while traversing the drain pipe or docking onto the main ROV.

The *microROV* contains a single 1250 gallon-per-hour (GPH) bilge pump motor for forward and backward movement, which we reused from last year. Since the *microROV* needs to navigate down a 2 m. pipe, the team determined that this motor would provide plenty of thrust to move the small, bullet-shaped vehicle.

Since the *microROV* is only used to travel inside a pipe, buoyancy control is not mandatory. Without buoyancy to keep it upright, the angular momentum of its rotating propeller causes the *microROV* to rotate as it travels. Although the resulting view from its camera is also spinning, it still captures any obstructions and keeps the *microROV* design as simple as possible.



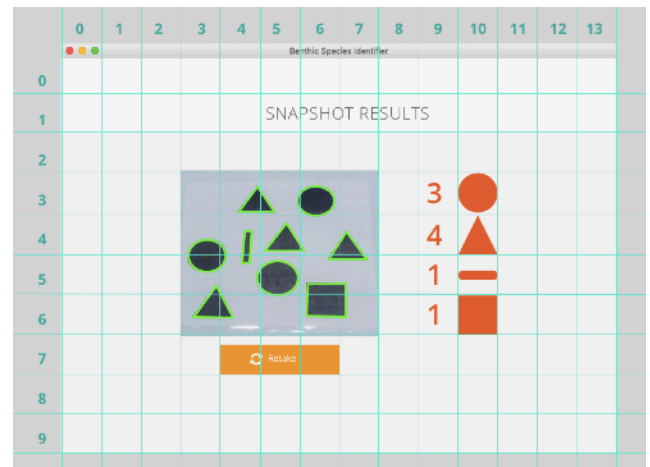
The autowinding spindle for the microROV.

An auto-winding tether spindle manages the length of tether from the main ROV. The tether winder is made up of a rod that rotates around the tether spindle, unwinding the tether as the *microROV* travels down the pipe. The rod's rotation is controlled by a waterproofed DC motor that rotates at 300 RPM. This gear ratio was the right compromise between the speed of tether winding and the torque delivered, which are inversely related. When the *microROV* is released from its dock, the rod steadily unwinds the tether from around the spindle; when the mission is complete, the rod reverses rotational direction, collecting the tether and pulling the *microROV* back inside the *Argo VI*. This tether winder also firmly holds the *microROV* when it is docked to provide a lateral movement for the main ROV.

The tether winding system was difficult to design and required many trial-and-error iterations. We facilitated most of its design iterations away from the main ROV by building a separate frame prototype to hold the

microROV dock and tether winder; this enabled the *microROV* team to work on its design without getting in the way of the main ROV design.

Benthic Species Identifier. Automatic species classification technology is beginning to emerge as a major area of growth in ecological study, as it reduces the number of tedious expert analysis hours required in manual inspection (University of Massachusetts Amherst, 2003). Keeping up with the latest innovations, we decided to develop software to identify benthic species. We direct one camera feed to a laptop during the mission, which runs a Python program to distinguish geometric shapes and classify organisms. It then utilizes the OpenCV library to compute the contours, or shape boundaries, within the image, to distinguish between the different shapes based vertex count and area.



*A mock-up of the Benthic Identifier app design.
(Created by Jamie Walton)*

Lift Bag. To recover the heavy cannon, we needed to a device with more lift power than the *Argo VI*. Adapting our model from the previous season, our lift bag is a circular bucket that we found on Amazon. It has enough volume to lift the heavy objects off the ocean bottom when it is partially filled with air. Hanging from the bottom of the bag is a 3D-printed handle for the ROV claw, as well as several hooks on the bottom to attach to the cannon. This piece is weighted to easily reach the cannon at the bottom of the pool.

Measurement Devices. The *Argo VI* uses both a modified ruler and tape measure to perform measurement tasks. We use the ruler to measure the cannon radii and the length of the cracks on the dam, which is ideal for its rigidity that emulates the linearity of the cracks. The tape measure allows us to measure the length of the cannon at any angle needed, which is especially important considering the variability of it position in the lake.

Magnetic Sensor. We used a magnet on a string to determine whether or not the cannon is made of iron or bronze, as the magnetic properties of the elements make them easily distinguishable (iron is magnetic, while bronze is not).



Lift bag

5. CRITICAL ANALYSIS

TESTING AND TROUBLESHOOTING (5.1)

Testing. Our team had two separate protocols for testing the complete *Argo VI*: our overall procedure and our day-to-day protocol. Our general procedure is to test the complete vehicle by driving through mission tasks underwater to detect any problems in specific tasks and give team members an opportunity to practice for the product demonstration. We strive to begin water testing a month before the competition in order to have ample time for practicing and testing. We have learned that the only way to gain an accurate picture of the ROV's function is to test it extensively in the actual pool environment— parts or ideas that worked in air

may perform completely differently underwater. After setting up all the props to simulate the actual competition missions, every team member participates in observing the vehicle's ease of piloting, speed, and maneuverability in completing the tasks. Everyone is responsible for reporting any malfunctions or safety hazards they observe, so the team can address them immediately. After finishing a practice mission run, we discuss constructional and piloting improvements for the next time and practice again, accordingly. This process, repeated over a period of a few weeks, ensures that the *Argo VI* is as functional and efficient as possible.

Within each testing day, we begin by verifying that all systems are functional before mission runs. After turning on the vehicle's power, we make sure that the power supply is at 12 volts and that the amperage draw is minimal, to eliminate the risk of a short. We then test every motor in both directions, as well as monitoring the current draw. Next, the pilot confirms that the cameras input to the display correctly, so the camera orientations can be adjusted for the pilot if needed. The waterproof enclosure at the top of the ROV must be checked for air leaking before every mission run; an air leak indicates a water intrusion, which must be addressed immediately. Finally, the enclosure is equipped with a leak detector display; if the display verifies that the ROV is operational, then the *Argo VI* can begin a mission run. If we reveal any system to be nonoperational or unsafe, our engineers work to fix the issue before placing the *Argo VI* in the water.



*Team members evaluating for mechanical and electrical issues after the detector indicated a leak.
(Photo Credit J. Walton)*

Troubleshooting. The *Argo VI* undergoes two stages of development: the design stage and the production stage. When troubleshooting, our team has a separate protocol for each stage.

1. A **design failure** occurs when a component malfunctions due to a flaw in the design. For electrical failures, our engineers use an ohm meter to test the connections, and a voltmeter and oscilloscope to test voltages and voltage drops. For example, in the initial testing stages, the current draw from the Blue Robotics motors spiked when the thrusters reversed direction. Measuring the voltage using a voltmeter allowed us to isolate the problem (see Challenges and Lessons Learned in §5.2). As for mechanical failures, our engineers examine breaking points in the frame and attachments; if necessary, our 3D design team strengthens custom-printed parts before reprinting damaged components. To increase the mechanical strength of a printed attachment, we also increase the plastic density on some attachments.

2. In contrast, a **product failure** occurs when the Argo VI breaks during a mission run. When the team encounters challenges during testing, the pilot delivers the Argo VI to the surface to be retrieved by the pool-side crew. Once the ROV is safely on land, engineers can inspect the problem more closely to deduce a solution. If necessary, the pilot uses the controls on land to demonstrate the malfunction, so the team can evaluate the source of the problem from a more direct view. Essential building tools such as screwdrivers, tape measures, and wire cutters are kept in a portable tool box near the pool during testing to be readily accessible in case of a malfunction. This way, engineers can work on the Argo VI on-site, which allows the ROV to return to the water immediately after repair. To further enhance our ability to identify problems quickly, we added a leak detector to the onboard electronics enclosure. Moreover, our team always keeps replacement parts on hand, such as motors, cameras, 3D-printed parts, and screws, in case of failure. For example, the newly waterproofed enclosure leaked with water during its first

underwater test. We immediately took the box out of the water to prevent damage to our electronics and proceeded to work together to find the source of the leak. After a thorough inspection, we found that the water came from the lid seal and not the cable feed-throughs in the epoxy layer. Upon reseating the lid, the leak stopped, and our newly assembled ROV was ready for further testing.

Prototyping. Every feature on the *Argo VI* adheres to a series of design parameters to maximize efficiency and performance. In addition to following MATE guidelines for voltage, current, size, and weight, our pilot outlines the qualities that make driving the *Argo VI* straightforward and practical. Our engineers incorporate these standards when prototyping a component—always keeping safety, usability, and client satisfaction as top priorities.

We choose motors and cameras based on voltage, current, speed, and cost for each model. Bilge pump motors and Blue Robotics motors both fit our voltage, current, and cost parameters. In previous models, we used bilge pump motors as a more cost-efficient and user-friendly option for the ROV thrusters. This year, though, the *Argo VI* is equipped with four Blue Robotics T100 thrusters. These thrusters are more expensive, both in cost and electrical power, than bilge pump motors, but their exceptional thrust makes them a perfect fit for our updated design.

CHALLENGES AND LESSONS LEARNED (5.2)

Technical. The first and most significant challenge we faced this year was the continual loss of power to the ROV, which coincided with our switch to the more powerful new Blue Robotics thrusters.

Lessons Learned: To isolate the problem, we learned how to calculate the voltage drop over a cable length using the cable specification. We discovered the importance of using a higher gauge wire and more secure solder connections when using components that draw high amounts of current.

In the initial testing stages of the complete ROV, the current draw from the Blue Robotics motors spiked when the thrusters reversed direction. The resulting voltage drop reset the thruster ESCs. To investigate, we placed a small voltage meter in the ROV electronics that enabled us to view the voltage while the vehicle was in use. We observed the voltage spike with the voltmeter and also discovered that only about half of the source voltage made it to the ROV when all four thrusters were at full speed. By measuring the voltage in the surface control box, we found that most of the voltage was lost in the tether, and a significant voltage was also dropped at the control box. The team responded by replacing the four 16-AWG conductors in the tether with two 8-AWG conductors, theoretically reducing our 15 m. tether resistance of 66%. We also replaced the cable connecting our control box to the external power supply with a thicker 12-AWG cable. Both of these steps reduced the electrical resistance significantly, thereby delivering as much voltage as possible to

the ROV.

Lessons Learned: Investigating the source of the problem taught us to use a voltmeter. We also learned about software fixes that detect large speed reversals and how to slow (or buffer) the transition.

Our next challenge was finding a way to wind the tether of the microROV. As design reliant on rotational physics, it was difficult to find the optimal structure and proportions of a winding system. We developed an auto-winding tether spool that efficiently coiled the tether around a fixed axis without knotting or snagging (see MicroROV in §4.6).

Lessons Learned: We learned the trade-off between winding speed and torque: namely that increased speed results in decreased torque. Through experimentation, we settled on a 300 RPM motor for the right balance.

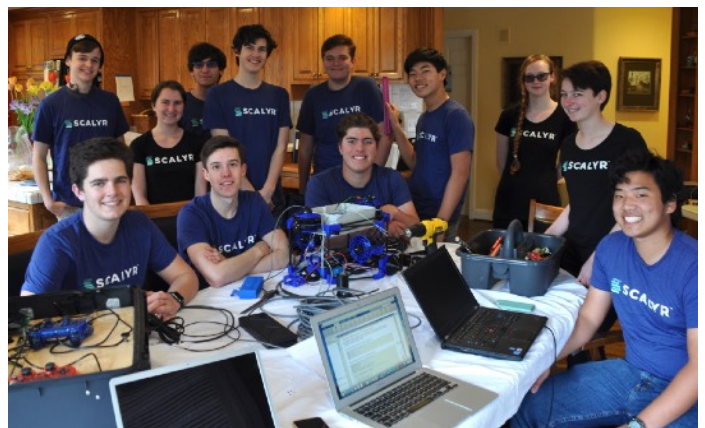
Finally, to examine benthic species underneath rocks, we developed an image recognition program that could make automatic assessments. Distinguishing between significant and insignificant shapes proved to be the largest challenge of creating the software; screws, debris, and shadow all form shapes, but they are not benthic species. To tackle the issue, we evaluated several different solutions, of which machine learning and size distinction were the most promising. While executing complicated new technology is always thrilling for our engineers, machine learning would require thousands of testing images and a great deal of time. Instead, we created an algorithm to distinguish significant figures based on size. Since the benthic species will all be the same size, we programmed the software to circumscribe a circle around each one and calculate its radius, which should be approximately the same for each. We then used a statistical analysis to identify the outlier radii belonging to unwanted shapes, which the program removes from the final organism count.

Lessons Learned: We learned basic concepts of image processing that helped guide our software development, such as thresholding, image moments, and image contours. We also learned the importance of simplicity in software design: while creating a neural network for machine learning was an exciting prospect for our programmers, we ultimately concluded that the most reliable and realistic approach should be as simple as possible.

Organizational. With the presentation of technical challenges came the problem of agreeing on solutions. We discovered that brainstorming was more effective when everybody took part; however, gathering people was difficult, especially after everyone splits up to work on their respective projects.

Lessons Learned: We found that the extra effort to call people back together saved time in the long run and resulted in better ideas. It also ensured that every team member was a part of the decision making process and agreed with proposed changes.

In our previous season, we also found that our members were not equally attending our work sessions. Beginning this year, we implemented attendance requirements for our meetings. Should a member fall below attendance requirements, they would be contacted and issued a warning. Optional sessions outside regular meeting times created opportunities to make up missed meetings.



The entire team attending a work session. (Photo Credit V. Da Costa)

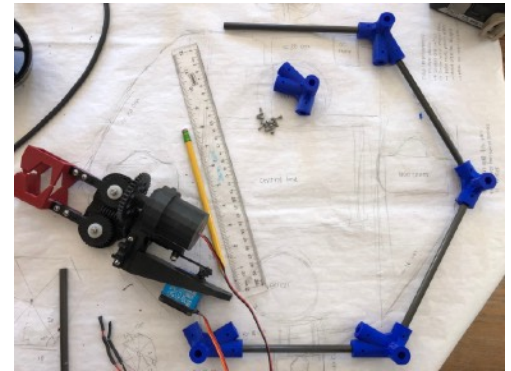
Lessons Learned: We observed that regular attendance by everyone improved overall morale and the distribution of the workload. In addition, it saved time because tasks were easier to manage and all members kept current and ready to work.

DEVELOPMENT OF SKILLS (5.3)

Mechanical. Instead of using the same aluminum tubes for the frame as last year, we instead decided to use carbon fiber rods for the *Argo VI* design. Using a new material for the frame provided definite areas of growth. We learned how to assemble with carbon fiber, which meant learning how to use a hacksaw and other tools safely and efficiently. We also gained a greater understanding of physical mechanical principles, from torque and angular momentum to more complicated drag considerations.

Software. Examining the benthic species required learning how to develop image processing software. Several members improved their Python and MATLAB programming skills to address this mission. More complex vehicle controls also meant becoming more proficient in Arduino, which allowed members to advance from both beginner to intermediate and intermediate to advanced. Designing new 3D components improved our CAD skills as well, especially as tools like the *microROV* tether winder required greater complexity. We also learned to enter schematics in a more organized and timely manner, which strengthened our ability to meaningfully communicate our engineering process.

Electrical. This year, for the first time, we included a waterproof enclosure on the ROV. Finding the best way to partition electronics between the poolside control box and the ROV's waterproof enclosure required skills that we hadn't used before. We learned to do bidirectional serial communication between the ROV and poolside using two Arduino Megas. The Blue Robotics thrusters we used this year taught us how to pick the correct wire gauge for the application (note: we learned this lesson the hard way). Upgrading to such a thick gauge of cable required learning to solder with a gun, which heats the wires to much hotter temperatures than the iron we were used to using. Working with increased temperatures meant a significant growth in our team's soldering skills.



*The beginnings of the claw and frame design
(Photo Credit J. Walton).*

6. FUTURE IMPROVEMENTS

We are always looking for future innovations to make the next model even better. After much experimentation and testing this year, we have decided on the following improvements we would like to tackle in our next season:

1. Over the years, we have changed the frame material from PVC tubing to aluminum test tubing to this year's carbon fiber rods. This year's carbon fiber was strong, economical, and easier to cut than the aluminum. However, drilling into carbon fibers rods was still quite difficult. Next year, we will resume our search for the **perfect frame material**.
2. This year, we also made the transition to onboard underwater electronics. While it opened many doors for us regarding the ROV's performance, we quickly discovered that our waterproof enclosure was much larger than we needed; the large size of the enclosure took up a lot of space in our frame and made the *Argo VI* very buoyant. We plan to feature a **more compact enclosure** in the next model. We also want to add an **air valve** that would pump air out of the waterproof enclosure, which would allow us to test for leaks, without needing to submerge the ROV.
3. We also want to explore using **finer grid guards for our thrusters**, so that they obstruct less water flowing through the gaurds. The 3D printed prop guards we downloaded from Thingiverse work well, but block approximately 30% of the water flowing through them. This efficiency improvement would give us even more thrust power.
4. The use of a hexagonal frame also created many new angles that we could monitor for more viewpoints, giving us a better idea of our ROV's placement as a result. However, the single monitor that we use made it hard to adequately view the feed from more than four cameras at a time. Furthermore, due to the size and layout of our control box, adding another monitor before the competition was simply not feasible. Next year, we want to explore adding **another monitor**, which would require replacing the case for the control box.

Every such improvement gives us the opportunity to improve our technical and problem solving skills each year, and create the best ROV possible.

7. ACCOUNTING

Budgeting and costing is a major part of the construction process. At the beginning of the year, we developed a budget based on our spending from previous years and projected new expenses. Throughout the season, our Chief Financial Officer keeps a detailed account of our spending in a shared spreadsheet. It records every expense, from screws to research and development materials. He then converts this comprehensive documentation to a summary of project costing, so it would be easy to see spending from the entire year. Every meeting, we review the spending from the week and document any needed materials, so that every member is up to date. This system of documentation provides clear data as a reference when monitoring our adherence to the annual budget, as well as forming the basis of a projected budget for future years.

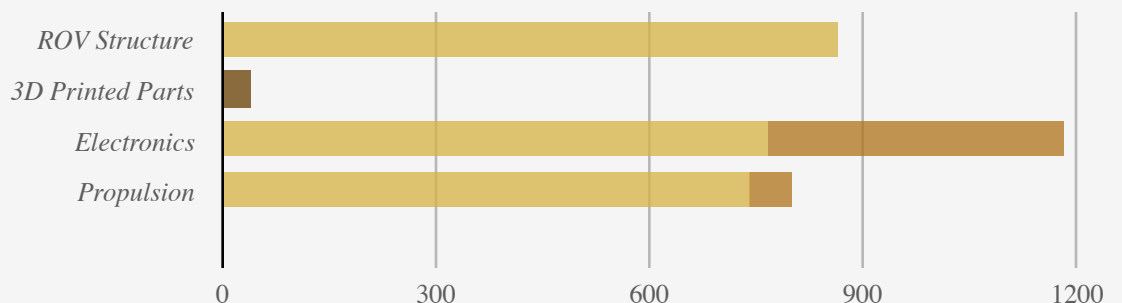
We believe that good accounting is crucial to a good company, so we strive to be as cost efficient and organized as possible. We always check multiple venues to balance functional materials and affordable prices, as well as 3D print and reuse parts whenever possible to save money (see §4.2). We fundraise throughout the year (even after submitting our Technical Documentation) to ensure that we cover our expenses, reaching out to local companies and hosting events to raise money for our school robotics program. With our focus on affordability and organized accounting system, the entire design and construction process is possible.

BUDGET (7.1)

<i>Expenses</i>					
CATEGORY	TYPE	EXAMPLES	PROJECTED COST	BUDGETED VALUE	
Hardware	Purchased	Carbon fiber rods, screws	\$500.00	\$500.00	
	Reused	DC Motor, bilge pump motor	\$150	-	
Electronics	Purchased	Control boards, wire	\$2,000.00	\$2,000.00	
	Reused	Bilge bump motor, monitor	\$416.19	-	
Sensors	Purchased	Ansyun fish camera, water sensors	\$300.00	\$300.00	
General	Purchased	Competition entry fee	\$200.00	\$200.00	
Travel	Purchased	Travel expenses	\$10,000	\$5,000.00	

Manufacturing Costs by Category (Actual)

- New
- Reused
- Built



PROJECT COSTING (7.2)

<i>Expenses</i>				
EXPENSE	TYPE	EXAMPLES	AMOUNT	RUNNING BALANCE
ROV Frame	Purchased	Carbon fiber rods, waterproof electronics enclosure	-\$404.11	-\$404.11
Propulsion	Purchased	T100 thrusters, DC motors	-\$740.22	-\$1,144.33
	Reused	Bilge pump motors	-\$59.04	-\$1,203.37
Control Box	Purchased	Screw shields	-\$146.75	-\$1,350.12
	Reused	Case, board	-\$416.19	-\$1,766.31
Topside Electronics	Purchased	Arduino Mega, extension cables	-\$213.99	-\$1,980.3
Onboard Electronics	Purchased	Sabertooth, cameras, ESCs	-\$404.79	-\$2,385.09
General	Purchased	Registration	-\$200.00	-\$2,585.09
	Donated	Team Shirts	-\$240.00	-\$2,825.09
Travel	Purchased	Air Fare	-\$4,644.00	-\$7,469.09
	Purchased	Hotel Rooms	-\$5,040.00	-\$12,509.09
	Purchased	Van Rental	-\$914.00	-\$13,423.09
	Purchased	Gas	-\$147.00	-\$13,570.09
	Purchased	Airport Parking	-\$202.00	-\$13,772.09
Misc.	Purchased	Screws, bolts, nuts	-\$458.89	-\$13,881.98
	Reused	PVC	-\$20.00	-\$13,901.98
<i>Income</i>				
EXPENSE	TYPE	SOURCE	AMOUNT	RUNNING BALANCE
Funds	Donated	Scalyr, Inc.	\$1,500.00	-\$12,401.98
	Donated	Aptos High School	\$500.00	-\$11,901.98
	Donated	MATE Center	\$500.00	-\$11,401.98
	Donated	GoFundMe Page	\$1,835.00	-\$9,566.98

Total Reused and Donated Parts	\$735.23
Total Raised	\$4,335.00
Total Spent	-\$13,515.75
FINAL BALANCE	-\$9,180.75

8. ACKNOWLEDGEMENTS

This year, many individuals and groups supported our team, donating their money, time, and experience. We first give our sincere thanks to Victor Da Costa and Mary Seamount for their invaluable mentorship. Their help through the entire design and marketing process helped us develop skills and technical knowledge that made building a complex robot possible. We are so grateful to have such amazing teachers in our community.

Next, we thank our sponsor, Scalyr Inc., for investing in our vision of building an award-winning robot. Their contribution was the foundation we needed to begin designing and constructing the *Argo VI*. We are deeply grateful for their incredible generosity.

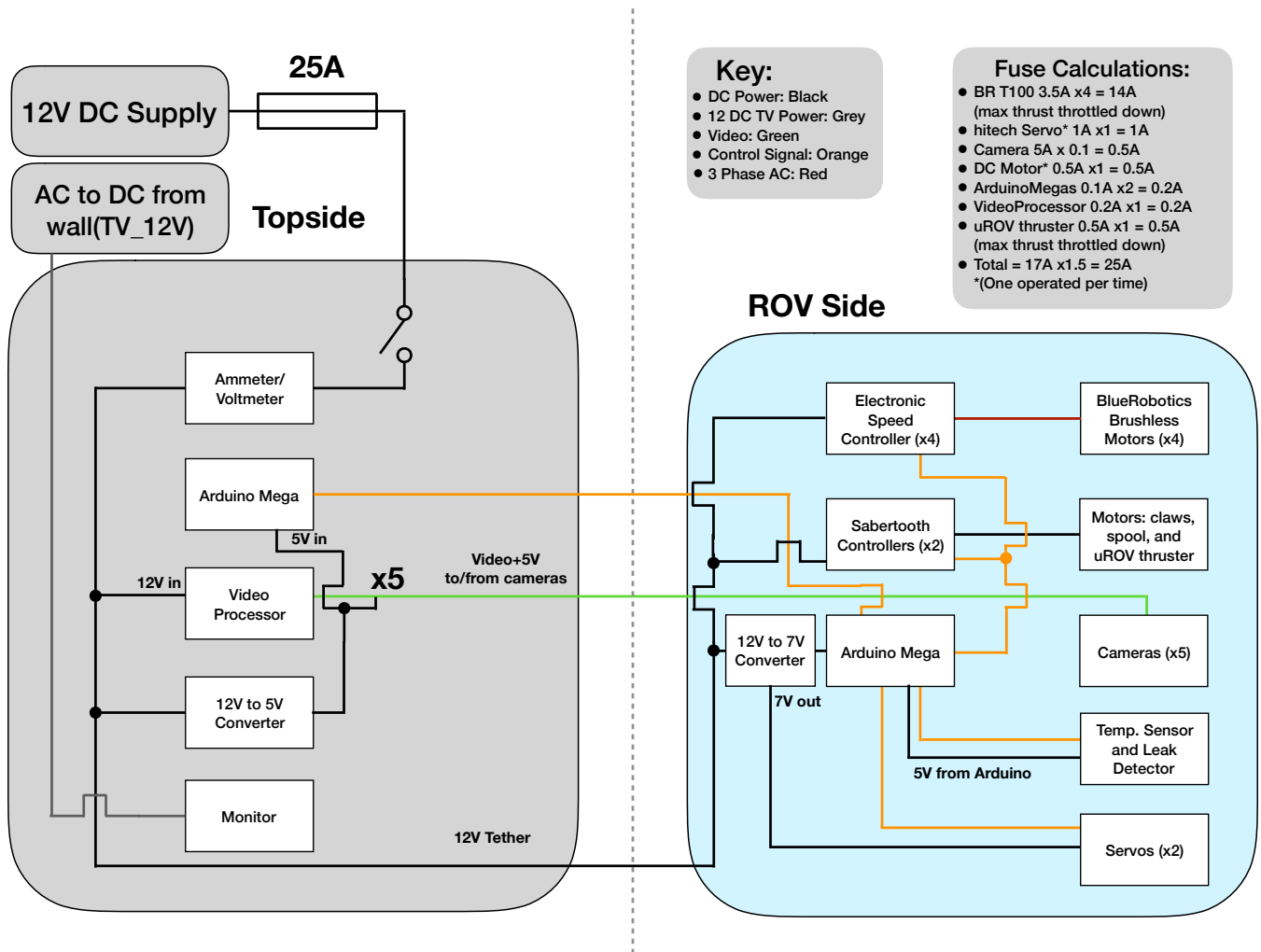
We also appreciate all the parents for keeping us fed, doing supply runs, and loaning us tools. Our appreciation goes to Tom Maschhoff of AquaVu for donating our underwater cameras featured on the *Argo VI* and the microROV. We also want to thank Joe McMinn of Jaco Machine Works and Mary Govaars of Cabrillo Makerspace for generously donating time and materials to print a durable version of our original claw design. We are also grateful to the Aptos High Booster Club, who generously donates funds to all the ROV teams at Aptos High School, as well as our club sponsor, Joe Manildi, who helped us navigate fundraising the program. Finally, we would like to thank MATE for hosting and organizing this competition; without them, the entire ROV competition experience would not exist and we would miss out on this wonderful experience.

9. REFERENCES

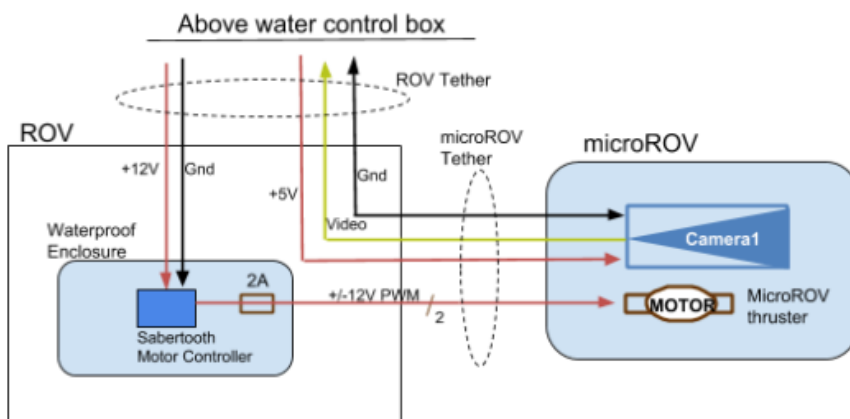
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10. APPENDIX

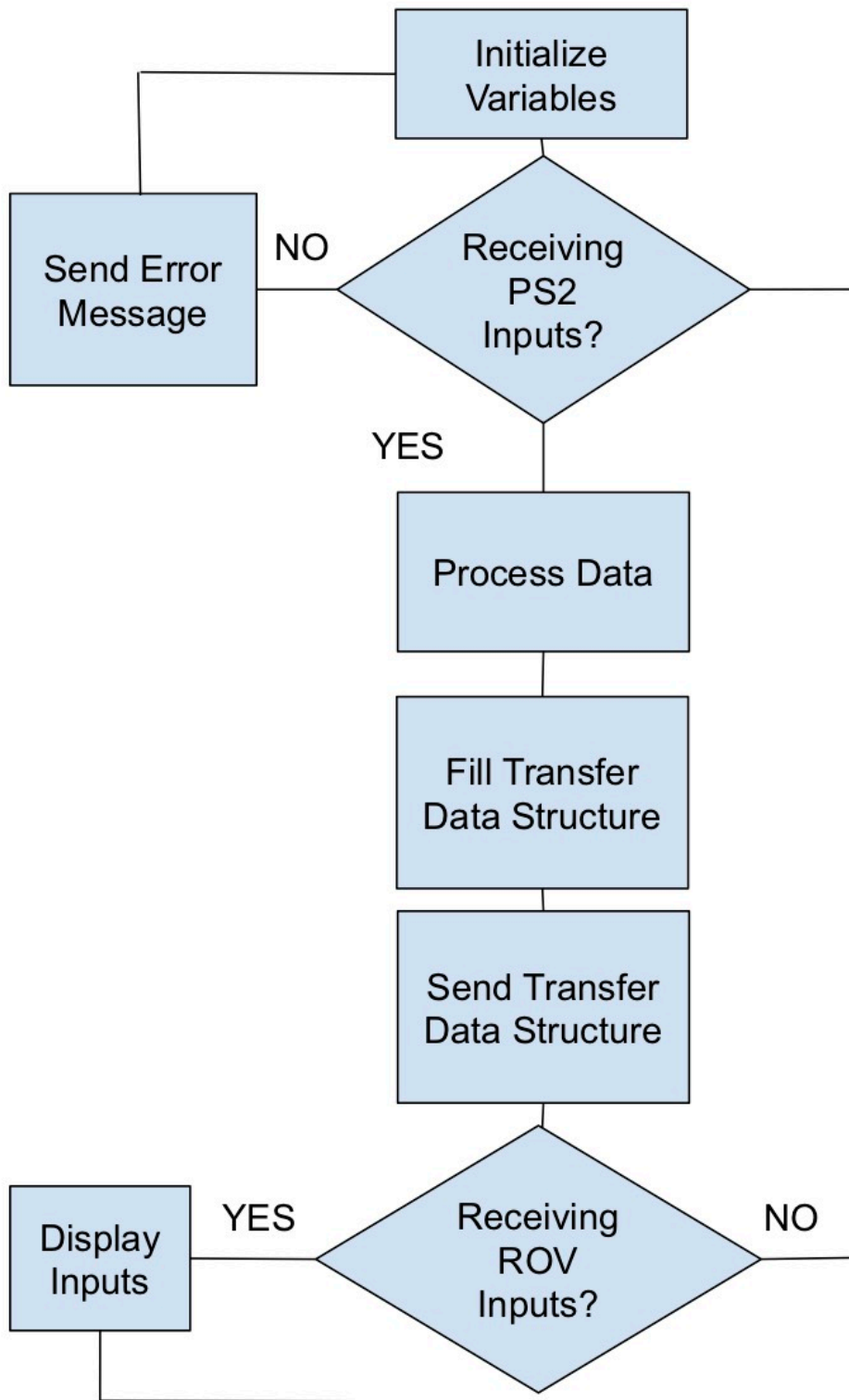
The Argo VI System Integration Diagram (SID)



The MicroROV System Integration Diagram (SID)



Sample Software Flowchart



Gantt Chart

